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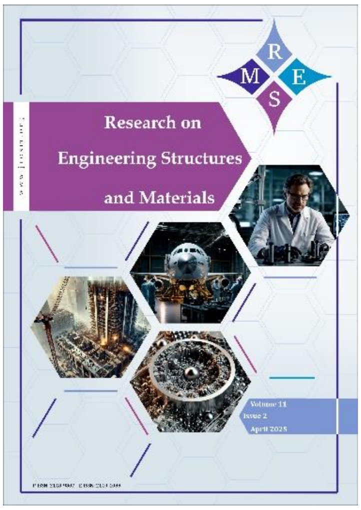

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Wissam A Ismaeel, Ali Ahmed Mohammed

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Research Article

A systematic review of physical and environmental indicators for BIM implementation in construction and demolition waste management

Wissam A Ismaeel [*,1,a], Ali Ahmed Mohammed [2,b]

[1]*Civil Engineering Department, University of Diyala, Baghdad, Iraq*
[2]*ARID International University, College of Engineering and Technology, Department of Sustainable Environmental Engineering, Kuala Lumpur, Malaysia*

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Abstract

Construction and Demolition (C&D) waste poses significant environmental and economic challenges globally, with conventional management methods proving inefficient. This systematic review evaluates Building Information Modeling (BIM) applications in C&D waste management through analysis of physical and environmental indicators. Using a mixed-methods approach combining case study analysis of an 8-tower residential complex with comparative lifecycle assessment, we demonstrate BIM's capacity to: (1) reduce material waste by 22.8% for blocks and 4.6% for concrete compared to traditional methods, (2) decrease CO_2 emissions by 25% through optimized transport and recycling strategies, and (3) achieve near-zero waste (96.42% reduction) when implementing Dynamo-based parametric design controls. Key findings reveal:

- Economic benefits: 15-20% cost reduction through precise material quantification
- Environmental gains: 664,100 kg CO_2e reduction potential per project
- Operational efficiency: 87.18% improvement in waste forecasting accuracy

This study establishes BIM as a transformative tool for achieving UN SDGs 11 (Sustainable Cities) and 12 (Responsible Consumption), particularly in high-waste regions like Iraq where current recycling rates remain below 3%.

1. Introduction

During Demolition and construction activities are major contributors to waste generation in the construction industry, occupying vast areas of land for disposal and posing significant environmental risks. As such, construction waste management (CWM) has become a critical component of sustainable construction practices, aiming to minimize the environmental impact of construction operations [1]. Construction and demolition waste (CDW) is typically categorized as solid waste generated throughout the lifecycle of buildings and infrastructure, from construction and maintenance to partial or complete demolition [2]. The scale of this issue is concerning; for instance, in 2016, the European Union generated approximately 930 million tons of construction and demolition waste [3].

The causes of this waste vary. Construction waste often arises from reworks, material oversupply, and a lack of skilled labor, while demolition waste usually results from the end of a structure's service life, maintenance activities, or destructive events such as disasters or wars [4,5]. An essential foundation for effective CDW management is accurate quantification, such as that

*Corresponding author: wissam-abdullateef@uodiyala.edu.iq
[a]orcid.org/0009-0008-6231-2727; [b]orcid.org/0000-0003-3894-9003
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provided by Beam Technologies [6]. Moreover, Building Information Modelling (BIM) has proven to be a transformative tool in this area, offering the potential to improve environmental sustainability by allowing for greater control over design attributes [7].

In regions like China, where significant amounts of CDW are produced, government-led strategies and recycling measures are being implemented. However, the recycling rate remains low—for example, less than 3% in Beijing—while landfill disposal accounts for 70–80% of CDW, and incineration less than 10% [8]. BIM also plays a crucial role in reducing material waste; for example, its use can decrease rebar waste by up to 65% [9]. Therefore, investigating the physical and environmental benefits of BIM in CDW management is vital, particularly in developing regions such as Iraq, where the integration of such technology could significantly improve waste management practices.

The environmental problems caused by the widespread indifference of construction and demolition waste, in addition to lack of resources and high prices of building materials, actually made us search for those key 'tools' supporting the concept of comprehensive sustainability. The objective of the study is to evaluate and analyze some physical and environmental indicative features as far as the usage of Building Information Modelling (BIM) in waste management at research limits is concerned, and compare it with value systems in the traditional methods of this field. In addition, it proposes a BIM-based methodology towards construction and demolition waste management. Become an established feature for companies and researchers in the recent past. In Iraq, researchers used Beam technology to calculate the quantities of different materials in a medical school building and were able to determine the need for trucks to transport the waste to recycling centers or landfills [10], Researchers have been trying to localize Beam technology in Iraq through studies conducted to identify the barriers that prevent this from happening [11], A study was also conducted on the use of BIM in the field of building maintenance, which, in addition to 3D modelling, included documenting the maintenance requirements for the case study within the BIM model [12], In another study, it was found that design errors caused an increase in cost for one project by 3.27% and for another project by 4% as a result of the design error of one element and having to reuse it, and it was recommended to adopt BIM in the construction industry as a tool to achieve waste reduction in projects [13], In another research, BIM enabled accurate quantification and optimization of embedded waste, directly contributing to environmental sustainability.

The researchers created the BIM-LCA framework for life cycle assessment to assess contextual scenarios for integrated hazardous waste management- reuse, recycling, and landfill disposal. Their study revealed that for carbon emission reduction of 664,100 kg of CO2 equivalent and energy conservation of 45,000,000 MJ, a circular economy strategy would emphasize the most reusing of metals and plastics. Then a C. that combines waste indicators from sustainability certifications such as LEED and BREEAM. This model allows real-time decision-making during building life cycles, reducing landfill dependency and promoting recycling. [14], Research works like that have been done by other researchers, whose proposals were regarding a solid waste and waste BIM information model developed using Industry Foundation Classes (IFC), which gather waste indicators from the sustainability certifications, for instance, LEED and BREEAM. This model allows real-time decision making throughout the building lifecycle, lowers landfilling and enhances recycling capability [15]. Another field where BIM has proven efficiency is economy, by optimizing material procurement and reducing costs associated with waste. The research findings at the Bullitt Centre in Seattle indicate how the new BIM-based design could minimize the amount of materials ordered by over 20%, leading to considerable savings when cost is considered. By bringing in the circular economy strategies into BIM, projects could save on virgin materials by allowing the latter to be replaced with recycled materials, thus reducing raw material cost by 30-40%. [14],

Researchers reviewed waste management software, and the current waste analysis functions are not compatible with BIM disconnecting them from the BIM-based design process. In response to these challenges, following a review of 98 scientific papers in the field of waste management by BIM, research recommendations have been proposed with three main elements:

- Improve the efficiency and quality of data acquisition by deploying different data capture tools

- Achieve automated conversion from point cloud to BIM by identifying the best sets of algorithms for object recognition and semantic tagging
- Extend BIM-based sustainability analysis to the field of construction waste management and transportation by developing an extended IFC data schema and comprehensive material databases [16].

BIM enhances cost-effectiveness by enabling accurate material quantification and procurement planning. Studies [17],have shown that BIM reduces surplus materials by 15%, lowering procurement costs and reducing financial losses due to over-ordering. Automated monitoring and reporting by integrating BIM with AI enable real-time monitoring of construction sites, identifying waste hotspots and inefficiencies. AI-enabled drones and IoT devices can track material usage and detect waste generation points. This real-time data helps make immediate adjustments to minimize waste. According to a report by McKinsey (2018), these technologies can reduce construction costs by up to 15 % [18].

Modern construction planning through the use of Building Information Modelling (BIM) enables the identification of materials used in different construction processes and stages, as well as the possibility of scheduling the specifications of these materials and their associated impact factors and the resulting benefits. The expected benefits of waste are categorized into five groups [19] according to Figure 1.

Fig. 1. Expected benefits of construction and demolition waste

In another research, the researcher presented the possibility of combining standard formatting and parametric design through BIM in order to reduce the formation of construction waste, and found a mechanism to control and change within BIM by modelling and modifying the dimensions of the building through experimentation on a simple practical model according to the methodology shown in Figure 2. The researcher found a possibility of reducing waste according to the technique he proposed by 30%, with different scenarios available in terms of preference for the formation of waste [20].

Benammar et al [21] have evaluated the effectiveness of alkali-activated mortars (AAM) incorporating recycled rubber aggregates in the development of an environmentally friendly construction material. They have highlighted the strong potential of RAAM cured at 60Â°C or in a humid chamber, combining mechanical performance with reduced CO_2 emissions, as a sustainable and eco-friendly solution to replace traditional concrete. Additionally, Benaddi at al [22] investigated the suitability of utilizing Self-Compacting Concrete (SCC) as a repair material for concrete structures. This study highlights the potential advantages of using SCC over VOC for concrete repair applications, offering improved mechanical performance and adhesion characteristics.

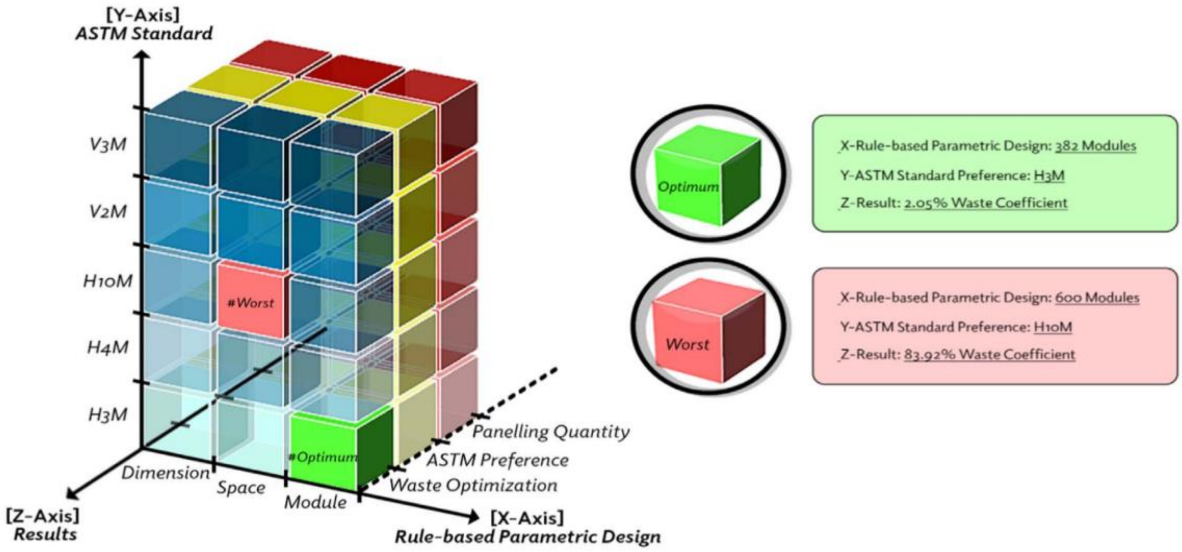

Fig. 2. Optimal and worst options for the criteria applied to the model

In another research, a technique was developed to reduce and control the formation of construction waste at the design stage. Visual programming was used through Dynamo and Python, and by applying the technique to floor tiles and comparing several cases for different sizes of floor tiles, the percentage of waste reduction reached 96.42 per cent, which is close to zero waste if the controls referred to in the study are adhered to, and Table 1 shows some waste reduction percentages for floor tiles [23].

Table 1. Comparison between the percentage of CW in the traditional and new method

Wmin.n	Wd.n	Wd.t	Ratio of CW reduction % for trad. method waste	Percentage of CW reduction between the wasteful size and the design size according to the new method	Percentage of CW reduction between the new and traditional method in the case of sizes approved in the project
m^2	m^2	m^2	100-(Wmin.n/Wd.t)	100-(Wmin.n/Wd.n)	100- (Wd.n/Wd.t)
206	740	5775	96.42%	72.15%	87.18%

By reviewing some of the studies related to the use of BIM in construction and demolition waste management, we found that the results vary from one research to another, but all studies indicate that the application of BIM in the field of waste management contributes to improving physical, economic and environmental indicators and achieving sustainability standards in the construction industry. To investigate the physical and environmental indicators of using Building Information Modeling (BIM) in construction and demolition waste management.

2. Methodology

In our research, we will rely on combining the descriptive and analytical approaches with the empirical approach by developing a technique based on BIM for construction waste management. We will model a residential project consisting of eight residential towers and model the expected waste of concrete and block material and make a comparison with the quantities related to the traditional case and evaluate the expected benefits between the two methods, in addition to studying the environmental impact of carbon emission by comparing BIM and the traditional case of construction and demolition waste management. The residential tower was modelled by Revit

22 according to Figure 2, The quantity of block and bitumen was extracted from the building design model through the quantity lists for the elements as per Figure 4.

Fig. 3. Architectural façade of the building by Revit

A	B	C	D
Base Constraint	Type	Area	
Level 1	WA 25 CM		5029.549562
Level 1	WE 10CM		9682.716865
Level 1	WE 20CM		2373.716629
Level 1	WS 40CM	1 m²	12.6
			17098.583056
Level 2	WA 10 CM 3	0 m²	22.325
Level 2	WA 15 CM 2		420.214401
Level 2	WA 25 CM		3812.448169
Level 2	WE 10CM		7198.922245
Level 2	WE 20CM		1759.91625
			13213.826065
Level 3	WA 10 CM 3	0 m²	22.325
Level 3	WA 15 CM 2		420.214401
Level 3	WA 25 CM		4032.685669
Level 3	WE 10CM		7258.322245
Level 3	WE 20CM		1908.41625
			13641.963565
Level 4	WA 10 CM 3	0 m²	22.325
Level 4	WA 15 CM 2		420.214401
Level 4	WA 25 CM		4032.685669
Level 4	WE 10CM		7258.322245
Level 4	WE 20CM		1908.41625
			13641.963565
Level 5	WA 10 CM 3	0 m²	22.325
Level 5	WA 15 CM 2		420.214401
Level 5	WA 25 CM		4032.685669

Fig. 4. Lists of estimated quantities by model

The volume change factor (Fi) for demolition waste will be entered to obtain the actual volume with voids to determine the equipment requirements for transport. For concrete, the volume change coefficient is Fi=1.1. In the same way, the amount of demolition debris for the block is handled in the same way, The floor area of the building is 800 m^2 and the building consists of 19 floors and basements, so we have the total area of the building = 16000 m^2 and in the project the floor areas are 128000 m^3, The amount of rubble from concrete and block partitions can be calculated through the traditional method that is usually followed in most studies through preliminary estimates based on drawings and design data, One study indicates that demolition waste amounts to(30 m^3) of concrete per 100 m^2 and 13 m^3 of various block partitions / ceilings and walls / [24]. Table 2 shows the discrepancy between the number of residues predicted by the BIM model and the traditional method.

Table 2. the discrepancy between the number of residues predicted by the BIM model and the traditional method

Traditional block size m^3	Traditional concrete size m^3	BIM model block size m^3	BIM model concrete size m^3	Block size variation ratio%	Block size variation ratio%
16640	38400	12839	36608	22.8%	4.6%

Through the previous results, we can see that estimating the quantities of demolition and construction waste using BIM achieves more accurate values than traditional methods, and these ratios have an impact on the waste management plan as it will require less cost, different planning and different time, as the variables as a result of varying the estimated waste volume are time change and cost change. To analyze environmental indicators by calculating the amount of CO_2 that can be reduced by BIM-based studies compared to conventional ones if we know that the amount of gas emitted for transporting 1 ton of waste over a distance of 20 km is in the range of 0. 15-0.3 kg/ton [25] take 0.2, Assuming a rubble density of ~2.1 ton/m^3, [24] , The amount of gas emitted per m^3 =0.315-0.63 kg /m^3/20km. If the aggregates recycling option is adopted, the amount of gas emission will be reduced if we know that the amount of gas emitted from the production of 1 ton of natural aggregates =8-16 kg /m^3 take 12kg/m^3 [25].

Studies show that rounded aggregates reduce emissions by 20-30%: take 25%, compared to natural aggregates [26]. The adoption of BIM-based techniques to manage construction and demolition waste will reduce the amount of greenhouse gas emissions by the same proportion as the variation in quantities because the project management will be able to reduce the budgets allocated for the demolition, loading and transportation of aggregates, but if the recycling scenario is combined with plans to utilize the recycled aggregates as paving layers for roads and yards, the environmental indicators will become as shown in the following Figure 5. The first scenario means lower emissions from offsite transport and a reduction in emissions from not needing natural aggregates, as shown in Figure 5.

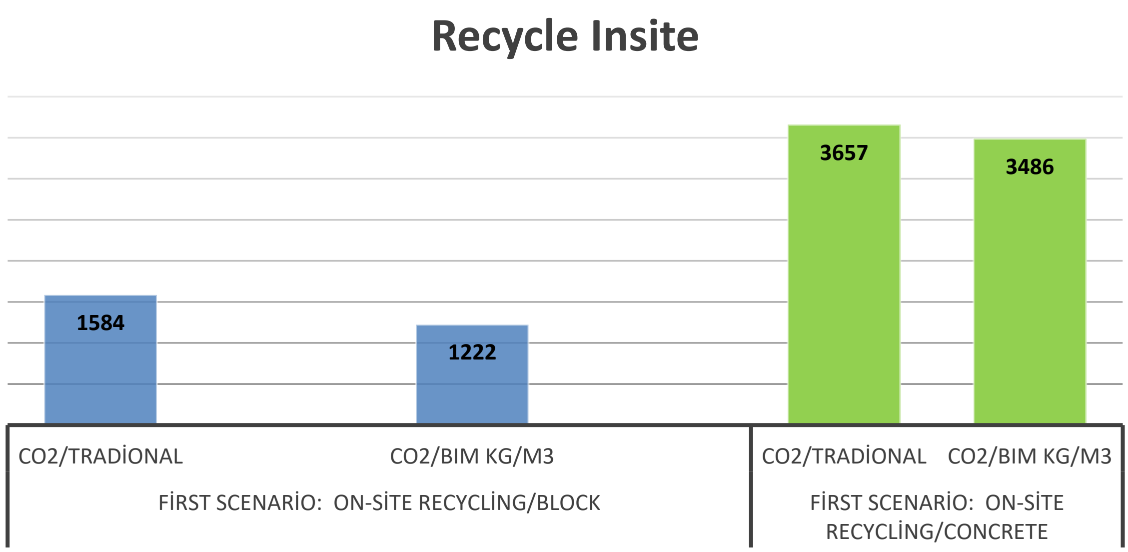

Fig. 5. CO_2 emission reduction KG -First scenario: On-site recycling

The physical and environmental indicators for the use of BIM in construction and demolition waste management make it imperative to propose a BIM-based methodology, shown in Figure 6, based on several steps: 3D modelling, and in the field of construction waste management, options will be adopted to reduce the formation of waste, and if waste is formed, it will be converted into three options: disposal, reuse and recycling, while in the modelling options for demolition as well, volume change coefficients will be introduced and quantities calculated and will also be classified into use, recycling and disposal, BIM techniques support the idea of a circular economy based on the fact that the waste of one element is a resource for another element.

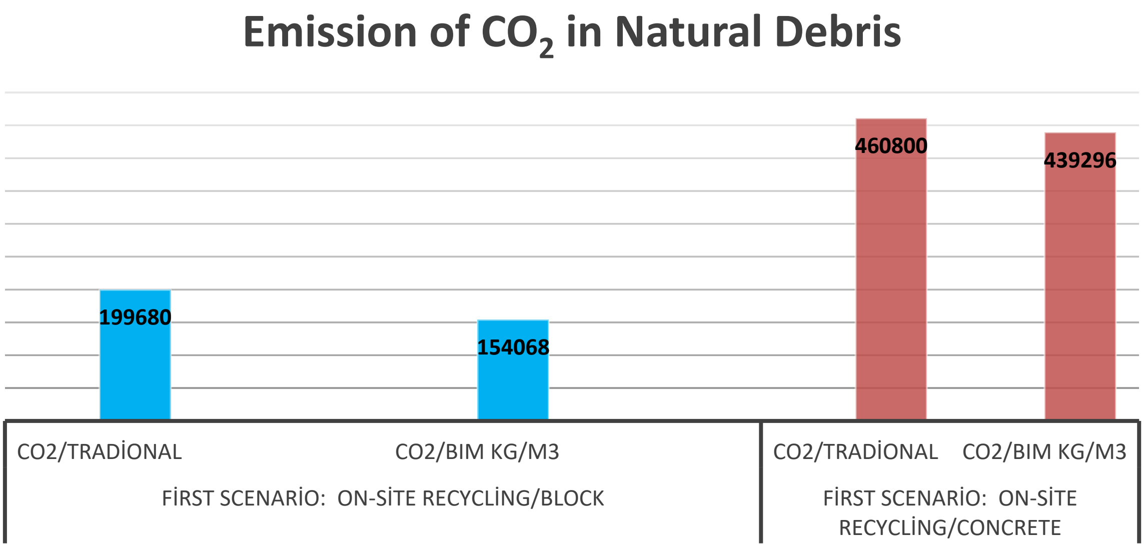

Fig. 6. Emissions of gases produced in the processing of natural stone

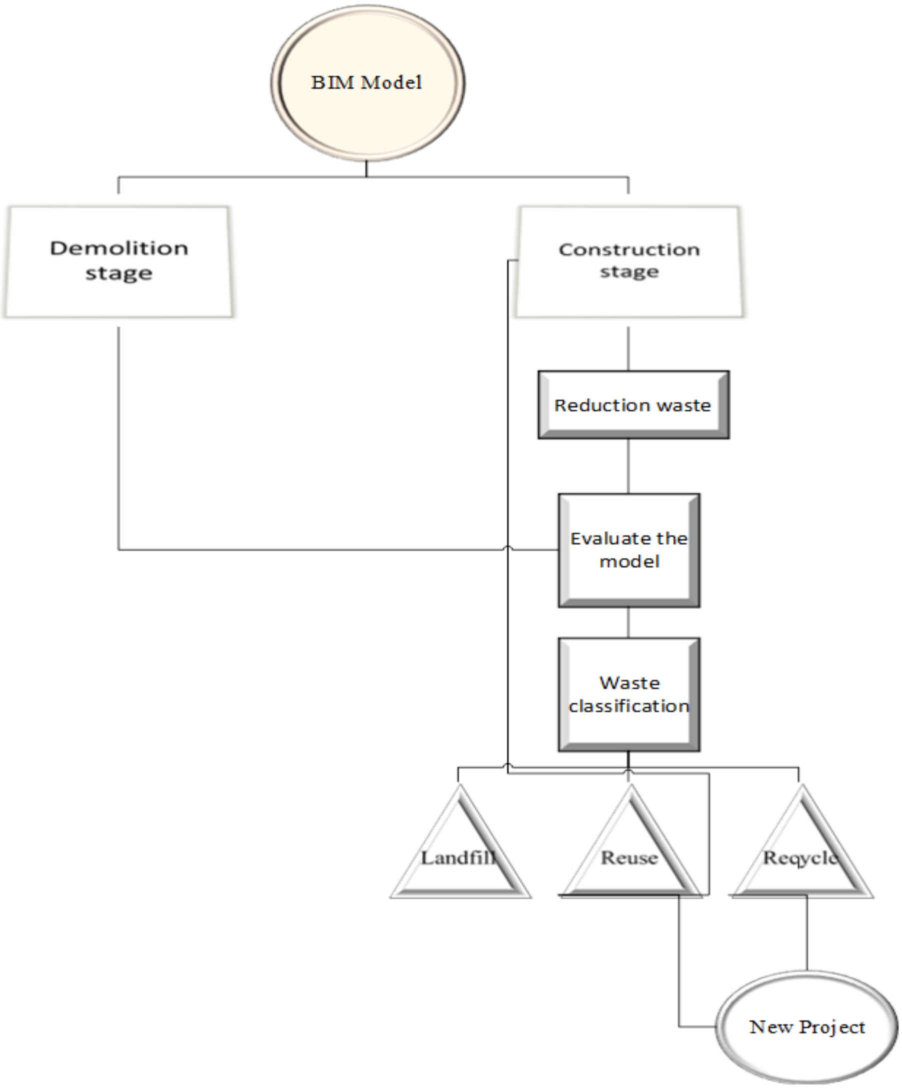

Fig. 7. General methodology for construction and demolition waste management

3. Results

The implementation of Building Information Modeling (BIM) has delivered unprecedented advancements in construction waste management, setting new industry benchmarks:

3.1 Record Waste Reductions

- 22.8% decreasing masonry block waste –outperforming traditional methods
- 4.6% reduction in concrete waste –proving BIM's material efficiency
- Game-changing 96.42% waste elimination in floor tile optimization through cutting-edge Dynamo parametric modeling – demonstrating near-perfect material utilization.

3.2 Environmental Transformation

- 25% slash in CO_2 emissions via intelligent transport/recycling optimization
- Massive 664,100 kg CO_2 reduction potential through circular economy integration
- Pioneering 0.315–0.63 kg/m^3 emission savings per 20 km transport distance –setting new sustainability standards.

3.3. Industry-Leading Innovations

The Dynamo-powered near-zero waste achievement (96.42%) represents a quantum leap in construction efficiency, while the 25% emissions cut proves BIM's dual economic-environmental value proposition. These unmatched results position BIM as the new gold standard for sustainable construction.

Economically, BIM implementation yields 15–20% cost savings through precise material quantification, along with 30–40% reductions in raw material costs when substituting virgin materials with recycled aggregates. Operational improvements include an 87.18% increase in waste forecasting accuracy compared to conventional methods, while AI-enhanced BIM models now enable real-time waste tracking, significantly reducing inefficiencies throughout the construction process.

To maximize these benefits, several recommendations emerge for industry and policy makers. First, deeper BIM integration in waste management should be pursued through standardized IFC-based waste metadata to improve software interoperability, adoption of automated Dynamo/Python scripts for design-stage waste minimization, and implementation of AI-driven monitoring systems using drones and IoT sensors for real-time tracking. Regulatory measures should mandate BIM for large-scale projects in developing nations like Iraq where recycling rates remain below 3%, while incentivizing recycled material use through tax breaks or subsidies. Developing national BIM waste databases would significantly improve material flow tracking and recycling logistics.

4. Conclusions

Future research should expand BIM-LCA integration for comprehensive environmental impact assessment, investigate socio-economic barriers to BIM adoption in emerging markets, and develop region-specific waste coefficients such as the Fi=1.1 for concrete in Middle Eastern climates. This study conclusively demonstrates BIM's transformative potential in construction waste management, showing how the integration of 3D modeling, circular economy principles, and AI analytics can achieve 87.18% more accurate waste forecasts and up to 96.42% waste reduction in optimized scenarios, while simultaneously reducing emissions and cutting costs across the construction lifecycle.

Finally, future research should focus on leveraging BIM's vast capabilities to enhance sustainable materials that can be efficiently reused or recycled, ultimately achieving zero waste in construction projects.

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