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Article

# Statistical Identification of Lean Waste Factors in RCC Road Construction Using the Importance Index Method (IMPI): Evidence from Surat City, India

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**Abstract:** Reinforced Cement Concrete (RCC) roads form the backbone of durable urban infrastructure, yet projects in this sector are routinely hampered by material wastage, equipment downtime, rework, and disrupted workflows that erode both productivity and long-term sustainability. This study identifies and ranks the principal factors driving waste in RCC road construction through the lens of Lean Construction. A structured questionnaire was distributed to 47 construction professionals – contractors, engineers, supervisors, and municipal officials – working on RCC road projects across the Surat region of India. Responses were evaluated using the Importance Index Method (IMPI), which combines a Frequency Index (FI) and a Severity Index (SI) to gauge the relative impact of each waste-causing factor. The analysis shows that poor workmanship, rework stemming from ambiguous drawings, inadequate coordination between design and site teams, and recurring design errors are the most damaging contributors to waste. Spearman's rank correlation between the frequency- and severity-based rankings exceeded 0.97, pointing to strong internal consistency in the survey responses. The results indicate that defects, communication breakdowns, and coordination gaps are the dominant inefficiencies in RCC road construction. Building on these findings, the study discusses how combining Lean Construction practices with Building Information Modelling (BIM) can strengthen project coordination, reduce rework, and stabilise workflows, offering practical direction for more efficient and sustainable infrastructure delivery.
**Keywords:** Lean Construction, BIM, RCC Roads, Waste Reduction, Infrastructure Projects, Construction Management

## 1. Introduction

Infrastructure development underpins economic growth and urban mobility, and road construction sits at the heart of that effort. Among the pavement options in use today, Reinforced Cement Concrete (RCC) roads have become a preferred choice in urban settings, valued for their durability, lower maintenance demands, and considerably longer service life compared with conventional flexible pavements.

Even so, RCC road projects are rarely free of operational difficulty. Workflow bottlenecks, material supply delays, equipment downtime, labour inefficiencies, and weak stakeholder coordination are common, and together they push up project costs, stretch timelines, and waste valuable resources (Hwang & Ng, 2013).

Lean Construction principles have increasingly been adopted across the industry to address such inefficiencies and remove non-value-adding activity. At its core, Lean Construction is about improving workflow reliability, reducing waste, and maximising value delivery across the project lifecycle (Koskela, 1992; Womack & Jones, 2003).

Building Information Modelling (BIM) has, in parallel, emerged as a digital technology that strengthens project visualisation, coordination, and decision-making (Eastman, Teicholz, Sacks, & Liston, 2018). Integrating Lean principles with BIM holds considerable promise for improving productivity and cutting waste in construction projects (Al-Hattab, Hamzeh, & Emdanat, 2022).

This study focuses on the Surat region, with the aim of identifying the specific factors that generate waste in RCC road construction and examining them through a Lean lens. It also considers the practical benefits that an integrated Lean–BIM approach could offer for improving construction efficiency and advancing sustainability goals.

## 2. Literature Review

Construction has long carried the reputation of being among the least productive of the major industrial sectors. Delays, resource wastage, rework, and coordination failures are not isolated incidents – they are systemic problems that limit project performance worldwide (Koskela, 1992). In response, researchers and practitioners have turned increasingly to Lean Construction principles and digital tools such as Building Information Modelling (BIM) as pathways toward greater efficiency and reduced waste.

Lean Construction grew out of the Toyota Production System and is fundamentally concerned with stripping away activities that consume resources without adding value (Womack & Jones, 2003). Its central goal is to raise productivity by tackling waste in all its forms – idle waiting, overproduction, defects, unnecessary transport, and redundant motion (Dekier, 2012). Applying Lean principles has repeatedly been shown to improve construction performance by encouraging disciplined workflow management, stronger collaboration, and a culture of continuous improvement (Aslam, 2024).

Scholars have examined construction waste from many angles, and a broad consensus has formed around eight principal categories: overproduction, waiting, transportation, motion, over-processing, inventory, defects, and the underutilisation of human potential (Harish & Selvam, 2015; Can & Taş, 2020). These categories were first articulated in manufacturing theory but have since been adapted to the realities of construction. Across this body of work, defects, design errors, poor communication, and inadequate supervision are consistently identified as the waste causes that most severely erode productivity (Aslam, 2024).

The growth of digital technology has opened new possibilities for Lean Construction. BIM in particular has established itself as a valuable tool, enabling richer visualisation, tighter coordination, and more effective information management across the project lifecycle (Eastman et al., 2018; Aziz, Nasreldin, & Hashem, 2024). By giving stakeholders shared access to an accurate digital model, BIM breaks down silos and encourages genuine collaboration among designers, engineers, and contractors (Al-Hattab et al., 2022).

Several studies show that BIM can substantially cut construction waste by catching coordination problems early, resolving design clashes before work begins on site, and keeping communication clear among the parties involved (Li, Lu, & Chen, 2023). Beyond these immediate benefits, BIM supports project management functions such as 4D scheduling, 5D cost estimation, and live progress monitoring, all of which sharpen planning and support better-informed decisions (Sacks, Brilakis, & Pikas, 2022).

The combination of Lean Construction and BIM has, not surprisingly, attracted considerable scholarly attention. Lean supplies the process discipline; BIM supplies the digital infrastructure needed to put that discipline into practice. Together, they offer a compelling proposition: more reliable workflows, fewer design errors, and stronger coordination across the project (Tezel, Koskela, & Aziz, 2022; Alnajjar & Atencio, 2025).

Despite the growing uptake of Lean and BIM in the building sector, their use in infrastructure projects – particularly highway and road construction – remains surprisingly limited (Mahalingam, 2015). Road construction has its own distinct character: projects unfold along linear corridors, concrete operations must proceed without interruption, and a large number of stakeholders must stay in sync. Each of these features creates waste-management challenges that generic building-sector solutions do not fully address (Wu, Zhao, Ma, & Yang, 2019).

RCC road projects compound these challenges further. They consume large volumes of material, demand rigorous quality standards, and require precise logistical coordination (Wu, Zhao, Ma, & Yang, 2022). When these elements are mismanaged, the consequences are predictable: rework triggered by design errors, machinery left idle while materials are in transit, and batching plants producing more concrete than sites can use (Zhou & Li, 2024). Addressing these inefficiencies calls for a systematic, evidence-based approach to identifying and prioritising the root causes of waste.

Pinpointing the most critical waste causes, and understanding their relative weight, is therefore essential for achieving meaningful efficiency gains. Statistical tools such as the Importance Index Method (IMPI) have proved useful in construction management research, offering a structured way to rank project factors based on expert judgment (Sri Susmitha, Raja, & Asadi, 2018; Sakhare & Patil, 2019). Applied to RCC road construction, this methodology makes it possible to identify the sources of waste that matter most and to design targeted strategies for addressing them.

### *2.1 Research Gap*

Although Lean Construction and BIM have been widely studied in the context of building projects, comparatively little research has focused specifically on waste identification in RCC road construction projects. Most existing studies concentrate on residential or commercial building sectors, while infrastructure projects such as road construction have received comparatively less attention (Mahalingam, Yadav, & Varaprasad, 2022).

Many earlier studies, in addition, analyse construction waste using either Lean principles or BIM technologies independently. The combined application of Lean waste-identification methods with BIM-based waste-mitigation strategies remains insufficiently explored in the context of infrastructure construction (Karaz & Teixeira, 2023).

Few studies, moreover, have investigated waste factors in urban RCC road projects in developing regions such as India, where rapid infrastructure development often results in coordination challenges, resource inefficiencies, and project delays (Dixit, Mandal, Sawhney, & Singh, 2017; Rana, Pipaliya, & Shah, 2024; Negi et al., 2024).

This study therefore addresses the following research gaps:

- Identification of major waste-generating factors in RCC road construction projects.
- Statistical prioritisation of waste factors using the Importance Index Method (IMPI).
- Examination of how Lean Construction principles and BIM technologies can jointly contribute to waste reduction in infrastructure projects.

By addressing these gaps, the present study aims to contribute to improving construction efficiency and sustainability in RCC road infrastructure development.

### *2.2 Objectives of the Study*

The main objectives of this research are:

- To identify the major waste generating factors affecting RCC road construction projects based on Lean Construction principles.
- To analyse and prioritise the identified waste factors using the Importance Index Method (IMPI) based on responses from construction professionals.
- To evaluate the potential role of Lean–BIM integration in minimising waste and improving efficiency in RCC road construction projects.

## 3. Research Methodology

This study was carried out in two sequential stages. The first involved a review of published literature – research articles, international journals, and established sources in construction management and Lean Construction – to compile a list of waste-generating factors commonly observed in RCC road construction. These findings then informed the design of a structured questionnaire used in the second stage. Primary data were gathered by surveying construction professionals in Surat, including project engineers, contractors, site supervisors, and municipal officials with direct experience of RCC road projects. The survey evidence was supplemented by field visits, professional conversations, and project records obtained from the Surat Municipal Corporation.

A purposive sampling strategy was used to ensure that all respondents possessed genuine domain expertise. While a sample of 47 is modest, it is considered appropriate for exploratory, expert-driven research of this kind (Sri Susmitha, Raja, & Asadi, 2018). The study recognises that relying on expert judgment introduces the possibility of response bias; this risk was mitigated through consistency checks and by triangulating survey responses with field observations and documentary evidence. Because IMPI is mathematically derived from FI and SI, a strong correlation between the two indices is to be expected and should be read as a sign of internal consistency rather than as independent corroboration.

The identified waste categories, drawn from the Lean Construction literature, are presented in the following section. Stakeholders evaluated each factor using three scales: Frequency of Occurrence (FI), Degree of Severity (SI), and Level of Importance derived through the Importance Index Method (IMPI).

**Table 1: Rating Scales for Evaluation**

| Scale | Frequency (IMPI) | Severity (IMPI) |
|---|---|---|
| a = 4 | Always | Extreme |
| a = 3 | Often | Great |
| a = 2 | Sometimes | Moderate |
| a = 1 | Rarely | Little |

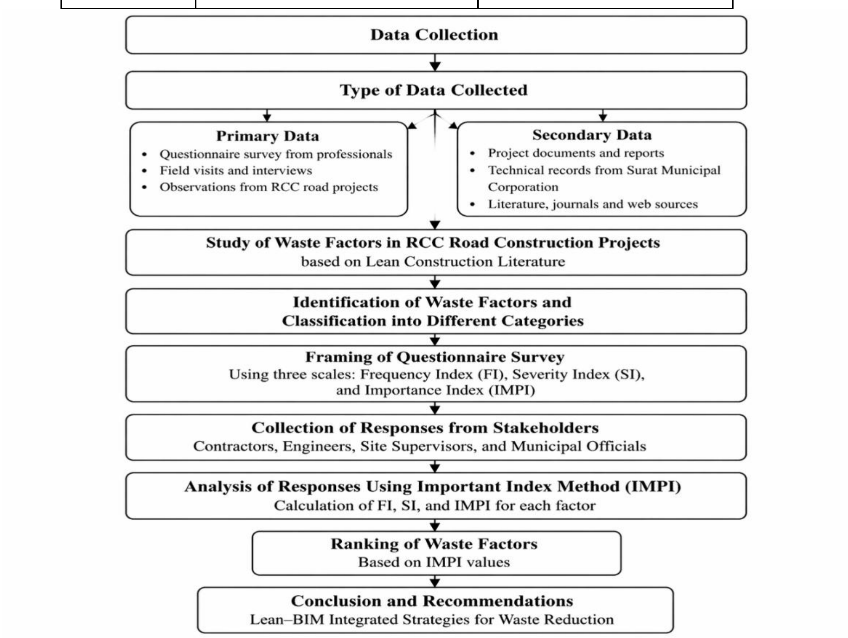



**Figure 1: Flow chart of research methodology**

## *3.1 Data Collection Framework*

To conduct the questionnaire survey, a list of eight major Lean waste categories, together with 39 associated waste causes relevant to RCC road projects, was identified (Harish & Selvam, 2015; Can & Taş, 2020). The eight categories are set out below.

**Table 2: Typical Causes of Waste Associated with Lean Categories**

| Category | Cause ID | Cause Description |
|---|---|---|
| Overproduction | 1.1 | Lack of coordination between design and site teams |
| Overproduction | 1.2 | Inaccurate demand forecasting |
| Overproduction | 1.3 | Poor planning of batching schedule |
| Overproduction | 1.4 | Unclear communication of work scope |
| Overproduction | 1.5 | Producing concrete mix in excess |
| Waiting | 2.1 | Idle machinery/labour due to late material delivery |

| | | |
|---|---|---|
| Waiting | 2.2 | Waiting for approvals or inspections |
| Waiting | 2.3 | Equipment breakdowns |
| Waiting | 2.4 | Poor sequencing of work |
| Waiting | 2.5 | Delay in drawing revisions or instructions |
| Transportation | 3.1 | Site layout not optimized |
| Transportation | 3.2 | Poor logistics planning |
| Transportation | 3.3 | Long haul distance for materials |
| Transportation | 3.4 | Lack of coordination between batching plant and site |
| Transportation | 3.5 | Repeated movement of equipment |
| Motion | 4.1 | Poor site layout causing extra walking or material handling |
| Motion | 4.2 | Lack of proper tool storage |
| Motion | 4.3 | Unorganized workstations |
| Motion | 4.4 | Improper placement of materials and machinery |
| Motion | 4.5 | Inadequate lighting/signage |
| Over Processing | 5.1 | Rework due to unclear drawings/specifications |
| Over Processing | 5.2 | Use of higher-grade materials unnecessarily |
| Over Processing | 5.3 | Excessive testing or documentation |
| Over Processing | 5.4 | Redundant checking by multiple parties |
| Over Processing | 5.5 | Poor understanding of client requirements |
| Inventory | 6.1 | Overstocking of cement, steel, aggregates |
| Inventory | 6.2 | Poor material tracking or record keeping |
| Inventory | 6.3 | Delays in work causing material accumulation |
| Inventory | 6.4 | Bulk purchase without requirement analysis |
| Inventory | 6.5 | Lack of space or poor storage management |
| Defects | 7.1 | Poor workmanship or inadequate supervision |
| Defects | 7.2 | Design errors or frequent design changes |
| Defects | 7.3 | Improper curing or mix proportioning |
| Defects | 7.4 | Lack of quality control and inspection |
| Defects | 7.5 | Inadequate skill training |
| Human Potential | 8.1 | Workers not involved in decision-making |
| Human Potential | 8.2 | Lack of suggestion/feedback mechanism |
| Human Potential | 8.3 | Poor communication between site staff and management |

| | | |
|---|---|---|
| Human Potential | 8.4 | No training or motivation initiatives |

## 3.2 Data Analysis Techniques

### *3.2.1 Importance Index Method (IMPI)*

IMPI was chosen in preference to conventional approaches such as the Relative Importance Index (RII) because it captures two dimensions of waste impact – how often a problem occurs and how serious it is when it does – producing a more complete and meaningful picture (Sri Susmitha, Raja, & Asadi, 2018; Sakhare & Patil, 2019).

For each waste cause, the Importance Index is computed by combining the Frequency Index and the Severity Index as follows:

$$\textbf{Importance Index \%} = [FI\% \times SI\%] / 100$$

where FI = Frequency Index, SI = Severity Index.

Frequency Index: this formula ranks waste causes based on the frequency of occurrence reported by the respondents:

$$\textbf{Frequency Index \%} = \Sigma a(n/N) \times 100 / 4$$

Severity Index: this formula ranks waste causes based on the severity reported by the respondents:

$$\textbf{Severity Index \%} = \Sigma a(n/N) \times 100 / 4$$

where a = weightage assigned to each response (1 to 4), n = frequency of the response, and N = total number of responses.

The same respondents evaluated frequency and severity separately in order to minimise response bias and improve the reliability of the results. The analysis was carried out using 47 responses collected for each survey item.

As a worked example, the Frequency Index for 'lack of coordination between design and site teams' is calculated as:

$[1(0/47) \times 100]/4 + [2(1/47) \times 100]/4 + [3(24/47) \times 100]/4 + [4(22/47) \times 100]/4 = 86.17$

The corresponding Severity Index is calculated as:

$[1(0/47) \times 100]/4 + [2(1/47) \times 100]/4 + [3(20/47) \times 100]/4 + [4(26/47) \times 100]/4 = 88.30$

and the resulting Importance Index is:

$(86.17 \times 88.30) / 100 = 76.09$

### *3.2.2 Data Accuracy Check (Spearman's Rank Correlation Method)*

To verify the reliability of the data, the degree of agreement between the frequency-based and severity-based rankings was assessed using Spearman's rank correlation coefficient, a statistical check that is standard practice in construction management research and provides a straightforward way of testing whether two sets of rankings tell a consistent story (Hermanto & Harliana, 2024).

The Spearman rank correlation coefficient measures the strength of association between two ranked datasets without relying on raw numerical values. It ranges from +1 (perfect positive agreement) to –1 (perfect negative agreement), with values closer to +1 indicating that the two sets of rankings closely mirror one another. The coefficient was calculated as follows:

$$r = 1 - [6\Sigma d^2 / (n(n^2 - 1))]$$

where r is Spearman's rank correlation coefficient between the two indices, d is the difference between the ranks assigned to each cause, and n is the number of parameters ranked.

## 3.3 Questionnaire Survey

### *3.3.1 Ranking of the Factors Affecting the Timeline of Construction*

Each factor was assigned an Importance Index score, and the factors were then ranked from highest to lowest. This ranking makes it possible to identify which waste causes deserve the most urgent attention in RCC road construction projects.

**Table 3: Frequency Index (FI) % Values for All Factors**

| Waste Cause | Rarely (a=1) | Sometimes (a=2) | Often (a=3) | Always (a=4) | FI (%) |
|---|---|---|---|---|---|
| Lack of coordination between design and site teams | 0 | 1 | 24 | 22 | 86.17 |
| Inaccurate demand forecasting | 0 | 9 | 33 | 5 | 72.87 |
| Poor planning of batching schedule | 0 | 7 | 32 | 8 | 75.53 |
| Unclear communication of work scope | 1 | 4 | 21 | 21 | 82.98 |
| Producing concrete mix in excess | 0 | 19 | 25 | 3 | 66.49 |
| Idle machinery/labour due to late material delivery | 0 | 4 | 29 | 14 | 80.32 |
| Waiting for approvals or inspections | 0 | 3 | 23 | 21 | 84.57 |
| Equipment breakdowns | 0 | 13 | 31 | 3 | 69.68 |
| Poor sequencing of work | 0 | 7 | 31 | 9 | 76.06 |
| Delay in drawing revisions or instructions | 1 | 9 | 28 | 9 | 73.94 |
| Site layout not optimized | 0 | 7 | 36 | 4 | 73.40 |
| Poor logistics planning | 0 | 4 | 36 | 7 | 76.60 |
| Long haul distance for materials | 1 | 13 | 29 | 4 | 69.15 |
| Lack of coordination between batching plant and site | 0 | 6 | 29 | 12 | 78.19 |
| Repeated movement of equipment | 1 | 16 | 29 | 1 | 65.96 |
| Poor site layout causing extra walking or material handling | 0 | 8 | 32 | 7 | 74.47 |
| Lack of proper tool storage | 0 | 19 | 24 | 4 | 67.02 |
| Unorganized workstations | 0 | 7 | 33 | 7 | 75.00 |
| Improper placement of materials and machinery | 0 | 8 | 30 | 9 | 75.53 |
| Inadequate lighting/signage | 0 | 21 | 24 | 2 | 64.89 |

| | | | | | |
|---|---|---|---|---|---|
| Rework due to unclear drawings/specifications | 0 | 0 | 22 | 25 | 88.30 |
| Use of higher-grade materials unnecessarily | 2 | 30 | 14 | 1 | 57.45 |
| Excessive testing or documentation | 0 | 11 | 35 | 1 | 69.68 |
| Redundant checking by multiple parties | 0 | 9 | 32 | 6 | 73.40 |
| Poor understanding of client requirements | 1 | 6 | 28 | 12 | 77.13 |
| Overstocking of cement, steel, aggregates | 0 | 2 | 27 | 18 | 83.51 |
| Poor material tracking or record keeping | 0 | 3 | 33 | 11 | 79.26 |
| Delays in work causing material accumulation | 1 | 7 | 32 | 7 | 73.94 |
| Bulk purchase without requirement analysis | 2 | 18 | 23 | 4 | 65.43 |
| Lack of space or poor storage management | 0 | 5 | 35 | 7 | 76.06 |
| Poor workmanship or inadequate supervision | 0 | 0 | 26 | 21 | 86.17 |
| Design errors or frequent design changes | 0 | 1 | 22 | 24 | 87.23 |
| Improper curing or mix proportioning | 0 | 5 | 24 | 18 | 81.91 |
| Lack of quality control and inspection | 0 | 6 | 24 | 17 | 80.85 |
| Inadequate skill training | 0 | 3 | 32 | 12 | 79.79 |
| Workers not involved in decision-making | 0 | 7 | 34 | 6 | 74.47 |
| Lack of suggestion/feedback mechanism | 0 | 9 | 30 | 8 | 74.47 |
| Poor communication between site staff and management | 0 | 4 | 20 | 23 | 85.11 |
| No training or motivation initiatives | 0 | 5 | 34 | 8 | 76.60 |

**Figure 2: Frequency of Occurrence of the Waste Causes**

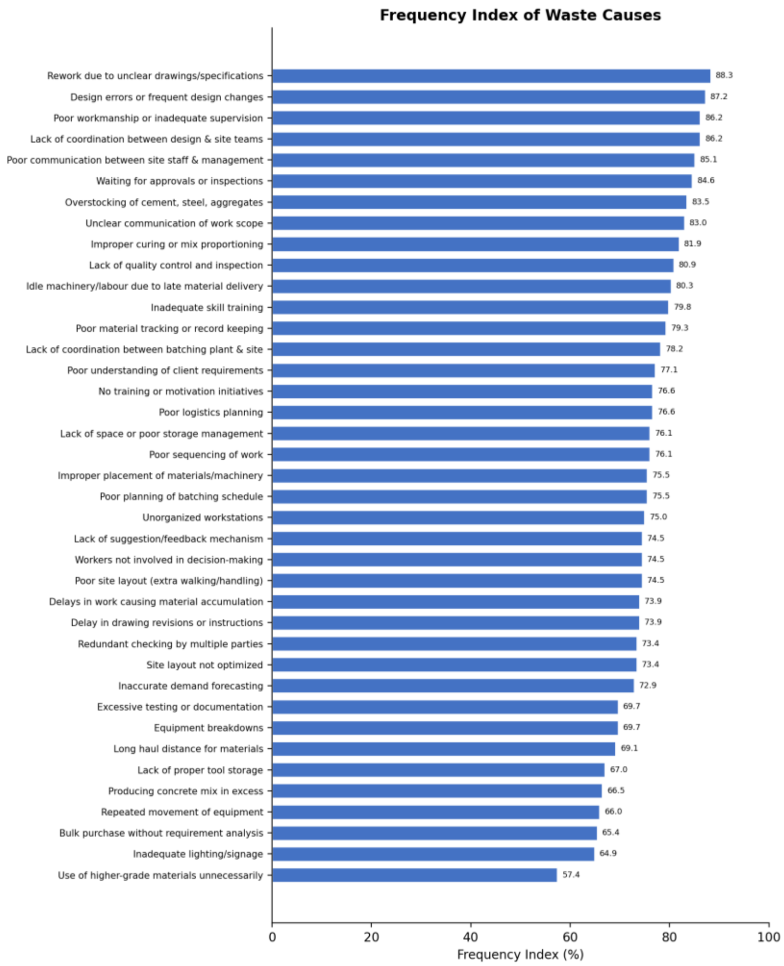


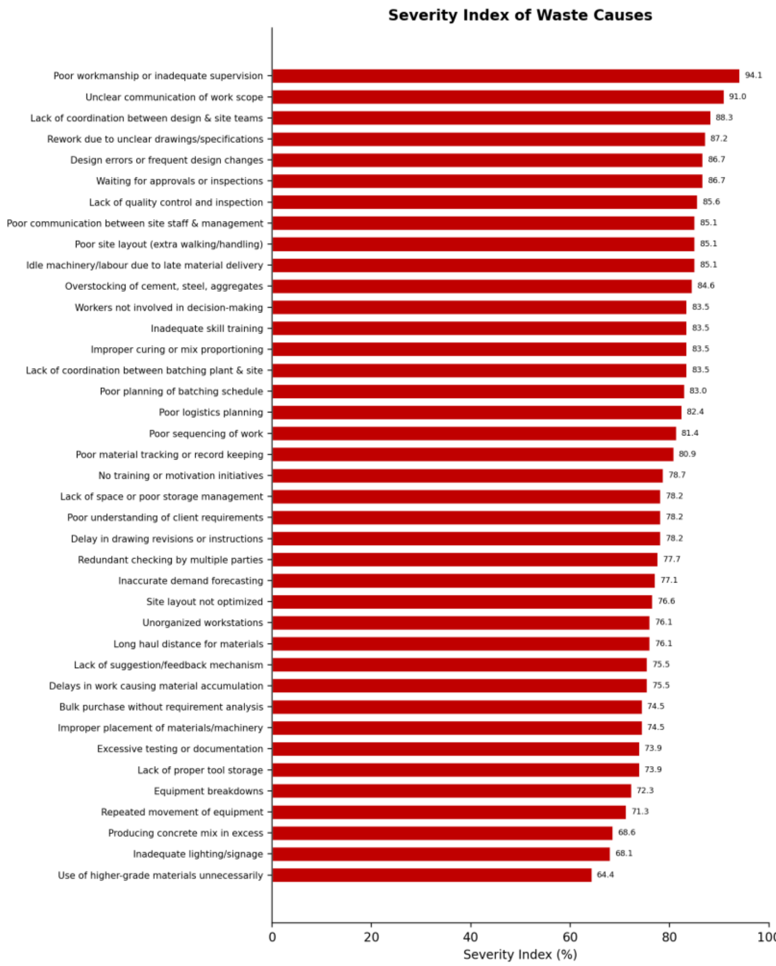

**Table 4: Severity Index (SI) % Values for All Factors**

| Waste Cause | Rarely (a=1) | Sometimes (a=2) | Often (a=3) | Always (a=4) | SI (%) |
|---|---|---|---|---|---|
| Lack of coordination between design and site teams | 0 | 1 | 20 | 26 | 88.30 |
| Inaccurate demand forecasting | 0 | 10 | 23 | 14 | 77.13 |
| Poor planning of batching schedule | 0 | 3 | 26 | 18 | 82.98 |
| Unclear communication of work scope | 0 | 0 | 17 | 30 | 90.96 |
| Producing concrete mix in excess | 0 | 16 | 27 | 4 | 68.62 |
| Idle machinery/labour due to late material delivery | 0 | 0 | 28 | 19 | 85.11 |

| | | | | | |
|---|---|---|---|---|---|
| Waiting for approvals or inspections | 0 | 2 | 21 | 24 | 86.70 |
| Equipment breakdowns | 0 | 11 | 30 | 6 | 72.34 |
| Poor sequencing of work | 0 | 6 | 23 | 18 | 81.38 |
| Delay in drawing revisions or instructions | 0 | 6 | 29 | 12 | 78.19 |
| Site layout not optimized | 0 | 6 | 32 | 9 | 76.60 |
| Poor logistics planning | 0 | 4 | 25 | 18 | 82.45 |
| Long haul distance for materials | 0 | 8 | 29 | 10 | 76.06 |
| Lack of coordination between batching plant and site | 0 | 2 | 27 | 18 | 83.51 |
| Repeated movement of equipment | 0 | 13 | 28 | 6 | 71.28 |
| Poor site layout causing extra walking or material handling | 0 | 1 | 26 | 20 | 85.11 |
| Lack of proper tool storage | 0 | 9 | 31 | 7 | 73.94 |
| Unorganized workstations | 0 | 6 | 33 | 8 | 76.06 |
| Improper placement of materials and machinery | 0 | 9 | 30 | 8 | 74.47 |
| Inadequate lighting/signage | 0 | 16 | 28 | 3 | 68.09 |
| Rework due to unclear drawings/specifications | 0 | 2 | 20 | 25 | 87.23 |
| Use of higher-grade materials unnecessarily | 1 | 20 | 24 | 2 | 64.36 |
| Excessive testing or documentation | 1 | 8 | 30 | 8 | 73.94 |
| Redundant checking by multiple parties | 1 | 3 | 33 | 10 | 77.66 |
| Poor understanding of client requirements | 0 | 6 | 29 | 12 | 78.19 |
| Overstocking of cement, steel, aggregates | 0 | 1 | 27 | 19 | 84.57 |
| Poor material tracking or record keeping | 0 | 3 | 30 | 14 | 80.85 |
| Delays in work causing material accumulation | 0 | 5 | 36 | 6 | 75.53 |
| Bulk purchase without requirement analysis | 1 | 6 | 33 | 7 | 74.47 |

| | | | | | |
|---|---|---|---|---|---|
| Lack of space or poor storage management | 0 | 6 | 29 | 12 | 78.19 |
| Poor workmanship or inadequate supervision | 0 | 0 | 11 | 36 | 94.15 |
| Design errors or frequent design changes | 0 | 1 | 23 | 23 | 86.70 |
| Improper curing or mix proportioning | 0 | 4 | 23 | 20 | 83.51 |
| Lack of quality control and inspection | 0 | 5 | 17 | 25 | 85.64 |
| Inadequate skill training | 0 | 2 | 27 | 18 | 83.51 |
| Workers not involved in decision-making | 0 | 1 | 29 | 17 | 83.51 |
| Lack of suggestion/feedback mechanism | 0 | 7 | 32 | 8 | 75.53 |
| Poor communication between site staff and management | 0 | 1 | 26 | 20 | 85.11 |
| No training or motivation initiatives | 0 | 6 | 28 | 13 | 78.72 |

**Figure 3: Severity of Occurrence of the Waste Causes**




## *3.4 Data Accuracy Check (Spearman's Rank Correlation Coefficient)*

The Spearman's rank correlation coefficient calculated between the Frequency Index (FI) and the IMPI (0.971), and between the Severity Index (SI) and the IMPI (0.974), indicates that the variation in expert opinion on ranking the waste-causing factors is extremely marginal. Both coefficients exceed 0.97 (Hermanto & Harliana, 2024).

These high coefficients suggest that the experts surveyed were remarkably consistent in their assessments. The close alignment between the frequency-based, severity-based, and overall importance rankings gives confidence that the analysis is robust and that the findings genuinely reflect conditions on the ground.

Calculation of Spearman's coefficient for FI and IMPI:

$r = 1 - (6\Sigma d^2 / (n^3 - n)) = 1 - (1692/59280) = 0.9714$

Calculation of Spearman's coefficient for SI and IMPI:

$r = 1 - (6\Sigma d^2 / (n^3 - n)) = 1 - (1512/59280) = 0.9744$

**Table 5: Importance Index (IMPI) % Values for All Factors**

| Category | Cause ID | Cause Description | FI | SI | IMPI |
|---|---|---|---|---|---|
| Overproduction | 1.1 | Lack of coordination between design and site teams | 86.17 | 88.30 | 76.09 |

| | | | | | |
|---|---|---|---|---|---|
| Overproduction | 1.2 | Inaccurate demand forecasting | 72.87 | 77.13 | 56.20 |
| Overproduction | 1.3 | Poor planning of batching schedule | 75.53 | 82.98 | 62.68 |
| Overproduction | 1.4 | Unclear communication of work scope | 82.98 | 90.96 | 75.48 |
| Overproduction | 1.5 | Producing concrete mix in excess | 66.49 | 68.62 | 45.62 |
| Waiting | 2.1 | Idle machinery/labour due to late material delivery | 80.32 | 85.11 | 68.36 |
| Waiting | 2.2 | Waiting for approvals or inspections | 84.57 | 86.70 | 73.33 |
| Waiting | 2.3 | Equipment breakdowns | 69.68 | 72.34 | 50.41 |
| Waiting | 2.4 | Poor sequencing of work | 76.06 | 81.38 | 61.90 |
| Waiting | 2.5 | Delay in drawing revisions or instructions | 73.94 | 78.19 | 57.81 |
| Transportation | 3.1 | Site layout not optimized | 73.40 | 76.60 | 56.22 |
| Transportation | 3.2 | Poor logistics planning | 76.60 | 82.45 | 63.15 |
| Transportation | 3.3 | Long haul distance for materials | 69.15 | 76.06 | 52.60 |
| Transportation | 3.4 | Lack of coordination between batching plant and site | 78.19 | 83.51 | 65.30 |
| Transportation | 3.5 | Repeated movement of equipment | 65.96 | 71.28 | 47.01 |
| Motion | 4.1 | Poor site layout causing extra walking or material handling | 74.47 | 85.11 | 63.38 |
| Motion | 4.2 | Lack of proper tool storage | 67.02 | 73.94 | 49.55 |
| Motion | 4.3 | Unorganized workstations | 75.00 | 76.06 | 57.05 |
| Motion | 4.4 | Improper placement of materials and machinery | 75.53 | 74.47 | 56.25 |
| Motion | 4.5 | Inadequate lighting/signage | 64.89 | 68.09 | 44.18 |
| Over Processing | 5.1 | Rework due to unclear drawings/specifications | 88.30 | 87.23 | 77.03 |
| Over Processing | 5.2 | Use of higher-grade materials unnecessarily | 57.45 | 64.36 | 36.97 |
| Over Processing | 5.3 | Excessive testing or documentation | 69.68 | 73.94 | 51.52 |
| Over Processing | 5.4 | Redundant checking by multiple parties | 73.40 | 77.66 | 57.01 |
| Over Processing | 5.5 | Poor understanding of client requirements | 77.13 | 78.19 | 60.31 |

| | | | | | |
|---|---|---|---|---|---|
| Inventory | 6.1 | Overstocking of cement, steel, aggregates | 83.51 | 84.57 | 70.63 |
| Inventory | 6.2 | Poor material tracking or record keeping | 79.26 | 80.85 | 64.08 |
| Inventory | 6.3 | Delays in work causing material accumulation | 73.94 | 75.53 | 55.85 |
| Inventory | 6.4 | Bulk purchase without requirement analysis | 65.43 | 74.47 | 48.72 |
| Inventory | 6.5 | Lack of space or poor storage management | 76.06 | 78.19 | 59.48 |
| Defects | 7.1 | Poor workmanship or inadequate supervision | 86.17 | 94.15 | 81.13 |
| Defects | 7.2 | Design errors or frequent design changes | 87.23 | 86.70 | 75.63 |
| Defects | 7.3 | Improper curing or mix proportioning | 81.91 | 83.51 | 68.41 |
| Defects | 7.4 | Lack of quality control and inspection | 80.85 | 85.64 | 69.24 |
| Defects | 7.5 | Inadequate skill training | 79.79 | 83.51 | 66.63 |
| Human Potential | 8.1 | Workers not involved in decision-making | 74.47 | 83.51 | 62.19 |
| Human Potential | 8.2 | Lack of suggestion/feedback mechanism | 74.47 | 75.53 | 56.25 |
| Human Potential | 8.3 | Poor communication between site staff and management | 85.11 | 85.11 | 72.43 |
| Human Potential | 8.4 | No training or motivation initiatives | 76.60 | 78.72 | 60.30 |

## 4. Results and Discussion

### *4.1 Category-Wise Interpretation of Results*

This section works through the waste causes falling under each of the eight Lean categories, highlights the issues that recur most often in RCC road construction, and discusses their practical consequences for project performance.

#### ***4.1.1 Overproduction Waste***

The leading causes identified were lack of coordination between design and site teams (IMPI = 76.09%) and unclear communication of work scope (IMPI = 75.48%). Both point to weaknesses in how information flows between the design office and the construction site – conditions that frequently trigger incorrect or premature execution of work. On RCC road projects, overproduction typically shows up as wasted concrete mix, costly rework, and unnecessary consumption of labour and materials.

#### ***4.1.2 Waiting Waste***

The key contributors here were waiting for approvals or inspections (73.33%) and idle labour or machinery caused by delayed materials (68.36%). Waiting waste is made worse by slow approval processes, ambiguous site instructions, and erratic material supply from batching plants – factors that are especially disruptive on linear RCC projects, where a continuous paving flow is essential.

***4.1.3 Transportation Waste***

The major factors were lack of coordination with the batching plant (65.30%) and poor logistics planning (63.15%). Transportation inefficiencies threaten the continuity that RCC paving demands: when haul distances are excessive or truck cycling is poorly managed, concrete arrives too late or too early, leading to cold joints, lower productivity, and surface defects that are costly to repair.

***4.1.4 Motion Waste***

The most prominent issues were poor site layout causing excessive movement (63.38%) and unorganised workstations (57.05%). Motion waste is largely a symptom of poor site setup and disorganised workspaces; excessive movement not only slows tasks down but also tires out workers and introduces unnecessary safety hazards.

***4.1.5 Over-Processing Waste***

The leading factors were rework due to unclear drawings (77.03%) and redundant checking by multiple parties (57.01%). Over-processing is largely a documentation problem: when drawings are unclear and standard workflows are absent, teams end up doing more work than is actually needed. RCC road projects are particularly vulnerable here because they demand precise alignment and level control, leaving little tolerance for interpretive errors.

***4.1.6 Inventory Waste***

Significant contributors were overstocking of materials (70.63%) and poor tracking or record keeping (64.08%). Poor inventory management leads to material deterioration as stocks sit exposed to the elements, congests already cramped sites, and ties up working capital unnecessarily. Excess aggregates and cement are recurring headaches on municipal RCC road contracts.

***4.1.7 Defects and Rework Waste***

Defects emerged as the most critical category overall, with the top-ranked causes being poor workmanship or inadequate supervision (81.13%), design errors or frequent design changes (75.63%), and improper curing or mix proportioning (68.41%). Defects carry the heaviest long-term consequences, eroding the durability and service performance of finished roads. Across all eight categories assessed, defects recorded the highest combined severity, confirming that quality failures are the single greatest source of waste in RCC road construction.

***4.1.8 Underutilisation of Human Potential***

The key concerns here were poor communication between site staff and management (72.43%) and a lack of training or motivation initiatives (60.30%). When workers are kept at arm's length from decisions and feedback is never sought, the consequences ripple outward: productivity suffers, rework rises, and quality standards become harder to maintain consistently.

Taken together, the elevated FI and SI scores recorded for defect-related factors confirm that these problems are both common and serious, marking them as the highest-priority targets for any organisation seeking to reduce waste in RCC road construction.

**Table 6: Waste Category Ranking**

| No. | Category | IMPI Ranking |
|---|---|---|
| 1 | Overproduction | 2 |
| 2 | Waiting | 4 |
| 3 | Transportation | 6 |
| 4 | Motion | 8 |
| 5 | Over Processing | 7 |
| 6 | Inventory | 5 |

| | | |
|---|---|---|
| 7 | Defects | 1 |
| 8 | Human Potential | 3 |

**Table 7: Top 10 Waste Causes According to IMPI**

| Rank | Cause ID | Waste Cause | IMPI % |
|---|---|---|---|
| 1 | 7.1 | Poor workmanship or inadequate supervision | 81.13 |
| 2 | 5.1 | Rework due to unclear drawings/specifications | 77.03 |
| 3 | 1.1 | Lack of coordination between design and site teams | 76.09 |
| 4 | 7.2 | Design errors or frequent design changes | 75.63 |
| 5 | 1.4 | Unclear communication of work scope | 75.48 |
| 6 | 2.2 | Waiting for approvals or inspections | 73.33 |
| 7 | 8.3 | Poor communication between site staff and management | 72.43 |
| 8 | 6.1 | Overstocking of cement, steel, aggregates | 70.63 |
| 9 | 7.4 | Lack of quality control and inspection | 69.24 |
| 10 | 7.3 | Improper curing or mix proportioning | 68.41 |

## *4.2 Key Insights Derived from the Analysis*

A synthesis of the overall analysis yields the following key insights:

- Defects and rework constitute the most severe and impactful waste category, significantly affecting quality and long-term performance.
- Communication failures recur across multiple waste categories and represent a major source of inefficiency.
- Coordination gaps between design teams, batching plants, and site operations contribute substantially to workflow disruptions.
- Waiting waste is amplified by procedural delays in approvals, inspections, and logistics.
- Inventory-related waste reflects ongoing challenges in material planning, forecasting, and tracking.
- Human talent remains underutilised, particularly with respect to decision-making and feedback-based improvement.
- Ineffective batching-schedule management directly affects concrete quality, paving continuity, and overall project flow.

## *4.3 Lean–BIM Integration for Waste Reduction*

A clear pattern emerges from the data: a large share of the waste identified in RCC road construction can be traced back to coordination failures, communication gaps, and design inconsistencies. These are precisely the kinds of problems that a well-implemented Lean–BIM integration is designed to solve. BIM creates a shared digital environment in which stakeholders can access up-to-date project information, visualise the work ahead, and coordinate their efforts (Kim, Fischer, & Kunz, 2023). Paired with Lean's process discipline, BIM becomes a powerful platform for cutting waste through better planning, scheduling, and workflow control (El Mounla, Beladjine, Beddiar, & Mazari, 2023).

Among the most promising applications of Lean–BIM integration in RCC road construction are:

- Clash detection and design validation to reduce design errors and rework.
- 4D BIM scheduling to improve construction sequencing and minimise waiting time, building on Lean scheduling tools such as the Last Planner System (Ballard, 2000).

- Digital quantity take-off to avoid material overstocking.
- Real-time project monitoring to improve coordination between batching plants and construction sites.
- Improved communication among stakeholders through shared digital models, complementing Lean tools such as value stream mapping (Barathwaj, Singh, & Gunarani, 2017).

The integration of Lean Construction and BIM therefore offers a systematic approach for enhancing productivity, reducing waste, and improving project sustainability in RCC road construction (Luo, Xue, & Wang, 2024; Zhang, Wang, & Chen, 2024).

### *4.4 Study Limitations*

This study is geographically bounded by the Surat region and draws on a sample of 47 professionals, so the findings should not be assumed to hold universally across other locations or types of infrastructure. Extending the research to other regions, enlarging the sample, and incorporating additional analytical methods would help test and refine these conclusions.

### *4.5 Lean–BIM Application for RCC Road Waste Reduction*

**Table 8: Mapping of Lean Tools and BIM Applications to Waste Types**

| Waste Type | Lean Tool | BIM Application |
|---|---|---|
| Defects | Standardized Work | Clash Detection |
| Waiting | Last Planner System | 4D Scheduling |
| Overproduction | Just-in-Time | Quantity Take-off |
| Inventory | 5S | Material Tracking |
| Transportation | Value Stream Mapping | Site Logistics Modelling |

## 5. Conclusion

This study set out to identify and rank the factors that generate waste in RCC road construction, using the Importance Index Method (IMPI) applied to survey responses from 47 construction professionals in the Surat region. Across the thirty-nine waste causes examined under eight Lean categories, defects, over-processing, waiting, and overproduction stood out as the most damaging to project performance. Defect-related factors recorded the highest combined frequency and severity scores, marking them as the most urgent targets for improvement.

At the level of individual causes, poor workmanship, rework arising from unclear drawings, weak coordination between design and site teams, and persistent design errors were the leading contributors to waste. Spearman's rank correlation analysis confirmed that the frequency-based and severity-based rankings were closely aligned, with coefficients above 0.97, lending strong support to the internal consistency of the data.

Taken together, the results indicate that communication failures, coordination gaps, and inadequate quality management are the defining inefficiencies in RCC road construction. The study suggests that integrating Lean Construction practices with BIM offers a practical way forward – better coordination, more reliable workflows, and sharply reduced rework (Alnajjar, Atencio, & Turmo, 2025). Adopted thoughtfully, this integrated approach has the potential to deliver more efficient and sustainable infrastructure, which is particularly valuable in cities and regions undergoing rapid urban growth.

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