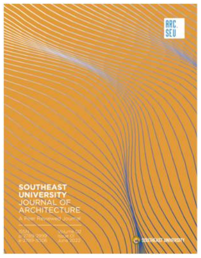

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Application of Life Cycle Assessment to Mitigate Climate Change Challenges in the Building and Construction Sector

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ABSTRACT

Building facilities are the basic requirement for human civilization. Its many forms and shapes are evolving according to our functional needs and requirements. Before the Iron Age, we were mostly dependent on natural building materials and resources like wood, stone, or mud, and physical labor to build our dwellings and other buildings. With the progression of human civilization, our choices and options of building construction, finishing, and decoration materials have also increased by many folds. Now in this 21st century, when we are in the 4th industrial revolution, we still lack an up-to-date national database of building materials with detailed specifications. Broadly because we are innovating, importing, and applying new building products frequently. With the realization of climate change, we aim to reduce our environmental footprint in this building sector to zero. However, our present global activity does not indicate much positive yield toward our goal. Despite some significant achievements in a few countries, much of the world still could not show any significant improvement in that regard. Life Cycle Analysis of a building could be a game-changing approach to access building environmental impacts, and thus architects and engineers can take real-time necessary measures in the early stage to manipulate building environmental impacts, and hence take part directly in climate change mitigation processes. This study will briefly discuss the available guidelines, and requirements to access the LCA of a building, potential benefits, and challenges.

1. Introduction

As per Paris Agreement or COP21 (Paris Climate Conference, December 2015), we were universally committed to limiting global warming to below 2^{0}C and to pursuing a further 1.5^{0}C compared to the pre-industrial level to avoid the adversity of dangerous climate change. At then it was anticipated that our global holistic actions might help us to slow down the global temperature rise within our goal till 2050. However, a report published by IPCC (The Intergovernmental Panel on Climate Change) on August 9 2021 on their website, where provides new estimates (reality check) based on the global greenhouse gas emission scenario that there is a chance of crossing the global warming level of 1.5^{0}C within the next decade. It is also anticipated that if we continue our business, as usual, our target might be beyond reach, and that is what we cannot afford.

On a gross scale, global major greenhouse gas emitters are the energy, transport, and building sectors. According to UNEP 2020 global status report for buildings and construction, we witness a record global highest greenhouse gas emissions of 38% from the building and construction industry alone, and energy (electricity) consumption for building operations was globally 55% (UNEP, 2020).

In the year 2019, our global average temperature was recorded as 1.1^{0}C warmer than the pre-industrial era (Trewin&Canadell, 2020), and as per the recent calculation of global average surface and ocean temperature considering the data till 2021, we are 0.84^{0}C warmer than the pre-industrial period (1880 – 1900) (Lindsey &Dahlman, 2022). To keep our planetary environment in a tolerable condition by addressing increased environmental calamities and threats to human and animal lives and living organisms, we must hold our global temperature rise below 1.5^{0}C, and push our effort to keep it low further (IPCC special report, Global Warming of 1.5^{0}C). to meet this target, our goal is to reduce our greenhouse gas emissions from building sector to net zero and to build a net zero carbon building stock by 2050 (UNEP, 2020). In that regard, our estimated plan is to reduce direct CO2 emissions from building by 50 percent and indirect building sector emissions by 60

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percent, by 2030 (UNEP Press Release, 2020).

To address this vigorous plan, we urgently need to reshape our building construction industry value chain. That is to say, we need to reform our building design and construction guidelines, codes, and policies by focusing on more sustainable development, promoting building refurbishment and renovation through systematic building decarbonization measures, promoting stimulation packages and reward policies for low carbon and zero carbon buildings to channel private and public investments into more sustainable building construction.Thus reducing building carbon footprint, and increasing the use of recycled building materials. Additionally, we also need to promote environment-friendly building products and materials and build an EPD (Environmental Product Declaration) Database reflecting local conditions. All these can be achieved by adopting the building Life Cycle Assessment (LCA) technique.

LCA can be accessed for any product, process, or service. Initial guidelines for accessing LCA were formulated by SETAC (Society of Environmental Toxicology and Chemistry), a non-profit professional organization. Further in-depth analysis, research, and development are still ongoing in the Life Cycle Assessment sector by various organizations, notably "The Life Cycle Initiative" hosted by UN Environment Program. Among their successful programs are GLAM (Global Guidance for Life Cycle Impact Assessment Indicators and Methods), GLAD (Global LCA Data Network), National LCA database development guidelines and roadmaps, etc., however, the standards to access the LCA were normalized and published by ISO (International Organization for Standardization) in their ISO 14040 series.

2. Discussion

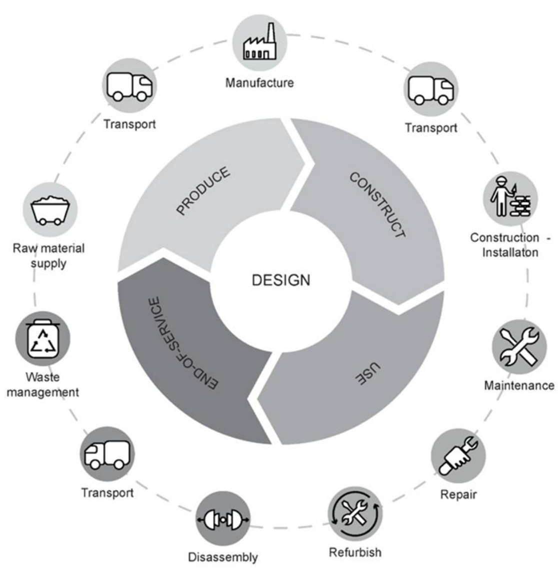

Figure 01: Life-cycle of a building.

[TUDelft, OpenCourseWare, "Life-Cycle of a Building," Accessed September 25, 2022, *https://ocw.tudelft.nl/course-readings/3-1-2-life-cycle-of-a-building/*]

It is clear that there are many available earthen construction techniques. However, the purpose of this study is to determine the best alternative to kiln-bricks among them.

Dug-out Earth, indured Cut-blocks are too site-specific to be applied elsewhere. Earth-bags, Shaped Earth, Cob, Wattle and Daub, Straw Clay, Poured Earth and Projected Earth aren't suitable for most modern construction due to their lack of standardized properties such as compressive strength and water absorption rate. Covered Earth is simply a secondary roofing insulation. This leaves rammed earth, Adobe bricks, extruded earth and stabilized (CSEB) or non-stabilized (CEB) compressed earth blocks as contenders.

In its simplest form, Life Cycle Analysis or LCA means a "cradle-to-grave" analysis of the environmental impact of any product or service. In this discussion, we consider the term "product" as a building product or the whole building itself and it can be defined as "building material and component combinations", in short BMCCs (SETAC, 2003). A building itself is a product that is a combination of various other products, that is BMCCs, and it goes through several processes and stages to become a usable product, e.g., transportation or acquisition of raw materials, manufacturing of building products, transportation of building materials to site, construction, assembling, etc. Then it consumes energy and other resources and generates wastes in various forms during its operational phase. During a building's lifetime, we do periodic maintenance to keep up the facility. Sometimes, we take major refurbishment decisions to extend the building's lifetime or to adopt new or different uses. These processes continue to go on through the entire lifespan of the building and the process stops at the demolition stage or end-of-life of the building facility. More elaborate life-cycle stages can be identified in Figure 01.

During all these life-cycle stages of a building product or the building as a whole (BMCCs), it leaves various types of impact on our environment, and we can measure those impacts to access those materials' environmental performances or environmental impacts, methodologically and scientifically. Broadly speaking, we measure the potential environmental impacts in several sectors, e.g., Land Use and Land Use Changes, Energy Demand, Climate change, Ozone depletion, Acidification, Eutrophication, Smog formation, Human and ecotoxicity, Water use and consumption, Water scarcity, etc., and the combined result can be accessed as LCA of that product/s.

In short, Life Cycle Assessment is a scientific and methodological process to access those performance and can assist in design decision-making, material selection and procurement process, construction methodology identification, building operational procedure, demolition and recycling methodology, etc. These scientific and methodological approaches have been standardized and normalized by International Organization for Standardization (ISO) in their ISO 14000 family – Environmental Management series. To be more specific, "ISO 14040 – Principles and Framework of Life cycle assessment", and "ISO 14044 – Requirements and guidelines for Life cycle assessment".

In the "ISO 14040 – Environmental management – Life cycle assessment – principles and framework", a theoretical framework for the product life cycle assessment process has been standardized. It identifies the key areas where we would be beneficial for analyzing LCA, e.g.

- Assessing the environmental performance of a product at its various lifecycle stages as well as their possible environmental impacts
- Strategic planning, decision-making, priority setting, product or process design, or redesigning
- Environmental performance measurement for relevant indicators and methodologies
- Environmental product declaration, claiming environmental certification, eco-labeling, marketing, etc.

On the other hand, "ISO 14044 – Environmental management – Life cycle assessment – Requirements and guidelines" standardizes the processes for conducting an LCA.

The more our understanding, research, and development are increasing over this LCA process, the bigger and more widespread its impact categories are becoming. Not to mention, with that potential, the LCA calculation process is also becoming complicated. Under these circumstances, we set forth to find a way for the AEC professionals to more actively participate in the climate change mitigation challenges from our building and construction sector by applying the LCA process. To address this climate change issue, in this paper, we focus only on one LCA impact category which is the "climate change potential impact category". Under this impact category scope, we quantitatively measure the greenhouse gas inventory analysis and we express it as Carbon dioxide equivalent (CO2e).

The greenhouse gases, which are a combination of Carbon Dioxide, Methane, Water Vapor, Nitrous Oxide, various fluorinated gases, etc., remains in our atmosphere, and their main purpose is to trap heat so that we do not die freezing. The more the presence of greenhouse gases in our atmosphere, the more our earth will trap heat. Due to the increase of this heat-trapping process, which is known as global warming, our climate is changing. Therefore, controlling the global warming process is the key to climate change, and it can be done by controlling our greenhouse gas emissions.

During the climate change impact category analysis, we prepare our emissions inventory, which eventually explores all the emission sources from a building, construction, operation, and end-of-life process. Here the GHG inventory operation is done by the guideline "Product Life Cycle Accounting and Reporting Standard", which is formulated by GHG protocol. With this standard, we prepare our GHGemission accounting in 1, 2, and 3 emission scope stages, where scope 1 explores the direct emission sources, scope 2 defines indirect sources, and scope 3 identifies the emission sources from the whole building and construction value chain [Figure 2]. These are the stages where AEC professionals can manipulate their future actions to explore other options available to reduce overall GHG emissions.

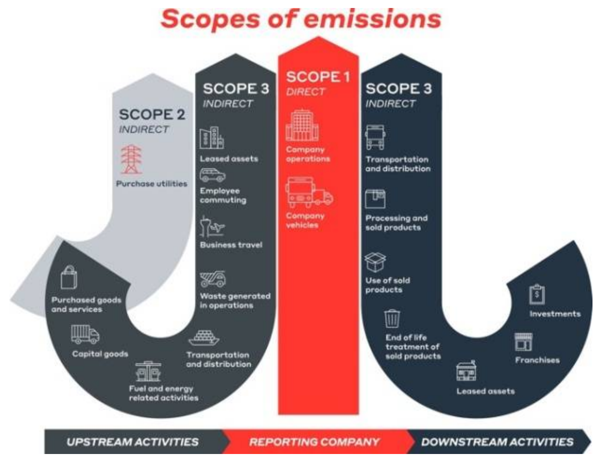

Figure 2: WSP USA 2022.

The GHG Protocol categorizes emissions into three scopes: Direct, Indirect and Emissions. https://www.wsp.com/en-us/insights/2022-life-cycle-assessment-and-greenhouse-gas-inventory

3. Findings

Building life cycle assessment is the result of all products and processes life cycle assessment which is associated with the building itself. The analysis requires a rich, very detailed, and dependable database to calculate the impact results, e.g., impact of energy use, carbon footprint, environmental impacts like - ozone depletion potential, acidification potential, various impacts on soil and water, and many more depending on our selection of analysis method. From the results of our analysis, we can pinpoint exactly which phase, sector, and stage our building and building materials, procurement strategy, construction procedure, building use behavior, maintenance and refurbishment, and demolition procedure might cause damage to the environment and can assume their degree of severity. With the total possible environmental damage picture in hand, we can now manipulate to reduce our emissions from building and building-related phases, and thus Life Cycle Analysis technique can directly help us to mitigate climate change challenges. Since greenhouse gas emission reduction is directly related to control over global warming, hence slowing down the pace of climate change.

LCA is a scientific methodology to access the environmental impacts of building materials and buildings, and thus evaluate the sustainability of a building before its execution. The flexibility of accessing the future environment result of our present action can directly help us to participate in climate change mitigation challenges.

Another major benefit of performing building LCA lies in the field of green building certification. E.g., whole building life cycle assessment impact reduction credits can also be used for LEED (Leadership in Energy and Environmental Design) certification. Green certification increases the real estate value. Other big-scale uses of LCA be impact analysis of building sites, infrastructure project life cycle analysis, city planning, etc.

3.1. Tools

Under the LCA analysis, for climate change impact assessment, we need to prepare our GHG inventory analysis. Tools in the form of Excel worksheets are available in the GHG Protocol web repository for detailed emission calculation. To fill out the worksheet, we need reliable databases of various materials and work processes GHG emission data. Emission databases can be prepared following the international guidelines, e.g., the “LCA Database Development Roadmap” (UNEP 2020), or we can acquire required LCA data and even upload and share our own investigated data to the Global LCA Data Network (GLAD) web repository. Readily available and action-dependent emission data may also be retrieved from the EFDB emission factor database (IPCC 2021), or available third-party databases from the “Life Cycle Databases” web repository of the GHG Protocol. Not to mention, these available datasets may not be universal, mostly country-specific, and it is advised to develop a national emission database following the UNEP LCA Database Development Roadmap.

For GHG emission report preparation, we need to convert our greenhouse gas inventory data to Carbon Dioxide equivalent (CO2e). Some country developed their own GHG equivalencies calculator and this report did not taste their universal application possibility.

Some open-source software is also available for life cycle and sustainability calculation, e.g., the openLCA. They also have large resources of LCA database, both open and commercial. By understanding the limitation of this report, we did not explore the usage possibility of this software for building and construction sector-related LCA calculation. Many other paid software is also available for LCA calculation; however, their calculation process is not transparent.

Regardless of whether paid or open-source, all the LCA software depends on the LCA database and the reliability of LCA calculation result very much depend on their database accuracy. We need both the software and the database to be reliable to perform a working LCA analysis. The LCA database can be divided into two types, the LCA database of environmental product declarations (EPDs), and the generic materials database. EPD databases are elaborate in nature with all the LCA data of that material. It also enables us to choose specific materials from a specific manufacturer. On the other hand, generic databases are prepared with industry-average data, which means highly performing materials are kept in the same database with the materials that emit a lot of CO2. Obviously, for transparent and reliable results, the EPD database should be the first choice. But the length and breadth of the database might vary from country to country. Even one environmental building product might not be available to another country, and if we would like to use the material for better environmental performance, transportation might cause additional CO2 in the bucket. Therefore, a country-specific or regional LCA database, developed as per available international standards, is advisable.

4. Conclusion

At this very moment, the earth is still our only visible habitat. With the scientific hands-on evidence, we are moving towards a climate change catastrophe, towards a global situation where our final standing is still unknown. In the building construction sector, a rapid and fast-forward building decarbonization target and net-zero carbon target have been set to slow down the coming climate adversity so that we can avoid the close call and can continue to thrive as a civilized nation. On a global scale, our target is enormous, and with the present knowledge and information in hand, so is our achieving potential. LCA in the building and construction sector could be a game-changing tool for AEC professionals in that regard. In addition, we also need to develop national-level reliable LCA EPD databases.

Compare to the global climate urgency, our response from this building sector is still minimal and that is evident from the UNEP 2020 global status report for buildings and construction where they mentioned, “in the building sector, for every $1 spent on energy efficiency, $37 is spent on conventional construction approaches”. Many reasons could be behind this scenario and in this discussion, our scope is limited to focus on that area. We should take the full potential of this 4th industrial revolution and should vigorously effort to reduce the knowledge gap and spread awareness and consequences of climate change, even in primary and elementary-level education. Because this is the generation level that is going to be affected by our present actions. We hope additional research could be carried out in this building sector area to expedite the meaningful use of LCA.

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