Evaluating Tile Wastage Minimization Strategies and Their Economic Consequences in Construction Projects: A Case Study

[1] Ar. Jameer Yusuf Mulani, [2]Dr. Archana Bhatnagar

[1,2] Department of Architecture,

[1] Vivekanand Education Society's College of Architecture, Mumbai Maharashtra

Orchid ID - 0009-0007-5633-1633

Abstract -Material wastage remains a persistent challenge in the construction industry, directly influencing both project sustainability and economic performance. Among finishing materials, ceramic tiles are particularly susceptible to wastage during handling, cutting, and installation. This study evaluates tile wastage minimization strategies and their economic consequences on overall project costing, using a case study approach supported by field data and analytical methods. Drawing inspiration from waste valorization research that emphasizes resource efficiency and recycling in material science , and adopting a structural performance-oriented perspective as seen in composite construction studies, this research extends the discussion to the domain of site-level management of finishing materials. The case study was conducted on an institutional building project where quantitative records of tile consumption, procurement, and wastage were systematically documented. Data were extracted from site records and cross-verified with bill of quantities (BOQ) and procurement invoices. Wastage patterns were analyzed with respect to tile sizes, cutting layouts, workmanship, and on-site storage practices. An Excel-based computation model was developed (see supporting dataset) to evaluate material utilization rates and to simulate alternative cutting and layout strategies. Findings indicate that tile wastage on conventional sites ranges between 8–12% of the total procurement, with cutting losses and breakages as the primary contributors. By implementing optimized layout planning, proper handling, and skilled workmanship, wastage could be reduced to as low as 4–5%. The economic analysis revealed that even a modest reduction of 3–4% in tile wastage translates into substantial cost savings at the project scale, accounting for approximately 1.2–1.5% of the total finishing budget. Beyond direct savings, minimizing wastage reduces project delays associated with reordering and lowers environmental impacts from material disposal. The study contributes to construction management literature by linking micro-level material handling practices with macro-level cost and sustainability implications. While prior studies in material science demonstrate how recycling and processing of waste can enhance material performance, and structural engineering research highlights optimization in resource use for performance gains, this research uniquely situates tile wastage reduction within site-level operational strategies. In conclusion, systematic wastage minimization offers a dual benefit: improving project economics and supporting sustainable construction. The findings underscore the importance of integrating tile utilization strategies into cost planning, procurement policies, and site execution protocols. Future research should explore digital tools such as Building Information Modelling (BIM)-enabled layout optimization and the integration of recycled tile waste into construction composites.

Keywords: Tile wastage, Construction economics, Case study, Material optimization, Sustainable construction

I. INTRODUCTION

The construction industry is a major contributor to global economic growth but also one of the leading generators of material waste. Studies consistently indicate that 25–30% of construction resources are lost through inefficiencies at various project stages, including procurement, handling, and execution. Among finishing materials, ceramic and vitrified tiles are particularly prone to wastage due to their fragile nature, cutting requirements, and the challenges of on-site handling [11]. Unlike structural materials, where wastage has been extensively studied, finishing materials such as tiles have received limited research attention, despite their significant impact on overall project quality and cost.

Tile wastage typically arises from cutting to fit irregular layouts, breakages during transportation and installation, improper storage, and errors in workmanship. While industry guidelines often prescribe an additional 5–10% procurement allowance to account for wastage, evidence from site observations suggests that actual wastage often exceeds these margins, reaching 12–15% in large-scale projects. This not only inflates project costs but also exacerbates environmental concerns through increased landfill disposal of ceramic waste. Addressing tile wastage is therefore critical for achieving cost efficiency and promoting sustainability in construction practices. Recent research in material science has emphasized the valorization of waste by transforming it into usable aggregates, ceramics, or composites Parallel studies in structural engineering highlight the importance of optimization strategies in material usage and performance enhancement However, little attention has been directed towards on-site operational strategies that directly minimize wastage of finishing materials during installation. By focusing on preventive measures rather than post-waste valorization, construction projects can achieve immediate economic savings and reduce environmental impacts at the source. India's construction Industry has witnessed exponential growth over the past two decades driven by rapid urbanization, population growth and Industrial expansion. This boom has significantly increased demand for essential building materials such as cement, steel, bricks and flooring materials. Vitrified tiles have become a preferred flooring option due to their strength, visual appeal and low maintenance requirements. However, the construction process inherently generates waste at multiple stages-from production and transportation to on-site installation. One significant yet underexplored component of this waste which occurs due to suboptimal layout planning, irregular room geometry and mismatched tile dimensions. Existing ROL emphasizes waste reduction in construction through material management, prefabrication and sustainable design (Keys Baldwin, 2018; Kaliannan etal, 2017) yet limited research has focused on the relationship between tile size and design wastage. This study addressed sizes resulting in proportionally higher design wastage during installation

A. *Objective*

1. To study impact of tile sizes on tile wastage due to architectural design and layout on percentage basis.
2. To study importance of tile layout plan working during planning stage for reducing cost of project and lowering environmental impact of construction

B. *Aim:*

To study strategies to minimise design tile wastage resulting in its lowering of construction cost and environmental impact.

II. LITERATURE REVIEW

Efficient material utilization in construction is central to achieving both economic and environmental sustainability. Several studies have examined construction waste generation, recycling approaches, and site-level management strategies. The following ten contributions are particularly relevant to the problem of tile wastage minimization and its economic consequences:

1. ***Godzierz et al. (2020)*** investigated the mechanical and physical properties of lightweight ceramic aggregates produced from waste glass and mining slates Their work highlights how valorization of

ceramic waste can reduce environmental burden while creating usable building materials. This provides a scientific basis for considering tiles not only as consumables but also as recyclable resources. The addition of glass improved strength while reducing porosity, proving that ceramic waste can be valorized into new construction products. This demonstrates the potential of recycling ceramic waste such as tiles instead of sending it to landfills [1].

2. ***Fayed et al. (2025)*** explored tubular steel–concrete composites with bolted shear connectors . Although structural in focus, their study underscores the role of optimization in material usage for improving performance and reducing redundancy — a principle applicable to finishing materials like tiles where layout optimization directly minimizes waste. Optimized connector use enhanced shear capacity by 217%, proving that material efficiency and design optimization significantly boost performance. For tiles, this highlights the importance of layout optimization to reduce cutting losses [2].

3. ***Poon et al. (2001)*** reported that construction and demolition (C&D) waste constitutes up to 30% of landfill volume in developed regions. They emphasized that finishing materials contribute disproportionately to solid waste due to design complexity and frequent replacements, making tile wastage a critical issue. Optimized connector use enhanced shear capacity by 217%, proving that material efficiency and design optimization significantly boost performance. For tiles, this highlights the importance of layout optimization to reduce cutting losses [3].

4. ***Bossink and Brouwers (1996)*** quantified construction waste in Dutch projects and found that 10–15% of purchased finishing materials were wasted, largely due to poor handling and site practices. Their findings align closely with observed tile wastage in Indian projects [4].

5. **Formoso et al. (2002)** studied material losses in Brazilian construction sites and stressed that over-ordering due to fear of shortages often amplified wastage. They proposed tighter monitoring and training of workers to reduce losses [5].

6. **Begum et al. (2009)** highlighted the economic implications of construction waste management in Malaysia, showing that preventive site-level measures offered higher financial returns than recycling alone. Their results support the view that tile wastage minimization should be prioritized before recycling strategies [6].

7. **Ekanayake and Ofori (2000)** identified poor workmanship and inadequate planning as key drivers of material wastage in Singapore’s construction sector. They proposed layout optimization and supervision as cost-effective strategies, which are directly relevant for tile installation [7].

8. **Tam et al. (2007)** investigated on-site waste management practices in Hong Kong and concluded that digital planning tools such as CAD-based layout optimization could substantially reduce material wastage. This insight paves the way for integrating BIM into tile wastage reduction strategies[8]

9. **Al-Hajj and Hamani (2011)** examined construction waste in Middle Eastern projects and highlighted the lack of standardized monitoring as a major obstacle. They recommended benchmarking wastage percentages for materials like tiles to create industry-wide guidelines [9]

10. **Ajayi et al. (2015)** emphasized that design-stage decisions contribute significantly to material wastage. For tiles, irregular floor layouts and frequent changes in architectural drawings often translate into higher cutting losses, underlining the need for early-stage planning and designer–contractor collaboration [10].

11. **S. N. Misra et. al. (2013)** Vitrified tiles are widely used in construction due to their high strength, durability, and varied finishes. During manufacturing, especially polishing, large quantities of fine vitrified tile sludge are generated and commonly discarded through open dumping or partial dewatering. This sludge, already finely ground, contains ~60–67% silica and ~18–24% alumina,

loses weight on firing due to organic binders, and requires no further grinding. Its thermo-physical and chemical properties make it suitable for reuse in ceramics, cement, and other construction materials. Recycling this waste reduces production costs, conserves natural resources, minimizes environmental impacts, and supports circular economy practices.

12. **Mohamad Azim Mohammad Azmi (26)**The study by Muhammad Haziq Fahmi Zainudin and Adib Irfan Naqiuddin Abu Bakar explores the use of Electric Arc Furnace (EAF) waste in tile manufacturing due to its low firing shrinkage, minimal water absorption, and high load-bearing capacity. Floor tiles are not ideal for wall cladding due to the risk of breakage, so the research suggests using waste materials to create safer tiles for such applications. Relevant keywords were identified to collect articles from reputable databases, followed by screening based on content relevance and publication date. The authors synthesized findings from various studies and analyzed the physical and chemical properties of EAF waste, plastic waste, boron waste, red mud, and other materials. Experimental evaluations included Modulus of Elasticity, Modulus of Rupture, and Water Absorption tests.

13. **Andrew Keys (27)** The construction industry produces around 70 million tonnes of waste annually, prompting the need for waste-minimising design strategies grounded in reduce, reuse, and recycle principles. Waste reduction is difficult in bespoke commercial and industrial projects, but more generic sectors like residential and civil works enable benchmarking. Current designs often overlook environmental concerns, so the paper recommends a Design-Manage-Construct (DMC) model to align designers and contractors early, supported by strong communication. Key methods include prefabrication, standardisation, realistic sizing, reduced temporary works, design life optimisation, use of recycled materials, designing for disassembly, and avoiding high-waste products. Prioritising high-value, low-volume waste streams and material choices with low embodied energy can significantly improve sustainability and resource efficiency.

III. METHODOLOGY

3.1 Research Design

This research adopts a *mixed-method case study* approach combining quantitative analysis of tile wastage with qualitative exploration of field practices. Quantitative data were obtained from procurement records, material measurements, and site-level usage logs, whereas qualitative data were collected from structured interviews, photographic evidence, and direct observations. This combination ensures a comprehensive understanding of how material management, site conditions, and human factors influence tile wastage and its economic consequences.

3.2 Case Study Description

The study was conducted on a residential-cum-commercial building project located on a plot area of approximately 10,800 sq.ft, with a built-up area of about 45,000 sq.ft. The project comprises ground and first floors with several residential units, service areas, and commercial spaces. The case was selected for its diverse tile usage and comprehensive documentation availability. Two tile types were used:

- Floor tiles: 1200 × 600 mm vitrified tiles
- Wall/Dado tiles: 600 × 600 mm ceramic tiles

At the time of the study, the project was in the *finishing stage* of the commercial part of the building, allowing direct observation of ongoing tile installation activities.

3.3 Data Collection Approach

Data were collected through four major methods to ensure rigor and reliability.

a) Document and Record Review

Procurement records, delivery challans, and Bills of Quantities (BOQs) were reviewed to identify the number of tiles ordered, received, and utilized per floor and tile dimension. This enabled the quantification of actual consumption and loss during transportation and installation.

b) Site Observation and Photographic Documentation

Systematic site visits were conducted during tile installation to capture photographs of cutting operations, storage, layout alignment, and observed damages (edge chipping, breakage, and offcuts). These images serve as visual validation of recorded wastage data and inform causal analysis in later sections.

c) Structured Interviews

A structured Google Form survey titled *"Survey on Design Tile Wastage"* was distributed to site engineers and supervisors. The survey aimed to gather perceptions about wastage sources, tile procurement strategies, and layout management. A representative response from **Mr. Shubham Kadam (B.E. Civil)**, collected on *26 September 2025 at 2:09 PM*, is summarized below:

Table I — Survey on Design Tile Wastage

Survey Question	**Response**
Name & Qualification	Shubham Kadam, B.E. Civil
Plot Area of Proposed Site	10,800 sq.ft
Built-up Area	45,000 sq.ft
Project Type	Residential + Commercial
Current Progress	Finishing work of Commercial part
No. of 1200×600 mm tiles ordered	1,000 tiles
No. of 600×600 mm tiles ordered (floor + dado)	400 tiles
Flooring tiles wasted during transport	310 sq.ft (≈ 4%)

These data were cross-validated with site measurement sheets and BOQ records to ensure accuracy.

	
Office Floor Tile Works	Shop Floor Tile Works
	
RCC slab curing	Office Floor Tile Works
	
AAC blocks fixing works	AAC block fixing work

Photograph 1- Site Photographs

d) Site Measurement Verification

Tile layout drawings and physical site measurements were analyzed to determine the number of full and partial tiles used per area. Floor-wise observations covered the Ground Floor, First Floor, Residential Flat, Passage, Staircase, and Service Areas. The counts were then used to evaluate layout efficiency and quantify theoretical cutting losses.

3.4 Data Classification and Compilation

Collected data were classified by tile type and area of installation. Parameters included:

- Tile size (600 × 600 mm, 1200 × 600 mm)
- Floor level (Ground, First, Residential Flat, Staircase, Passage, Service Area)
- Wastage type (Transport, Cutting, Installation Damage, or Replacement)
- Full vs Partial tile usage
- Total measured area (sq.ft)

All quantitative data were compiled in **Microsoft Excel** and analyzed using embedded formulae to calculate wastage percentages and economic impact.

3.5 Quantification of Tile Wastage

Tile wastage was computed using two main indicators:

(a) Actual Site Wastage (ASW):

$$ASW(\%) = \frac{A_{wasted}}{A_{procured}} \times 100$$

(1)

(b) Theoretical or Optimized Wastage (TOW):

$$TOW(\%) = \frac{A_{cutloss}}{A_{required}} \times 100$$

(2)

where:

- A_{wasted}= total tile area wasted on-site (sq.ft)
- $A_{procured}$= total tile area procured (sq.ft)
- $A_{cutloss}$= area lost during optimal cutting
- $A_{required}$= actual tile-covered area

The **avoidable wastage** was then determined as:

$$Avoidable\ Wastage = ASW - TOW$$

(3)

3.6 Economic Evaluation

The economic implications of tile wastage were analyzed using the equation:

$$E_{loss} = (A_{wasted} \times C_{tile}) + C_{reorder} + C_{disposal}$$

(4)

where:

- C_{tile}= unit cost of tile (₹/sq.ft)
- $C_{reorder}$= additional cost due to reorder or delay
- $C_{disposal}$= disposal and handling cost of waste

Two comparative cost scenarios were developed:

- Scenario A (Existing practice): Current layout and installation method.
- Scenario B (Optimized layout): Improved cutting layout and handling practice using CAD-aided optimization.

The resulting cost savings were expressed as:

$$Cost\ Savings(\%) = \frac{E_{lossA} - E_{lossB}}{E_{lossA}} \times 100$$

(5)

3.7 Data Validation and Reliability

To ensure methodological rigor, several validation procedures were adopted:

- Triangulation: Correlation of BOQ data, interview findings, and photographic evidence.
- Cross-verification: Measured tile areas were compared with installation logs.
- Peer validation: Results reviewed by site engineers for accuracy.
- Random rechecks: Conducted on selected floors to confirm full and partial tile counts.

Table II — Data Validation

Validation Parameter	Source	Purpose
Procurement Quantities	Bill of Quantities (BOQ) and Delivery Challans	To confirm the correspondence between material supply and on-site usage
Wastage Observation	Site Photographs and Daily Progress Reports	To provide visual proof and quantitative verification of physical tile losses
Interview Feedback	Structured Google Form Survey	To identify practical causes of tile wastage and validate qualitative observations
Layout Accuracy	Floor Plans and Field Measurements	To verify accuracy of area coverage and tile layout conformity

3.8 Analytical Tools

- **Microsoft Excel 365** – Data tabulation, formula-based analysis, and charting.
- **NVivo 12** – Qualitative coding of interview responses and thematic mapping.
- **AutoCAD 2023** – Layout optimization and calculation of theoretical cutting losses.

3.9 Ethical Considerations

All participants provided informed consent prior to the interviews. The survey responses were anonymized, and photographs were taken with permission solely for research documentation. No confidential or commercially sensitive data have been disclosed.

3.10 Summary of Key Input Data

Table III – input data Summary

Parameter	**Value / Description**
Tile Types	600×600 mm, 1200×600 mm
Total Tiles Ordered (1200×600 mm)	1,000 tiles
Total Tiles Ordered (600×600 mm)	400 tiles
Observed Transport Damage	310 sq.ft (≈4%)
Project Type	Residential + Commercial
Plot Area	10,800 sq.ft
Built-up Area	45,000 sq.ft
Work Stage	Finishing (Commercial section)
Survey Respondent	Shubham Kadam, B.E. Civil

4. Results and Discussion

4.1 Overview

The collected quantitative and qualitative data were analyzed to identify the magnitude of tile wastage across different floors and tile dimensions and to evaluate the associated economic implications. The findings also correlate visual site observations and survey responses with the measured data to provide a holistic interpretation of waste causation and mitigation. The present case study evaluates tile wastage minimization strategies and their associated economic consequences in a Residential and Commercial Building project located at S. No. 80/39, Village Manjari, Taluka Haveli, District Pune. The project, developed by The R Buildcon and named "The Gracia", provided a practical construction environment to analyze actual tile consumption, wastage patterns, and cost implications during execution.

The analysis of tile usage at *The Gracia* project revealed that tile wastage constituted a significant portion of finishing-stage material losses when conventional procurement and installation practices were followed. Initial observations indicated that wastage primarily occurred due to improper cutting practices, inadequate planning of tile layouts, damage during handling and storage, and frequent design changes during execution. These factors collectively led to excess material procurement beyond the theoretical quantity estimated during the planning phase. After implementing tile wastage minimization strategies—such as optimized tile layout planning, accurate quantity estimation with realistic wastage allowances, improved on-site handling practices, skilled labor deployment, and better coordination between design and execution teams—a noticeable reduction in tile wastage was observed. The results demonstrated that systematic planning and controlled execution reduced unnecessary tile breakage and off-cuts, leading to a measurable improvement in material utilization efficiency.

From an economic perspective, the reduction in tile wastage directly translated into cost savings for the project. Lower wastage levels reduced the need for excess tile procurement, thereby decreasing material costs. Additionally, improved installation efficiency reduced rework, labor hours, and project delays, contributing to indirect cost savings. The cumulative financial impact highlighted that even a modest reduction in tile wastage resulted in substantial monetary benefits, particularly in large-scale residential and commercial developments like *The Gracia*. Furthermore, the results emphasized that tile wastage minimization not only enhances economic performance but also supports sustainable construction practices. Reduced material waste lowered the burden of disposal and minimized environmental impacts associated with manufacturing, transportation, and waste handling. This aligns with contemporary construction objectives focused on cost efficiency, sustainability, and resource optimization. Overall, the findings from *The Gracia* project clearly indicate that proactive tile wastage minimization strategies significantly improve both material efficiency and economic outcomes. The results validate the importance of integrating wastage control measures into planning, procurement, and execution stages of construction projects. These outcomes provide strong empirical support for adopting systematic tile management practices in similar residential and commercial construction projects to achieve cost-effective and sustainable development.

4.2 Floor-wise Analysis of Tile Usage and Wastage

Tile installation was recorded across multiple building zones including the Ground Floor, First Floor, and one representative Residential Flat, as well as passage, staircase, and service areas. Two tile types—1200×600 mm vitrified tiles and 600×600 mm ceramic tiles—were evaluated separately to compare size-related efficiency.

Table IV – Floor-wise Tile Usage and Wastage Summary

Parameter	**Ground Floor (GF)**	**Mezzanine Floor (MF)**	**1st Floor (FF)**	**Total**
Carpet Area (Sq. m)	99.65	59.26	445.79	604.70
Full Tiles Consumed (Nos.)	100	64	540	704
Break Tiles Consumed (Nos.)	56	27	111	194
Total Tiles Consumed (Nos.)	156	91	651	898
Tile Consumption on Site (Sq. m)	111.32	65.52	469.72	646.56
Design Tile Wastage (Sq. m)	12.67	6.26	22.93	41.86
Average Tile Wastage (%)	12.75	10.36	5.08	6.92

The total carpet area of 604.70 sq. m required 898 tiles, resulting in an actual tile coverage of 646.56 sq. m. The cumulative design tile wastage amounted to 41.86 sq. m, corresponding to an overall wastage of 6.92 %. This level of wastage highlights the significance of layout planning, break-tile optimization, and skilled installation practices in minimizing material loss during finishing works.

4.3 Categorization of Wastage Causes

Analysis of field photographs and survey responses identified four dominant causes of tile wastage:

Tabel V- Categorization of Tile Wastage Causes

Wastage Category	Description	Relative Contribution (%)
Transport & Handling	Cracks, corner breakage during offloading and shifting	40
Cutting & Layout Loss	Excess cutting in irregular areas (toilets, stairs, passages)	30

Installation Errors	Edge chipping, misalignment, replacement after fixing	20
Design or Color Mismatch	Wrong batch mixing, aesthetic replacements	10

4.4 Comparative Evaluation: Actual vs Theoretical Wastage

The theoretical (optimized) wastage was computed using CAD-based layout simulations for each floor. These simulations assumed ideal placement minimizing partial cuts. The results show a clear difference between actual and optimized performance.

Tabel VI- Comparative Analysis of Actual vs. Theoretical Tile Wastage

Tile Type (mm)	Actual Wastage (%)	Theoretical Wastage (%)	Avoidable Wastage (%)
1200×600	3.9	2.2	1.7
600×600	4.2	2.5	1.7
Average	4.0	2.3	1.7

4.5 Economic Impact Analysis

Using the procurement rate derived from project cost data (₹50/sq.ft for floor tiles, average market rate for 2025), the direct material loss and potential savings were calculated as follows:

Table VII - Economic Impact of Tile Wastage Reduction Strategies

Parameter	Value
Total Tile Area Procured	7,750 sq.ft
Actual Waste	310 sq.ft (4.0%)
Unit Tile Cost	₹50/sq.ft
Material Loss Cost	₹15,500
Additional Handling & Disposal	₹3,000
Total Economic Loss (Existing Practice)	₹18,500
Theoretical Optimized Waste (2.3%)	178 sq.ft
Economic Loss (Optimized Layout)	₹8,900
Potential Savings	₹9,600 (≈52% reduction)

5.1 Conclusion

This study evaluated tile wastage minimization strategies and their economic consequences through a detailed case analysis of a mixed-use residential and commercial construction project. Based on quantitative measurement, survey feedback, and on-site observation, the following conclusions are drawn:

1. Measured wastage averaged 4.0%, which is lower than the typical industry benchmark of 8–10%, indicating a relatively efficient installation process.
2. The primary sources of waste were transport damage (40%) and cutting inefficiencies (30%), followed by installation errors (20%) and design mismatches (10%).
3. Theoretical optimization using CAD-based layouts showed potential to reduce wastage to 2.3%, revealing 1.7% avoidable loss, primarily from cutting and misalignment.
4. Economically, this reduction translates into potential cost savings of ₹9,600, equivalent to a 52% decrease in wastage expenditure, achieved without altering tile specifications.
5. Findings confirm that proactive design coordination, trained manpower, and proper handling are more cost-effective than reactive corrective measures after wastage occurs.
6. The correlation between interview responses, photographic documentation, and BOQ records demonstrates methodological reliability and reinforces the value of integrating field data with quantitative analysis.

In summary, tile wastage minimization not only enhances project economy but also supports environmental sustainability by reducing material disposal and embodied energy loss. The approach contributes to achieving UN SDG 12 (Responsible Consumption and Production) in the construction sector.

5.2 Managerial and Practical Implications

From a project management perspective, the study offers the following practical insights:

- Design-phase coordination: Early alignment between architects, engineers, and procurement teams can ensure that tile dimensions suit room geometry, minimizing offcuts.
- Digital optimization: Implementing BIM or CAD-based layout simulation before material ordering significantly improves cutting accuracy and cost forecasting.
- Handling and storage: Enforcing structured storage protocols and protective packaging can prevent over 40% of observed transport-related damages.
- Skill training: Regular workshops for tile installers can reduce on-site damage and rework, improving quality consistency.
- Procurement policy: Including wastage performance metrics in contractor evaluation encourages accountability and continuous improvement.

5.3 Limitations

While comprehensive, this research has several limitations:

1. The case study represents a single project, and results may vary with project type, scale, and contractor practices.
2. Only two tile sizes (600×600 mm and 1200×600 mm) were analyzed; future work should include varying dimensions and material types (porcelain, granite, etc.).
3. Economic analysis was based on current market rates and may require adjustment for regional cost variations.
4. Although qualitative validation was conducted, broader participation from multiple stakeholders would strengthen generalizability.

5.4 Future Scope

Building on the findings, future studies can explore:

1. Integration of BIM-driven optimization models to automatically generate low-waste tile layouts and cost predictions.
2. Real-time digital tracking of material usage and waste, linking site inventory systems with procurement software.
3. Lifecycle assessment (LCA) of tile wastage to quantify environmental impact and embodied carbon reduction.
4. Circular reuse strategies, where tile offcuts and broken pieces are reprocessed into aggregates, mosaics, or composite materials.
5. Multi-case benchmarking studies across diverse building types to develop an industry-standard wastage index.
6. Development of an AI-based decision support system for tile layout planning and waste prediction during early design stages.

The study demonstrates that even marginal improvements in tile wastage control can yield measurable economic and environmental benefits. Through design optimization, data-driven management, and site-level discipline, construction projects can move towards zero-waste objectives, achieving both cost efficiency and sustainable material management.

REFERENCES

[1] M. Godzierz, P. Kordek, and M. Podsiadło, "Lightweight aggregates produced from waste glass and mining slates: Physical and mechanical properties," *Materials*, vol. 13, no. 15, p. 3367, 2020, doi: 10.3390/ma13153367.

[2] A. M. Fayed, M. A. Zayed, and A. M. Abd El-Rahman, "Experimental behavior of tubular steel–concrete composite members with bolted shear connectors," *Structures*, vol. 52, pp. 1033–1048, 2025, doi: 10.1016/j.istruc.2025.03.098.

[3] C. S. Poon, A. T. W. Yu, L. H. Wong, and E. Cheung, "Management of construction waste in Hong Kong," *Waste Management*, vol. 21, no. 6, pp. 505–513, 2001, doi: 10.1016/S0956-053X(00)00116-0.

[4] B. A. G. Bossink and H. J. H. Brouwers, "Construction waste: Quantification and source evaluation," *Journal of Construction Engineering and Management*, vol. 122, no. 1, pp. 55–60, Mar. 1996, doi: 10.1061/(ASCE)0733-9364(1996)122:1(55).

[5] C. T. Formoso, C. H. Soibelman, C. De Cesare, and E. L. Isatto, "Material waste in building industry: Main causes and prevention," *Journal of Construction Engineering and Management*, vol. 128, no. 4, pp. 316–325, Aug. 2002, doi: 10.1061/(ASCE)0733-9364(2002)128:4(316).

[6] R. A. Begum, C. Siwar, J. J. Pereira, and A. H. Jaafar, "A benefit–cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia," *Resources, Conservation and Recycling*, vol. 48, no. 1, pp. 86–98, May 2006, doi: 10.1016/j.resconrec.2006.01.004.

[7] L. L. Ekanayake and G. Ofori, "Building waste assessment score: Design-based tool," *Building and Environment*, vol. 39, no. 7, pp. 851–861, July 2004, doi: 10.1016/j.buildenv.2004.01.007.

[8] V. W. Y. Tam, C. M. Tam, and W. S. Chan, "Management of construction waste in Hong Kong: On-site practice and performance," *Construction Management and Economics*, vol. 25, no. 7, pp. 695–706, July 2007, doi: 10.1080/01446190701321816.

[9] A. Al-Hajj and K. Hamani, “Material waste in the UAE construction industry: Main causes and minimization practices,” *Architectural Engineering and Design Management*, vol. 7, no. 4, pp. 221–235, 2011, doi: 10.1080/17452007.2011.594576.

[10] S. O. Ajayi, L. O. Oyedele, O. O. Akinade, M. Bilal, H. A. Alaka, H. A. Owolabi, and K. O. Kadiri, “Reducing waste to landfill: A need for cultural change in the UK construction industry,” *Journal of Building Engineering*, vol. 4, pp. 185–193, Dec. 2015, doi: 10.1016/j.jobe.2015.09.006.

[11] M. A. Arias Ocampo and A. F. Rojas González, “Ceramic waste reuse and valorization alternatives: A review,” *Revista EIA*, vol. 20, no. 40, art. Reia4018, 2023, doi: 10.24050/reia.v20i40.1818.

[12] P. Zhang, P. Zhang, J. Wu, Z. Guo, Y. Zhang, and Y. Zheng, “Mechanical properties and durability of sustainable concrete manufactured using ceramic waste: A review,” *Journal of Renewable Materials*, vol. 11, no. 2, pp. 937–974, 2023, doi: 10.32604/jrm.2023.029851.

[13] S. Basak, “Performance of ceramic tile waste as partial replacement in concrete,” *International Journal of Engineering Research & Technology (IJERT)*, vol. 13, no. 5, pp. 650–654, May 2024, doi: 10.17577/IJERTV13IS050247.

[14] K. Hosen and A. Bărbulescu, “Sustainable concrete using ceramic tile waste as a substitute for brick aggregate,” *Recycled Materials Research*, vol. 1, no. 1, pp. 15–23, Jan. 2025, doi: 10.1016/j.rmr.2025.01.002.

[15] A. O. Tanash, A. A. Abd El-Gawad, and E. R. El-Khodary, “Utilization of ceramic tile waste as cement replacement in sustainable construction,” *Journal of Building Engineering*, vol. 69, art. 108675, 2024, doi: 10.1016/j.jobe.2024.108675.

[16] A. A. Adekunle, K. R. Abimbola, and A. O. Familusi, “Utilization of Construction Waste Tiles as a Replacement for Fine Aggregates in Concrete,” *Engineering, Technology & Applied Science Research*, vol. 7, no. 5, pp. 1930–1933, Oct. 2017.

[17] “Eco-friendly concrete with waste ceramic tile as coarse aggregate: mechanical strength, durability, and microstructural properties,” *Asian Journal of Civil Engineering*, vol. 24, pp. 3363–3373, 2023.

[18] K. Hosen and A. Bărbulescu, “Sustainable Concrete Using Ceramic Tile Waste as a Substitute for Brick Aggregate,” *Materials*, vol. 18, no. 13, art. 3093, 2025.

[19] “Recycling of ceramic tile waste into construction materials,” *Developments in the Built Environment*, vol. 18, art. no. 100431, Apr. 2024.

[20] “Utilisation of Ceramic Stoneware Tile Waste as Recycled Aggregate in Concrete,” *Buildings*, vol. 13, no. 8, art. 1968, 2023.

[21] “Experimental and numerical investigation of the properties of concrete with ceramic tile waste and stone dust as substitutes for natural aggregates,” *Discover Civil Engineering*, vol. 1, art. no. 120, 2024.

[22] B. Subedi, D. K. Wagle, and K. Basnet, “Utilization of Crushed Ceramic Tile Wastes as Partial Replacement of Coarse Aggregate in Concrete Production,” *International Journal of Engineering Research & Technology (IJERT)*, vol. 9, no. 7, Jul. 2020.

[23] Dilay Özuyar, Berkay Sözüdöğru, Mustafa Tosun, Gökhan Ünal, and Burak Özkal, “The Use of Ceramic Tile Waste as a Calcite Substitute in Construction Chemicals,” *Journal of Material Characterization and Applications*, vol. 2, no. 3, pp. 125–135, Dec. 2024.

[24] Sumanth C., Mahendra K. R., Yashwanth H. B., Nikil H., Arun Kumar B. R., and Uma A, “Utilization of Ceramic Tiles Waste as a Partial Replacement of Fine Aggregate in Cement Mortar,” *IJRASET: International Journal for Research in Applied Science & Engineering Technology*, 2023.

[25] “Optimization Models for Reducing Off-Cuts of Raw Materials in Construction Site,” *Mathematics*, vol. 10, no. 24, art. 4651, Dec. 2022

[26] Hamid, N. B., Mohammad Azm, M. A. ., Abdullah, N. H. ., Mokhtar, M., Prasetijo, J. ., Che Muni, M. F. ., Zainudin, M. H. F., & Abu Bakar, A. I. N. . (2020). A Review: Potential of Waste Materials in Tiles Production . *Multidisciplinary Applied Research and Innovation*, *2*(1), 91-102.

[27] Keys, Andrew; Baldwin, Andrew; Austin, Simon (2000). Designing to encourage waste minimisation in the construction industry. Loughborough University. Conference contribution. https://hdl.handle.net/2134/4945