Optimising Sustainable Deconstruction Strategies for Concrete Structures: A Multi-Criteria Decision Framework Approach

IBE, Chukwumaobi <http://orcid.org/0000-0002-2093-7082>

emerald PUBLISHING International Journal of Building Pathology and Adap

Optimising Sustainable Deconstruction Strategies for Concrete Structures: A Multi-Criteria Decision Framework Approach

Journal:	*International Journal of Building Pathology and Adaptation*
Manuscript ID	IJBPA-09-2024-0181.R3
Manuscript Type:	Original Article
Keywords:	Sustainable deconstruction, Concrete structures, multi-criteria decision analysis, Demolition strategies

Optimising Sustainable Deconstruction Strategies for Concrete Structures: A Multi-Criteria Decision-Making Framework Approach

Abstract

Purpose:

This study proposes a Multi-Criteria Decision Analysis (MCDA) framework to optimise sustainable deconstruction strategies for precast concrete buildings. The framework aims to maximise material recovery, minimises environmental impacts, and ensures cost-effectiveness, providing stakeholders with an evidence-based tool for decision-making.

Design/methodology/approach:

The framework integrates the Analytic Hierarchy Process (AHP) and VIKOR methods to evaluate eighteen deconstruction strategies across four categories: concrete component removal, reinforcement separation, structural dismantling, and material recycling. A case study of a four-storey university building was modelled using *DesignBuilde*r software to simulate material flows and assess performance metrics. Stakeholder input was used to determine criteria weights, balancing environmental, economic, and technical dimensions.

Findings:

Selective removal strategies, particularly staircase dismantling (D3) and wall panel removal (D1), yielded optimal material recovery and cost efficiency while minimising environmental and safety risks. Scenario S1 demonstrated adaptability as an early-stage strategy for precast panel removal.

Practical Implications:

This framework serves as a practical tool for contractors, policymakers, and environmental agencies, enabling the prioritisation of deconstruction strategies that align with sustainability objectives. It supports global climate goals by reducing emissions and enhancing the value of recycled materials.

Originality/Value:

This study advances sustainable deconstruction by integrating AHP and VIKOR into a cohesive MCDA framework. It offers a practical decision-making tool for contractors, policymakers, and environmental agencies, contributing new insights to the construction industry and supporting global sustainability goals.

Keywords:

Sustainable deconstruction, concrete structures, Multi-Criteria Decision Analysis, demolition strategies.

Paper Type: Research paper.

1. Introduction

The adoption of precast concrete construction has revolutionised the built environment, offering efficiency, cost-effectiveness, and improved quality control (Elliott, 2017; Jacinto *et al.*, 2024). However, the end-of-life phase of precast structures poses unique challenges, particularly in the dismantling of modular components and recovering embedded materials (Durmisevic *et al.*, 2017). These challenges increase material waste and contribute to

environmental degradation, undermining the construction industry's sustainability goals (Alhawamdeh *et al.*, 2024). As global populations grow and urbanisation intensify, the demand for innovative solutions to manage construction and demolition (C&D) waste sustainably is critical (Ababio *et al.*, 2023). One such approach involves integrating adaptable design principles at the early stages of construction, which can significantly enhance deconstruction efficiency by facilitating material reversibility and reuse, thereby aligning with the circular economy principles (Ollár, 2024).

Existing deconstruction frameworks primarily focus on cost and time, often neglecting broader sustainability metrics such as emissions and material recovery. (Wong and Loo, 2022). This oversight underscores a significant scientific gap in the integration of environmental, economic, and social considerations into decision-making processes for precast concrete deconstruction. Furthermore, the literature lacks comprehensive models tailored to modular precast systems, which require specialised approaches to optimise resource recovery and reduce environmental impacts (Akbarnezhad *et al.*, 2014; Poon *et al.*, 2004). Recent studies emphasise the need for adaptive frameworks that incorporate emerging technologies, such as digital twins and advanced material recovery methods, to enhance deconstruction efficiency (Kusi *et al.*, 2024; Peiris *et al.*, 2023). Without such a framework, achieving a balanced and sustainable approach to precast deconstruction remains a challenge.

To address this gap, this study proposes a Multi-Criteria Decision Analysis (MCDA) framework to evaluate deconstruction strategies for precast concrete buildings. By integrating AHP and VIKOR, the framework systematically optimises material recovery while minimising environmental impact. The research question guiding this study is:

1. How can sustainable deconstruction criteria be assessed, quantified, and optimised using an MCDA framework?

The hypotheses underpinning this research are:

- Sustainable deconstruction strategies can be optimised by integrating quantitative and qualitative criteria into a cohesive decision-making framework.
- AHP-VIKOR analysis provides a robust mechanism for identifying balanced solutions that align with technical, economic, and environmental objectives.

This paper is structured as follows: Section 2 reviews the state of the art in sustainable deconstruction and MCDA methodologies, highlighting gaps in current practices. Section 3 details the methodology, including case study selection, stakeholder involvement, and criteria weighting processes. Section 4 presents the results, comparing the performance of deconstruction strategies against sustainability metrics. Section 5 discusses these findings in relation tom existing literature and their implications for practice. Finally, Section 6 concludes with key insights, limitations, and recommendations for future research.

By building upon recent global advancements in deconstruction science and decision analysis, this study contributes to the development of a more sustainable approach to managing the end-of-life phase of precast concrete structures, aligning with circular economy principles.

2. State of the Art in Sustainable Deconstruction and MCDA Methodologies

The fields of sustainable deconstruction and Multi-Criteria Decision Analysis (MCDA) have witnessed significant advancements in recent years, driven by the urgency to address construction and demolition (C&D) waste challenges. Table I summarises key contributions and research gaps across these domains, highlighting critical developments and areas requiring further exploration.

Table I: Summary of key contributions and research gaps in sustainable deconstruction and MCDA methodologies

Advanced technologies and standardised deconstruction processes promote circular economy principles (Gambato *et al.*, 2023). Their effectiveness in sustainable deconstruction depends on procurement models that facilitate collaboration and data integration, as highlighted in prior research on Building Information Modelling (BIM) adoption challenges in the public sector (Alhusban *et al.*, 2024). Several studies have reviewed critical factors for assessing building deconstructability, including economic, social, environmental, and technical dimensions, emphasising the need for holistic approaches (Balogun *et al.*, 2024a).

The integration of artificial intelligence (AI) into deconstruction planning and execution has emerged as a promising trend. AI and robotics enhance automation in sorting, cost estimation, and workflow planning, thereby improving decision-making and sustainability (Balogun et al., 2024). These advancements directly support sustainability goals by promoting efficiency and reducing waste.

AHP and VIKOR have proven effective in balancing conflicting criteria in construction MCDA applications. The importance of implementing uncertainty-based procedures and integrating smart technologies to refine multi-criteria design frameworks has been widely recognised (Bianchi *et al.*, 2024). However, significant gaps remain in adapting these methods for modular precast deconstruction (Kanters, 2018).

This study aims to bridge these gaps by leveraging the AHP-VIKOR approach to optimise deconstruction strategies while incorporating the latest advancements in digital technologies and circular economy principles.

3. Materials and Methods

This study develops a framework to identify sustainable deconstruction strategies for precast concrete buildings, incorporating a case study and stakeholder input. The case study selection was based on key parameters, with deconstruction strategies simulated using *DesignBuilder* software, see ~~(~~Figure 2~~)~~. The evaluation metrics included material recovery rates, greenhouse gas emissions, and economic costs. Prior research, such as Akbarnezhad et al., (2014) on environmental assessments of deconstruction, and Peiris et al., (2023) on digital tools for retrofitting, informed the framework's development.

Figure 1 presents a flowchart outlining the research steps, from identifying the research gap to generating results, providing clarity on methodology and the theoretical foundation.

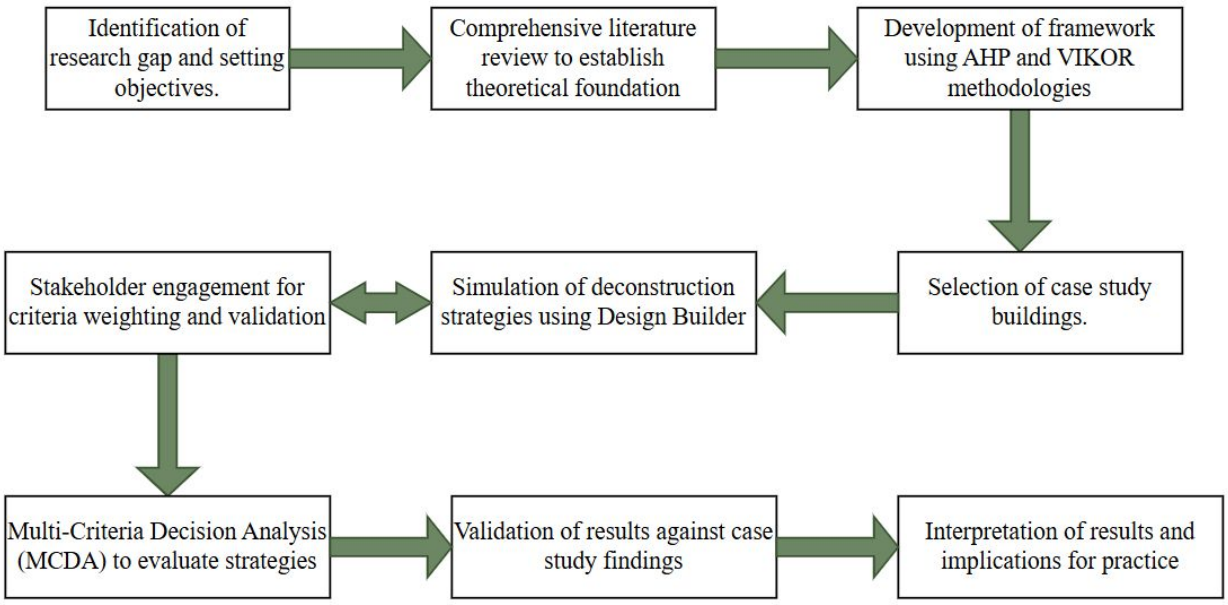
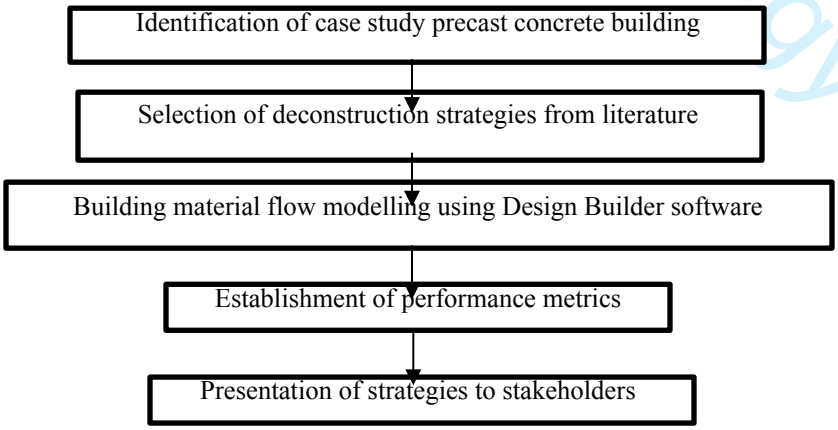


Figure 1: Research Methodology flowchart Source: Authors own creation

The framework integrates multiple theoretical approaches to support the identification and evaluation of sustainable deconstruction strategies. The Analytic Hierarchy Process (AHP) and VIKOR methodologies were selected to balance conflicting criteria such as material recovery, greenhouse gas emissions, and economic costs. AHP was used to determine criteria weighting, while VIKOR was employed to rank and select optimal deconstruction strategies.

Circular economy principles emphasise resource recovery and waste minimisation, guiding the selection of performance metrics like material recovery rates. Environmental assessment tools, including Life Cycle Assessment (LCA), were incorporated to comprehensively evaluate greenhouse gas emissions and broader environmental impacts. This builds on prior studies, such as (Akbarnezhad *et al.*, 2014), which highlight the importance of environmental metrics in deconstruction planning.

Stakeholders, including experts and policymakers, were engaged to ensure industry alignment in criteria weighting and validation.



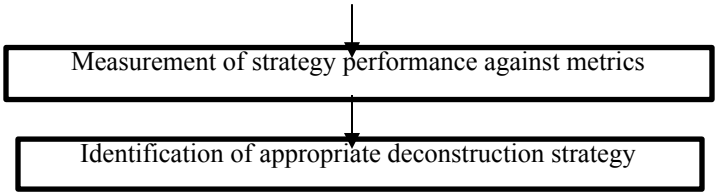


Figure 2: Proposed Framework for Identifying Appropriate Deconstruction Strategy Source: Authors own creation

3.1. Stakeholders

Thirty stakeholders representing academia (40%), industry (40%), and government (20%) were selected as Decision Makers (DMs) to ensure a balanced and diverse evaluation of deconstruction strategies. The selection criteria prioritised expertise in precast concrete structures, sustainability assessment, and deconstruction practices. Stakeholders were deliberately chosen from different geographic and regulatory contexts to enhance applicability across various deconstruction scenarios.

To quantify the importance of each criterion, the Analytic Hierarchy Process (AHP) was employed. Stakeholders compared six performance criteria through structured surveys. These comparisons were translated into numerical scores using Saaty's (2022) scale, ranging from 1 (equal importance) to 9 (extreme importance). The pairwise comparison matrix was analysed using the eigenvector method, producing weight coefficients that indicate the relative importance of each criterion. The final criteria weights were computed and tested for consistency, ensuring a consistency ratio (CR < 0.10) to ensure logical coherence (see Appendix 1). The derived weights, summarised in Table II, guided the strategy evaluation process.

Table II: Description of performance criteria

These results align with (Sánchez-Garrido *et al.*, 2022), which emphasised resource depletion and material recovery as key sustainability indicators. However, unlike Bianchi et al. (2024), which prioritised environmental considerations, this study assigns greater weight to revenue from materials (C5: 20.3%), reflecting practical industry concerns.

3.2. Building model

A building material flow model was developed in *DesignBuilder* software, integrating detailed architectural plans, material specifications, and structural connection details from the case study building. This model played a crucial role in estimating the quantities of recoverable materials across different deconstruction scenarios.

The model validation process followed four key steps:

Architectural and structural details were validated against historical deconstruction data.

Material Quantification: The software generated material take-offs for key components, including precast panels, reinforced concrete slabs, and embedded steel reinforcements.

Calibration and Adjustment: Simulated material quantities were compared with actual deconstruction data from case studies, ensuring deviations remained within 5% (see Table VI).

Sensitivity Analysis: Multiple simulation runs were conducted to account for uncertainties in material composition, connection types, and removal efficiency.

The *DesignBuilder* model provided real-time quantitative estimates of material recovery rates, associated deconstruction costs, and waste generation. The high calibration accuracy (<5% deviation) reinforces its applicability for practical deconstruction projects.

3.3. *Performance criteria selection*

Performance criteria were derived from literature reviews and stakeholder feedback, ensuring alignment with industry practices. The evaluation framework categorised performance criteria as beneficial (to be maximised) or non-beneficial (to be minimised). Beyond traditional metrics such as material recovery, greenhouse gas emissions, and economic costs, additional considerations - health and safety risks (e.g., hazardous waste exposure, structural instability during deconstruction) and scalability (the feasibility of implementing strategies across different project sizes and geographic contexts) - were identified as critical. Stakeholders emphasised that deconstruction approaches must not only optimise resource efficiency but also address worker safety challenges and ensure practicality for large-scale applications. Weighting of criteria was informed by (Guerra and Leite, 2021) and refined using stakeholder surveys.

Normalisation was performed to ensure comparability among criteria expressed in different units (e.g., cost in USD, emissions in kg CO_2). The linear min-max scaling method was applied, transforming all values to a standardised 0–1 scale, where 1 represents the most favourable performance and 0 the least favourable.

Figure 32 summarises the classification of performance criteria.

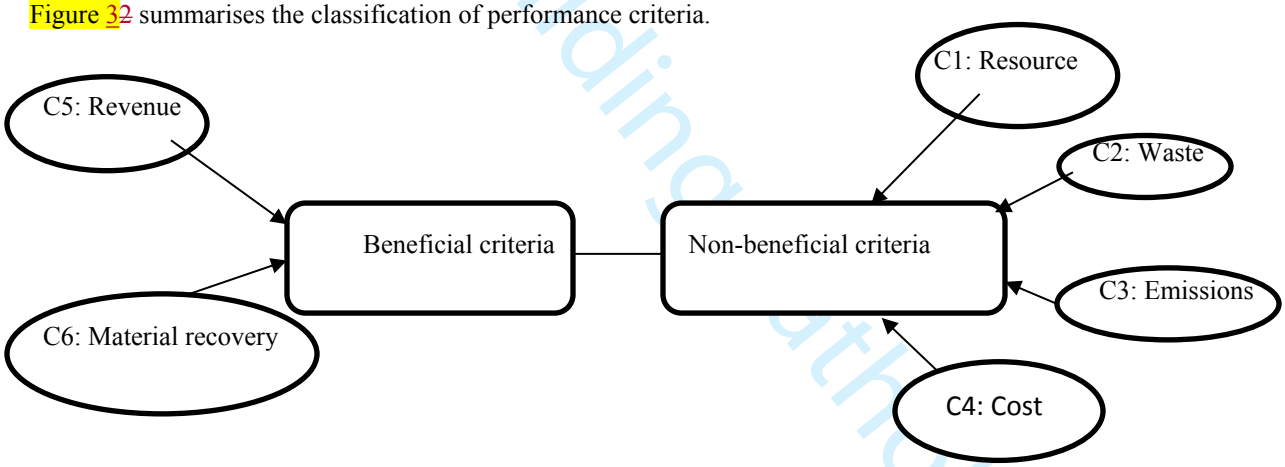


Figure 3: Classification of performance criteria Source: Authors own creation

3.4. Deconstruction strategies

Eighteen deconstruction strategies were identified and categorised into four groups:

1. Concrete Component Removal Strategies (D1-D6): Selective removal of precast concrete wall panels, floors/beams, and staircase components.
2. Reinforcement Recovery Strategies (D7-D9): Cutting and separating embedded steel rebar from demolished concrete sections for material recovery.
3. Structural Dismantling Strategies (D10-D12): Dismantling of reinforced concrete frames, pillars, and foundation systems.

4. Material Recycling Strategies (D13-D18): Centralised aggregate crushing on-site to produce recycled concrete mix (RCM), sorting of scrap steel, and transportation of recovered materials to recycling facilities.

These strategies were derived from previous works, including Durmisevic et al., (2017) on modular dismantling and Ababio et al., (2023) on circular economy practices in deconstruction. Stakeholder feedback further refined the strategies to reflect practical constraints and opportunities. Table III describes these deconstruction strategies.

Table III: Description of individual deconstruction strategies

3.5. Deconstruction scenarios

To facilitate comparative evaluation, the eighteen strategies were grouped into six integrated deconstruction scenarios (S1–S6), designed to balance selective dismantling, material recovery, and cost efficiency. Table IV outlines the scenarios and their composition:

Table IV: Deconstruction scenarios for evaluation

The scenarios considered in the study are described as follows:

S1: Prioritises selective removal of precast panels.

S2: Focuses on dismantling structural systems.

S3: Emphasises material recycling through centralized processing.

S4: Combines selective dismantling with sorting for recycling.

S5: Integrates component segmentation with material recovery.

S6: Represents a fully integrated scenario combining all strategy categories.

The scenarios were validated through stakeholder consultation ensuring alignment with practical industry challenges.

3.6. Multi-criterion decision analysis using AHP-VIKOR

To rank and evaluate the deconstruction scenarios, a hybrid AHP-VIKOR approach was implemented:

AHP Weighting Calculation: The stakeholder-derived criteria weights (Table II) were applied to standardise the assessment framework.

Performance Scoring: The six scenarios (S1–S6) were evaluated using *DesignBuilder* simulation outputs (Table VII), assessing performance across cost, time, material recovery, and environmental impact.

VIKOR Compromise Ranking: The VIKOR method was employed to determine the best-ranked deconstruction scenario by minimising disadvantages across conflicting criteria.

Final Scenario Ranking: The computed VIKOR indices (Table VIII) provided a decision hierarchy, where S1 (Precast Panel Removal) and S4 (Reinforcement Separation) emerged as the most balanced options.

The inclusion of sensitivity analysis ensured robustness, allowing the model to account for varying weight allocations and uncertainty levels. The results align with Yang et al., (2024) and Durmisevic et al., (2017), who advocated for modular dismantling as an effective deconstruction approach.

3.7. Case Study Building

The case study focused on the National University Engineering Building (Gimenez Hall) at the University of the Philippines Diliman, Metro Manila. Constructed in 1990, this four-storey reinforced concrete structure spans approximately 4,300 square meters (Table V). The building features precast concrete panels, solid concrete interior walls, and a ceramic-tiled concrete slab roof. Mechanical and electrical systems include air conditioning, laboratory fume hood exhausts, plumbing, and comprehensive power distribution.

Climatic data from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) were used to inform the study. The building's specifications were input into *DesignBuilder* software to simulate material flows for each deconstruction scenario outlined in Table 3. The AHP-VIKOR framework was then applied to assess the eighteen deconstruction strategies, categorised into concrete components, reinforcement, structural systems, and material recycling. The scenarios are then assessed using the decision-making tool to balance technical, economic, and environmental sustainability factors, aiming to recommend the most suitable deconstruction approach.

Table V: Building information of the National University Engineering Building (Gimenez Hall)

4. Results and Discussions

Thirty stakeholders evaluated performance metrics (Table II). Eighteen responses met consistency criteria, ensuring diverse input. Industry professionals comprised 50%, with academia and government at 30% and 20%, respectively. Stakeholders prioritised resource depletion (C1), material recovery potential (C6), and revenue generation (C5) with weights of 26.4%, 24.1%, and 20.3%, respectively, as shown in Figure 4. These results highlight the importance of strategies that minimise raw material depletion, maximise recyclables, and enhance economic returns. Metrics for hazardous waste generation (C2) and greenhouse gas emissions (C3) were weighted similarly at 14.6% and 14.5%, emphasising environmental sustainability.

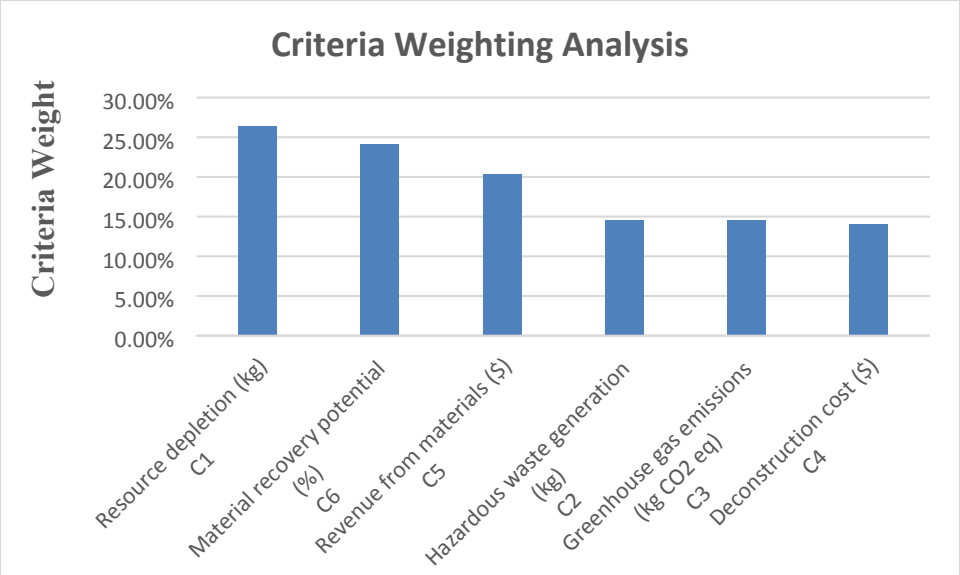


Figure 4: Criteria weighing analysis Source: Authors own creation

The performance of 18 individual strategies (D1–D18) was evaluated using *DesignBuilder* simulations and literature benchmarks. Figure 5 illustrates normalised scores, indicating that concrete component removal strategies like wall panel dismantling (D1) and floor beam segmentation (D2) excel in resource efficiency but face constraints in recycling potential due to material composition. Reinforcement strategies (D7–D9) achieved high steel recovery rates but incurred significant emissions and costs. Structural dismantling strategies (D10–D12) underperformed due to complexity, while material recycling strategies (D13–D18) excelled in recovery potential but struggled with high costs and emissions.

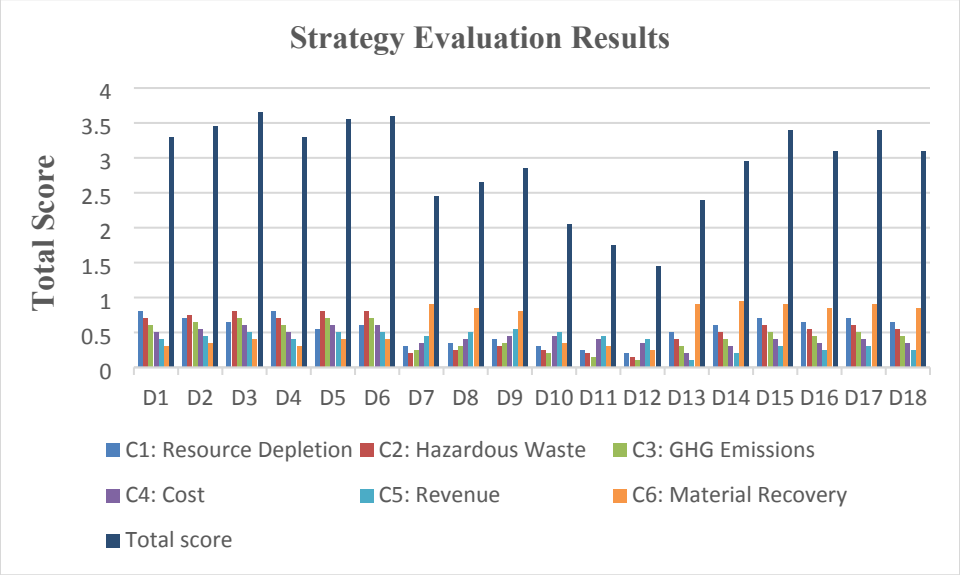


Figure 5: Strategy Evaluation Results Source: Authors own creation

These findings align with Akbarnezhad et al., (2014) but diverge in the relative prioritisation of economic returns, reflecting regional regulatory differences.

Deconstruction scenarios (S1–S6) were evaluated by aggregating individual strategy performances, as shown in Figure 4. Scenarios S1 and S4 emerged as the most balanced options, prioritising selective removal and reinforcement separation, respectively. Scenario S6, representing a fully integrated approach, ranked lower due to logistical challenges and high costs.

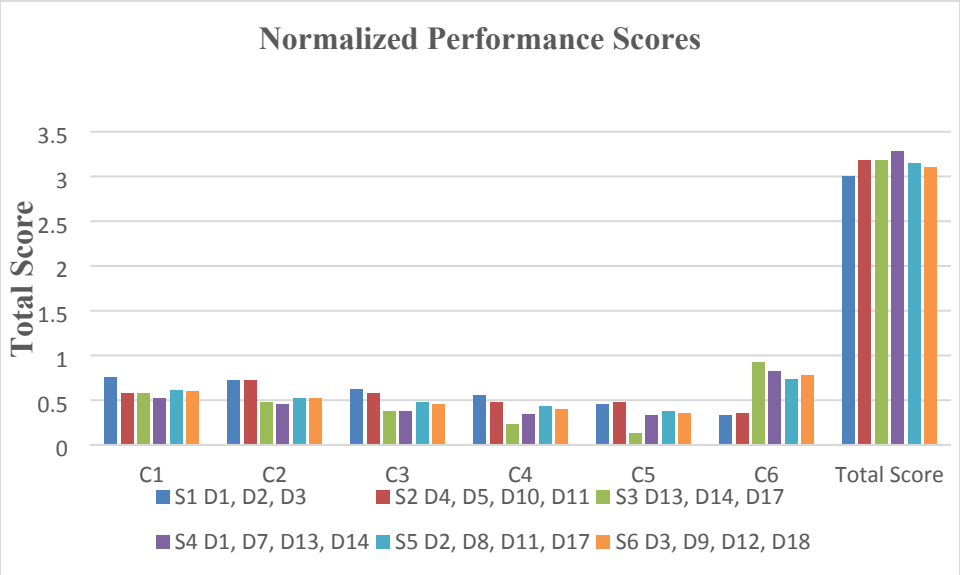


Figure 6: Normalized Performance Scores of Deconstruction Scenarios Source: Authors own creation

Expert validation confirmed the practicality of S1 and S4, aligning with industry needs. VIKOR intervals demonstrated that these scenarios minimised disadvantages across conflicting criteria, highlighting their potential as compromise solutions.

4.1. Building Model

The *DesignBuilder* simulation results for Scenario S1 are detailed in Table VI. Calibration results demonstrated deviations within a 5% threshold, confirming model accuracy. Additional validation benefitted from insights attributed to on-site observations and stakeholder feedback, ensuring the simulation reflected practical conditions.

Table VI: Building Model Parameters and Calibration Results

Table VII summarises simulation outputs with Table VIII providing the AHP-VIKOR analysis. For instance, D1 recovered 75 tonnes of concrete and 5 tonnes of steel, while S1 achieved 200 tonnes of concrete and 30 tonnes of steel. Material recycling strategies demonstrated strong recovery potential but required substantial infrastructure investment.

Table VII: Performance scores from Design Builder simulations

Table VIII: AHP-VIKOR Analysis of Deconstruction Strategies

4.2. Health, Safety, and Scalability

Health and safety risks varied significantly among strategies. Staircase removal (D3) posed higher risks due to elevated work environments, while recycling strategies required extensive handling of hazardous debris. AI-based safety monitoring and IoT-enabled equipment tracking could mitigate these risks, enhancing worker safety and operational efficiency. Scalability challenges were evident for material recycling strategies, particularly in regions lacking advanced processing facilities. Stakeholders emphasised modular approaches to facilitate incremental adoption in resource-constrained contexts.

4.3. Implications for Practice and Policy

The results underscore the importance of integrating circular economy principles into deconstruction projects. By maximising material recovery and reducing waste, the framework supports the development of secondary material markets, fostering a more resilient and resource-efficient construction sector.

Policymakers are encouraged to introduce targeted incentives such as tax breaks, subsidies, and streamlined regulatory pathways to accelerate the adoption of material recycling and deconstruction best practices. This would not only strengthen environmental policies but also enhance economic opportunities by creating new markets for reclaimed materials and supporting businesses specialising in sustainable deconstruction.

Practitioners can leverage digital tools, such as *DesignBuilder*, to optimise deconstruction strategies and mitigate environmental impacts. The integration of advanced decision-support models empowers contractors and developers with data-driven insights, improving cost-efficiency, planning accuracy, and risk management in deconstruction projects. The adaptability of the AHP-VIKOR framework across geographic and regulatory contexts further enhances its utility for global application. By providing a structured, quantifiable approach to evaluating deconstruction strategies, this study offers a replicable decision-making model that construction firms and policymakers can integrate into existing sustainability guidelines.

Emerging technologies like AI and IoT offer opportunities to refine strategy implementation, addressing scalability and safety challenges while improving operational efficiency. By bridging gaps between theory and practice, this study provides actionable insights for advancing sustainable deconstruction practices worldwide.

5. Conclusion

This study developed an MCDA framework to optimise precast concrete deconstruction by balancing material recovery, cost, and environmental impact. By leveraging stakeholder input and integrating the Analytic Hierarchy Process (AHP) with VIKOR, the study validated its hypotheses that deconstruction strategies can be optimised to balance technical, economic, and environmental criteria.

The findings revealed that strategies prioritising selective component removal, such as wall panel dismantling (D1) and staircase removal (D3), achieved the most favourable outcomes across multiple criteria. Scenario S1, focusing on precast panel removal, emerged as a practical early-stage deconstruction strategy, while the staircase removal strategy (D3) excelled in material recovery and cost-efficiency. These insights contribute to filling a critical literature gap by

providing a data-driven framework for decision-making in deconstruction projects, advancing both theoretical understanding and practical applications.

However, the study's reliance on a single case limits generalisability, and stakeholder input may introduce bias despite efforts to ensure diversity. Future iterations should incorporate localised environmental data and expand the application to diverse building types and geographic contexts to validate the framework's broader applicability.

To address these limitations, the study recommends further refinement of environmental metrics by integrating localised greenhouse gas emission factors and sustainability benchmarks. It also encourages the exploration of emerging technologies, such as AI-driven optimisation and blockchain-based traceability, to enhance the precision and scalability of deconstruction strategies.

In conclusion, this study presents a robust, adaptable framework for guiding sustainable deconstruction practices, providing valuable insights for both practice and theory. The framework bridges gaps in the literature by offering a comprehensive tool for evaluating deconstruction strategies, addressing both immediate project needs and long-term sustainability goals. Future research should build upon these findings to expand the framework's applicability and leverage technological advancements for improved decision-making in construction and demolition management.

References

Ababio, B.K., Lu, W. and Ghansah, F.A. (2023), "Transitioning from green to circular procurement in developing countries: a conceptual framework for Ghana's construction sector", *Building Research & Information*, Routledge, Vol. 51 No. 7, pp. 798–815, doi: 10.1080/09613218.2023.2229456.

Akbarnezhad, A., Ong, K.C.G. and Chandra, L.R. (2014), "Economic and environmental assessment of deconstruction strategies using building information modeling", *Automation in Construction*, Elsevier, Vol. 37, pp. 131–144, doi: 10.1016/J.AUTCON.2013.10.017.

Alhawamdeh, M., Ferriz-Papi, J.A. and Lee, A. (2024), "Examining the Drivers to Support Improved Construction and Demolition Waste Management for a Circular Economy: A Comprehensive Review Using a Systematic Approach", *Sustainability 2024, Vol. 16, Page 6014*, Multidisciplinary Digital Publishing Institute, Vol. 16 No. 14, p. 6014, doi: 10.3390/SU16146014.

Alhusban, M., Nasereddin, M., Alghossoon, A. and Hatamleh, M.T. (2024), "A hybrid conceptual procurement framework for BIM uptake to enhance buildings' sustainability performance in the Jordanian public sector", *International Journal of Building Pathology and Adaptation*, Emerald Publishing, Vol. 43 No. 1, pp. 93–116, doi: 10.1108/IJBPA-07-2022-0109/FULL/PDF.

Balogun, H., Alaka, H., Ajayi, S. and Egwim, C.N. (2024a), "Critical factors for assessing building deconstructability: Exploratory and confirmatory factor analysis", *Cleaner Engineering and Technology*, Elsevier, Vol. 21, p. 100790, doi: 10.1016/J.CLET.2024.100790.

Balogun, H., Alaka, H., Ajayi, S. and Egwim, C.N. (2024b), "Critical factors for assessing building deconstructability: Exploratory and confirmatory factor analysis", *Cleaner Engineering and Technology*, Elsevier, Vol. 21, p. 100790, doi: 10.1016/J.CLET.2024.100790.

Bianchi, S., Andriotis, C., Klein, T. and Overend, M. (2024), "Multi-criteria design methods in façade engineering: State-of-the-art and future trends", *Building and Environment*, Pergamon, Vol. 250, p. 111184, doi: 10.1016/J.BUILDENV.2024.111184.

Durmisevic, E., Beurskens, P.R., Adrosevic, R. and Westerdijk, R. (2017), "Systemic view on reuse potential of building elements, components and systems: comprehensive framework for assessing reuse potential of building elements", 23 June.

Elliott, K.S. (2017), "Precast concrete structures / Kim S. Elliott.", *Taylor & Francis, CRC Press*, p. 733.

Gambato, C., Guante Henriquez, L., Zerbi, S., Frontini, F. and Mosca, C. (2023), "DeCO - Guidelines for the deconstruction of recent buildings", *Journal of Physics: Conference Series*, IOP Publishing, Vol. 2600 No. 19, p. 192012, doi: 10.1088/1742-6596/2600/19/192012.

Guerra, B.C. and Leite, F. (2021), "Circular economy in the construction industry: An overview of United States stakeholders' awareness, major challenges, and enablers", *Resources, Conservation and Recycling*, Elsevier, Vol. 170, p. 105617, doi: 10.1016/J.RESCONREC.2021.105617.

Jacinto, J.M., Tombado, E.D., Tan, H.C. and Dela Cruz, O.G. (2024), "Value Engineering of Precast Slab to Ease Construction Project Schedule and Cost", *Lecture Notes in Civil Engineering*, Springer, Singapore, Vol. 369, pp. 1005–1018, doi: 10.1007/978-981-99-4049-3_77.

Kanters, J. (2018), "Design for Deconstruction in the Design Process: State of the Art", *Buildings 2018, Vol. 8, Page 150*, Multidisciplinary Digital Publishing Institute, Vol. 8 No. 11, p. 150, doi: 10.3390/BUILDINGS8110150.

Kusi, E., Boateng, I. and Danso, H. (2024), "Energy consumption and carbon emission of conventional and green buildings using building information modelling (BIM)", *International Journal of Building Pathology and Adaptation*, Emerald Publishing, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/IJBPA-09-2023-0127/FULL/PDF.

Ollár, A. (2024), "Circular building adaptability in multi-residential buildings – the status quo and a conceptual design framework", *International Journal of Building Pathology and Adaptation*, Emerald Publishing, Vol. 42 No. 7, pp. 1–17, doi: 10.1108/IJBPA-08-2023-0110/FULL/PDF.

Peiris, M., Gamlath, I. and Bandara, S. (2023), "OPTIMUM ROUTE PLAN FOR EFFECTIVE COLLECTION OF AN INDUSTRY LEVEL BY PRODUCT/WASTE", Sri Lanka Institute of Information Technology, pp. 321–330, doi: 10.54389/BCOC8887.

Poon, C.S., Yu, A.T.W. and Jaillon, L. (2004), "Reducing building waste at construction sites in Hong Kong", *Construction Management and Economics*, Vol. 22 No. 5, pp. 461–470, doi: 10.1080/0144619042000202816.

Sánchez-Garrido, A.J., Navarro, I.J. and Yepes, V. (2022), "Evaluating the sustainability of soil improvement techniques in foundation substructures", *Journal of Cleaner Production*, Elsevier, Vol. 351, p. 131463, doi: 10.1016/J.JCLEPRO.2022.131463.

Wong, R.W.M. and Loo, B.P.Y. (2022), "Sustainability implications of using precast concrete in construction: An in-depth project-level analysis spanning two decades", *Journal of Cleaner Production*, Elsevier, Vol. 378, p. 134486, doi: 10.1016/J.JCLEPRO.2022.134486.

Yang, Y., Luk, C., Zheng, B., Hu, Y. and Chan, A.P.-C. (2024), "Disassembly and Reuse of Demountable Modular Building Systems", *Journal of Management in Engineering*, American Society of Civil Engineers, Vol. 41 No. 1, p. 05024012, doi: 10.1061/JMENEA.MEENG-6243.

Table I: Summary of key contributions and research gaps in sustainable deconstruction and MCDA methodologies

Domain	Key Studies	Highlights	Research Gaps
Sustainable Deconstruction	Crowther (2000); Guy & Ciarimboli (2002); Durmisevic & Brouwer (2002); Akbarnezhad et al. (2014); Akinade et al. (2015); Adams et al. (2017); Chini & Bruening (2019); Hosseini et al. (2021); Favi et al. (2022); Balogun et al. (2024)	Early works emphasised design for deconstruction principles and the importance of material recovery. Recent studies have explored Building Information Modelling (BIM) tools for deconstruction planning and identified critical factors influencing deconstructability.	Limited integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and robotics in practical deconstruction applications. Need for standardised procedures and guidelines to facilitate deconstruction processes.
Circular Economy	Webster & Costello (2005); Kibert (2007); Adams et al. (2017); Pomponi & Moncaster (2017); Geissdoerfer et al. (2017); Kirchherr et al. (2018); Leising et al. (2018); Ghisellini et al. (2018); Guerra & Leite (2021); Ababio & Lu (2023)	Advocated for circular approaches in construction, focusing on the economic and environmental benefits of material reuse and recycling. Recent studies have emphasised the need for systemic changes to implement circular economy principles effectively in the construction industry.	Lack of comprehensive frameworks for implementing circular economy principles in construction projects. Need for case-specific evaluations considering varying geographic and regulatory contexts.
MCDA in Construction	Saaty (1980); Belton & Stewart (2002); Mardani et al. (2015); Zavadskas et al. (2016); Sánchez-Garrido et al. (2022); Peiris et al. (2023); Colapinto et al. (2020); Bianchi et al. (2024)	Developed foundational MCDA methodologies such as AHP and TOPSIS. Recent applications in construction have utilised these methods to evaluate sustainability criteria, optimise resource allocation, and support decision-making processes.	Limited application of integrated MCDA models (e.g., AHP combined with VIKOR) specifically tailored for evaluating deconstruction strategies. Need for incorporating dynamic and uncertain factors in MCDA models.
Emerging Technologies	Volk et al. (2014); Bilal et al. (2016); Oesterreich & Teuteberg (2016); Olawumi & Chan (2019); Peiris et al.	Explored the integration of digital tools such as BIM, digital twins, IoT, and AI to optimise deconstruction	Practical applications and scalability of these technologies in real-world deconstruction projects

	(2023); Jain et al. (2019); Gambato et al. (2023)	processes. Recent studies have highlighted the potential of these technologies to improve efficiency, accuracy, and sustainability in deconstruction projects.	remain underexplored. Need for studies addressing the challenges of technology adoption in the construction industry.
Source: Authors own creation			

Table II: Description of performance criteria

Code	Criteria	Description	Type
C1	Resource depletion (kg)	Depletion of raw material resources through deconstruction	Non-beneficial
C2	Hazardous waste (kg)	Generation of hazardous chemicals and substances	Non-beneficial
C3	GHG emissions (kg CO_2 eq)	Release of greenhouse gases affecting climate change	Non-beneficial
C4	Deconstruction cost ($)	Financial expense of deconstruction works	Non-beneficial
C5	Revenue from materials ($)	Income from sale of recovered materials	Beneficial
C6	Material recovery rate (%)	Proportion of components reused or recycled	Beneficial

Source: Authors own creation

Table II: Description of individual deconstruction strategies

Strategy	Component	Operations	Material	Yields	Recycling Potential
D1	Wall panels	Cut panels; load onto trucks	Aggregates: 75%; Steel: 5%	High yields	Minimal processing
D2	Floor beams	Cut beams; load onto trucks	Aggregates: 70%; Steel: 10%	Moderate yields	Simple cutting
D3	Staircase	Cut precast stairs; load	Aggregates: 55%; Steel: 15%	Good recycling with minimal dismantling	Minimal dismantling

D4	Foundations	Excavate strip foundations; load	Aggregates: 80%; Steel: 5%	High potential with bulk material recovery	Bulk material recovery
D5	Columns	Cut columns; load sections	Aggregates: 55%; Steel: 15%	Challenging due to complex reinforcement	Complex reinforcement
D6	Beams	Saw-cut beams; load sections	Aggregates: 60%; Steel: 12%	Requires specialized saw equipment	Specialized saw equipment
D7	Reinforcement 4 bars	Cut and separate rebar; bundle	Steel: 95%	Ideal for future steel fabrication	Future steel fabrication
D8	Reinforcement 10 bars	Cut and separate; bundle	Steel: 90%	Steel bar diameter affects yields	Steel bar diameter
D9	Stirrups	Cut and separate; bundle	Steel: 85%	Labor-intensive due to congested bars	Congested bars
D10	Frame	Dismantle; load onto trucks	Aggregates: 30%; Steel: 40%	High structural stability issues arise	Structural stability issues
D11	Pillars	Dismantle; load sections	Aggregates: 25%; Steel: 35%	Complex cutting around reinforcement	Reinforcement cutting
D12	Foundation	Dismantle; load onto trucks	Aggregates: 20%; Steel: 30%	Heavy-duty equipment required	Heavy-duty equipment
D13	Aggregates	Crush and screen concrete	RCM: 90%	High potential; requires centralized facility	Centralized facility
D14	Scrap steel	Separate; transport to recyclers	Steel: 98%	Provides feedstock for steel mills	Steel mills feedstock
D15	Wood	Recycle lumber components; transport	Wood: 95%	Small volumes; finding end-markets is key	End-markets
D16	Plastics	Sort debris; transport for recycling	Plastics: 80%	Challenging to separate from mixed debris	Mixed debris separation

D17	Glass	Separate; crush and transport	Glass: 90%	Potential for recycled aggregates/cullet	Aggregates and cullet
D18	Metals	Separate various scrap; transport	Metals: 90%	Requires dismantling and sorting efforts	Dismantling and sorting

Source: Authors own creation

Table IV: Deconstruction scenarios for evaluation

Scenario Code	Strategies	Scenario grouping
S1	D1, D2, D3	Concrete Removal
S2	D4, D5, D10, D11	Structure Dismantling
S3	D13, D14, D17	Material Recycling
S4	D1, D7, D13, D14	Multi-modal
S5	D2, D8, D11, D17	Hybrid
S6	D3, D9, D12, D18	Integrated

Source: Authors own creation

Table II: Building information of the National University Engineering Building (Gimenez Hall)

Element	Description
Building Name	Gimenez Hall
Building Era	1990
Location	University of the Philippines Diliman, Quezon City, Metro Manila
Total Floor Area	4,300 sqm
Number of Floors	4 floors above ground, basement
Architectural Shape	Rectangular building
Structural System	Reinforced concrete columns, walls and slabs
Exterior Wall Material	Precast concrete panels
Window Type	Aluminium framed single glazed
Roof Type	Concrete slab with ceramic roof tiles
Interior Partitions	Solid concrete walls
Door Types	Metal
Floor and Wall Finishes	Plastered and painted internal walls; ceramic tile flooring in some areas
Mechanical Systems	Air conditioning, laboratory exhaust, plumbing
Electrical Systems	Power distribution, lighting, equipment connections

Source: Authors own creation

Table VI: Building Model Parameters and Calibration Results

Parameter	Value	Material	Actual Quantity (t)	Simulated Quantity (t)	Deviation (%)
No. of Floors	4	Concrete Slabs	900	910	1.1
Total Floor Area (m2)	4,300	Concrete Walls	600	605	0.8
Wall Type	Precast concrete panels	Reinforcing Steel	60	58	3.3
Floor Type	Reinforced concrete slab				
No. of Columns	30				
Connection Type	Grouted joints/dry fits				
Source: Authors own creation					

Table VII: Performance scores from Design Builder simulations

Strategy	Concrete Recovery (tons)	Steel Recovery (tons)	Cost ($)	Time (weeks)	Environmental Impact	Health & Safety Risk
D1 (Wall Panels)	75	5	15,000	2	Moderate	Low
D2 (Floor Beams)	70	10	20,000	3	Moderately High	Moderately High
D3 (Staircases)	55	15	25,000	1	Low	Moderately High
S1 (Precast Only)	200	30	50,000	4	Moderately High	Moderate
Source: Authors own creation						

Table VIII: AHP-VIKOR Analysis of Deconstruction Strategies

Strategy	Concrete	Steel	Cost	Time	Environ	Safety	Total Score	Group	VIKOR
Weights	**20%**	**15%**	**25%**	**20%**	**15%**	**5%**			
D1 (Wall Panels)	0.75	0.33	1.00	0.50	0.67	1.00	4.25	1	0.59
D2 (Floor Beams)	0.70	0.67	0.80	0.25	0.33	0.67	3.42	2	0.82
D3 (Staircases)	0.55	1.00	0.60	1.00	1.00	0.67	4.82	3	0.29
S1 (Precast Only)	1.00	1.00	0.20	0.00	0.33	0.80	3.33	4	0.94
Source: Authors own creation									

Rating Scale

Rating	Definition
9	Row extremely more important
8	Row very strongly to extremely more important
7	Row very strongly more important
6	Row strongly to very strongly more important
5	Row strongly more important
4	Row moderately to strongly more important
3	Row moderately more important
2	Row equally important to moderately more important
1	Row and column equally important
1/2	Column equally important to moderately more important
1/3	Column moderately more important
1/4	Column moderately to strongly more important
1/5	Column strongly more important
1/6	Column strongly to very strongly more important
1/7	Column very strongly more important
1/8	Column very strongly to extremely more important
1/9	Column extremely more important

CR Value = -0.070 Reasonable Consistency

Pairwise comparisons

Item Numb	**Item Number**	1	2	3	4	5	6	7	8	9	10
	Item Description	Resource D	Material re	Revenue fr	Hazardous	Greenhous	Deconstruc				
1	Resource Depletion	1.00	1.10	1.30	1.81	1.82	264.00				
2	Material recovery rate	0.91	1.00	1.19	1.65	1.66	241.00				
3	Revenue from materials	0.77	0.84	1.00	1.39	1.40	203.00				
4	Hazardous waste generatic	0.55	0.61	0.72	1.00	1.01	146.00				
5	Greenhouse gas emissions	0.55	0.60	0.71	0.99	1.00	145.00				
6	Deconstruction cost	0.00	0.00	0.01	0.01	0.01	1.00				
7								1.00			
8									1.00		
9										1.00	
10											1.00
5	Sum	3.78	4.15	4.93	6.85	6.90	1000.00				

STANDARDIZED MATRIX

		Resource D	Material re	Revenue fr	Hazardous	Greenhous	Deconstruc				
1	Resource Depletion	0.26	0.27	0.26	0.26	0.26	0.26				
2	Material recovery rate	0.24	0.24	0.24	0.24	0.24	0.24				
3	Revenue from materials	0.20	0.20	0.20	0.20	0.20	0.20				
4	Hazardous waste generatic	0.15	0.15	0.15	0.15	0.15	0.15				
5	Greenhouse gas emissions	0.15	0.14	0.14	0.14	0.14	0.15				
6	Deconstruction cost	0.00	0.00	0.00	0.00	0.00	0.00				
7											
8											
9											
10											

CI and CR worksheet

		Resource D	Material re	Revenue fr	Hazardous	Greenhous	Deconstruc				
1	Resource Depletion	0.26	0.27	0.26	0.26	0.26	0.24				
2	Material recovery rate	0.24	0.24	0.24	0.24	0.24	0.22				
3	Revenue from materials	0.20	0.20	0.20	0.20	0.20	0.19				
4	Hazardous waste generatic	0.15	0.15	0.15	0.15	0.15	0.13				
5	Greenhouse gas emissions	0.15	0.14	0.14	0.14	0.14	0.13				
6	Deconstruction cost	0.00	0.00	0.00	0.00	0.00	0.00				
7											
8											
9											
10											

Saaty's CIr values for matrices are given by the following table

Size of Matrix	Random Consistency (CIr)	
1	0	1
2	0	2
3	0.58	3
4	0.90	4
5	1.12	5
6	1.24	6
7	1.32	7
8	1.41	8
9	1.45	9
10	1.49	10

Weight
26.4%
24.1%
20.3%
14.6%
14.5%
0.1%

SUM	SUM/Weig
1.56	5.92
1.43	5.92
1.20	5.92
0.86	5.92
0.86	5.92
0.00	3.81

count	6.00
mbda max	5.567
CI	-0.087
CR	**-0.07**
constant	1.24

Stakeholder Responses

	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde
Resource depletion	1.0248	1.0104	0.9982	1.0129	1.0130	1.0313	0.9614
Material recovery rate	0.9819	0.9047	0.9142	0.9012	0.9214	0.9315	0.9412
Revenue from material	0.7793	0.7832	0.7389	0.8005	0.8418	0.7782	0.7425
Hazardous waste generation	0.5250	0.5784	0.5527	0.5228	0.5819	0.5516	0.6090
Greenhouse Gas emissions	0.5350	0.5368	0.5581	0.5208	0.5433	0.5121	0.5282
Deconstructi on cost	0.0039	0.0040	0.0039	0.0042	0.0041	0.0041	0.0039

Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde
1.1061	1.0140	0.9497	1.0260	0.9143	0.9865	0.9735	0.9675	1.0418
0.9302	0.9262	0.9094	0.9202	0.9102	0.8325	0.9848	0.9223	0.9363
0.7603	0.7381	0.7382	0.8259	0.7746	0.7198	0.7651	0.7893	0.8150
0.5896	0.5851	0.5567	0.6102	0.5591	0.5483	0.5322	0.5318	0.5608
0.5555	0.5727	0.5302	0.5291	0.6067	0.5471	0.5521	0.5571	0.5830
0.0043	0.0041	0.0040	0.0038	0.0038	0.0039	0.0038	0.0039	0.0040

Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholde
1.0118	1.0140	0.9885	0.9389	1.0154	1.0247	1.0136	0.9790	0.9694
0.9388	0.9319	1.0271	0.8936	0.9108	1.0265	0.9113	0.9084	0.9019
0.8020	0.8313	0.7479	0.7826	0.7857	0.7459	0.7533	0.7681	0.7501
0.5785	0.5035	0.5430	0.5306	0.5958	0.5671	0.5449	0.5580	0.5365
0.5708	0.5726	0.5406	0.4927	0.5642	0.5549	0.5573	0.5325	0.5662
0.0038	0.0039	0.0042	0.0040	0.0038	0.0042	0.0045	0.0039	0.0043

Stakeholde	Stakeholde	Stakeholde	Stakeholde	Stakeholder 30
1.0184	0.9489	1.0420	1.0525	0.9914
0.8481	0.9396	0.8379	0.9890	0.8815
0.7796	0.7682	0.7699	0.7901	0.7690
0.5377	0.5477	0.5557	0.5510	0.5816
0.5829	0.5677	0.5994	0.5610	0.5371
0.0039	0.0039	0.0040	0.0040	0.0042