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Development of a Construction Management Decision Framework for the Use of Crumb Rubber-Modified Concrete Masonry Units

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Abstract

Concrete Masonry Units (CMUs) are widely used for non-load-bearing walls in building construction; however, conventional CMUs are often produced with material properties that exceed the functional requirements of such applications, leading to material inefficiencies. This study developed a Construction Management decision framework for selecting crumb rubber–modified concrete masonry units for non-load-bearing applications. The study evaluated the performance characteristics of conventional and crumb rubber–modified CMUs, with and without steel mesh reinforcement, in terms of density, compressive strength, and strength development. Laboratory results were analyzed and benchmarked against applicable standards for non-load-bearing masonry units. The findings show that crumb rubber modification influences CMU density and compressive strength, producing properties that may be suitable for non-load-bearing applications, while steel mesh reinforcement can enhance mechanical performance. Based on the experimental results and standards-based evaluation, a structured decision framework was developed to support construction managers and engineers in selecting appropriate CMU alternatives for non-load-bearing walls. The study provides a practical decision-support tool that links laboratory performance data with construction management requirements.

Keywords: concrete masonry units, crumb rubber modification, non-load-bearing walls, construction management, decision framework

INTRODUCTION

Conventional Concrete Masonry Units (CMUs) used in non-load-bearing applications often exceed functional strength requirements, resulting in material inefficiency and high resource consumption. To address this, the integration of crumb rubber - recycled tire granules with a low specific gravity of 0.9–1.2 compared to 2.6–2.71 for natural aggregates - offers a sustainable path toward reducing unit weight and improving resource utilization (Mohajerani et al., 2020; Bu et al., 2022).

While previous research indicates that crumb rubber can influence density, compressive strength, and deformation behavior (Hasan, et al., 2024; Strukar et al., 2019), it often leads to a more porous concrete matrix and reduced mechanical performance. To mitigate these effects, steel mesh reinforcement is utilized to enhance tensile properties and crack resistance. The effectiveness of this reinforcement is highly dependent on fiber orientation and the "bridging action" across crack planes, which facilitates post-cracking load capacity and toughness (Faustmann et al., 2024; Gali & Subramaniam, 2017).

Despite the potential of rubberized concrete, there is a significant lack of structured guidance for construction managers to translate laboratory performance into site-level decision-making.

This study bridges that gap by adopting an Independent/Dependent Variable (IV-DV) model to develop a decision framework for selecting crumb rubber–modified CMUs in non-load-bearing applications. The Independent Variables (concrete mix design, crumb rubber content, and steel mesh reinforcement) are analyzed as predictors for the Dependent Variables (density and compressive strength).

LITERATURE REVIEW

Concrete Masonry Units in Non-Load-Bearing Construction. Concrete masonry units are primarily categorized by density and internal geometry, where normal-weight units utilize dense aggregates to provide high strength at the expense of increased dead load, while lightweight units incorporate expanded shale, clay, or industrial by-products to improve thermal properties and reduce handling effort (ASTM International, 2022, 2022b; Drysdale, 2011; Mehta, 2014). In terms of configuration, hollow blocks are the industry standard for non-load-bearing partitions due to material volume savings and service routing, whereas solid blocks are reserved for high-impact use (Neville & B.J.J., 2010). Modern production is increasingly shifting toward sustainability by integrating recycled materials like fly ash and slag to reduce environmental impacts (Mehta, 2014), supporting the use of crumb rubber as a partial aggregate replacement to align mechanical properties with the functional demands of infill systems. By balancing these internal geometries with alternative material streams, construction managers can optimize building performance while maintaining adherence to established compliance standards.

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Performance Requirements for Non-Load-Bearing CMU. Non-load-bearing CMUs must adhere to rigorous performance standards, such as those in ASTM C129, which establish minimum compressive strength thresholds sufficient for handling and in-service stresses without the over-engineering typical of structural units (ASTM International, 2022b). Beyond strength, density and weight are critical for minimizing dead loads in seismic regions and multi-story structures (Mehta, 2014), while strictly enforced durability and water absorption limits prevent issues like shrinkage and moisture penetration (Neville & B.J.J., 2010). Regulatory oversight by TMS 402/602, the National Structural Code of the Philippines (NSCP), and DPWH specifications ensures these materials are applied safely within their intended scope and clearly identified to prevent accidental structural use (ASEP, 2020; DPWH, 2016b). This framework emphasizes that alternative units, such as rubber-modified CMUs, must maintain stringent quality control regarding absorption and dimensional stability to be credibly adopted in professional practice.

Typical Construction and Usage Practices. In modern construction, non-load-bearing CMUs are the primary solution for partitions and infill within structural frames, typically installed after the primary structure to carry only their self-weight and minor lateral loads (Drysdale, 2011). Standard installation requires laying horizontal courses with cement-sand mortar, utilizing specific joint thicknesses and flexible isolation gaps to accommodate building movement and prevent unintended load transfer (Neville & B.J.J., 2010; The Masonry Society, 2022). From a management perspective, CMU partitions remain the default choice due to their use of local materials, support for labor-intensive employment, and high site adaptability; however, despite being heavier and slower to install than dry partition systems, their industry familiarity and workflow compatibility ensure their continued dominance. Understanding these practical constraints is essential for identifying opportunities to introduce performance-optimized masonry units that improve on-site efficiency.

Limitations of Conventional CMUs in Construction Practice. Conventional concrete masonry units (CMUs) - typically produced using hydraulic cement, water, and mineral aggregates - remain widely used because they are standardized, available, and generally durable. However, in day-to-day construction practice (especially for partitions and infill that are non-load-bearing), conventional CMUs present limitations that appear in three recurring areas: (1) material efficiency and waste reduction, (2) performance mismatch between what is provided versus what the application actually needs, and (3) constructability/handling constraints that influence labor productivity and site efficiency. These limitations are not merely technical; they also connect directly to construction management concerns such as procurement efficiency, waste control, productivity, and quality outcomes (ASTM International, 2023).

Material Efficiency and Waste Issues. The production of conventional CMUs relies heavily on natural aggregates, incurring significant environmental costs through quarrying and high-emission transport while creating supply chain vulnerabilities and price volatility as urban expansion limits local material access (de Bortoli, 2023; Zegardło, et al., 2021). This aggregate-intensive nature means even minor mix inefficiencies result in substantial cumulative financial and environmental impacts on large-scale projects. Furthermore, material wastage is a persistent limitation caused by production rejects and on-site breakage—an inherent part of masonry operations acknowledged by industry standards—which often relegates rejected units to low-value debris in the construction and demolition (C&D) waste stream (Masonry & Hardscapes Association, 2025; Mineral Products Association, 2023). Without robust recycling infrastructure or deliberate waste planning, this frequent landfilling highlights a critical need for circular economy strategies in CMU practice to improve material valorization (USEPA, 2025).

Performance Mismatch in Non-Load-Bearing Applications. A significant limitation in current construction practice is the "performance mismatch," where conventional CMUs are supplied at strength levels far exceeding the actual demands of non-structural partitions due to manufacturer compliance buffering and simplified "general-purpose" procurement strategies (ASTM International, 2023; Structure Magazine, 2022). This overdesign results in unnecessarily high cement content and material intensity, leading to avoidable environmental and financial costs. This mismatch extends to density, as high self-weight increases dead loads on the building frame and complicates site logistics; from a management perspective, these heavier units reduce installation productivity and increase labor fatigue, especially in vertical handling or high-repetition tasks (Anton et al., 2005; ASTM International, 2023). These inefficiencies highlight the critical need for engineered modifications, such as lightweighting and recycled material substitutions, to better align CMU properties with their functional roles in modern building systems (Hu, et al., 2025; Pešta, et al., 2020).

Constructability and Handling Concerns. In masonry construction, unit weight serves as a primary ergonomic risk factor that directly impacts worker health, safety, and project productivity, with heavier blocks significantly increasing muscle loading and the incidence of musculoskeletal disorders (Anton et al., 2005; Entzel, 2007). From a management perspective, these physical demands translate into project risks - such as slower cycle times, increased supervision, and variable workmanship quality - particularly during high-repetition partitioning tasks (McFarland, et al., 2025). Furthermore, the interaction between block weight and site constraints, like vertical handling limits, can escalate indirect costs through material breakage and reduced installation efficiency (Entzel, 2007; Mineral Products Association, 2023). While conventional CMUs offer procurement simplicity, their "overbuilt" weight creates a bottleneck in non-load-bearing contexts, underscoring the value of lighter, modified units that reduce physical demand without sacrificing functional performance.

Crumb Rubber as an Alternative Material in Concrete and Masonry. Crumb rubber (CR) - ground particles derived from end-of-life tires - has been widely investigated as a partial replacement for mineral aggregates in cement-based materials to reduce reliance on virgin resources and divert difficult-to-manage tire waste from disposal. Because tire rubber is lightweight, resilient, and relatively inert, its incorporation tends to shift concrete and masonry performance toward “lighter and tougher” behavior, though often with trade-offs in stiffness and compressive strength that must be managed through mix design and quality control. (Ahmad et al., 2022; Xiao et al., 2022).

Sources and Properties of Crumb Rubber. Waste tires pose a significant environmental challenge due to their bulkiness and degradation resistance, making material recovery via ambient grinding—which produces rough particles - or cryogenic grinding - which yields smoother granules—essential for sustainable disposal (Xiao et al., 2022; Lapkovskis et al., 2020). When integrated into concrete, crumb rubber creates lighter composites; however, its hydrophobic nature typically results in a weak interfacial transition zone (ITZ) between the rubber and cement paste. This poor bonding leads to increased porosity and reduced compressive strength as the rubber acts as "soft inclusions" that disrupt internal load-transfer mechanisms (Ahmad et al., 2022; Kara De Maeijer et al., 2021). Consequently, successful adoption in CMU requires careful mix proportioning or surface treatments to mitigate these losses while capturing the benefits of reduced unit weight.

Effects of Crumb Rubber on Concrete Properties. Substituting mineral aggregates with crumb rubber consistently reduces concrete density, facilitating easier manual handling, lower transportation costs, and simplified installation for non-load-bearing elements (Hasan, et al., 2024; Ohemeng & Yalley, 2023). While this modification typically declines compressive strength and elastic modulus due to rubber's low stiffness, air entrapment, and weak interfacial bonding - often requiring pre-treatments like alkali washing to maintain integrity - the material exhibits superior ductility and energy dissipation (Awan et al., 2021; Kardos & Durham, 2015). The deformable rubber particles allow for higher ultimate strain and improved damping under dynamic loading, leading to controlled cracking patterns rather than the brittle failure typical of conventional concrete (Abdo, 2024; Tahwia, et al., 2024). Ultimately, these enhanced serviceability traits and increased toughness suggest that "fitness for use" in non-structural masonry should be evaluated based on functional performance rather than compressive capacity alone.

Use of Crumb Rubber in Masonry Units. Research into rubberized Concrete Masonry Units (CMUs) confirms that replacing fine aggregates with crumb rubber reduces unit weight and compressive strength while increasing porosity and water absorption, requiring a careful balance to maintain compliance with ASTM C129 and ASTM C140 benchmarks (Intaboot & Kanbua, 2022; Mohammed, et al., 2022). In the Philippine context, these units must also align with DPWH specifications to ensure local project requirements for dimensional tolerances and durability are met (ASTM International, 2022b; DPWH, 2016a). While benefits include reduced labor strain, enhanced insulation, and improved impact deformation, these are offset by risks like increased efflorescence and manufacturing variability during low-slump compaction (Gheni et al., 2017). Consequently, rubberized units are technically plausible alternatives only when performance penalties are managed through controlled replacement levels, providing the rationale for a construction management decision framework that weighs these technical trade-offs against constructability gains and regulatory compliance (Ahmad et al., 2022; Kara De Maeijer et al., 2021).

Steel Mesh Reinforcement in Masonry and Layered Concrete Units. Steel mesh reinforcement - commonly fabricated as welded wire reinforcement (WWR) or welded wire mesh - provides distributed reinforcement through closely spaced wires in two orthogonal directions. In conventional reinforced concrete, WWR can be used as flexural, axial, or shrinkage-and-temperature reinforcement when it complies with material specifications in ASTM A1064/A1064M and detailing requirements in structural codes. This distributed configuration makes steel mesh particularly relevant for applications where crack control and uniform stress transfer are priorities rather than relying solely on discrete bars at wider spacing. In the context of this thesis, the reinforcement concept is more specific: transverse steel mesh layers placed between concrete lifts/layers within a unit, intended to control cracking across layer interfaces and improve composite action of a layered concrete masonry unit (CMU)-type element (Wire Reinforcement Institute, 2021).

Role of Steel Mesh in Concrete. Steel mesh reinforcement mitigates the inherent tensile weakness of concrete by bridging microcracks and redistributing stresses across its grid-like structure, promoting a distribution of multiple fine cracks that maintains serviceability and a continuous tensile path (Wire Reinforcement Institute, 2021). Experimental research indicates that this distributed reinforcement supports uniform strain fields and gradual post-cracking behavior, while in layered concrete units, transverse mesh acts as a mechanical bridge to promote composite action and prevent interlayer separation (Mebrahtom et al., 2024; Yu et al., 2024). Although mesh enhances flexural capacity and energy absorption, its effectiveness remains sensitive to bond and detailing under ASTM A1064/A1064M (Hong et al., 2023; ASTM International, 2022a). From a management perspective, integrating mesh in CMU-sized elements requires strict control to prevent defects like poor consolidation or "shadowing," making transverse reinforcement a deliberate strategy to ensure a monolithic response while balancing mechanical benefits against the practical challenges of small-scale production.

Use of Mesh in Masonry and Composite Units. In masonry construction, steel reinforcement traditionally ensures structural integrity through vertical bars, bond beams, or factory-fabricated welded wire assemblies in mortar joints, which serve as the industry standard for controlling shrinkage-induced cracks (Concrete Masonry & Hardscapes Association, 2025). Regulatory standards like TMS 402/602 dictate the placement and embedment of this reinforcement to maintain durability, with experimental data showing that its primary benefit is transforming brittle failure modes into ductile responses by enhancing crack resistance and deformation capacity (The Masonry Society, 2022; Jasiński, 2019; Łukasz et al., 2021). Building on recent explorations of mesh within specific unit types to optimize shear behavior, this study applies a "stitching" logic to layered units, where transverse steel mesh acts as an internal mechanism to prevent delamination and mitigate vulnerabilities like differential shrinkage or compressive splitting at material interfaces (Lyngkhoi et al., 2024; Sun et al., 2025). Preferred for their ability to produce fine crack distributions and superior post-cracking stability, welded square meshes offer a viable mechanical shear transfer, provided that bond integrity and geometry are strictly controlled (Alaa et al., 2025; Mebrahtom et al., 2024).

Construction Management Approaches to Material Selection. Material selection in construction is both a management and technical decision, as the optimal material is defined by its performance within project constraints such as cost, schedule, labor capability, and risk exposure. Contemporary literature emphasizes that these choices must be traceable through explicit criteria and repeatable processes, utilizing multi-criteria decision-making (MCDM) to balance performance, constructability, and sustainability under conditions of uncertainty (Bajwa et al., 2025a). For crumb-rubber modified masonry with transverse steel mesh, the selection logic shifts toward a performance-based and constructability-aware approach that transcends simple compressive strength. This framework evaluates critical management indicators, including weight reduction benefits, damage tolerance, the buildability of layered casting, and the necessary quality controls to mitigate workmanship-related defects (Bui et al., 2025).

Performance-Based Material Selection in Construction. Performance-based selection shifts the focus from rigid compliance to specific service outcomes, evaluating materials against indicators like minimum compressive strength, maximum unit weight, and durability to reduce "overdesign by habit" and provide a defensible basis for innovative materials (Govindan et al., 2016). By translating project needs into measurable targets, construction managers can move toward optimized systems that align with actual functional demands rather than one-size-fits-all procurement (Villalba et al., 2024). Within this framework, constructability serves as the vital link between laboratory performance and field execution, where success is determined by technical metrics alongside impacts on labor productivity, scheduling, and quality risks. For layered masonry, this involves evaluating field indicators such as mesh placement feasibility and consolidation requirements, ensuring the final selection is technically viable, economically sound, and compatible with the practical realities of site management (Inyim et al., 2016).

Multi-Criteria Decision Making in Construction Management. Construction material selection is inherently multi-objective, necessitating Multi-Criteria Decision-Making (MCDM) frameworks to navigate conflicting priorities like the trade-off between unit weight and compressive strength. Systematic reviews highlight that methods such as AHP and TOPSIS provide an auditable logic for ranking alternatives by weighting criteria based on stakeholder priorities, moving beyond unit price to incorporate Life-Cycle Costing (LCC) for logistics and labor impacts (Bajwa et al., 2025b; ISO, 2017). This framework integrates technical performance measures with constructability indicators - such as installation complexity and labor skill requirements - which are essential for quantifying risks like workmanship variability in innovative layered units (Yardimci & Kurucay, 2024; Abolmaali & Safi, 2022). Ultimately, MCDM enables construction managers to operationalize risk through the probability of nonconformance, transforming subjective judgments into a multi-dimensional and defensible decision support tool (Villalba et al., 2024).

Decision Frameworks in Construction Material Selection. A construction-management-oriented decision framework is structured through three layers: threshold compliance (must-pass), weighted trade-off scoring (best-fit), and rule-based implementation (how-to-adopt). This layered approach integrates classic decision matrices with MCDM methods like AHP or TOPSIS to evaluate innovative materials, such as rubber-modified CMUs, by grouping criteria into technical performance, constructability, cost, and risk for transparent stakeholder communication (Govindan et al., 2016; Bajwa et al., 2025a). The framework's effectiveness relies on weighted scoring to formalize priorities - such as favoring handling ease over surplus strength for partitions - and often employs fuzzy extensions to manage subjective judgments from contractors and owners (Ma & Wang, 2024). This is operationalized through rule-based selection using "IF-THEN" logic to automate material rejections or trigger mandatory quality controls, such as specialized inspection checkpoints, if a layered unit's constructability risk exceeds defined thresholds (Grčić & Šperac, 2024).

Theoretical Framework. Incorporating rubber crumbs into concrete significantly reduces its density because their specific gravity (0.9–1.2) is much lower than that of natural aggregates (2.6–2.71), a transition further influenced by the rubber's irregular texture which increases void formation and air entrapment (Bu, et al., 2022). Parallel to these density changes, the mechanical integrity of the composite - particularly in Steel Fiber-Reinforced Concrete (SFRC) - relies heavily on fiber orientation; aligning fibers perpendicular to anticipated crack planes optimizes tensile strength and crack resistance by effectively bridging gaps (Faustmann et al., 2024). This bridging action is vital for post-cracking performance, as it allows the material to maintain load-carrying capacity and enhances toughness through either deflection-softening or hardening behavior (Gali & Subramaniam, 2017). Ultimately, the effectiveness of this reinforcement is governed by the fibers' volume fraction and embedment length, which dictate the transition between brittle and ductile regimes in the concrete matrix.

Conceptual Framework. This study utilizes the Independent Variable (IV) and Dependent Variable (DV) Model. The IV consists of the parameters for making the concrete masonry, specifically, the concrete mix design, the crumb rubber content, and the number of steel mesh reinforcement. They act as potential predictors of the outcome under DV. The IV consists of the mechanical properties of concrete masonry, specifically the Density of Concrete Masonry and the Compressive Strength of Concrete Masonry. This outcome variable is dependent on the parameters of making concrete masonry.

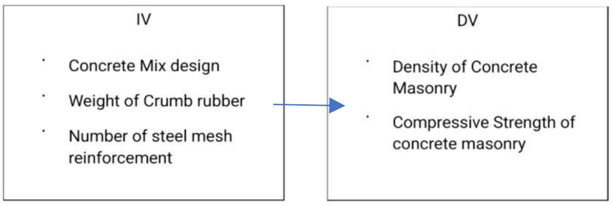

Figure 1
Research Paradigm

This study aims to develop a construction management decision framework by evaluating the limitations of current practices and investigating the performance of crumb rubber-modified concrete masonry units, both with and without steel mesh reinforcement, for non-load-bearing applications. Specifically, the study sought to answer the following questions:

1. What is the current situation of concrete masonry unit (CMU) usage in construction projects in terms of the following:
   1.1 Material type;
   1.2 Performance requirements for non-load bearing applications; and,
   1.3 Common construction and usage practices?

2. What limitations exist in current CMU practice in terms of the following:
   2.1 Material waste reduction;
   2.2 Compliance with performance requirements for non-load bearing walls; and,
   2.3 Constructability and material efficiency?

3. What performance characteristics do crumb rubber–modified concrete masonry units, with and without steel mesh, exhibit in terms of the following:
   3.1 Density;
   3.2 Compressive strength; and,
   3.3 Strength development?

4. What Construction Management framework can be developed for selecting crumb rubber–modified concrete masonry units for non-load bearing applications?

METHODS

Research Design. Experimental research is defined as a systematic and scientific method where the researcher manipulates one or more independent variables and observes the effect on a dependent variable while controlling for extraneous variables (Mahmoud S Abdallah, 2025). This design is appropriate for the study as it allows for the establishment of cause-and-effect relationships between the use of transverse steel mesh reinforcement and the sustainability of waste tire rubber concrete masonry. By using controlled conditions, the study can accurately measure the impact of the reinforcement on the Compressive strength performance and density of the masonry. Therefore, this design will provide robust and reliable data to support the study's objectives.

Experimental Procedure for Crumb Rubber–Modified CMUs. The experiment utilizes a standardized methodology to evaluate the performance of crumb rubber–modified CMUs (200mm x 400mm x 150mm) against established benchmarks, specifically ASTM C129 for non-load-bearing units and applicable DPWH and Philippine National Standards (PNS) for cementitious materials (ASTM, 2023). The concrete mix design follows a 1:3 cement-to-sand ratio by volume with a controlled 0.45 water-cement ratio, incorporating Ordinary Portland Cement (OPC), natural fine aggregates, and recycled waste tire rubber as a partial mass replacement ranging from 0kg to 20kg. To enhance structural integrity, commercially sourced welded steel mesh (1.0mm diameter, 1.0cm–1.2cm grid) is integrated as a transverse reinforcement mechanism for crack control. The preparation and testing phase involves precision mixing, standardized mold casting, and aquatic curing, followed by rigorous analysis using a compression testing machine for load-bearing capacity and density testing equipment to quantify material efficiency. Data is subsequently processed through statistical software to validate the relationship between these material variables and their adherence to national and international engineering standards.

Preparation of Rubberized Concrete Specimens. The experimental procedure began with the dry-blending of Ordinary Portland Cement, natural aggregates, and processed waste tire rubber to ensure a uniform distribution and prevent particle clustering, followed by the gradual addition of potable water to achieve a homogeneous, workable mix. Casting was performed in oiled molds through a layered sequence where a base layer of rubberized concrete was poured, followed by the precise transverse placement of pre-cut steel mesh - positioned perpendicular to anticipated crack planes to maximize bridging efficiency - before being encapsulated by a subsequent concrete layer. Consistent tamping was applied to ensure consolidation without disturbing the reinforcement alignment, after which the specimens were finished, demolded, and subjected to standard water-curing to reach optimal design strength.

RESULTS

Current Situation of Concrete Masonry Unit (CMU) Usage in Construction Projects in terms of Material Type. Conventional CMUs are typically manufactured from Portland cement, water, and natural mineral aggregates, often utilizing identical compositions for both load-bearing and non-load-bearing units despite their different functional demands. While compliance with ASTM International and the National Structural Code of the Philippines ensures safety and quality control, these prescriptive standards prioritize uniformity and economies of scale over application-specific optimization, lacking explicit incentives for material reduction or sustainability-driven improvements. Consequently, current manufacturing remains focused on production convenience and functional overdesign rather than resource efficiency.

Current Situation of Concrete Masonry Unit (CMU) Usage in Construction Projects in terms of Performance Requirements for Non-Load-Bearing Applications. Non-load-bearing CMUs are subject to minimum compressive strength requirements that, while typically lower than structural masonry, remain conservatively high; in practice, many units used for partitions and infill walls meet or exceed strengths intended for load-bearing elements despite not being required to resist significant structural loads. Density and weight considerations are also critical performance parameters from a construction management standpoint, yet conventional CMUs remain relatively heavy, leading to increased labor demand, slower installation rates, and higher handling-related risks on site. While relevant benchmarks for compressive strength, unit weight, and absorption are specified in ASTM standards and referenced by national codes, these benchmarks function primarily as minimum acceptance criteria rather than performance targets tailored to specific functions, reinforcing a practice that emphasizes compliance over efficiency and the continued use of dense, overdesigned units where such capacity is not functionally necessary.

Current Situation of Concrete Masonry Unit (CMU) Usage in Construction Projects in terms of Common Construction and Usage Practices. In typical construction projects, CMUs are widely used for partition walls, infill panels, and enclosure walls where they serve no primary structural role; however, the manual handling, alignment, and joint finishing required under tight schedules mean the weight of conventional units directly affects labor productivity, fatigue, and the risk of injuries, particularly in multi-story construction. From an operational perspective, while contractors favor CMUs due to their availability and predictable performance, this reliance leads to practical limitations including inefficient material usage, increased transportation loads, higher embodied environmental impacts, and material waste from breakage during transport and installation. These practices reveal a significant gap between current usage and optimal construction management outcomes, as conventional CMUs satisfy code requirements but fail to support goals related to sustainability, labor efficiency, or material optimization, highlighting a critical need for alternative designs that maintain performance while improving constructability and resource efficiency.

Limitations in Current CMU Practice in terms of Material Efficiency. Conventional CMUs rely heavily on natural fine and coarse aggregates extracted through energy-intensive quarrying, contributing to a high environmental footprint in non-load-bearing applications where these virgin materials provide no proportional functional benefit. A significant limitation exists in the overdesign of material composition, as the same aggregate-rich mix designs used for structural masonry are frequently applied to non-structural partitions, resulting in excessive usage of cement and aggregates. From a construction management standpoint, this lack of differentiation prioritizes production convenience over application-specific efficiency, translating to unnecessary material costs, higher transportation loads, and increased embodied carbon without improving project-level performance. This persistent standardization underscores a critical need for alternative material strategies that reduce resource consumption while still meeting essential performance requirements for non-load-bearing systems.

Limitations in Current CMU Practice in terms of Compliance with Performance Needs. Although conventional CMUs satisfy minimum compressive strength requirements prescribed by standards such as those referenced by ASTM International and the National Structural Code of the Philippines, the achieved strength levels often exceed the actual functional demands of non-load-bearing walls. In practice, partitions and infill walls are not intended to carry vertical loads beyond their self-weight, yet they are constructed using units capable of significantly higher compressive capacities, creating a mismatch between required and provided performance that leads to inefficient use of materials. High compressive strength is achieved at the expense of increased density and weight—factors that are not advantageous for non-structural applications—and instead of optimizing CMUs for ease of handling, speed of installation, and reduced dead load, current practice favors strength margins that are largely unused during the service life of the wall. This approach reflects a compliance-driven mindset rather than a performance-based one, where the absence of tailored performance criteria for non-load-bearing CMUs limits innovation and discourages the adoption of lighter, more efficient masonry units that could better support construction management objectives.

Limitations in Current CMU Practice in terms of Constructability and Material Utilization. The relatively high unit weight of conventional CMUs presents significant practical challenges, as manual handling of heavy blocks increases labor fatigue, slows installation rates, and elevates the risk of work-related injuries, factors that directly impair construction productivity in tight-scheduled or multi-story projects where material handling is more demanding. In addition to physical strain, heavier CMUs contribute to higher breakage rates during transportation and on-site handling, resulting in material waste and increased indirect costs related to manpower, supervision, and equipment use. Despite these clear operational drawbacks, conventional CMUs remain widely used due to industry familiarity and supply availability rather than constructability efficiency, highlighting a critical limitation where material utilization is not aligned with labor efficiency and site productivity goals. Because non-load-bearing walls represent a vast portion of building construction, these cumulative inefficiencies at scale can substantially diminish overall project performance.

Performance characteristics of crumb rubber–modified concrete masonry units with or without steel mesh exhibit in terms of density. The incorporation of crumb rubber has a pronounced effect on CMU density, with the downward trend in the density graph attributed to the lower specific gravity of crumb rubber compared to conventional fine aggregates; when rubber particles replace an equivalent mass of sand, the resulting concrete matrix exhibits increased internal voids and reduced overall unit weight. This reduction in density is a highly desirable outcome for non-load-bearing walls, as lighter CMUs contribute to easier handling, reduced transportation loads, and improved labor efficiency during installation. Unlike conventional CMUs, which often exceed the functional requirements of non-structural walls, these rubber-modified units demonstrate a material-efficient approach by aligning density more closely with actual application needs. Crucially, the observed density reduction does not indicate instability or inconsistency in specimen formation, suggesting that crumb rubber can be successfully integrated without adversely affecting the basic integrity of the masonry unit.

Table 1
Specimen Weight with Varying Rubber Content

Rubber Content	Average Weight	Sample Weight
0 %	26.24	26.236
		26.621
		25.848
5 %	24.07	23.992
		24.538
		23.684
10 %	20.91	20.201
		21.466
		21.068
20 %	19.43	19.194
		19.748
		19.358

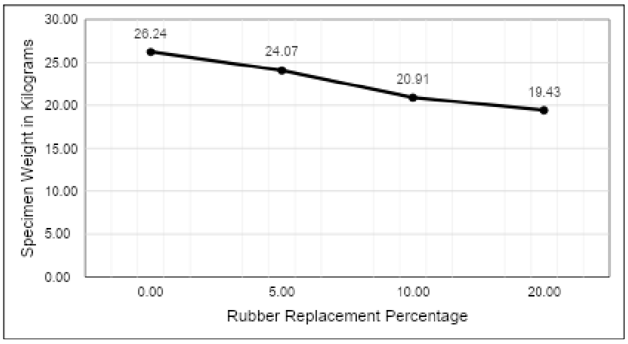

Figure 2
Specimen Weight with Varying Rubber Content

Performance characteristics of crumb rubber–modified concrete masonry units with or without steel mesh exhibit in terms of compressive strength. The incorporation of crumb rubber resulted in a reduction in compressive strength relative to the conventional CMU, a trend attributed to the lower stiffness and strength of rubber particles compared to mineral aggregates, as well as the weaker interfacial bond between rubber and the cementitious matrix. This reduction should not be interpreted solely as a disadvantage; in non-load-bearing applications, excessively high compressive strength does not translate to improved functional performance, and instead, the observed reduction reflects a rebalancing of material properties where unnecessary structural capacity is reduced in favor of improved material efficiency and sustainability.

Table 2
Specimen Compressive Strength with Varying Rubber Content

SAMPLE	Trial 1 3 Layers	Trial 2 5 Layers	Trial 3 7 Layers
0 % Rubber	1060.33	1084.00	1347.00
5 % Rubber	732.33	812.33	891.67
10 % Rubber	507.00	639.00	653.00
20 % Rubber	338.67	359.00	470.67

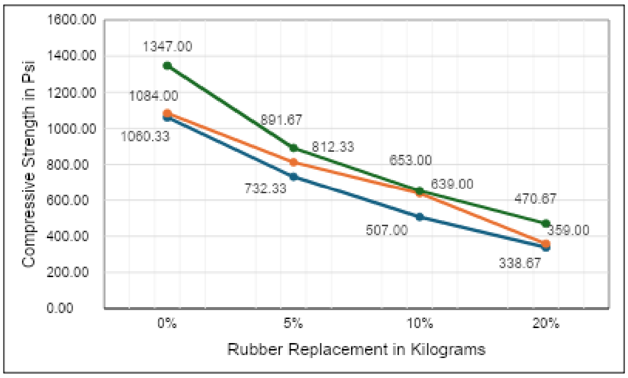

Figure 3
Specimen Compressive Strength with Varying Rubber Content

Ultimately, the compressive strength of the rubber-modified CMUs remained within ranges appropriate for non-load-bearing masonry applications, demonstrating that crumb rubber can be incorporated without compromising functional adequacy for partition and infill walls.

Table 3
Specimen Compressive Strength with Steel Mesh Layer

SAMPLE	Trial 1 0Kg Rubber	Trial 2 5Kg Rubber	Trial 3 10Kg Rubber	Trial 4 20Kg Rubber
3 Layers	1060.33	732.33	507.00	338.67
5 Layers	1084.00	812.33	639.00	359.00
7 Layers	1347.00	891.67	653.00	470.67

The inclusion of transverse steel mesh layers improved the compressive strength performance of rubber-modified CMUs compared to unreinforced counterparts; while the mesh may not significantly alter peak compressive strength in all cases, it contributes to improved load distribution and delayed crack propagation during testing. By enhancing the structural integrity of the masonry unit—particularly in rubber-modified configurations where strength reduction was observed—the steel mesh acts to partially compensate for the loss of compressive capacity associated with crumb rubber incorporation.

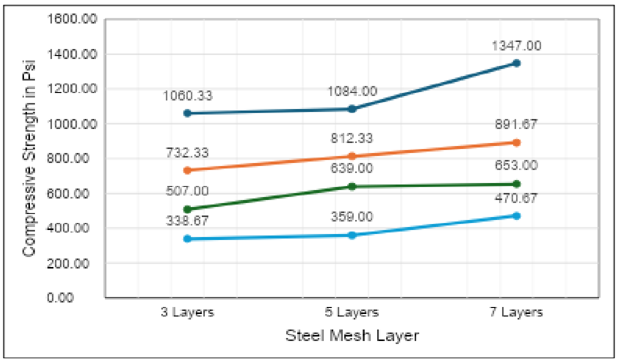

Figure 4
Specimen Compressive Strength with Varying Steel Mesh Layer

Ultimately, the mesh provides a targeted performance enhancement without significantly increasing unit weight, establishing a critical balance between strength improvement and weight control for the practical adoption of alternative CMU configurations.

Performance characteristics of crumb rubber–modified concrete masonry units with and without steel mesh exhibit in terms of strength development. The strength development results indicate that conventional CMUs exhibit a more rapid early-age strength gain compared to crumb rubber–modified units, a behavior consistent with the use of dense mineral aggregates that contribute to faster stiffness development during early curing.

Table 4
Effect of Rubber to Specimen Compressive Strength Development

SAMPLE	CURING TIME		
	7 DAYS	14 DAYS	28 DAYS
0% Rubber	1163.78	1345.56	1495.67
5% Rubber	812.11	889.56	804.11
10% Rubber	599.67	663.44	666.78
20% Rubber	389.44	427.00	413.44

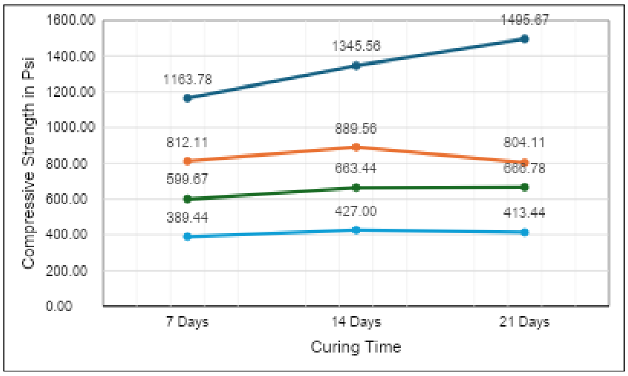

Figure 5
Effect of Rubber to Specimen Compressive Strength Development

In contrast, rubber-modified CMUs showed a more gradual trend with lower initial strength, yet gain continued at later ages, indicating that the presence of crumb rubber does not inhibit long-term hydration or strength progression. While crumb rubber primarily affects the rate of early gain rather than the ability to develop adequate strength over time, the specimens demonstrated consistent behavior across curing ages, suggesting stable material performance without introducing the variability or unpredictability that could complicate construction planning and quality control.

Table 5
Effect of Steel Mesh Layer on Compressive Strength Development

SAMPLE	CURING TIME		
	7 DAYS	14 DAYS	28 DAYS
3 Layers	1060.33	1209.67	1370.00
5 Layers	1084.00	1329.00	1392.67
7 Layers	1347.00	1498.00	1724.33

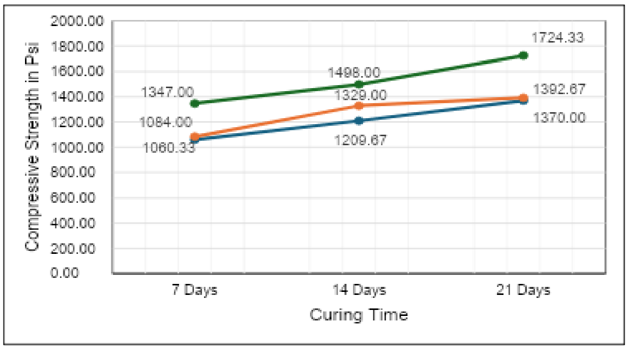

Figure 6
Effect of Mesh Layer to Specimen Compressive Strength Development

The inclusion of transverse steel mesh layers influenced the strength development trend of the CMUs by improving performance at later curing stages; while the mesh has limited impact on early-age compressive strength, its presence contributes to enhanced load redistribution and crack control as the cementitious matrix matures. For rubber-modified CMUs, the mesh inclusion resulted in a more favorable strength development profile compared to unreinforced specimens by providing additional confinement and integrity, which allowed the masonry unit to better utilize strength gained at later ages. These findings suggest that while the slower early-age gain of rubber-modified CMUs necessitates adequate curing periods before installation, the improved later-age development—especially in mesh-reinforced units—supports their suitability for non-load-bearing walls where immediate high strength is not a critical requirement.

Construction Management Framework for Selecting Crumb Rubber–Modified Concrete Masonry Units for Non-Load Bearing Applications. The decision criteria were developed based on experimental results and aligned with prevailing construction management practices, emphasizing fitness-for-purpose rather than maximum strength for non-load-bearing CMUs. Density was considered a primary indicator because it directly influences unit weight, ease of handling, and labor productivity, while compressive strength ensured compliance with minimum safety standards without unnecessary overdesign.

Table 6
Decision Matrix for CMU Selection

CMU Configuration	Density Suitability	Strength Adequacy	Strength Development	Constructability	Overall Suitability
Conventional CMU	Low (High Weight)	Excessive	Rapid	Moderate	Acceptable
Rubber-Modified CMU (No Mesh)	High	Adequate	Gradual	High	Suitable
Rubber-Modified CMU (With Steel Mesh)	High	Adequate to Improved	Gradual to Stable	High	Highly Suitable

Strength development behavior was evaluated to confirm compatibility with construction schedules, specifically regarding curing time and masonry sequencing. Consequently, the decision matrix demonstrates that while conventional CMUs remain acceptable, rubber-modified units—particularly those with steel mesh reinforcement—exhibit superior alignment with construction management objectives by balancing density suitability, strength adequacy, and constructability for non-load-bearing wall systems.

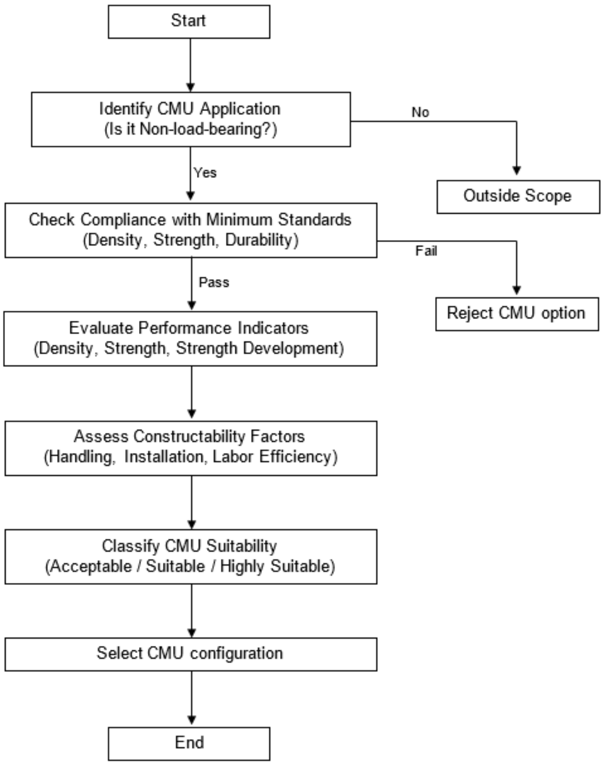

Figure 7
Diagram for Decision Framework for Non-Load-Bearing Applications

Based on the decision criteria and matrix evaluation, a step-by-step Construction Management Decision Framework is proposed. This framework is designed for practical use by construction managers during material selection and planning stages.

DISCUSSION

The study revealed that while conventional CMUs possess the highest density and strength levels that often exceed functional requirements, the incorporation of crumb rubber significantly reduces unit weight, enhancing handling efficiency and suitability for non-load-bearing applications. Although rubber modification leads to a more gradual strength gain and a reduction in overall compressive strength, the values remain well within the acceptable thresholds for non-structural use, especially when supplemented by transverse steel mesh which improves structural integrity without compromising weight reduction. These technical performance indicators—density, strength, and curing behavior—were successfully integrated into a performance-based Construction Management Decision Framework, providing a practical matrix for evaluating masonry alternatives based on productivity and standards-based thresholds.

Consequently, it is concluded that conventional non-load-bearing CMUs are often material-intensive and overdesigned, making the use of crumb rubber an effective strategy for improving resource utilization and constructability. The study demonstrates that rubber-modified units maintain adequate performance for their intended use, and the addition of steel mesh successfully mitigates the strength losses associated with aggregate replacement. Ultimately, the proposed decision framework offers a systematic and defensible method for construction managers to align material selection with functional requirements and sustainability goals, moving beyond conservative compliance-based approaches toward a more tailored, application-specific logic.

To advance the commercialization and technical maturity of these units, it is recommended that future research focus on pilot-scale production, constructability trials, and collaboration with masonry manufacturers to evaluate industrial feasibility. Further studies should investigate the long-term durability of rubber-modified CMUs under environmental stressors—such as moisture exposure and UV radiation—while exploring alternative lightweight reinforcements like fiber composites to further optimize the strength-to-weight ratio. Additionally, performing comprehensive life-cycle cost analyses and investigating the impact of varying rubber crumb sizes will be essential for validating the commercial viability and guiding the large-scale adoption of these sustainable masonry units in real-world construction settings.

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REFERENCES

Abdo, A., El-Sisi, A., El Sayed, S., Hassan, H., & Ahmed, S. (2024). Properties and stress-strain curve of rubberized concrete cast with uncoated or pre-coated rubber with cement/waste materials. *Case Studies in Construction Materials, 20,* e03226. https://doi.org/10.1016/j.cscm.2024.e03226

Ahmad, J., Alsaedi, M., Zaid, O., & Aslam, F. (2022). Overview of concrete performance made with waste rubber: A review. *Materials, 15*(17), 5897.

Abolmaali, A., & Safi, M. (2022). Implementing a choosing-by-advantages decision-making method to evaluate the critical success factors of mass-timber building materials in the US. *Journal of Construction Engineering and Management, 148*(10), 04022100. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002356

Alaa, M., ElGawady, M. A., & Dawood, M. (2025). Flexural behavior and cracking performance of steel wire mesh–reinforced cementitious composites. *Construction and Building Materials, 402*, 133048.

Anton, D., Cook, T. M., Gerr, F., Merlino, L. A., & Rosecrance, J. C. (2005). Effect of concrete block weight and wall height on electromyographic activity and heart rate of masons. *Ergonomics, 48*(10), 1314–1330. https://doi.org/10.1080/00140130500274168

Association of Structural Engineers of the Philippines (ASEP). (2020). *National Structural Code of the Philippines (NSCP 2020)*. Quezon City, Philippines: ASEP.

ASTM International. (2023). *ASTM C90-23: Standard specification for loadbearing concrete masonry units.* West Conshohocken, PA: ASTM International.

ASTM International. (2022a). *ASTM A1064/A1064M-22: Standard specification for carbon-steel wire and welded wire reinforcement, plain and deformed, for concrete.* West Conshohocken, PA: ASTM International.

ASTM International. (2022). *ASTM C90-22: Standard specification for loadbearing concrete masonry units.* West

Conshohocken, PA: ASTM International.

ASTM International. (2022b). *ASTM C129-22: Standard specification for nonloadbearing concrete masonry units.* West Conshohocken, PA: ASTM International.

ASTM International. (2023). *ASTM C90/C90M: Standard specification for loadbearing concrete masonry units.* West Conshohocken, PA: ASTM International.

Awan, H. H., Hussain, M., Akhtar, M. N., & Iqbal, S., & I. M. F. (2021). Experimental evaluation of untreated and pretreated crumb rubber in concrete. *Crystals, 11*(5), 558.

Bajwa, A. U. R., Siriwardana, C., Shahzad, W., & Naeem, M. A. (2025a). Material selection in the construction industry: a systematic literature review on multi-criteria decision making. *Environment Systems and Decisions, 45*(1). https://doi.org/10.1007/s10669-025-10001-w

Bajwa, A. U. R., Siriwardana, C., Shahzad, W., & Naeem, M. A. (2025b). Material selection in the construction industry: A systematic literature review on multi-criteria decision making. *Environment Systems and Decisions, 45*, Article 8.

Bu, C., Zhu, D., Lu, X., Liu, L., Sun, Y., Yu, L., Xiao, T., & Zhang, W. (2022). Modification of Rubberized Concrete: *A Review. In Buildings (Vol. 12*, Issue 7). MDPI. https://doi.org/10.3390/buildings12070999

Bui, T., Domingo, N., & Le, A. (2025). Factors affecting the selection of sustainable construction materials: A study in New Zealand. *Buildings, 15*(5), 834.

Concrete Masonry & Hardscapes Association. (2025). *Masonry joint reinforcement: Design and application.* Indianapolis, IN: CMHA.

de Bortoli, A. (2023). Understanding the environmental impacts of virgin aggregates production (field-data-based LCA). *Journal of Cleaner Production, 415,* 137629. https://doi.org/10.1016/j.jclepro.2023.137629 (doi.org in Bing)

Department of Public Works and Highways (DPWH). (2016a*). Department Order No. 230, s. 2016: Masonry works specification—strength/absorption/density classification requirements.* Manila, Philippines: DPWH.

Department of Public Works and Highways (DPWH). (2016b). *Standard specifications for public works and highways – Item 1046 Masonry Works.* Manila, Philippines: DPWH.

Drysdale, R. G., H. A. A., & B. L. R. (2011). *Masonry structures: Behavior and design* (2nd ed.). CRC Press.

Entzel, P., et al. (2007). *Best practices for preventing musculoskeletal disorders in masonry.* Applied Ergonomics.

Faustmann, S., Kronau, M., & Fischer, O. (2024). Direct tensile tests on steel fiber reinforced concrete with focus on wall effect and fiber orientation. *Materials and Structures/Materiaux et Constructions, 57*(8). https://doi.org/10.1617/s11527-024-02463-2

Gali, S., & Subramaniam, K. V. L. (2017). Shear behavior of steel fiber reinforced concrete using full-field displacements from digital image correlation. *MATEC Web of Conferences, 120*, 04003.

https://doi.org/10.1051/matecconf/201712004003

Gheni, A. A., ElGawady, M. A., & Myers, J. J. (2017). Mechanical characterization of concrete masonry units manufactured with crumb rubber aggregate. *ACI Materials Journal, 114*(1), 65–76.

Govindan, K., Shankar, M., & Kannan, D. (2016). Sustainable material selection for construction industry: A hybrid multi criteria decision making approach. *Renewable and Sustainable Energy Reviews, 55*, 1274–1288.

Grčić, E., & Šperac, M. (2024). Application of expert systems in civil engineering. *Građevinar, 76*(9), 839–852.

Hasan, A., Rana, M. M., & Khan, R. M. (2024). Mechanical properties of concrete using crumb rubber and human hair fiber. *International Journal of Sustainable Building Technology and Urban Development, 15*(1), 97–108. https://doi.org/10.22712/susb.20240008

Hong, Z., Zhang, Y., L., & Chen, B. (2023). Mechanical performance of welded wire mesh reinforced concrete elements under flexural loading. *Engineering Structures, 287*, 116151.

Hu, K., Gillani, S. T. A., Tao, X., Tariq, J., & Chen, D. (2025). Eco-friendly construction: Integrating demolition waste into concrete masonry blocks for sustainable development. *Construction and Building Materials, 460,* 139797. https://doi.org/10.1016/j.conbuildmat.2024.139797

Intaboot, N., & Kanbua, P. (2022). Investigation of concrete blocks mixed with recycled crumb rubber: A case study in Thailand. *Engineering and Applied Science Research, 49*(3), 413–424. https://doi.org/10.14456/easr.2022.42

Inyim, P., Zhu, Y., & Orabi, W. (2016). Analysis of time, cost, and environmental impact relationships at the building-material level. *Journal of Management in Engineering, 32*(4), 04016005.

International Organization for Standardization. (2017). *ISO 15686-5:2017 Buildings and constructed assets—Service life planning—Part 5: Life-cycle costing.* Geneva, Switzerland: ISO. https://www.iso.org/standard/61148.html

Jasiński, R. (2019). Influence of bed joint reinforcement on the shear behavior of masonry walls. *Materials, 12*(15), 2468.

Kara De Maeijer, P., Craeye, B., & Van den Heede, P. (2021). Crumb rubber in concrete—The barriers for application in the construction industry. *Civil Engineering and Architecture, 6*(8), 116.

Kardos, A. J., & Durham, S. A. (2015). Strength, durability, and environmental properties of concrete utilizing recycled tire rubber aggregates for partial fine-aggregate replacement. *Construction and Building Materials, 104*, 247–257.

Lapkovskis, V., Mironovs, V., Kasperovich, A., Myadelets, V., & Goljandin, D. (2020). Crumb rubber as a secondary raw material from waste rubber: *A review. Atmosphere, 11*(10), 32.

Łukasz, D., Kwiecień, A., & Rybak, J. (2021). Effect of joint reinforcement on cracking and deformation capacity of masonry walls. *Materials, 14*(3), 623.

Lyngkhoi, T., Choudhury, S., & Dutta, A. (2024). Structural performance of AAC masonry walls reinforced with steel wire mesh in bed joints. *Construction and Building Materials, 383*, 131274.

Ma, J., & Wang, X. (2024). A multi-criteria decision-making approach for assessing the sustainability of an innovative pin-connected structural system. *Buildings, 14*(7), 2221.

Abdallah, M. S. B. (2025). Scientific research methodology and experimental design in education and language learning studies: Basics and guidelines. [Publisher information not yet available].

Masonry & Hardscapes Association. (2025). *Estimating concrete masonry materials (TEK 04-02A).* Indianapolis, IN: Masonry & Hardscapes Association.

McFarland, T. C., Rosecrance, J. C., Anton, D., Cook, T. M., & Gerr, F. (2025). Attitudes, needs, and opportunities for training on ergonomic hazards in masonry. *Safety and Health at Work, 16*(1), 1–8. https://doi.org/10.1016/j.shaw.2024.12.001

Mebrahtom, A. K., Zewdu, T., & Kim, J. R. (2024). Crack control and flexural response of concrete reinforced with different welded wire mesh configurations. *Structures, 55*, 1053–1065.

Mehta, P. K., & M. P. J. M. (2014). *Concrete: Microstructure, properties, and materials* (4th ed.). McGraw-Hill.

Mineral Products Association. (2023). *Wastage rates for blocks and ready-mixed concrete* (desk study report).

Mohajerani, A., Burnett, L., Smith, J. V., Markovski, S., Rodwell, G., Rahman, M. T., Kurmus, H., Mirzababaei, M., Arulrajah, A., Horpibulsuk, S., & Maghool, F. (2020). Recycling waste rubber tyres in construction materials and associated environmental considerations: A review. *Resources, Conservation and Recycling, 155*, 104679. https://doi.org/10.1016/J.RESCONREC.2020.104679

Mohammed, B. S., Adamu, M., & Shafiq, N. (2022). *Properties of crumb rubber hollow concrete block*. Waste Management, 32(8), 1538–1545.

Mohammed, S., Anwar Hossain, M., Ting, J., Swee, E., Wong, G., & Abdullahi, M. (2022). *Properties of crumb rubber hollow concrete block* Author links open overlay panelBashar. https://doi.org/10.1016/j.jclepro.2011.10.035Get

Neville, A. M., & B. J. J. (2010). *Concrete technology* (2nd ed.). Pearson.

Ohemeng, E. A., & Yalley, P. P. (2023). Models for predicting the density and compressive strength of rubberized concrete pavement blocks. *Construction and Building Materials, 47*, 656–664.

Pešta, J., et al. (2020). Sustainable masonry made from recycled aggregates: LCA-based comparison. *Sustainability, 12*(4), 1581.

Structure Magazine. (2022). *Specifying masonry component strength.* STRUCTURE Magazine. Retrieved from https://www.structuremag.org/?p=22989

Strukar, K., Kalman Šipoš, T., Miličević, I., & Bušić, R. (2019). Potential use of rubber as aggregate in structural reinforced concrete element – *A review. In Engineering Structures (Vol. 188*, pp. 452–468). Elsevier Ltd. https://doi.org/10.1016/j.engstruct.2019.03.031

Sun, Y., Wang, L., & Zhang, H. (2025). Mechanical behavior and interlayer bonding performance of layered cement-based composites. *Cement and Concrete Composites, 147*, 105192.

Tahwia, A. M. et al. (2024). Experimental investigation of rubberized concrete slab-on-grade: fracture behavior, cracking, and toughness. *Innovative Infrastructure Solutions, 9*, Article.

The Masonry Society. (2022). *TMS 402/602-22: Building code requirements and specification for masonry structures.* Longmont, CO: The Masonry Society. https://doi.org/10.21012/TMS402-22

United States Environmental Protection Agency [USEPA]. (2025). *Construction and demolition debris: Material-specific data.* Washington, DC: USEPA. Retrieved from https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/construction-and-demolition-debris-material-specific-data

Villalba, P., Sánchez-Garrido, & A. J., & Y. V. (2024). A review of multi-criteria decision-making methods for building assessment, selection, and retrofit. *Journal of Civil Engineering and Management, 30*(5), 465–480.

Wire Reinforcement Institute. (2021). *Manual of standard practice for welded wire reinforcement.* Washington, DC: Wire Reinforcement Institute.

Xiao, Z., Pramanik, A., & Basak, A. K. (2022). Material recovery and recycling of waste tyres—A review. *Cleaner Materials, 6,* 100094. https://doi.org/10.1016/j.clema.2022.100094

Yardimci, Y., & Kurucay, E. (2024). LCA-TOPSIS integration for minimizing material waste in the construction sector: A BIM-based decision-making. *Buildings, 14*(12), 3919.

Yu, J., Li, Z., & Xu, S. (2024). Interface shear transfer mechanisms in concrete layers reinforced with steel wire mesh. *Construction and Building Materials, 395*, 132489.

Zegardło, B. (2021). Comparative assessment of environmental effects by LCA method of natural aggregates extraction processes and production of their substitutes from waste in the city mining system. *Journal of Ecological Engineering, 22*(8), 251–257. https://doi.org/10.12911/22998993/139119