Comparison of sustainable life cycle assessment on building construction methods: IBS versus conventional

Nik Muhammad Akif Nik Mazlan[1], *Sushilawati* Ismail[1]*, *Hendi* Saryanto[2], *Wan Anwar Faiz* Wan Nasaruddin[3], *Ikhwan Shah Tisadi* Tukiat[4]

[1] Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia
[2] Mechanical Engineering Programme, Universitas Muhammadiyah Prof. Dr Hamka, Jl. Tanah Merdeka No.6, Pasar Rebo, 13830 Jakarta Timur, DKI Jakarta, Indonesia
[3] Bestari Bina Ventures (M) Sdn Bhd, No. 7, Jalan TTS 2/1, Taman Tasik Semenyih, 43500 Semenyih, Selangor
[4] Sustainable Manufacturing & Recycling Technology (SMART), Advanced Manufacturing and Materials Centre (AMMC), Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia

Abstract. Industrial Building Systems (IBS) is prominently known as one of the sustainable construction options. However, some construction practitioners still doubt the sustainability of this method, which may be due to their lack of awareness and knowledge. Furthermore, the construction industry, particularly in Malaysia, does not yet have precise and reliable figures demonstrating the amount of carbon footprint reduction attributable to the usage of IBS. Therefore, this study aims to evaluate the IBS building sustainability performance based on carbon emission values. A life cycle assessment (LCA) comparison between conventional methods and the IBS method will be conducted to see the carbon footprint percentage based on comparing these two methods. In the end, LCA will consider every single flow and relate the activity when analyzing the sustainability issues of the building. Materials, energy, and product waste throughout the life cycle will be identified so that the environmental impact can be determined from before the design and manufacturing phase starts until the completion of the construction activities. This study is expected to prove the sustainability of the IBS method compared to the conventional methods to increase the confidence level of construction implementers and further expand the implementation of the IBS method. It is also hoped that the awareness of the sustainability characteristics of IBS construction can change the perception of the construction implementers by starting to think about long-term implications such as GWP when in the phase of decision-making in a

[1*] Corresponding author: sushila@uthm.edu.my

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construction project development.

1. Introduction

In the context of the changing capabilities required for the built environment, it is widely recognized that buildings are the major contributor to fossil fuel energy consumption and CO_2 emissions. The construction industry is estimated to use 21% of global energy consumption in 2040, and operational energy for buildings is also expected to increase by 32% by 2040 due to urbanization growth in non-OECD countries [1]. Excessive carbon dioxide (CO_2) emissions are one of the challenges in the construction sector in Malaysia that indirectly contribute to global warming. In addition, Malaysia's industrialized building system and conventional method are the main methods that are occasionally used in any building construction. Building construction projects significantly impact energy consumption, greenhouse gas (GHG) emissions, and, most importantly, global warming potential GWP [2]. Excessive carbon dioxide (CO_2) emissions are one of the challenges in the construction sector in Malaysia that indirectly contribute to global warming. Malaysia needs to realize the importance of sustainable development and green buildings.

In addition, Malaysia still does not yet have strong statistics to show the total carbon footprint results of adopting the uses of IBS through life cycle assessment [3]. Malaysia must recognize the significance of sustainable development and green construction practices. Furthermore, it should be noted that Malaysia currently lacks comprehensive statistical data about the overall carbon footprint implications associated with the utilization of Industrialized Building Systems (IBS) as determined by life cycle assessment [3]. Therefore, various initiatives have been taken by local authorities and the government to encourage implementers in the construction industry to apply sustainable development through the use of IBS because it can reduce the impact on the environment and positively affect construction [2]. According to [1], sustainability is a development technology that focuses on ecological capacity to preserve natural resources for future generations. Construction sustainability can only be achieved by considering environmental conservation, social equality, and economic prosperity [1].

This paper aims to provide a literature review on life cycle assessment (LCA) and the future of LCA in Malaysia. This paper seeks to provide the fundamental knowledge of LCA and emphasize the barriers to its implementation. A comprehensive study was conducted by retrieving relevant journal articles published between 2000 and 2022. A literature review revealed that the ability to enhance the quality of construction projects decreased the proportion of GWP and its impact on the environment.

2. The current sustainability limitation of IBS studies

IBS contributes a lot to the development of the construction industry by reducing material waste in construction, energy consumption, carbon emissions, noise and soil pollution, dust emissions, water consumption, construction time, and accident rates on construction sites [4]. IBS is also more sustainable for the environment when compared to conventional construction methods [3]. This shows that IBS can positively impact the environment and improve the concept of safety at the construction site. In addition, the progress and technology of IBS in the manufacturing process, selection of raw materials, design, and performance improvement have improved the construction process and quality in general. This is because IBS has advantages in terms of reducing contained energy (MJ) and percent global warming potential (GWP) towards low-carbon development [2]. However, although

this construction method has been started for a long time, since the 1960s, there are still executors in the field of construction, such as contractors who are still not exposed to the latest technology in the manufacture of components, especially the variety of types of materials that can be used [5].

The construction industry in Malaysia has a low level of IBS adoption due to resistance to change and a lack of understanding of the concept of sustainable development [3]. In addition, problems in construction work often arise due to a lack of knowledge in determining the properties found in each, which usually happens when implementing small-scale projects. Most contractors only use it without knowing detailed information about IBS for construction projects [6]. Therefore, to encourage a more comprehensive application of IBS as recommended by the Malaysian government, the variety of options can help contractors, consultants, designers, and developers produce more creative constructions with the best performance. According to [2], the construction industry in Malaysia needs to realize the importance of IBS towards sustainable and green development. The authorities should take a vital initiative to educate construction practitioners in applying IBS in a construction project [7]. Unlike traditional or conventional construction methods, the industrialized construction system approach idealizes and simplifies construction work where understanding and knowledge are essential to delivering the concepts used in IBS [8].

3. Fundamental Knowledge of LCSA

The challenge of maintaining sustainability in the construction industry has attracted quite a lot of attention over the past few decades. This is caused by too much environmental pollution, so many natural disasters occur in our country. However, the challenges we face today are often seen in terms of environmental threats, such as uncontrolled carbon dioxide emissions from industries involved in construction. Thus, this assessment emphasizes sustainability in structure [9]. In addition, ideas related to the life cycle are expanded into more diverse branches, such as Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA), and all of them are combined as Life Cycle Sustainability Assessment (LCSA). In bringing it all together, sustainability and a cycle-based approach can only be brought together under the LCSA framework [10]. [11] This paper has framed all the cycles in one formula, LCSA=LCA+LCC+SCLA, as shown in Fig. 1. However, this paper only focuses on life cycle assessment compared to IBS and conventional. LCA studies conducted for buildings mainly focus on energy requirements and greenhouse gas emissions, but only a small number focus on environmental impacts, and they are inconsistent [12].

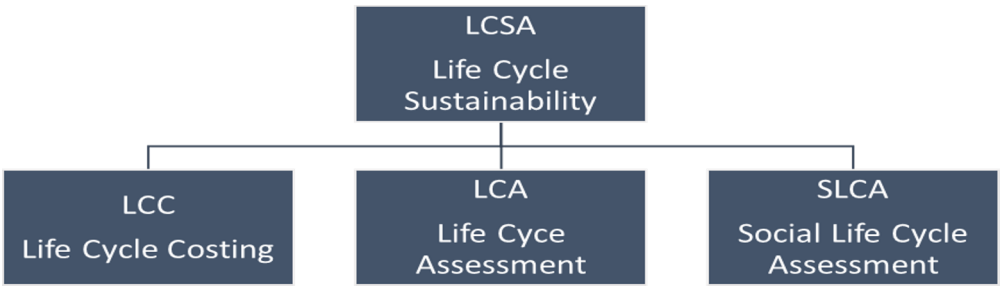

Fig. 1. Life cycle sustainability assessment framework [12].

The life cycle assessment methodology assesses the input and output analysis for each structural element at each product life cycle and the environmental impact related to the

product assessment during the whole life cycle stage [13]. Choosing the most sustainable building materials will reduce global warming emissions from construction and air pollution [14]. With that, the quantity of emissions of energy consumption and material resources during the life cycle of the IBS building can be estimated. Nowadays, climate change and the lack of resources for a cleaner environment threaten a good economy [15]. The need for efficient data collection in life cycle assessment for each stage in construction requires that ISO 14040 be followed to validate the research and ensure the results are reliable [16]. A life cycle assessment is necessary to reduce global climate change, where CO2 emissions will be 50% of current levels by 2050 [15]. Life cycle assessment was a relatively popular method at the beginning because many people thought it could be an excellent tool to support the environment and be used immediately in the construction marketing process [17].

4. Research of LCA in project construction

The building construction industry is responsible for more than 40 percent of global energy consumption and up to one-third of greenhouse gas emissions in developed and developing nations [18]. Most of the materials used in a building affect gas emissions in the air. Therefore, the country needs to build more sustainable or environmentally friendly buildings to change this trend and reduce the negative impact on the environment [19]. Each party in the construction sector should reduce the use of products capable of increasing carbon-intensive effects. Various aspects of design and materials should be considered in creating a more sustainable construction. The building design phase is essential, where selecting sustainable and suitable materials is to be included in the project while positively impacting climate change [20]. This is because building is a phase of activity that involves various flows, including the flow of raw materials, the flow of waste construction materials, and the flow of pollution during and after construction. For example, the wood used in building construction materials comes from nature, and after being demolished, it will return to nature through the process of disposal or burning [21].

However, this study only focuses on the LCA assessment and does not include electricity use in the construction process because it does not have CO2 gas emissions. Indeed, LCA is used to identify materials, energy, and product waste throughout its life cycle so that the environmental impact can be determined before the start of design and manufacturing operations, in addition to bringing benefits to the environment and cost savings [22]. In other words, LCA is a technique that considers every single flow and related activity when examining the sustainability issues of a building. Awareness of the sustainability characteristics of buildings has been chiefly widely accepted by the people in addition to their knowledge about the increasing needs of the environment, and this begins by assessing how their activities affect the environment [23]. Environmental performance is now a significant issue when many companies and decision-makers are trying to find new approaches to minimize the impact of construction on the environment [24]. This shows that various factors should be considered in assessing the effects of using LCA. The concept of LCA was created because it can identify materials, energy, and waste products throughout its entire life cycle to determine the impact on the environment before entering the design and manufacturing phase [25]. Previous studies show that using LCA can also positively affect the environment and save on construction costs [26]. Based on studies related to LCA, it is very suitable to be used as a measuring material to determine the effects of global warming in the construction industry.

5. LCA Standard based on ISO14040

The ISO 14040 (1997) standard takes up this recommendation. It describes three types of critical review which are generally preferred. Still, the LCA study used to make comparative assertions disclosed to the public is strengthened by the revised standards ISO 14040 and 14044 formulas, and it is even more strict and not added further [27]. Taking into account various cost and time constraints, the LCA method was formulated according to the principles of the guidelines set by the Society of Environmental Toxicology and Chemistry (SETAC) [28]. In addition, ISO 14040:2006, which includes LCA studies and life cycle inventory studies, does not explain LCA techniques in detail or even specify specific methodologies [29]. This is because the results of LCA are considered based on the definition of clear goals and scope. The latest ISO 14040 and ISO 14044 are related to each other according to the principles established in ISO 14040, where the detailed rules and requirements of 14044 must be followed [27].

6. Global warming potential in the construction sector

Global warming occurs when the sun shines on the earth, and the atmosphere traps heat [30]. Nowadays, scientists in the field of climate say that human activity is the leading cause of the increase in global temperature, which is 0.7°C above the pre-industrial temperature level, and the latest reading shows that the temperature has increased by 2°C above the worldwide warming level [31]. Thus, global warming potential is developed to allow comparison of the effects of different gases on global warming. In other words, it precisely measures how much energy will be absorbed by releasing 1 ton of gas in a specific time compared to releasing 1 ton of carbon dioxide [32].

In theory, carbon dioxide gas and other greenhouse gases act like a blanket to store heat, making heat no longer able to leave the atmosphere and return to space, causing the planet to become warmer [33]. In recent years, researchers have shown that the release of CO2 gas into the atmosphere is caused by human activity, especially in the burning of fossil fuels, and this causes an increase in the average temperature around the world due to pollution through burning [34]. The effects of global warming will cause significant climate change events worldwide. This is because many countries cannot bear the risks of climate change, such as floods, droughts, and storms. The risk becomes higher when the warm climate around the world becomes more caused by the emission of greenhouse gases due to human activities [35]. Based on the average lifespan for a building of 100 years, nowadays, most of the materials used in buildings have the effect of gas emissions in the air.

7. Conclusion

Based on this study, understanding regarding LCSA still needs to be increased among construction industry players. This is because some construction industry players still lack knowledge of matters related to IBS and the importance of LCSA in the concept of IBS and conventional construction. Indeed, this paper shows some of the references that can be used to gather information about IBS and conventional construction based on LCSA. By adding information from this paper, it is hoped that it can become a reference in the future.

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References

1. S. Y. Janjua, P. K. Sarker, and W. K. Biswas. Sustainability assessment of a residential building using a life cycle assessment approach. Chem. Eng. Trans., vol. 72, no. September 2018, pp. 19–24, (2019) doi: https://doi.org/10.3303/CET1972004
2. T. J. Wen, H. C. Siong, and Z. Z. Noor. Assessment of embodied energy and global warming potential of building construction using life cycle analysis approach: Case studies of residential buildings in Iskandar Malaysia. *Energy Build.*, vol. 93, pp. 295–302, (2015) doi: https://doi.org/10.1016/j.enbuild.2014.12.002
3. P. Y. Lim *et al.* Carbon Footprint of Construction using Industrialised Building System. IOP Conf. Ser. Mater. Sci. Eng., vol. **271**, no. 1, pp. 0–8, (2017) doi: https://doi.org/10.1088/1757- 899X/271/1/012107
4. R. E. López-Guerrero, S. Vera, and M. Carpio. A quantitative and qualitative evaluation of the sustainability of industrialised building systems: A bibliographic review and analysis of case studies. *Renew. Sustain. Energy Rev.*, vol. **157**, no. July 2021, (2022) doi: https://doi.org/10.1016/j.rser.2021.112034
5. M. A. O. Mydin, N. Sani, and M. Taib. Industrialised Building System in Malaysia : A Review 2 Industrialised Building System History In Malaysia. vol. **01002**, pp. 1–9, (2014).
6. A. H. M. H. Al-Aidrous, Y. Rahmawati, K. Wan Yusof, A. Omar Baarimah, and A. M. Alawag. Review of Industrialized Buildings Experience in Malaysia: An Example of a Developing Country. *IOP Conf. Ser. Earth Environ. Sci.*, vol. **682**, no. 1, pp. 0–8, 2021, doi: https://doi.org/10.1088/1755-1315/682/1/012003
7. T. J. Wen. Life Cycle Assessment of Energy and CO2 Emissions from Cast In-Situ and Industrialised Building System. *Αγαη*, vol. **8**, no. 5, p. 55, (2019).
8. M. A. Fauzi, S. H. Hassan, J. N. Yunus, H. Sulaiman, and N. A. Ramli. A review of supply chain management in IBS construction industry: Challenges. *J. Eng. Appl. Sci.*, vol. **12**, no. Specialissue5, pp. 6911–6915, 2017, doi: https://doi.org/10.3923/jeasci.2017.6911.6915
9. R. T. Fauzi, P. Lavoie, L. Sorelli, M. D. Heidari, and B. Amor. Exploring the current challenges and opportunities of Life Cycle Sustainability Assessment. *Sustain.*, vol. **11**, no. 3, pp. 1–17, (2019) doi: https://doi.org/10.3390/su11030636
10. N. Kralisch, Dana and Minkov. Roadmap for Sustainability Assessment in European Process Industries – MEASURE. no. April, (2016)
11. W. Kloepffer. Life cycle sustainability assessment of products (with Comments by Helias A. Udo de Haes, p. 95). *Int. J. Life Cycle Assess.*, vol. **13**, no. 2, pp. 89–95, (2008), doi: https://doi.org/10.1065/lca2008.02.376.
12. C. K. Chau, T. M. Leung, and W. Y. Ng. A Review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on Buildings. *Appl. Energy*, vol. **143**, no. 1, pp. 395–413, (2015), doi: https://doi.org/10.1016/j.apenergy.2015.01.023
13. J. G. Backes and M. Traverso. Application of life cycle sustainability assessment in the construction sector: A systematic literature review. *Processes*, vol. **9**, no. 7, (2021), doi: https://doi.org/10.3390/pr9071248
14. Y. H. Dong and S. T. Ng. A Life Cycle Assessment Model for Evaluating The Environmental Impacts of Building Construction in Hong Kong. *Build. Environ.*, vol. **89**, pp. 183–191, (2015), doi: https://doi.org/10.1016/j.buildenv.2015.02.020.
15. A. T. Balasbaneh and A. K. B. Marsono. Life Cycle Assessment of IBS in Malaysia and Comparing Human Health on Timber and Concrete Pre-cast. *Res. J. Appl. Sci.*

Eng. Technol., vol. **06**, no. 24, pp. 4697–4702, (2013), doi: https://doi.org/10.19026/rjaset.6.3489

16. H. J. Kluppel. The Revision of ISO Standards 14040-3 - ISO 14040: Environmental management – Life cycle assessment – Principles and framework - ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines. (2005), doi: https://doi.org/10.1065/lca2005.03.001
17. A. T. Balasbaneh and A. K. B. Marsono. Life cycle assessment of two different IBS of Recipe Endpoint (E) LCIA method. pp. 475–480, (2013).
18. X. Zhong *et al.* Global Greenhouse Gas Emissions from Residential and Commercial Building Materials and Mitigation Strategies to 2060. *Nat. Commun.*, vol. **12**, no. 1, pp. 1–10, (2021), doi: https://doi.org/10.1038/s41467-021-26212-z
19. H. Chappells and E. Shove. Debating the future of comfort: Environmental sustainability, energy consumption, and the indoor environment. *Build. Res. Inf.*, vol. **33**, no. 1, pp. 32–40, (2005), doi: https://doi.org/10.1080/0961321042000322762
20. P. O. Akadiri, E. A. Chinyio, and P. O. Olomolaiye. Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings*, vol. **2**, no. 2, pp. 126–152, (2012), doi: https://doi.org/10.3390/buildings2020126
21. I. Jahan, G. Zhang, M. Bhuiyan, and S. Navaratnam. Circular Economy of Construction and Demolition Wood Waste—A Theoretical Framework Approach. *Sustain.*, vol. **14**, no. 17, (2022), doi: https://doi.org/10.3390/su141710478
22. J.W.Owen. Life-Cycle Asssesssment. (2000).
23. J. P. W. Scharlemann *et al.* Towards Understanding Interactions Between Sustainable Development Goals: The Role of Environment–Human Linkages. *Sustain. Sci.*, vol. **15**, no. 6, pp. 1573–1584, (2020), doi: https://doi.org/10.1007/s11625-020-00799-6
24. Z. Wu and M. Pagell. Balancing Priorities: Decision-Making in Sustainable Supply Chain Management. *J. Oper. Manag.*, vol. **29**, no. 6, pp. 577–590, (2011), doi: https://doi.org/10.1016/j.jom.2010.10.001
25. D. A. Salas, A. D. Ramirez, C. R. Rodríguez, D. M. Petroche, A. J. Boero, and J. Duque- Rivera. Environmental Impacts, Life Cycle Assessment and Potential Improvement Measures for Cement Production: A Literature Review. *J. Clean. Prod.*, vol. **113**, pp. 114–122, (2016), doi: https://doi.org/10.1016/j.jclepro.2015.11.078
26. R. Hoogmartens, S. V. Passel, K. V. Acker, and M. Dubois. Bridging The Gap Between LCA, LCC, and CBA as Sustainability Assessment Tools. *Environ. Impact Assess. Rev.*, vol. **48**, pp. 27–33, (2014), doi: https://doi.org/10.1016/j.eiar.2014.05.001
27. W. Klöpffer. The Critical Review of Life Cycle Assessment Studies According to ISO 14040 and 14044. *Int. J. Life Cycle Assess.*, vol. **17**, no. 9, pp. 1087–1093, (2012), doi: https://doi.org/10.1007/s11367-012-0426-7
28. A. Fava, A. Smerek, A. B. Heinrich, and L. Morrison. The Role of the Society of Environmental Toxicology and Chemistry (SETAC) in Life Cycle Assessment (LCA) Development and Application. (2014).
29. S. Toniolo, R. C. Tosato, F. Gambaro, and J. Ren. Life Cycle Thinking Tools: Life Cycle Assessment, Life Cycle Costing, and Social Life Cycle Assessment. Elsevier Inc., (2019).

30. S. Braide, J. Alucho, C. H. Ohabughiro, N. B. Adeleye. Global Climate Change and Changes in Disease Distribution: A Review in Retrospect. *Int. J. Adv. Res. Biol. Sci*, vol. **8**, no. 6, pp. 1–5, (2020), doi: https://doi.org/10.22192/ijarbs
31. G. L. Budiono. Environmental Pollution and Global Climate Change: A Strategic Deterrence Business and Social Problem. *Int. J. Sci. Eng.*, vol. **1**, no. 63628, pp. 129–133, (2015).
32. A. S. Daw. Global Warming Potential and Its Importance. *Dict. Ecol. Econ.*, pp. 247–247, (2019), doi: https://doi.org/10.4337/9781788974912.g.17
33. M. Hagen and A. Azevedo. Climate Changes Consequences from Sun-Earth Connections and Anthropogenic Relationships. *Nat. Sci.*, vol. **14**, no. 02, pp. 24–41, (2022), doi: https://doi.org/10.4236/ns.2022.142004
34. D. J. Wuebbles and A. K. Jain. Concerns about Climate Change and The Role of Fossil Fuel Use. *Fuel Process. Technol.*, vol. **71**, no. 1–3, pp. 99–119, (2001,) doi: https://doi.org/10.1016/S0378-3820(01)00139-4
35. W. Greaves. Climate Change and Arctic Security. Springer International Publishing, (2020).