

Engineering Design of a Recycled Plastic Based Batako Molding Machine for Small Scale Applications

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Abstract—Plastic waste accumulation continues to increase in developing countries, while its use in construction materials has mostly emphasized material performance rather than production technology. Batako, a nonstructural masonry block widely applied in small-scale construction, offers an opportunity for recycled plastic utilization because of its functional role and simple manufacturing process. This study aims to develop and conceptually validate the engineering design of a recycled plastic-based batako molding machine suitable for small-scale production. A systematic engineering design methodology is applied, including requirement analysis, conceptual system configuration, mechanical subsystem design, pressing force modeling, structural safety evaluation, and manufacturability assessment. Analytical calculations determine pressing force requirements, lever system advantage, stress distribution, deflection limits, buckling safety, and overall structural feasibility. The proposed design adopts a vertical press configuration with a manually operated lever mechanism, standardized batako mold dimensions, and a rigid steel frame fabricated from locally available materials using common workshop tools. Results of the analytical evaluation indicate that the configuration is mechanically feasible for manual operation, provides adequate compaction force for nonstructural masonry blocks, and maintains structural safety under repetitive loading. Although physical prototyping and experimental testing are not included, the design establishes a technically justified framework that bridges recycled plastic material research with practical small-scale manufacturing solutions. This work provides a foundation for future prototyping, experimental validation, and implementation in community-based construction settings, supporting sustainable practices and circular economy principles.

Keywords— Batako molding machine, nonstructural masonry block, engineering design, small-scale production, sustainable construction.

I. INTRODUCTION

Plastic waste has become a global environmental problem because plastic materials persist in the environment, production volumes continue to increase, and natural decomposition does not occur within a reasonable time [1], [2]. Developing countries such as Indonesia experience increasing pressure as plastic consumption grows while recycling infrastructure remains limited [3]. This situation leads to large amounts of plastic waste accumulating in landfills and natural environments, creating long-term ecological problems and reducing environmental quality [4]. These conditions encourage research efforts focused on recycling approaches that reduce waste while producing materials applicable in practical contexts [2][5].

One approach to plastic waste utilization involves its application in construction materials. Batako is a non-structural masonry block commonly used for partition walls, fencing, and low-rise buildings, especially in Indonesia and other developing regions [6][7]. Producers typically manufacture batako using simple molding and pressing processes with cement-based or alternative composite mixtures [8]. Batako does not function as a primary load-bearing element and therefore does not require strict structural performance criteria [9]. Its role is mainly architectural and functional. These characteristics allow material modification and innovation, including the use of recycled plastic, without affecting its intended application [10][11].

Communities widely use batako because production costs remain low, fabrication processes remain simple, and

manufacturing can be operated at a small scale [12]. These conditions match the operational characteristics of micro and small enterprises, which often face limitations in capital, machinery, and technical resources [4][7]. Batako therefore provides a suitable medium for construction innovation that combines material efficiency, environmental considerations, and practical manufacturability [4][13].

Previous research has focused mainly on the material properties of plastic-based batako. Researchers have examined replacing cement or sand with recycled plastics such as high-density polyethylene and polyethylene terephthalate [6]. These studies evaluate parameters including compressive strength, water absorption, durability, and density [14]. Reported results indicate that incorporating plastic can reduce material weight and improve moisture resistance [15]. These findings demonstrate the feasibility of plastic-based batako as a non-structural construction material. Most studies, however, remain limited to laboratory-scale testing and provide only limited discussion of production technology and manufacturing feasibility under practical conditions [16][14]. Small-scale enterprises often cannot adopt such systems due to financial constraints, limited technical expertise, and maintenance challenges [19].

Research attention toward production machinery remains limited despite the growing evidence supporting plastic-based batako materials [17]. Existing batako molding machines are generally designed for conventional cement sand mixtures or for industrial-scale production [18]. Small-scale enterprises often cannot adopt such systems due to financial constraints, limited technical expertise, and maintenance challenges [19].

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The gap between material development and appropriate production technology limits the practical adoption of recycled plastic batako[13]. Small enterprises face difficulties in implementing plastic-based batako without affordable, easy-to-operate molding machines [18][13]. Addressing this limitation requires an engineering approach that focuses on machine design while accounting for constraints in small-scale production environments [20].

This paper focuses on the engineering design and conceptual validation of a batako molding machine for small-scale applications using recycled plastic. The design process emphasizes structural configuration, mold design, pressing mechanism, and manufacturability[20][21]. Analytical evaluation and engineering calculations support the assessment of mechanical feasibility, cost considerations, and compatibility with commonly available materials and basic workshop facilities. The scope of this work is limited to design development and conceptual validation and does not include physical fabrication, experimental testing, or field application.

This work contributes to the development of appropriate production technology by connecting recycled plastic material research with practical manufacturing requirements for small enterprises. The proposed machine design prioritizes simplicity, ease of fabrication, and maintenance. The objective of this paper is to develop and conceptually validate an engineering design for a batako molding machine that uses recycled plastic and supports small-scale production. The presented design provides a technical foundation for future prototyping, experimental evaluation, and community-based implementation[13] [21].

II. LITERATURE REVIEW

A. Engineering Challenges in Nonstructural Masonry Block Production

Nonstructural masonry blocks are commonly produced through simple molding and pressing methods, especially in small-scale construction. These systems depend on press configuration, force transmission, mold rigidity, and dimensional stability during demolding. Most studies describe masonry blocks mainly as material products, focusing on strength, density, or durability[22]. As a result, engineering aspects such as pressing mechanism design, load distribution, and the structural behavior of molding equipment receive little attention. This lack of focus creates uncertainty when alternative materials, such as recycled plastics, are introduced into conventional production systems[23][24]. This condition indicates the need for closer integration between material characteristics and machine design in nonstructural masonry block production

B. Influence of Material Characteristics on Pressing and Molding Systems

Material properties play a critical role in the performance of molding and pressing systems. Parameters such as particle stiffness, internal friction, and elastic recovery affect

compaction efficiency, stress distribution, and mold filling behavior. Conventional cement-based mixtures with mineral aggregates generally respond predictably under compressive loading, allowing standard press designs to achieve consistent densification[19]. Recycled plastic-based mixtures exhibit different mechanical behavior due to lower stiffness and higher elasticity. These characteristics alter the way pressure is transmitted during pressing and influence demolding performance and dimensional stability[25]. While several studies report changes in density and water absorption when recycled plastics are incorporated, limited attention is given to how these material properties interact with pressing mechanisms and mold structures[6][17]. This gap shows the need to view molding machines as adaptable systems rather than fixed tools.

C. Limitations of Existing Molding Machine Designs

Molding machines for masonry blocks are generally categorized into manual presses and industrial-scale automated systems. Manual presses are widely used in small-scale production because of their simplicity and low cost, but they often lack consistent control of compaction force and dimensional accuracy[11]. Variability in operator input can result in uneven block quality.

Industrial-scale systems provide high productivity and controlled compaction but require complex mechanisms, high energy input, and advanced control systems. These characteristics make them unsuitable for micro and small enterprises. In addition, machines designed for conventional cement-sand mixtures may not provide adequate pressure distribution or structural stability when applied to recycled plastic-based materials[26][4]. Few studies provide detailed engineering evaluations of these mismatches, leaving an important gap in the literature.

D. Design-Oriented Approaches for Small-Scale Production Machinery

Engineering design research emphasizes the importance of conceptual and analytical validation before physical implementation, especially in resource-limited environments. Such studies often evaluate structural configuration, force transmission, and manufacturability using analytical methods. For small-scale block production, machines must combine mechanical effectiveness with fabrication simplicity[20][17]. Press mechanisms should generate enough compaction force without complex power systems, while molds must maintain dimensional accuracy and remain easy to fabricate and maintain. Despite these clear requirements, only a limited number of studies propose molding machine designs specifically for recycled plastic-based masonry blocks[27]. Most research remains focused on material properties, leaving the engineering design of production machinery underexplored. This gap highlights the need for systematic design studies that integrate material behavior with machine configuration to support small-scale and community-based production.

III. METHODOLOGY

This research employs a systematic engineering design

methodology to develop and conceptually validate a recycled plastic-based concrete masonry block (batako) molding machine intended for small-scale production environments.

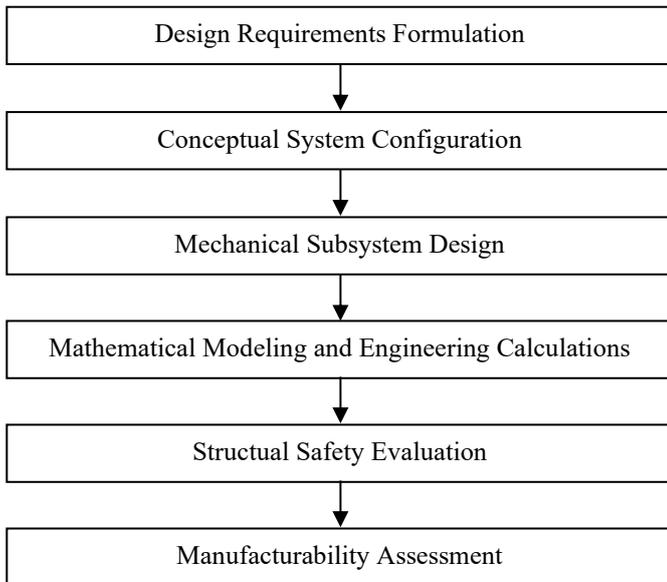


Fig. 1. Engineering Design Methodology of the Molding Machine

A. Design Requirements Analysis

The first stage involves defining both functional and non-functional requirements. Functionally, the machine must be capable of producing blocks with consistent geometry through a pressing process suitable for recycled plastic-based mixtures. It must provide sufficient compaction force to consolidate the material while maintaining the dimensional stability of the molded product. Non-functional requirements include low fabrication cost, ease of operation, reliance on locally available materials, and simple maintenance. Structural stability, operator safety, and durability under repetitive loading are also considered essential design criteria.

B. Conceptual System Design

The second stage develops the conceptual system configuration. The machine is divided into four primary subsystems: the supporting frame, the mold assembly, the pressing mechanism, and the force transmission interface. The frame ensures structural integrity, the mold defines block geometry, the pressing mechanism generates compaction force, and the transmission interface transfers operator input to the pressing system. Alternatives such as lever-based and screw-driven presses are evaluated based on mechanical advantage, operational simplicity, and manufacturability. A simple and robust concept is selected to ensure feasibility for small-scale implementation.

C. Mechanical Subsystem Design

The third stage involves detailed mechanical design of each subsystem. The frame is dimensioned to resist axial, bending, and shear loads during pressing. The mold assembly is designed to maintain dimensional accuracy while facilitating compaction and demolding. The pressing mechanism is designed to

generate the required force through mechanical advantage, while keeping operator effort within acceptable limits.

D. Pressing Force Modeling and Design Calculations

The fourth stage focuses on establishing the mechanical feasibility of the pressing process by modeling the force requirements needed to compact recycled plastic mixtures into consistent block shapes. The analysis begins by determining the effective pressing area, which is governed by the geometric dimensions of the mold cavity:

$$A = L \times W$$

where A is the pressing area (m^2), L is block length (m), and W is block width (m).

Based on this area, the minimum pressing force is calculated to meet the target compaction pressure necessary for material consolidation:

$$F_{press} = P_{target} \times A$$

where F_{press} is the required pressing force (N) and P_{target} is the target compaction pressure (Pa).

To ensure that the machine can deliver this force efficiently, two mechanical alternatives are considered: lever-based and screw-based pressing mechanisms. For the lever system, the force transmission is analyzed using moment equilibrium principles:

$$F_{in} \times l_{in} = F_{out} \times l_{out}$$

thus,

$$F_{out} = F_{in} \times \frac{l_{in}}{l_{out}}$$

where F_{in} is the operator input force (N), F_{out} is the output pressing force (N), and l_{in} , l_{out} are lever arm lengths (m).

In the screw-based configuration, the mechanical advantage is derived from the relationship between the handle radius and the screw pitch:

$$MA = \frac{2\pi r}{p}$$

and the output force is estimated by:

$$F_{out} = \eta \times MA \times F_{in}$$

where r is the handle radius (m), p is the screw pitch (m), and η is the mechanical efficiency.

These formulations provide a quantitative foundation for selecting and dimensioning the pressing mechanism, ensuring that it can achieve the required compaction force under manual operation in small-scale production settings.

E. Structural Safety Evaluation

The fifth stage evaluates the structural safety of the molding machine to ensure that all components can withstand the applied loads during pressing operations. This evaluation involves several aspects of mechanical analysis, including axial, bending, and shear stresses; buckling stability; deflection limits; and safety factor determination. Each of these parameters is assessed to confirm that the design remains structurally sound under repetitive manual operation.

Axial stress is examined for frame members subjected to compressive or tensile loads, ensuring that the cross-sectional area can resist the applied force:

$$\sigma_{axial} = \frac{F}{A_c}$$

Bending stress is analyzed for horizontal members that experience flexural loads during pressing:

$$\sigma_{bending} = \frac{M \cdot c}{I}$$

Shear stress is considered for pins and bolts that transfer forces within the assembly:

$$\tau = \frac{V}{A_s}$$

Buckling stability of vertical frame members is assessed using Euler's critical load equation, which determines the maximum load a column can sustain before instability occurs:

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

The applied compressive load must satisfy the requirement:

$$F_{column} < \frac{P_{cr}}{n}$$

Deflection analysis is performed to ensure dimensional stability during pressing. For a simply supported beam with a central load, the maximum deflection is:

$$\delta_{max} = \frac{FL^3}{48EI}$$

For a uniformly distributed load, the deflection is:

$$\delta_{max} = \frac{5wL^4}{384EI}$$

Finally, the safety factor is calculated to provide a conservative margin between allowable stress and maximum calculated stress:

$$n = \frac{\sigma_{allow}}{\sigma_{max}}$$

This comprehensive evaluation ensures that the machine design achieves adequate strength, stiffness, and stability, thereby guaranteeing safe and reliable operation in small-scale production environments.

F. Manufacturability Assessment

The final stage assesses manufacturability. Evaluation considers material availability, fabrication processes, assembly simplicity, and maintenance accessibility. The design prioritizes standard steel sections, conventional fasteners, and basic fabrication techniques such as cutting, drilling, and welding. This ensures alignment with appropriate technology principles and feasibility for implementation in small-scale workshops.

IV. MECHANICAL DESIGN AND SYSTEM DESCRIPTION

The mechanical design of the proposed recycled-plastic-based batak molding machine is illustrated through multiple projections to clearly describe the system configuration, component alignment, and force-transmission mechanism. An isometric overview and orthographic views are provided to support the detailed explanation of each mechanical subsystem, as shown in Figures 2–6.

A. Overall System Configuration

The proposed batak molding machine adopts a vertical press configuration consisting of four main subsystems:

1. Supporting frame,
2. Mold and hopper assembly,

3. Pressing plate and vertical guide system, and
4. Manual lever-based force transmission mechanism.

The machine's overall dimensions are designed to ensure stability during operation while maintaining a compact footprint suitable for small workshops.

Overall machine dimensions (design specification):

- Total height: ≈ 1500 mm
- Overall width: ≈ 600 mm
- Overall depth: ≈ 700 mm

This configuration allows vertical load transfer directly from the pressing mechanism to the base frame, minimizing eccentric loading and improving structural reliability. The overall configuration and spatial arrangement of the supporting frame, mold and hopper assembly, pressing plate, and manual lever mechanism are illustrated in the isometric view shown in Figure 2, which provides a comprehensive visualization of the integrated mechanical system.

B. Supporting Frame Structure

The supporting frame serves as the primary load-bearing structure and is designed to resist compressive loads generated during the pressing process. The frame consists of four vertical columns connected by horizontal cross members at the base, mid-height, and top sections.

Frame design characteristics:

1. Frame type: rigid welded steel structure
2. Material: structural steel hollow sections
3. Vertical column section: $40 \text{ mm} \times 40 \text{ mm} \times 2 \text{ mm}$
4. Horizontal bracing section: $30 \text{ mm} \times 30 \text{ mm} \times 2 \text{ mm}$

The vertical columns are arranged symmetrically to support the pressing plate and guide system. A widened base frame distributes reaction forces to the ground, improving stability during manual operation. The symmetrical frame structure and vertical alignment between the pressing plate and mold cavity are clearly illustrated in the front view shown in Figure 3, highlighting the load-bearing arrangement and the frame's structural stability during pressing operations.

C. Mold and Hopper Assembly

The mold assembly defines the geometry of the batak and ensures dimensional consistency during compaction. The design uses a single-cavity mold suitable for non-structural batak production.

Batak mold cavity dimensions (design target):

- Length (L): 390 mm
- Width (W): 190 mm
- Height (H): 100 mm

These dimensions correspond to commonly used non-structural batak sizes in small-scale construction.

The mold walls are designed with straight vertical surfaces to facilitate uniform compaction and ease of demolding. The hopper is mounted above the mold cavity and serves as a guide for material loading. Its sloped geometry assists gravity-fed feeding of the recycled plastic-based mixture while minimizing material spillage. The mold assembly is detachable, allowing cleaning, maintenance, and potential size modification without altering the main frame.

The geometry of the mold cavity and the relative placement

of the hopper are illustrated in the top view presented in Figure 4, which demonstrates how material feeding is guided directly into the mold cavity to support consistent filling and compaction.

D. Pressing Plate and Guide System

The pressure plate is positioned directly above the mold cavity and is aligned concentrically to ensure uniform pressure distribution. The plate moves vertically along guide rods attached to the frame, preventing lateral displacement during operation.

Pressure Plate Dimensions:

- Pressure Area: 390 mm × 190 mm
- Plate Thickness: 8–10 mm steel plate

The guide system ensures that the pressure force is applied perpendicular to the mold surface, reducing uneven density distribution and minimizing wear on the mold walls. As shown in Figure 5, the pressure plate is aligned vertically with the mold cavity. It is constrained by the guide system, ensuring uniform force application and preventing lateral displacement during compaction.

E. Pressing Mechanism and Lever System

The pressing mechanism is activated by a manually operated lever connected to the pressure plate via a mechanical linkage. The lever provides a mechanical advantage, allowing the operator to generate sufficient pressing force with controlled effort.

Lever system design parameters:

- Lever length (input arm): ≈ 900 mm
- Lever pivot distance to output linkage: ≈ 150 mm

The lever-based pressing mechanism and its geometric relationship to the pressure plate in a side view are shown in Figure 6, highlighting the mechanical advantage and vertical force transmission path adopted in the proposed design.

F. Force Transmission Path

The force transmission path follows a direct vertical line from the lever input through the linkage to the pressure plate and mold cavity. This alignment minimizes bending moments and reduces stress concentrations within the frame.

The pivot connection is designed using standard steel pins and bushings to accommodate repeated loading cycles while maintaining smooth operation. The simplicity of the force transmission system contributes to easy maintenance and long-term use. Figure 6 shows the direct vertical force transmission path from the lever input to the pressure plate, demonstrating how the design minimizes bending moments and increases structural efficiency.

G. Operational Sequence

The operational sequence of the machine consists of:

1. Loading the recycled plastic-based mixture into the mold via the hopper
2. Actuating the lever to apply a vertical compressive force
3. Holding the press momentarily to allow material consolidation
4. Releasing the lever and removing the molded batako

This sequence is intentionally simple and repeatable,

minimizing operator training requirements and supporting consistent production output.

H. Design Integration with Engineering Calculations

All major dimensions and component selections are directly linked to the engineering calculations presented in the Design Methodology. The pressing area corresponds to the area used in force calculations, the lever geometry reflects the required mechanical advantage, and frame member dimensions are selected based on stress, deflection, and buckling considerations.

This integration ensures that the mechanical design is not only visually coherent but also analytically justified.

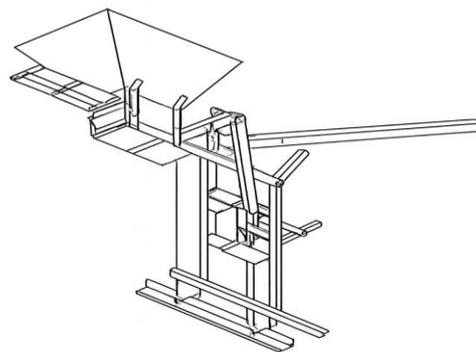


Fig. 2. Isometric view of the proposed recycled plastic-based batako molding machine design.

Figure 2 presents the isometric view of the proposed batako molding machine, illustrating the overall mechanical configuration and spatial arrangement of the main subsystems. The figure highlights the integrated structure of the supporting frame, mold and hopper assembly, pressing plate, and manual lever-based pressing mechanism. This view provides a comprehensive representation of the machine geometry and demonstrates the vertical press configuration adopted to ensure direct load transfer and structural stability during the molding process.

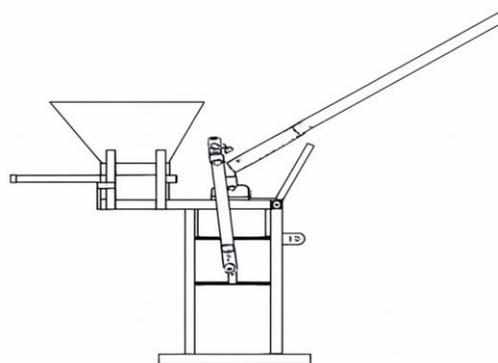


Fig. 3. Front view illustrating frame structure, mold position, and pressing plate alignment.

Figure 3 shows the front view of the batako molding machine, emphasizing the symmetrical arrangement of the supporting frame and the vertical alignment between the pressing plate and the mold cavity. The figure illustrates how the pressing plate is positioned directly above the mold to enable uniform distribution of compressive force across the

batako cross-section. The front view also highlights the vertical guide system, which constrains the pressing plate's motion and prevents lateral displacement during operation.

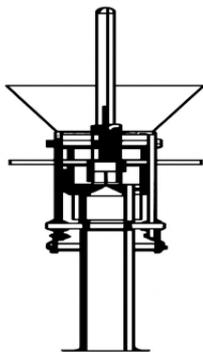


Fig. 4. Side view showing lever mechanism and vertical force transmission path.

Figure 4 presents the side view of the machine, focusing on the manual lever mechanism and the force transmission path from the operator input to the pressing plate. The figure illustrates the lever arm geometry and pivot location that provide a mechanical advantage, enabling sufficient pressing force to be generated through manual operation. The vertical alignment of the force transmission path is shown to minimize bending moments and ensure efficient transfer of compressive loads to the mold assembly.

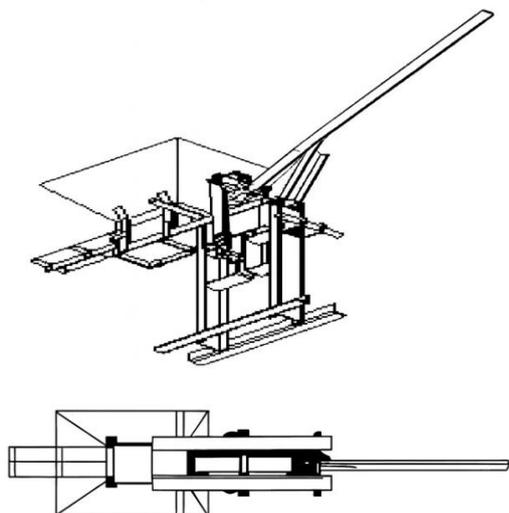


Fig. 5, 6. Top view highlighting mold cavity dimensions and hopper placement.

Figure 5 and figure 6 shows a top view of the batako molding machine, highlighting the mold cavity geometry and the hopper's placement relative to the pressing area. The figure illustrates the rectangular mold cavity designed to produce non-structural batako with consistent dimensions. The hopper placement above the mold cavity is shown to facilitate uniform material feeding, minimize spillage, and improve loading convenience.

Together, Figures 2–6 provide a complete visual representation of the proposed batako molding machine, supporting the analytical design and dimensional specifications discussed in this section. The integration of isometric and

orthographic views ensures clarity in understanding the mechanical configuration, component interactions, and load-transfer mechanisms underlying the proposed design.

V. DISCUSSION

The primary limitation of this study lies in the absence of physical prototyping and experimental validation of the proposed batako molding machine design. Although the vertical press configuration and lever-based force transmission system are analytically designed to provide sufficient compaction force while maintaining simplicity and ease of operation, their actual performance under real operating conditions has not yet been verified. Similarly, the mold configuration, which uses standardized batako dimensions and a detachable structure to enhance accessibility and manufacturability, has been evaluated only at the conceptual level. As a result, factors such as material behavior during pressing, operational ergonomics, structural durability under repeated loading, and production consistency remain unexamined. These limitations indicate that further work, including prototype fabrication and experimental testing, is required to confirm the practical effectiveness of the proposed design in small-scale production environments.

VI. CONCLUSION

The proposed design adopts a vertical pressing layout with a simple hand-operated lever mechanism, intended for fabrication and use in small workshop environments. The contribution of this work lies in addressing production technology as a key factor enabling the practical implementation of non-structural building blocks made from recycled plastic. By prioritizing ease of fabrication and adaptability over high production capacity, the proposed design bridges the gap between materials-oriented research and manufacturable solutions, providing a technical basis for future prototyping, experimental validation, and further refinement toward sustainable small-scale production of construction materials.

VII. FUTURE WORK

Physical prototyping and experimental evaluation may be conducted to validate the analytical assumptions and mechanical configuration of the proposed molding machine. Prototype fabrication would enable assessment of structural behavior, force transmission, and operational usability under practical conditions. Experimental testing using recycled plastic-based mixtures could further examine material response during pressing, demolding behavior, and dimensional consistency of the produced blocks. Design refinement may also focus on improving the pressing mechanism and mold configuration to enhance adaptability for small-scale production. Field-based evaluation in workshop or community settings may provide feedback on usability and maintenance, supporting the transition from conceptual design toward practical implementation within sustainable construction frameworks.

REFERENCES

- [1] C. A. Foedarsono, J. L. Gunawan, N. X. Indrajaya, and N. A. Karim, "From Trash to Treasure: The Benefit of Adopting Eco-block as a Construction Material," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1564, no. 1, 2025, doi: 10.1088/1755-1315/1564/1/012116.
- [2] J. A. Oyewale, L. K. Tartibu, and I. P. Okokpujie, "A Comparative Bibliometric Analysis on Plastic Waste Recycling," *Int. J. Sustain. Dev. Plan.*, vol. 18, no. 11, pp. 3401–3417, 2023, doi: 10.18280/ijstdp.181106.
- [3] N. Sakr and M. AbouZeid, "Recycling of Plastic Waste in the Construction Industry," *Polymers (Basel)*, vol. 17, no. 9, 2025, doi: 10.3390/polym17091282.
- [4] M. Riduwan and T. R. Sahroni, "Enhancing Plastic Recycling Efficiency through Automated Screen Mesh Cleaning: A Quantitative-Experimental Study," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1564, no. 1, 2025, doi: 10.1088/1755-1315/1564/1/012111.
- [5] R. Kumar *et al.*, "Impacts of plastic pollution on ecosystem services, sustainable development goals, and need to focus on circular economy and policy interventions," *Sustain.*, vol. 13, no. 17, pp. 1–40, 2021, doi: 10.3390/su13179963.
- [6] I. Antonopoulos, G. Faraca, and D. Tonini, "Recycling of post-consumer plastic packaging waste in EU: Process efficiencies, material flows, and barriers," *Waste Manag.*, vol. 126, pp. 694–705, 2021, doi: 10.1016/j.wasman.2021.04.002.
- [7] O. Kehinde, O. J. Ramonu, K. O. Babaremu, and L. D. Justin, "Plastic wastes: environmental hazard and instrument for wealth creation in Nigeria," *Heliyon*, vol. 6, no. 10, p. e05131, 2020, doi: 10.1016/j.heliyon.2020.e05131.
- [8] F. A. Salih, F. Usman, G. Hayder, and Y. Al-Ani, "Evaluation of Some Beneficial Environmental Impacts and Enhanced Thermal Properties Resulting from Waste Plastic Integration into Concrete," *Ann. Chim. Sci. des Mater.*, vol. 47, no. 3, pp. 165–178, 2023, doi: 10.18280/acsm.470306.
- [9] A. Singh *et al.*, "Utilization of Plastic Waste for Developing Composite Bricks and Enhancing Mechanical Properties: A Review on Challenges and Opportunities," *Adv. Polym. Technol.*, vol. 2023, 2023, doi: 10.1155/2023/6867755.
- [10] B. F. Apriadi, R. P. Setiawan, and I. Firmansyah, "Policy scenario of plastic waste mitigation in Indonesia using system dynamics," *Waste Manag. Res.*, vol. 42, no. 11, pp. 1008–1018, 2024, doi: 10.1177/0734242X241231396.
- [11] J. P. Lange, "Managing Plastic Waste-Sorting, Recycling, Disposal, and Product Redesign," *ACS Sustain. Chem. Eng.*, vol. 9, no. 47, pp. 15722–15738, 2021, doi: 10.1021/acssuschemeng.1c05013.
- [12] A. S. Al-Luhybi and D. N. Qader, "Mechanical Properties of Concrete with Recycled Plastic Waste," *Civ. Environ. Eng.*, vol. 17, no. 2, pp. 629–643, 2021, doi: 10.2478/cee-2021-0063.
- [13] J. B. Parulian, "Design of Batako Molding Machine Using Value Engineering Method," *Pros. CELSciTech*, vol. 4, pp. 14–17, 2019, [Online]. Available: https://scholar.google.com/citations?view_op=view_citation&hl=en&user=sCkxre4AAAAJ&pagesize=100&citation_for_view=sCkxre4AAAAJ:zYLM7Y9cAGgC
- [14] K. Shanmugam, S. Bryngelsson, K. Östergren, and E. Hallström, "Climate Impact of Plant-based Meat Analogues: A Review of Life Cycle Assessments," *Sustain. Prod. Consum.*, vol. 36, pp. 328–337, 2023, doi: 10.1016/j.spc.2023.01.014.
- [15] S. Saetta and V. Caldarelli, "Lean production as a tool for green production: The Green Foundry case study," *Procedia Manuf.*, vol. 42, no. 2019, pp. 498–502, 2020, doi: 10.1016/j.promfg.2020.02.042.
- [16] C. Feng and S. Huang, "The analysis of key technologies for sustainable machine tools design," *Appl. Sci.*, vol. 10, no. 3, 2020, doi: 10.3390/app10030731.
- [17] K. Babaremu, A. Adediji, N. Olumba, S. Okoya, E. Akinlabi, and M. Oyinlola, "Technological Advances in Mechanical Recycling Innovations and Corresponding Impacts on the Circular Economy of Plastics," *Environ. - MDPI*, vol. 11, no. 3, pp. 1–21, 2024, doi: 10.3390/environments11030038.
- [18] Dan William C. Martinez, "Optimized Compression Molding Machine for Biocomposite Production from Agricultural Waste," *Int. J. Sci. Multidiscip. Res.*, vol. 3, no. 2, pp. 171–190, 2025, doi: 10.55927/ijsmr.v3i2.48.
- [19] O. Oguntola, K. Boakye, and S. Simske, "Towards Leveraging Artificial Intelligence for Sustainable Cement Manufacturing: A Systematic Review of AI Applications in Electrical Energy Consumption Optimization," *Sustain.*, vol. 16, no. 11, 2024, doi: 10.3390/su16114798.
- [20] A. Ramos, V. G. Angel, M. Siqueiros, T. Sahagun, L. Gonzalez, and R. Ballesteros, "Reviewing Additive Manufacturing Techniques: Material Trends and Weight Optimization Possibilities Through Innovative Printing Patterns," *Materials (Basel)*, vol. 18, no. 6, 2025, doi: 10.3390/ma18061377.
- [21] A. Setyadi, S. Pawirosumarto, and A. Damaris, "Rethinking Sustainable Operations: A Multi-Level Integration of Circularity, Localization, and Digital Resilience in Manufacturing Systems," *Sustain.*, vol. 17, no. 15, pp. 1–47, 2025, doi: 10.3390/su17156929.
- [22] S. Sultana, K. U. Sarker, and Z. Islam, "Comparative Analysis of Compression Molded Products of Recycled Waste Poly (Vinyl Chloride) and Virgin Poly (Vinyl Chloride) Fill Material," vol. 54, no. 4, 2022, doi: 10.5614/j.eng.technol.sci.2022.54.4.12.
- [23] M. Contreras-Ilanes, M. Romero, M. Jes, and J. Pedro, "Recycled Aggregates from Construction and Demolition Waste in the Manufacture of Urban Pavements," 2021.
- [24] J. Zhu, X. Tang, A. Etxeberria, and E. Y. Chen, "Packaging materials with desired mechanical and barrier properties and full chemical recyclability," *Nat. Commun.*, pp. 1–7, 2019, doi: 10.1038/s41467-019-11525-x.
- [25] S. Ahmed and M. Ali, "Tensile and Flexural Properties of Recycled HDPE for Application in Building Products," vol. 01038, 2024.
- [26] J. Oti, B. O. Adeleke, M. Rathnayake, and J. M. Kinuthia, "Strength and Durability Characterization of Structural Concrete Made of Recycled Plastic," 2024.
- [27] B. Vogt, "Effect Of Recycled Plastic In Concrete On Its Compressive And Thesis Advisor," no. May, 2024.