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Life Cycle Assessment of Interlocking Blocks with Recycled Plastic Waste for Pedestrian Walkway Pavements

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Abstract:

The Life Cycle Assessment (LCA) of interlocking blocks incorporating plastic waste for pedestrian walkway pavements addresses sustainability in construction practices. This study analysed the carbon emissions of interlocking blocks used in pedestrian walkways, covering the entire life cycle from cradle to cradle. The evaluation includes various materials commonly used in pathway construction, such as concrete, gravel, and recycled materials. It assesses the environmental impacts throughout the entire life cycle, encompassing material extraction, production, transportation, construction, and maintenance. The primary objective is to compare the life cycle of pedestrian pathways made from recyclable plastic with those made from conventional materials. This involves examining the materials used during production, the manufacturing stages, construction methods, usage practices, end-of-life assumptions, and the specific procedures for constructing pathway networks. The findings indicate that using recycled plastic in interlocking blocks offers significant environmental benefits compared to traditional materials like cement and aggregate, particularly in terms of reducing carbon emissions and promoting sustainability in construction.
Key words: *Life cycle analysis, pedestrian walkways, environmental impact, recycle plastic*

Introduction

The global environmental crisis caused by the accumulation of plastic waste is severe, with millions of tons of non-biodegradable plastics contributing to land pollution annually. This persistent environmental issue necessitates innovative and sustainable waste management strategies. One promising approach is recycling plastic waste into construction materials, particularly for pedestrian walkways. This not only reduces the amount of plastic waste but also promotes a circular economy where materials are reused and repurposed, thus minimising environmental impact (Noviandini, 2020).

Interlocking blocks made from recycled plastic waste offer a sustainable alternative to traditional construction materials such as concrete, gravel, and sand. Previous studies have demonstrated that recycled plastic in paving blocks enhances material properties while significantly reducing environmental damage compared to conventional materials (Heiniger, 2022: Agyeman, 2019). These sustainable paving solutions not only address plastic pollution but also contribute to the overall sustainability profile of construction projects by reducing carbon emissions and preserving natural resources. These include the diversity of plastic waste types affecting homogeneity and quality, different melting points of plastics, and potential impacts from load and weather conditions.

However, several challenges must be addressed to increase the widespread adoption of recycled plastic blocks in construction. Variations in plastic types can affect the homogeneity and quality of the pavers, with differences in melting points and susceptibility to load and weather conditions potentially compromising block integrity (Han et al., 2024). Additionally, real-world applications have highlighted issues with durability and wear over time, necessitating rigorous quality control and standardisation in manufacturing processes to ensure safety and performance.

The main objective of this study is to focus on the whole lifecycle of pedestrian pathways made from recyclable plastic and conventional materials in the construction sector. This involves a thorough analysis of the processes and progress of manufacture to provide a holistic review of the environmental impact from production to disposal.

Research Methodology

The study employs a Life Cycle Assessment (LCA) framework to analyse the environmental impacts of using interlocking blocks made from recycled plastic waste for pedestrian walkways. The LCA covers the entire life cycle from raw material extraction to disposal or recycling. The system boundaries include production, construction, use, end-of-life, and benefits or loads beyond the system boundaries stages. Figure 1 outlines the life cycle analysis framework for studying interlocking blocks made from plastic waste for pedestrian walkways. It presents a systematic approach, starting with an introduction and clear objectives, followed by the Life Cycle Analysis (LCA) research method. The framework defines system boundaries, including materials like aggregate, cement, sand, and plastic. It involves collecting primary data, analyzing it by using tools such as Open LCA and OriginPro, and producing results and findings. This structured process ensures a comprehensive evaluation of the environmental impacts throughout the entire life cycle of the walkway, from raw material extraction to end-of-life disposal or recycling, providing a holistic view of the sustainability of using recycled plastic in construction.

Data collection methods are used to gather information on energy consumption, process data, transportation, labor input, emissions, and waste or recycling data. This comprehensive data collection enables a thorough analysis of the environmental impact of waste management and disposal processes related to the walkway materials. The study examines four main materials: cement, aggregate, sand, and plastic. For each material, the LCA considers all stages from extraction to disposal, including transportation, manufacturing, construction, use, maintenance, and end-of-life processes. The analysis accounts for the machinery, energy use, and emissions associated with each stage of the materials' lifecycles.

The project focuses on developing an 800-metre pedestrian pathway at Politeknik Ungku Omar. This real-world application allows for the consideration of geographical characteristics, climate, pedestrian traffic, and local ecosystem interactions in evaluating the suitability and resilience of recycled plastic blocks compared to conventional materials. The study utilizes tools such as Open LCA and OriginPro for data analysis and visualization. These tools help quantify and compare the environmental impacts, particularly carbon emissions, of different materials and processes throughout the life cycle of the pedestrian walkway. The results are presented in various graphs and tables, enabling a detailed comparison of the environmental performance of recycled plastic blocks against traditional construction materials.

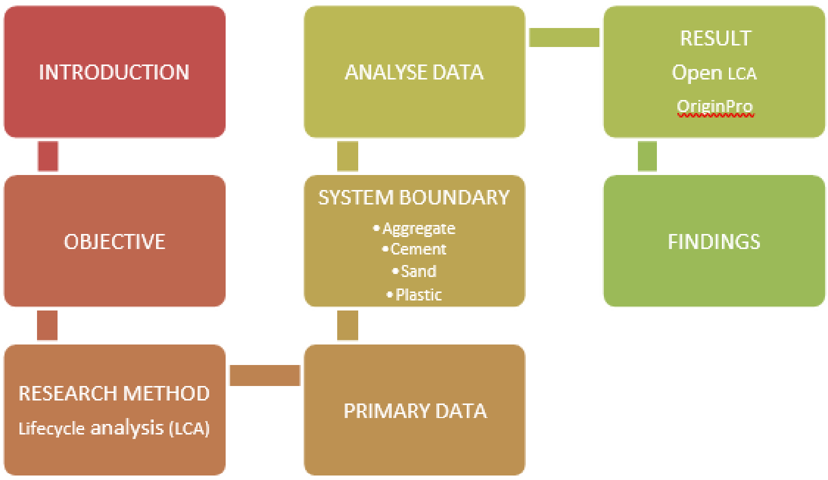

Figure 1: Life cycle analysis framework

Result and Discussion

The Life Cycle Inventory (LCI) study quantifies all materials and energy inputs and outputs within the defined system boundaries. This includes energy and raw material inputs, as well as emissions to air, water, and land, along with solid waste, goods, and co-products as outputs. The carbon emissions comparison across different materials (plastic, sand, cement, and aggregate) shows that plastic has very low emissions except during the production and construction stages. Sand emits a considerable amount of gases, with the highest emissions during the transportation stage. Cement proves to be the most environmentally harmful, with the highest emissions during production.

Figure 2 compares the carbon emissions of four materials - plastic, sand, cement, and aggregate - across various life cycle stages. This visual representation allows for a clear comparison of the environmental impact of each material throughout its use in construction. For most materials, manufacturing and transportation are the most carbon-intensive stages. The maintenance, repair, and disposal phases have the least emissions, indicating that the environmental impact of construction materials is smallest during these stages. This finding suggests that focusing on reducing emissions during the production and transportation stages, particularly for cement and sand, could have the most significant impact on overall carbon emissions in construction.

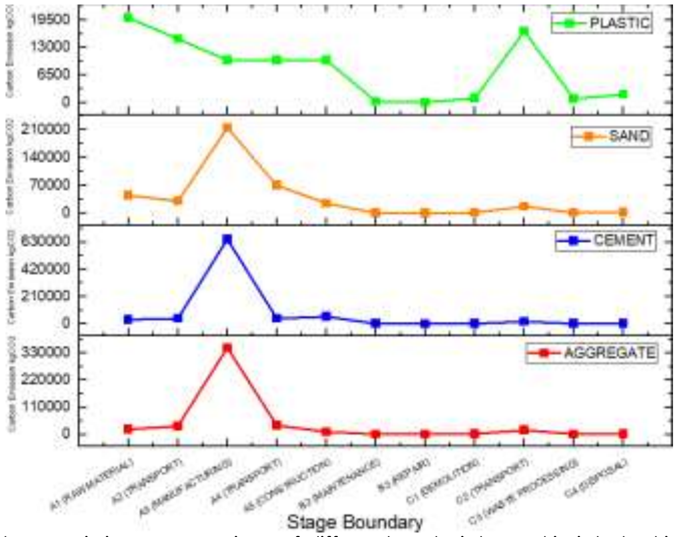

Figure 2: Life cycle carbon emissions comparison of different materials used in interlocking bricks

Figure 3 provides a detailed comparison of carbon emissions for aggregate, cement, and sand throughout the construction lifecycle stages. The graph reveals distinct emission patterns for each material. Aggregate shows relatively low emissions across all stages, with a slight peak during manufacturing, indicating it's a more environmentally friendly option. Cement, however, exhibits extremely high emissions during the manufacturing stage, far surpassing the other materials and stages. These stark peak underscores cement's significant contribution to the construction industry's carbon footprint, primarily due to its energy-intensive production process (Dong, 2023: Gungat et al., 2024). Sand displays low emissions throughout most stages but shows a noticeable increase during transportation. This highlights the environmental impact of sand logistics, suggesting that local sourcing could potentially reduce its carbon footprint. The graph effectively illustrates that among these traditional construction materials, cement is the primary concern for environmental impact, while aggregate and sand have comparatively lower emissions. This visualisation emphasises the need for innovative solutions or alternatives to cement to significantly reduce the construction industry's overall carbon emissions.

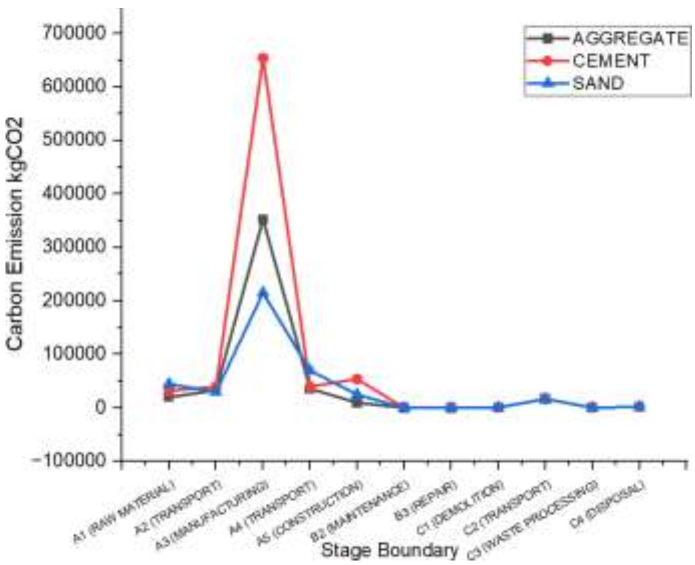

Figure 3: Carbon emissions by material type throughout construction lifecycle stages

Figure 4 presents a comparative analysis of carbon emissions between conventional and plastic interlocking bricks across various lifecycle stages. For conventional bricks, the graph shows a dramatic spike in emissions at the "A3 CEMENT" stage, indicating that cement production is by far the most carbon-intensive part of the process. This peak produces emissions from all other stages, highlighting cement as the primary environmental concern in conventional brick production. In contrast, the plastic interlocking brick graph shows a more distributed emission pattern. While it still has a peak at "A3 PLASTIC," representing the plastic manufacturing stage, this peak is significantly lower than the cement peak in conventional bricks. The plastic brick graph also shows a smaller secondary peak at "A5 SAND," likely related to the use of sand in the production process. Overall, the plastic interlocking brick demonstrates lower and more evenly distributed emissions across its life cycle compared to conventional bricks. This comparison clearly illustrates the potential environmental benefits of using recycled plastic in construction materials, particularly in reducing the carbon footprint associated with cement production in conventional methods (Shanmugavalli et al., 2017: Zainuri et al., 2024).

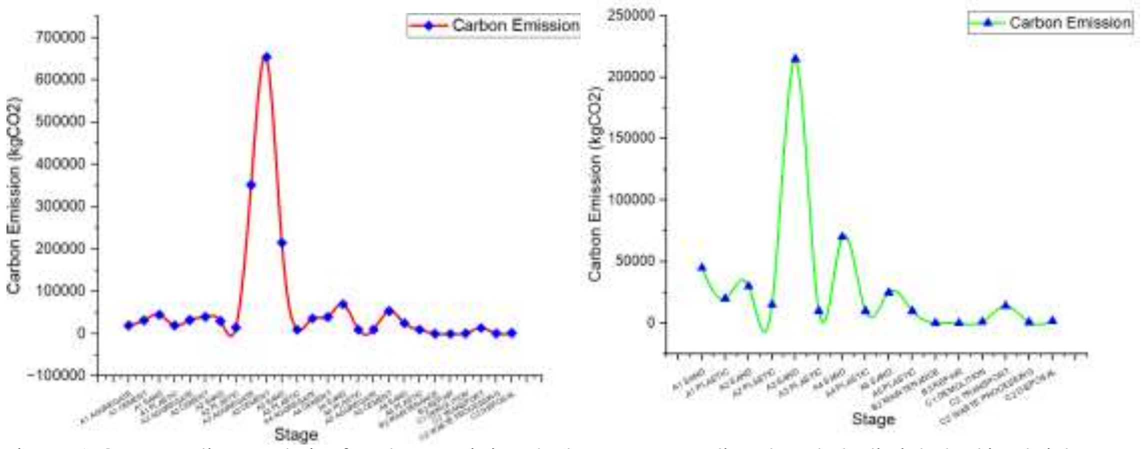

Figure 4: Comparative analysis of carbon emissions between conventional and plastic interlocking bricks

Conclusions

The study underscores the significant environmental benefits of utilizing recycled plastics in the construction of pedestrian walkways. The Life Cycle Assessment (LCA) results indicate that plastic interlocking blocks produce lower carbon emissions compared to traditional materials like cement and aggregate, particularly during the production, transportation, and disposal stage. This finding supports the shift towards sustainable construction practices, emphasizing the conservation of natural resources and the diversion of plastic waste from landfills, thereby contributing to a circular economy (Sastrawidana et al., 2022: Han et al., 2024). Despite the promising results, several limitations are acknowledged. The analysis does not fully encompass life cycle emissions, resource depletion, biodiversity loss, or potential toxicity associated with the materials. Additionally, economic factors such as cost comparisons and practical considerations like durability and performance under various environmental conditions were not comprehensively addressed. Future research should aim to fill these gaps by incorporating a broader range of environmental impact indicators and evaluating the long-term performance and economic viability of using recycled plastics in construction.

To further enhance the environmental sustainability of using plastic interlocking blocks, the study proposes several mitigation strategies. These include optimizing the manufacturing process through advanced techniques such as temperature and pressure control to reduce energy consumption and emissions. Additionally, integrating renewable energy sources like solar or wind power into the production process can further lower the carbon footprint of the manufacturing facilities. Developing a robust supply chain for recycled plastics and investing in processing equipment are crucial. While the initial costs may be high, these investments are expected to be offset by long-term benefits such as lower material costs and potential government incentives for sustainable practices. Implementing these strategies requires a collaborative approach involving industry stakeholders, policymakers, and researchers. By addressing identified environmental hotspots and improving the efficiency of production and supply chain processes, the construction sector can significantly reduce its carbon footprint and move towards more sustainable building practices.

References

Noviandini, Z. P., Dewi, O. C., Laksitoadi, B., & Widyarta, M. N. (2020). The Effect of Permeable Pavement on Pedestrian Walkway for Human Comfort. IOP Conference Series: Earth and Environmental Science, 409(1). https://doi.org/10.1088/1755-1315/409/1/012009

Sastrawidana, D. K., Sukarta, I. N., Saraswati, L. P. A., Maryam, S., & Putra, G. A. (2022). Plastic waste reinforced with inorganic pigment from red stone in manufacturing paving blocks for pedestrian application. Journal of Achievements in Materials and Manufacturing Engineering, 110(2), 49–58. https://doi.org/10.5604/01.3001.0015.7042

Sastrawidana, I. D. K. (2021a). Plastic Waste Conversion Reinforced with Rice Husk Ash and Red Stone Powder as Partial Sand Replacement for Paving Blocks Production. IOP Conference Series: Materials Science and Engineering, 1115(1), 012070. https://doi.org/10.1088/1757- 899X/1115/1/012070

Shanmugavalli, B., Gowtham, K., Jeba Nalwin, P., & Eswara Moorthy, B. (2017). Reuse of Plastic Waste in Paver Blocks. www.ijert.org

Zainuri, Yanti, G., & Megasari, S. W. (2022). Utilization of plastic waste as an eco-friendly construction material. IOP Conference Series: Earth and Environmental Science, 1041(1). https://doi.org/10.1088/1755-1315/1041/1/012084

Agyeman, S., Obeng-Ahenkora, N. K., Assiamah, S., & Twumasi, G. (2019). Exploiting recycled plastic waste as an alternative binder for paving blocks production. Case Studies in Construction Materials, 11. https://doi.org/10.1016/J.CSCM.2019.E00246

Dong, Q. (2023). Research Methods of Carbon Emissions. Highlights in Science, Engineering and Technology, 40, 412–417. https://doi.org/10.54097/HSET.V40I.6782

Gungat, L., Anthony, F., Mirasa, A. K., Asrah, H., Bolong, N., Ispal, N. A., & Matlan, S. J. (2021). Development of Paver Block Containing Recycled Plastic. IOP Conference Series: Materials Science and Engineering, 1144(1), 012094. https://doi.org/10.1088/1757-899x/1144/1/012094

Heiniger, S., Leterrier, Y., Bastien Masse, M., & Vaucher, J. (2022). Development of Interlocking Composite Bricks Made From Recycled Plastic and Construction Waste 1 Structural Xploration Lab (SXL) EPFL / 2 Laboratory for Processing of Advanced Composites (LPAC), EPFL Motivation and Objectives.

Arulrajah, A., Yaghoubi, E., Wong, Y. C., & Horpibulsuk, S. (2017). Recycled plastic granulesand demolition wastes as construction materials: Resilient moduli and strength characteristics.
Construction and building materials, 147, 639-647.

Han, S. H., Khayat, K. H., Park, S., & Yoon, J. (2024). Machine learning-based approach for optimizing mixture proportion of recycled plastic aggregate concrete considering compressive strength, dry density, and production cost. Journal of Building Engineering, 83, 108393.

Zou, S. L., Xiao, L. P., Yin, W. Z., Gui, T., Zhang, Y., Li, Q., & Sun, R. C. (2024). Biodegradable, recyclable, waterproof, antibacterial and high-strength supramolecular plastic fabricated from lignin derivatives. Sustainable Materials and Technologies, e00861.