Enhancing Construction and Demolition Waste Management through BIM Implementation: A Pathway to Circular Economy

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Abstract

The construction industry is facing growing concerns over the environmental impacts and sustainability of its waste management practices, particularly in relation to construction and demolition waste. This research paper explores the potential of Building Information Modeling (BIM) implementation as a means to enhance construction and demolition waste management and pave the way for a circular economy. The present study has examined the current state of construction and demolition waste management practices, highlighting the significant environmental and economic impacts associated with traditional linear waste disposal methods. It then delves into the principles of a circular economy, emphasizing the importance of reducing waste generation, promoting recycling and reuse, and minimizing resource consumption.

1. Introduction

India's construction industry has indeed experienced rapid growth in recent years, leading to a substantial increase in the demand for construction materials. Several factors contribute to this upward trend. Firstly, India's population continues to grow, resulting in a need for more residential and commercial spaces (Singh & Singh, 2019). Additionally, urbanization and infrastructure development projects further drive the demand for construction materials (Sharma et al., 2018). Furthermore, government initiatives such as "Housing for All" and "Smart Cities" have spurred construction activities across the country (Government of India, 2015; Ministry of Urban Development, 2015).

Researchers have highlighted the challenges posed by the increasing demand for construction materials in India. These challenges include rising costs, environmental impacts, and supply chain disruptions (Saxena et al., 2020). The construction sector is responsible for a significant portion of India's carbon emissions and resource depletion (National Council for Cement and Building Materials, 2019). Therefore, there is a pressing need for sustainable practices in material sourcing, construction techniques, and waste management to address these issues (Choudhary et al., 2021).

The management of construction and demolition wastes (C&D wastes) is a crucial aspect of sustainable construction in India. C&D wastes comprise various materials such as concrete, bricks, timber, metals, and plastics, and their proper disposal is essential to minimize environmental impacts (Kumar et al., 2020). However, studies indicate that C&D waste management in India faces numerous challenges. Inefficient waste segregation and collection systems, lack of awareness among stakeholders, inadequate recycling facilities, and limited government regulations contribute to the mismanagement of C&D wastes (Chakraborty et al., 2019; Kumar et al., 2020). The improper handling and disposal of C&D wastes lead to pollution of land, air, and water resources, as well as occupational health hazards (Kumar et al., 2020). Table 1 presents the composition of various construction and demolition wastes and its generation percentage in India (Kumar et al., 2020).

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Type of Construction and Demolition Waste</th>
<th>Generation in India (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Concrete- Rubble, Masonry materials</td>
<td>23</td>
</tr>
<tr>
<td>2.</td>
<td>Metals- Steel, Aluminum, Copper, Wiring</td>
<td>05</td>
</tr>
<tr>
<td>3.</td>
<td>Bitumen- Road construction and repair work</td>
<td>02</td>
</tr>
<tr>
<td>4.</td>
<td>Wood- Timber, Plywood, and other wooden components</td>
<td>02</td>
</tr>
<tr>
<td>5.</td>
<td>Brick and Timber- Reusable broken bricks, Masonry materials</td>
<td>31</td>
</tr>
<tr>
<td>6.</td>
<td>Soil, Sand, and Gravel</td>
<td>36</td>
</tr>
<tr>
<td>7.</td>
<td>Other Items- Glass, Tiles, Ceramics, Insulation materials, Flooring materials, Carpet</td>
<td>01</td>
</tr>
</tbody>
</table>

So, there is a dire need of implementing effective waste management strategies to address these challenges. The present paper emphasizes on the improved waste segregation practices at the source (Smith et al., 2019), enhanced recycling and reuse initiatives (UNEP, 2018), and the establishment of robust regulatory frameworks thereby creating a pathway for the circular economy (Ellen MacArthur Foundation, 2015). Additionally, the promotion of awareness campaigns (EPA, 2019), capacity building (World Bank, 2017), and collaboration among stakeholders (UNEP, 2016) are essential for sustainable C&D waste management in India.

The concept of a circular economy is gaining traction in the construction sector of India as a sustainable alternative to the linear "take-make-dispose" model. The circular economy aims to minimize waste generation, maximize resource efficiency, and promote the reuse,
recycling, and recovery of materials (Sarkar et al., 2021). Studies highlight the potential benefits of adopting circular economy principles in the Indian construction sector. By implementing strategies such as designing for disassembly, promoting modular construction, and using recycled and locally sourced materials, the industry can reduce resource consumption, carbon emissions, and waste generation (Jain et al., 2020; Singh et al., 2021). Furthermore, circular economy practices can contribute to job creation, cost savings, and the development of a resilient and sustainable construction sector, especially when integrated with transformative technologies like Building Information Modelling (BIM) (Singh et al., 2021).

Figure 1 presents the process flow of circular economy in the construction sector. The process flow is divided into 5 phases: raw material phase, construction phase, use phase, end-of-life phase, and the generation of construction and demolition wastes. In the traditional scenario, the generated construction and demolition wastes are dumped into landfills. However, in the circular economy approach, it is suggested to make a reuse of the construction and demolition wastes (Jain et al., 2020).

The application of Building Information Modeling (BIM) in effective construction and demolition waste management can offer new opportunities for waste management and promoting circular economy principles. BIM provides a digital platform that facilitates effective waste management strategies throughout the construction lifecycle (Panuwatwanich et al., 2021).

Studies have shown that BIM allows for early identification and quantification of potential waste sources, enabling proactive waste reduction measures (Aranda-Mena et al., 2009). BIM’s visualization capabilities aid in material tracking, waste segregation, and optimization of material use, thereby reducing waste generation (Sawhney et al., 2019). The ability to simulate and analyze different scenarios using BIM enhances waste management decision-making processes (Kim et al., 2019).

Indeed, BIM can be integrated with waste management databases or platforms to enable stakeholders to monitor waste generation, recycling rates, and resource recovery in a more comprehensive manner (Yuan et al., 2020). This linkage enhances transparency and facilitates data-driven decision-making in waste management processes.

BIM promotes collaboration and transparency among project participants, leading to efficient waste management. By enabling multidisciplinary teams to work on a shared model, BIM facilitates seamless communication and coordination, reducing material waste and rework (Azhar et al., 2012). The collaborative nature of BIM fosters a holistic approach to waste management throughout the project lifecycle. Furthermore, BIM’s information-sharing capabilities empower stakeholders to make informed decisions regarding waste reduction, recycling, and material recovery, thereby supporting circular economy practices (Alawadhi et al., 2018). The availability of accurate and up-to-date data in the BIM platform enables better waste management planning and optimization of resource utilization.

BIM supports Design for Deconstruction (DfD) strategies, which aim to facilitate efficient and safe disassembly of structures at the end of their life cycle. BIM’s 3D modeling and clash detection capabilities assist in designing structures that are easily dismantled and materials that can be recycled or reused (Barlish & Sullivan, 2012). The integration of BIM with DfD principles ensures that waste management considerations are incorporated during the design phase, minimizing waste generation and optimizing resource recovery (Jia et al., 2021).

Table 2 shows the most commonly used BIM tools by researchers for construction and demolition waste management. There is a wide range of Building Information Modeling (BIM) tools that can be effectively applied to manage and optimize the processes involved in waste management (Salman et al., 2020). Figure 2 shows the network map of topics in the area of circular economy in the construction sector. It highlights the wide connection between building information modeling and the circular economy (Jain et al., 2020).

<table>
<thead>
<tr>
<th>Implementation area</th>
<th>BIM tools</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material banks and RFID</td>
<td>Autodesk Revit, scan-to-BIM, RFID data tags</td>
<td>Copeland, S., &amp; Bilec, M. (2020)</td>
</tr>
<tr>
<td>(BIM)-Based System Framework to reduce C &amp; D waste</td>
<td>BIM-LCA integration tool, SMARTWaste</td>
<td>Handayani et al. (2022)</td>
</tr>
<tr>
<td>Disassembly and deconstruction analytics system (D-DAS) for construction</td>
<td>Disassembly and deconstruction analytics system (D-DAS)</td>
<td>Akanbi et al. (2019)</td>
</tr>
</tbody>
</table>

Overall, the researchers (Fig. 3) have highlighted the increasing demand for construction materials, the management challenges associated with construction and demolition wastes, and the potential of circular economy principles in transforming the construction
sector. These issues call for concerted efforts from policymakers, industry stakeholders, and researchers to promote sustainable practices and address the environmental and social impacts of the construction industry in India.

The present paper reports the BIM’s capabilities in waste identification, tracking, and optimization, along with its collaborative and transparent communication features, offer promising avenues for the sustainable waste management. The paper’s main focus is on the identifying the best practices for implementing circular economy principles using BIM.

2. Methodology

This study aimed to investigate the fundamental elements of Building Information Modeling (BIM) and the principles of the circular economy. The goal was to develop a viable method for effectively managing construction and demolition waste. To address the research gap and delve into the practical implementation of the BIM process, a case study approach was utilized. The findings propose a strategy that utilizes BIM to optimize the circular economy within the current framework of building construction practices.

A case study of a residential building was utilized to demonstrate the implementation and framework of BIM. The residential building in question encompasses a total of four floors, including the ground floor, with a built-up area of 741 square meters. Each floor has a floor-to-floor height of 3 meters, and the building utilizes M25 concrete slabs with a thickness of 150 mm.

The BIM-based tool Autodesk Revit 2022 was used to create a comprehensive building model. Figure 4 showcases various perspectives of the building model, including plan view, elevation view, and a 3D representation.

Autodesk Revit efficiently organizes all relevant information pertaining to individual building components. This systematic storage enables accurate material take-off (quantity estimation) and facilitates the implementation of circular economy strategies to support sustainable construction practices. The tool was utilized to calculate the quantities of materials consumed and their associated costs. Additionally, the Demolition and Deconstruction approach was applied to determine the quantities of reusable materials, specifically construction and demolition waste. Figure 5 illustrates the sequential procedure followed for the analysis.

3. Circular Economy Strategy Results

The quantity of materials and cost for the G + 3 residential building were determined through the computational analysis. For reducing the waste generation and encouraging the reuse and recycling of materials, the innovative approaches of Materials Banks and Materials Passports were addressed. The created material banks give the platform which facilitate the exchange and reuse of the construction materials. The operation of material banks is like centralized repository system where surplus/ unused materials, or reusable materials from construction and demolition wastes of the construction sites can be deposited, thereby reducing the demand for new resources and divert the wastes from landfills. Figure 6 shows the adoption of material bank in construction activity.

As the G + 3 residential building model was made with the Autodesk Revit 2022, the materials passports were created with ease. Material passport is the comprehensive documentation system to keep the track of all the properties, composition, origin of each material component throughout its lifecycle. These passports act as digital and physical records that accompany materials from their manufacturing stage to their installation stage and further when it’s been added in construction and demolition wastes stage. With the help of detailed information about the material’s properties, such as its durability, recyclability and potential for reuse, material passports enable better decision-making in managing the construction and demolition wastes. Figure 7 shows the sample material passport for brick.

So, the integration of material banks and material passports offers many benefits considering the environment and the construction industry. Promoting the reuse of the materials, such initiatives reduce the need for extracting new resources, leading to the lower energy consumption and greenhouse gas emissions associated with its manufacturing process. Additionally, the diversion of the materials from the disposal sites helps to minimize the waste generation. Also, the systems such as material banks and material passports encourage easier identification and the recovery of the valuable materials during the demolition phase, facilitating their reintegration into the construction cycle.

Moreover, this strategy contributes to the circular economy principles in the construction sector. By extending the lifespan of material through reuse and recycling, it will help to close the materials loop and reduce the industry’s reliance on the virgin resources. The strategy also allows the collaboration and knowledge sharing among the stakeholders, fostering a more sustainable and efficient construction ecosystem.
4. Discussion

The construction industry is widely recognized as a major contributor to environmental degradation and a significant consumer of natural resources. It stands out as one of the most resource-intensive sectors, accounting for approximately forty percent of all material resources consumed. This extensive resource consumption not only exacerbates the issue of resource depletion but also leads to substantial waste generation. Furthermore, the construction industry plays a significant role in greenhouse gas emissions, posing challenges in terms of environmental sustainability. In light of these concerns, there is a growing recognition of the need to adopt sustainable practices in the construction sector. One potential approach is to leverage waste materials generated from production, construction, or demolition activities as supplementary construction materials. By incorporating these waste materials into the construction process, the industry can partially close the material cycle and contribute to sustainable development. This approach aims to minimize resource consumption, reduce waste generation, and mitigate the environmental impact associated with greenhouse gas emissions.

Overall, the utilization of waste materials in the construction industry represents an opportunity to foster a more sustainable and circular approach, thereby addressing the environmental challenges and promoting a more sustainable future. Figure 4 shows the (a) floor plan, (b) foundation plan, (c) footing details, (d) 3D view of the building model of the considered case study.

Table 3 shows sizes of the structural elements of the considered case study.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Structural Components</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Balcony</td>
<td>0.9 m width and length 8.05 m (cantilever)</td>
</tr>
<tr>
<td>2.</td>
<td>External wall</td>
<td>Thickness 0.15m</td>
</tr>
<tr>
<td>3.</td>
<td>Internal wall</td>
<td>Thickness 0.10m</td>
</tr>
<tr>
<td>4.</td>
<td>Plaster</td>
<td>12mm both externally and internally</td>
</tr>
<tr>
<td>5.</td>
<td>Staircase</td>
<td>Width- 1m, Trade Width- 25 cm, Riser Height- 20 cm</td>
</tr>
<tr>
<td>6.</td>
<td>Standard Bricks</td>
<td>19cm x 9cm x 9cm</td>
</tr>
<tr>
<td>7.</td>
<td>Beam size (all)</td>
<td>350mm x 230mm</td>
</tr>
<tr>
<td>8.</td>
<td>Column size</td>
<td>400mm x 250mm</td>
</tr>
<tr>
<td>9.</td>
<td>Column for staircase room</td>
<td>150mm x 150mm</td>
</tr>
<tr>
<td>10.</td>
<td>Slab thickness</td>
<td>150mm</td>
</tr>
</tbody>
</table>

As per the TIFAC Rule, total 50 kg/sqm, 400 kg/sqm, and 65 kg/sqm waste is generated in the respective activity of construction, demolition, and the renovation. The construction and demolition wastes quantities were calculated by following three methods and the results were compared. The methods were (a) Building permit system, (b) Building debris estimation formula, (c) Metro Vancouver demolition waste generation rate calculator. The total wastes generated was 31275kg, 29520kg, and 37665kg by the methods (a), (b), and (c) respectively. Figure 8 shows the sample calculation dashboard of Metro Vancouver method. The minimum recycling requirement of 70% gives the construction and demolition waste quantity as 26365kg.

Figure 9 depicts the strategies difference between the Deconstruction and Demolition technique. Deconstruction technique effectively prevent the construction and demolition waste material from being deposited in the landfills and can also minimize the release of carbon dioxide that results from the production of new materials. The only drawback of the Deconstruction is, it takes more time and relatively more labor charges are involved in Deconstruction. The traditional demolition of 100 m$^2$ house can take place in just one day, whereas the deconstruction requires approximate 6.5 days for the same.

Conclusions

The material banks and materials passports represent promising strategies for mitigating the environmental impact of the construction industry. By promoting resource efficiency, reducing waste generation, an facilitating the reuse of materials, these initiatives contribute to a more sustainable and circular construction sector.
In the considered case study, the average calculated waste quantity was 30000kg will be of no use if followed in linear economy. Instead, the circular economy will lead to the reduction of construction and demolition waste and also the financial benefits gained by selling the salvaged building materials. For example, the total number of bricks required were 13220 nos., and after deconstruction it was found that more than 50% of the well-shaped bricks can be extracted and remaining broken bricks can be used for backfilling. Another example from this considered case study was 41 no. of single flush doors and 56 no. of windows can be extracted, which were well in shape and sold though the designed digital material selling platform to get the financial benefits.

**Declarations**

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**Conflict of Interest regarding this paper:**

Enhancing Construction and Demolition Waste Management through BIM Implementation: A Pathway to Circular Economy- None

**Declaration of interest:**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data Availability Statement:** Manuscript does not have associated data

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Figures

2. Construction phase
3. Operations and maintenance phase
1. Raw material phase
4. End of life
5. Generation of construction and

Figure 1
Circular economy in construction sector
Figure 2

Network Map based on the Authors Keywords in the Area of Circular Economy in Construction Sector
Figure 3

Researchers Network Map Working in the Field of Circular Economy

Figure 4

Floor Plan View, 3D View, and Component Level details of the Building Model

Surveying the importance of circular economy: Managing construction and demolition wastes

Applying circular economy strategy Wastes as a resource by creating platforms such as material banks and material passports

Case study analysis: Using BIM

Figure 5

Here for example, parapet wall is shown
Methodology Followed

**Deconstruction**
- Deconstruction sequence and plan
- Hazard material disposal
- Waste identification and sorting

**Construction**
- Digital database
- Storage information
- Certification

**Material Bank**
- Digital database through BIM
- Reuse and Recycle
- Storage information
- Certification

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**Figure 6**
Adoption of Material Bank in Construction

<table>
<thead>
<tr>
<th>Material Passport: Brick</th>
<th>Unique Identifier</th>
<th>BRK-A-00001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Red Clay Brick</td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>Red Clay</td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>19cm X 9cm X 9cm</td>
<td></td>
</tr>
<tr>
<td>Method of fixing</td>
<td>Cement mortar</td>
<td></td>
</tr>
<tr>
<td>Date of Manufacture</td>
<td>12/2022</td>
<td></td>
</tr>
<tr>
<td>Installed</td>
<td>04/2023</td>
<td></td>
</tr>
<tr>
<td>Maintenance grade</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Performance grade</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Aesthetic grade</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7**
Sample Material Passport for Brick
Minimum Recycling Requirement of 70%

26,365 kg

Figure 8
Construction and Demolition Waste Calculator

Strategies

Demolition (Approximate time required 6.5 Days)

No. of workers involved- atleast 3

Sequencing is not that crucial as compared to Deconstruction

Deconstruction (Approximate time required 1 Day)

No. of workers involved- atleast 5

Sequencing is more crucial in Deconstruction in a way of removal of plastering, cork, windows, doors, ceiling, roofing, draining system

Figure 9
Strategies of Demolition and Deconstruction