ANALYSIS AND PREDICTION MODEL FOR MANAGEMENT OF RESIDENTIAL BUILDING CONSTRUCTION WASTE BASED ON MACHINE LEARNING TECHNIQUES

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Civil Engineering

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2024

DECLARATION

I, hereby declared that the presented work in the thesis entitled "**Analysis and Prediction Model for Management of Residential Building Construction Waste Based on Machine Learning Techniques**" in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of Dr. R.L. Sharma, working as Professor in the School of Civil Engineering and Dr. Prashant Borkar, working as Vice President in Mastersoft ERP Private Ltd., Nagpur, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled "Analysis and Prediction Model for Management of Residential Building Construction Waste Based on Machine Learning Techniques" submitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the School of Civil Engineering, is a research work carried out by Akshay Ashok Gulghane, 41900283, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

(Signature of Supervisor)	**(Signature of Co-Supervisor)**
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ABSTRACT

One of the crucial and essential components of managing a building project is the management of materials waste. Such a big investment necessitates careful planning, supervision, and management in order to reduce construction waste, which undoubtedly affects an organization's internal performance. Million tonnes of construction waste are produced by construction materials each year all over the world. One of the most significant issues facing the whole construction sector is without a doubt building waste. As a result, it is now absolutely essential and necessary to handle construction waste from actual construction sites properly and effectively. The significant increase in economic growth of emerging countries, as well as mass urbanisation, has resulted in a great number of construction infrastructure operations, which undoubtedly generate construction waste of various types on a larger scale. The study's main goal is to determine the prevalent methods used in the construction industry and the main issues connected to it. To investigate the real-time project practises, a case study has been commissioned. In the companion case study, concern areas were identified and current practises was analysed using a suitably streamlined and structured questionnaire survey procedure. The outcome demonstrates the better management practises used to reduce construction waste, as well as the numerous significant problem areas related with the management of construction materials and trash, as well as the repercussions.

In many cases, the amount of waste produced during the construction process exceeds the initial estimates made during the planning phase. This is primarily due to the significant amounts of waste that are generated during each stage of construction, which can vary in terms of their characteristics. Therefore, it is crucial to accurately identify and quantify the waste produced at each stage in order to minimize its creation. The study also tries to determine the key elements that lead to construction waste generation during the project's lifecycle. The characteristics of the waste were grouped into four categories based on their similarities, and then ranked according to their relative impact using the RII method. To decrease the overall amount of waste generated, it is helpful to predict how much waste will be produced at each stage of construction. As a result,

the primary goal of this research was to create a machine learning model capable of precisely estimating the amount of waste generated during various stages of building projects. The researchers gathered waste data from 134 construction sites and utilized decision trees and the K-nearest neighbors method for data analysis. Given the fluidity of building activity, it becomes crucial to predict waste generation accurately in each phase. The resulting prediction model from this study enables precise forecasts of waste sources and volumes. To assess the neural network model's effectiveness, the researchers also supplied estimates of gross floor area and materials.

The study reveals that construction processes generate a considerable amount of waste, with distinct waste types produced at different stages. The model employed in the study displays a satisfactory level of accuracy, as indicated by its RSME value of 0.49, enabling reliable predictions. Using both the decision tree and the KNN algorithms produced average accuracy of 88.32% and 88.51%. These findings hold significant value in enhancing construction waste management practices. The construction industry may successfully reduce waste creation from the start by precisely estimating and managing construction waste, contributing to a more sustainable building sector. The precise prediction of waste quantities at each construction stage offers an efficient strategy to minimize the overall waste generated throughout the project.

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Last but not least, I want to acknowledge the participants of this study, without whom this research would not have been possible. Their willingness to share their experiences and perspectives has enriched my understanding of the phenomena under investigation.

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Abbreviations and Acronym

CWM	Construction Waste Management
WMP	Waste Management Plan
SSR	State Schedule Rate
AI	Artificial Intelligence
ML	Machine Learning
MFA	Material Flow Analysis
LCA	Life Cycle Assessment
CWDCS	Construction Waste Disposal Charging Scheme
CE	Circular Economy
C & D	Construction and Demolition
m	Meter
kg	Kilogram
DT	Decision Tree
KNN	K-Nearest Neighbor
ANN	Artificial Neural Network
RF	Random Forest
%	Percentage

CHAPTER - 1

INTRODUCTION

1.1 General

The opening chapter serves as the introduction to the complete thesis topic. It is an opportunity to capture the reader's attention and provide a brief outline of what they may anticipate to learn in the subsequent chapters. In this chapter, the author may provide the background information and context for the topic they will discuss, outline the purpose and objectives of the content, and introduce key concepts and terminology that will be used throughout the work. Additionally, the introduction may include information on the author's motivation for writing the content and why the topic is important. Ultimately, the introduction serves as a crucial component of the content that can make or break the reader's engagement and understanding of the material. This first chapter provides an outline of the study project's history, the basic framework of the project, as well as the purpose and significance of this topic, ultimately outlining what to expect from the entire thesis.

1.2 Thesis Background

The construction and infrastructure industry has both economic and social benefits, but it also plays a significant role in environmental pollution and the depletion of non-renewable resources. It generates various kinds of waste streams, which can have serious consequences. It is also responsible for a reduction in natural resources, reduction in greenhouse gas emissions, and reduction in global waste [1]. Residential construction project in particular monopolizes a huge quantity of all required resources and is considered as substantial contributor to the abasement of the environment. Because of the rapid urbanisation of living areas, management of waste generated by construction project is the censorious subject round the globe [2]. Trash is generated during all phases of construction, and the amount of trash generated is determined by a variety of criteria such as project type, amount of work, complexity level, design precision, work methodology, communication, and work quality. [3]. For instance, in a residential construction project, the expected waste amount is between 0.95 and 1.15 kilograms for each square foot [4]. As a project progresses through its various stages, the volume of construction waste steadily rises. It becomes imperative to effectively curb the escalating waste generation at each phase in order to not only cut down on overall project expenses but also to address the environmental repercussions resulting from excessive waste. [5]. Despite the fact that there are set rules and regulations in India for managing construction waste, the effectiveness of waste management strategies for infrastructure projects falls short of expectations. This shortcoming can be attributed to a number of issues, including insufficient implementation by authorities, a lack of knowledge among construction agencies, the agenda's complexity, communication obstacles, and insufficient monitoring within the system. [6]. The market demand for building materials exceeds the supply of the material, and most of the time the quality of the material is inferior to the desired one. As a result, one of the most significant components in meeting market demand is recycling, so reusing and recycling are important terms in the market to meet market demand for construction materials. Construction waste management is divided into several categories. It is most important to manage the waste generated in an efficient way by accurate implementation of waste management strategy as well utilization of waste to its optimum potential. A hierarchical approach to manage and utilized the waste can be adopted as it provides the vital guidelines to the project managers and transact a way towards the sustainable development. As management of construction and infrastructural waste extends much beyond the disposal methodology and concept a robust and well-defined approach certainly provides a greater guidance towards reducing waste creation rate at all stages of the project [7]-[10]. A particular and proper stream line data is required for the identification of amount of wastage, time period of generation of waste, type and category of waste location, and area of waste for accurate and efficient formulation of waste management plan. Examining the economic dimensions of minimizing construction waste in the context of construction projects in India reveals a critical need for cost-effective strategies. A deficiency in site waste management systems, coupled with a lack of awareness regarding waste minimization in the Indian construction industry, has led to the significant generation of material waste. This not only poses environmental challenges but also results in economic repercussions, particularly in terms of increased costs associated with handling and managing waste materials. Addressing these issues is paramount for fostering sustainable construction practices and optimizing economic resources within the industry, putting the industries on backfoot in a highly competitive market. [1][2][7].

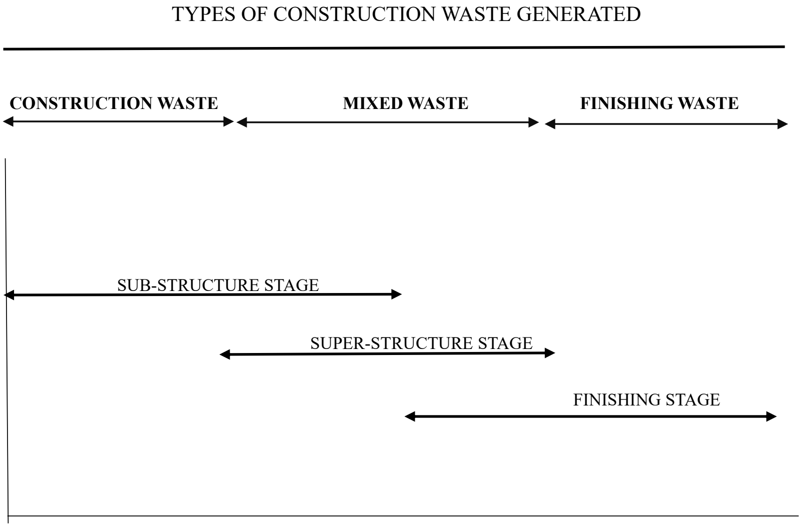


Figure 1.1: Category of waste generated during various stages of project

Figure 1.1 illustrates the schematics depicting the patterns of wastages generated during various stages of a building project. Accurate predicting construction waste generation, it is crucial to identify the sources of waste with precision. These sources can significantly differ based on the project type, materials utilized, and construction techniques employed. Hence, it becomes imperative to pinpoint potential waste sources before estimating the waste amount. One effective approach to achieve this is by conducting a comprehensive site analysis, which involves examining design plans, construction documents, and material specifications. This can help in identifying the types and quantities of materials that are likely to be used and the expected waste that will be generated during construction [11]-[13]. Additionally, site visits can provide an opportunity to observe and document the current practices of construction workers and the existing waste management infrastructure. This can help to identify areas where waste reduction measures can be implemented and improve waste management practices on site. Another important approach to source identification for construction waste generation prediction is to analyse the waste data from previous projects. This offers valuable perspectives on the categories and volumes of waste generated, the factors influencing waste production, and the efficiency of the employed waste management strategies. Analysing the waste data can help in identifying the common sources of waste across various construction projects and the trends in waste generation over time. Subsequently, this data can be employed to formulate plans for reducing waste, establish waste reduction objectives, and enhance waste management procedures for upcoming construction endeavours. Moreover, it facilitates the identification of potential prospects for material reuse and recycling, thus holding promise for substantial reductions in construction project waste. [14]-[17]

Quantifying construction waste is an important step in estimating the amount of waste that will be generated during a building project. Process involves identifying the different types of waste produced, measuring their quantities, and analysing the data to determine the trends and patterns of waste generation. Various techniques can be used to quantify construction waste, including on-site weighing, material flow analysis, and waste characterization studies [18]. On-site weighing involves weighing the waste generated during the construction process using scales or weighing equipment. Material flow analysis encompasses monitoring the flow of materials and waste within the construction site, while waste characterization studies entail scrutinizing the composition and properties of the generated waste. Upon quantifying the construction waste, it becomes feasible to forecast the projected amount of waste during the course of the project. This information is crucial for proper waste management planning and can help project managers develop effective strategies for minimizing waste and reducing the environmental impact of construction activities [19]-[20]. Predicting construction waste can also assist in budget planning and ensure that sufficient resources are allocated to waste management activities. By quantifying and predicting construction waste, project managers can take proactive steps towards achieving sustainable and efficient construction practices

Accurately gauging the overall waste generated in a construction project is crucial, demanding an estimation of waste production at each project phase. Measuring the waste at every stage is essential but challenging, as it entails precise calculations and identifying waste characteristics. [21]-[22]. Construction waste segregation is critical in establishing the exact amount of waste created. Nevertheless, owing to the ever-changing nature of construction tasks, ascertaining and measuring the precise amount of construction waste can prove to be quite a challenging endeavour. Inadequate record-keeping, particularly in terms of waste generated, makes data collection on construction waste management problematic. The amount and composition of waste produced during construction differ depending on the project's stage. Moreover, the effectiveness of waste management policies adopted and implemented at the site affects the amount of waste generated. Without being able to properly separate and identify the characteristics, It is incredibly difficult to correctly measure and monitor the overall amount of garbage generated. Until recently, there was a little emphasis on well-defined approach of gathering and formatting the required information on construction waste generation and its utilization for further process [23]. A vigorous observation, guesses based on experiences and simplifies approaches are used by the most of the project managers and coordinators for decision making at site.

The profuse activities involving in construction projects are typically itemised and taken into account using the project's quantification map and price list. However, wastes were frequently estimated as representing 5% of the total estimated construction materials for the purpose of the required proposal for pricing of the project and surveying [24]. Considering this as a one of the best approaches, because without accurate measurement or quantification of the generated wastes on the construction site, the verifiable quantity and classification remain unknown, making adequate waste management difficult. This calculated waste quantity is an important metric for comparing waste management practises at any building site. As a result, quantification becomes an important tool for making environmentally and economically sound decisions. Such decisions based on well-founded quantitative data for each activity on a construction site contribute significantly to progress. Each contractor will then be able to base their prices on hard data from their own practises rather than guesswork [25]-[26]. Furthermore, contractors will be able to pinpoint the critical parameters in waste generation, allowing them to effectively minimise waste generation and become highly competitive. This waste generation pattern, on the other hand, is predictable. Benchmarking is used to compare a company's performance to that of its peers in the industry. However, in waste management, a lack of data has meant that the necessary foundation for a sound benchmarking process in the construction industry remains a pipe dream. The lack of benchmarking has seriously hampered the implementation of more sustainable and innovative construction practises.

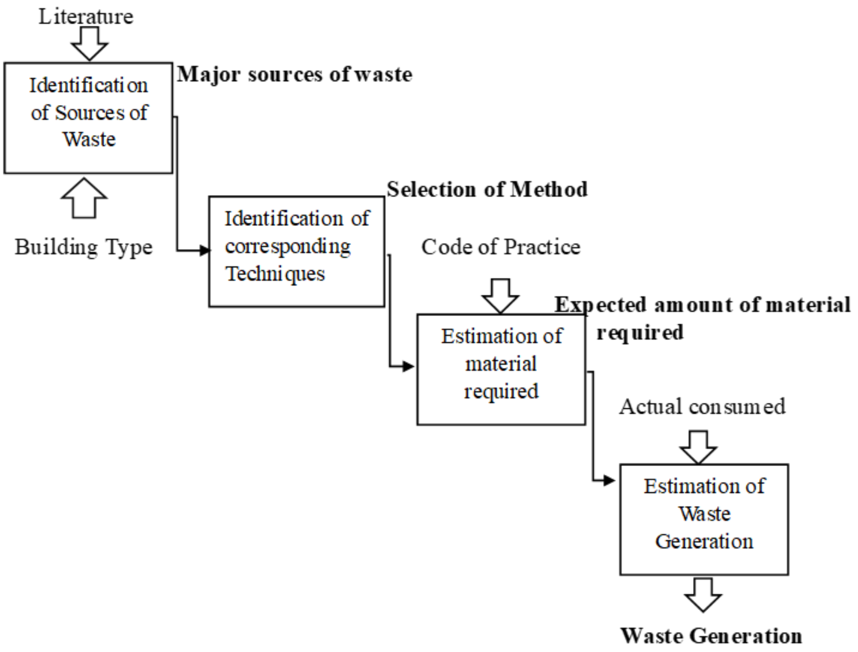


Figure: 1.2 Waste Estimation at various stages of construction project

In Figure 1.2, the waste estimation process for different stages of a construction project is depicted. Accurately determining the volume of waste produced in construction projects relies on suitable estimation and prediction methods. Estimation involves calculating past waste generation, while prediction utilizes historical data to project future waste production. Making predictions about future construction waste is crucial for efficient urban waste management and resource utilization. Waste prediction forms the foundation of waste management and aids in project planning and decision-making. The primary objective of waste prediction is to provide precise data during the project design phase. Anticipating future construction waste output is vital for improved project planning, strategic waste treatment, and optimal resource usage. Decisions in this context are often based on quantified measurements or numerical projections. Construction waste prediction involves estimating the amount and type of waste generated during construction activities. This prediction is critical for effective waste management and disposal planning, reducing the impact on the environment, and optimizing resource use. Accurate waste prediction can help construction managers and stakeholders identify potential waste reduction opportunities and develop strategies to minimize waste generation [27]-[30]. To achieve this, the prediction model must consider various factors, including the type of construction activity, the site location, project duration, workforce, and materials used. A reliable waste prediction model requires accurate data on previous construction projects, local waste disposal regulations, and current construction industry trends. Additionally, factors such as the adoption of sustainable building practices, green building codes, and circular economy principles can significantly affect waste generation during construction. Therefore, stakeholders must continually update their waste prediction models to reflect the changing dynamics in the industry. By accurately predicting construction waste generation, stakeholders can develop effective waste management plans and strategies that reduce the environmental impact and promote sustainability [31].

Waste prediction at the primary stages is critical for all residential projects in order to minimize waste at all stages. Machine Learning is a rapidly developing science with enormous promise for transformational applications, providing a solid foundation for developing prediction models. Recently, researchers have leveraged Artificial Intelligence (AI) technology to forecast construction outcomes. While many studies have focused on using Machine Learning techniques with continuous input variables, like artificial neural networks, support vector machines, adaptive neuro-fuzzy inference systems, decision trees, linear regression analysis, and genetic algorithms, these methods may not always be reliable when applied to categorical data. This study aims to enhance waste management precision in construction facilities by predicting construction waste generation through the use of Machine Learning algorithms. This prediction is achieved using a compiled dataset, offering valuable insights for better waste management practices. Machine Learning is crucial because it has the potential to transform different scientific and management domains, including industrial information processing [32]. Figure 1.3 illustrates the workflow of the Prediction model.

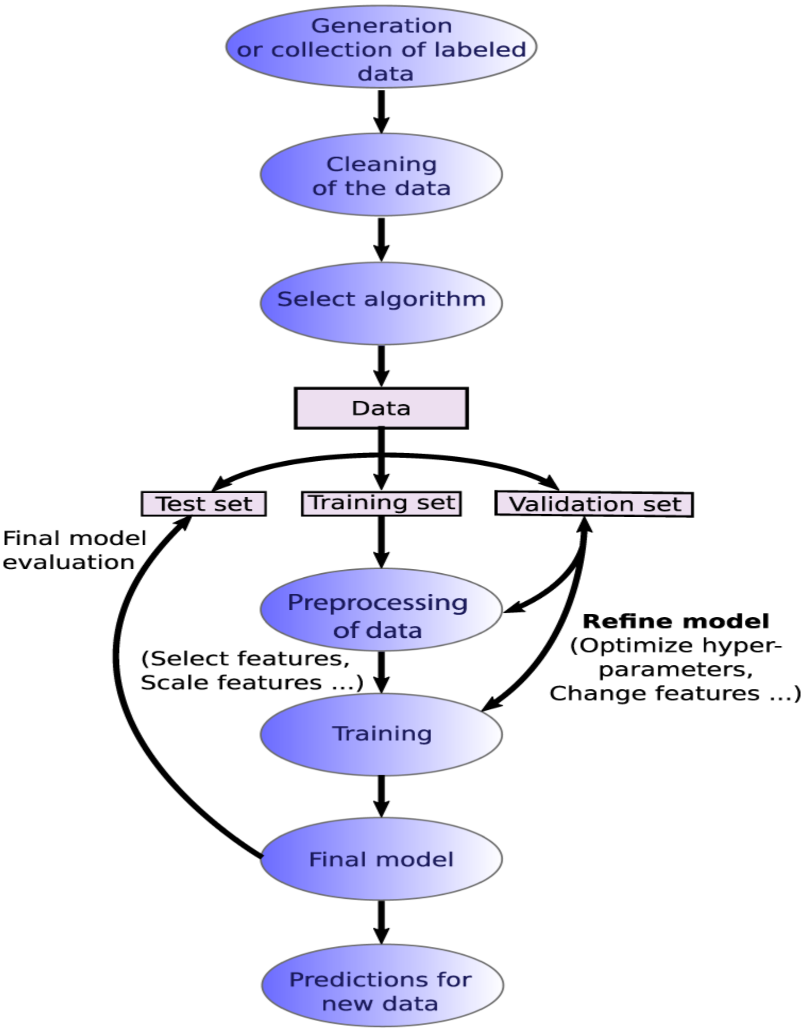


Figure: 1.3 Prediction model workflow (Jonathan Schmidt et.al,2019)

Certainly, understanding and addressing potential challenges and barriers to implementing waste reduction strategies in real-world construction projects is crucial for successful implementation. Here are some common challenges that may be associated with implementing such strategies Resistance to Change: One of the primary challenges is the resistance to change within the construction industry. Construction processes are often deeply ingrained, and stakeholders may be reluctant to adopt new methods or technologies. Cost Considerations: Initial investment costs for implementing waste reduction strategies, such as incorporating new technologies or training personnel, can be a barrier. Many construction projects operate on tight budgets, and convincing stakeholders to allocate resources for these initiatives may be challenging. Lack of Awareness and Education: Some stakeholders may not be fully aware of the benefits of waste reduction strategies or may lack the necessary knowledge to implement them effectively. Education and awareness programs may be needed to ensure that all parties involved understand the importance of these initiatives. Fragmented Supply Chain: Construction projects often involve multiple stakeholders, including contractors, subcontractors, suppliers, and regulatory bodies. Coordinating efforts and ensuring consistent waste reduction practices across the entire supply chain can be challenging. Regulatory Compliance: Adhering to existing regulations while implementing waste reduction strategies is essential. However, navigating complex regulatory frameworks and ensuring compliance can pose a challenge for construction projects. Logistical Challenges: Construction sites are dynamic environments with various logistical challenges. Coordinating the timely delivery of materials, managing on-site storage, and ensuring efficient waste disposal can be complex, especially in urban areas with limited space. Technology Integration: Implementing advanced technologies for waste reduction may require the integration of new systems with existing ones. Compatibility issues and the learning curve associated with adopting new technologies can be obstacles. Project Timelines: Construction projects often operate on tight schedules, and any disruptions to the workflow can have significant consequences. Introducing waste reduction measures may impact project timelines, and finding a balance between sustainability goals and project deadlines is crucial. Risk Management: Introducing new processes or technologies can introduce uncertainties and risks. Stakeholders may be concerned about potential disruptions to the project or unforeseen complications arising from the implementation of waste reduction strategies. Measurement and Reporting: Establishing effective metrics for measuring the success of waste reduction strategies and implementing reporting mechanisms can be challenging. Clear and standardized metrics are essential for demonstrating the benefits of these initiatives and identifying areas for improvement.[3][6][15].

1.3 Need of Research

Materials are crucial in the operations of the construction industry since their unavailability can halt production and, in general, is responsible for the probable cessation of tasks until the needed material is available. A well-executed material management and waste management programme can certify the scheduled delivery of the required materials to the project site, enabling the proper and efficient planning, increment in productivity of labour, precise scheduling and curtailing overall cost of project, less waste, and overall sustainability. Because material waste has a negative influence on the economy and the environment of the country, a systematic effort should be made to reduce waste generation at the source, which ultimately leads to lower overall project costs and time utilisation through waste minimization. This clearly demonstrates that organisations should prioritise material management and construction waste control in order to avoid unnecessary costs and protect the environment. Early prediction of waste generation during the pre-construction stage can undoubtedly aid in achieving the goal of less waste on the job site. A structured quantification of generated waste ensures the perfect input parameter for the development of the prediction model.

1.4 Significance of the Study

The research holds importance in various aspects, and this segment examines its significance from theoretical and practical angles. Initially, the study integrates research streams with theoretical advancements in waste management and the strategies employed globally for managing waste. On the other hand, over a few decades, the cost economics of construction waste play an important role. Nonetheless, there exists a scarcity of research examining the forecasting of waste generation across different construction phases.

In the existing literature on construction waste prediction modelling, numerous factors have been explored. However, this study focuses on a different aspect by aiming to identify potential sources of waste generation in diverse construction projects. Additionally, the review highlights the value of prediction tools in early detection of waste sources at the construction site. This early identification can lead to a reduction in waste generation rates and the formulation of an effective waste management strategy. The importance of early prediction and identification has grown exponentially, and waste generation reduction has become a corporate competitive weapon to reduce construction waste. As a result, data from developing countries makes it easier to compare findings to those from developed countries.

Reducing construction waste can yield substantial environmental and economic benefits. From an environmental standpoint, minimizing construction waste helps preserve natural resources by reducing the demand for raw materials. It curtails the energy-intensive processes associated with extracting, processing, and transporting these materials, thereby lowering carbon emissions and mitigating the environmental impact of resource extraction. On an economic front, efficiency gains emerge through reduced material procurement and disposal costs. Moreover, streamlined construction processes, driven by waste reduction initiatives, can lead to shorter project timelines and lower labour costs. The adoption of sustainable construction practices not only fosters environmental stewardship but also aligns with a growing global trend towards green building, attracting environmentally conscious consumers and investors.

1.5 Research Objectives

The major goal is to develop a forecasting system that can accurately predict the amount of waste produced throughout various phases of a construction project. Consequently, the objectives for achieving this goal are outlined below: -

I. To study the existing practices of construction industry for management of construction material and construction waste to establish key problem areas and elements of good practice.

II. To identify and analyze the causative factors of construction waste and rank them according to their relative importance.

III. Quantify the amount of construction waste and compute the associated cost at various phases of construction project.

IV. To develop the prediction model by using machine learning techniques to predict the sources of wastage, amount of wastage and cost associated with it.

1.6 Thesis Outline

In this section, the general structure and layout of the thesis are examined. The thesis consists of six chapters, and each chapter is introduced in the following manner.

1st chapter: **Introduction**: This delves into the world of construction waste, covering topics such as quantification and forecasting. It also provides background information on the research and the need for additional research, as well as discusses its relevance. The chapter also introduces a framework for guiding the research that is based on related literature.

2nd Chapter: **Literature Review**: The literature review concentrates on four primary aspects that bring together the examination of theories, the overall emphasis on managing construction waste, studies that analyse the quantity of waste, and forecasting construction waste. This also discusses the gap identification and the objectives drafted as a result of the gap identification.

3rd Chapter: **Practices in construction industry**: Effective construction waste management is a vital element within the construction sector, demanding the adoption of specialized practices. The practices are intended to ensure that waste is handled and managed responsibly.

4th Chapter: **Identification and Analysis of Sources Generating Construction Waste**: In this chapter, the main focus is on determining the primary causes of construction waste using both qualitative and quantitative methods for this research. This involves examining aspects such as the population and sample, response rate, unit of analysis, survey data, quantitative data analysis tools, qualitative data collection, protocol, and approach to analysing qualitative data.

5th Chapter: **Quantification Analysis and Prediction Model for Construction Waste**: In order to keep track of construction waste accurately, it is necessary to identify, categorize, and measure it at different stages of the project. This chapter covers the creation of models that can predict the amount of construction waste. These models evaluate each construction measure separately and then combine them into an overall measurement model to validate the accuracy of the measurements. Additionally, proposed models are compared to existing models to ensure the reliability and validity of the measurements. This chapter of the study also includes a discussion on the reliability and validity of prediction models.

6th Chapter: **Conclusion**: This chapter provides a summary and analysis of the study's results. It combines the research outcomes to present the implications for researchers and practitioners, aiming to provide a comprehensive answer to the research question and objective. Additionally, it discusses the contributions made to theory and the existing knowledge, and outlines potential avenues for future research based on the present findings and background. Finally, the chapter identifies and discusses the limitations of the research.

Future Scope: The future scope chapter of a thesis typically discusses the potential for further research or development in the field based on the findings and conclusions of the study. This chapter outlines the potential for future work, identify areas where further research could be conducted, and suggest ways to expand upon the current study.

1.7 Summary

The first chapter of this study has given an introduction to the thesis, which includes both the background and the overview of the research. The background part has included a detailed account of different aspects related to construction waste generation, management, measurement, and prediction. The research problem, research question, and study justification clearly indicate the significance of this research. Additionally, this chapter has presented a summary of the investigation, which includes the research framework, methodology, and areas of contribution. Based on this framework, the subsequent chapter will provide a comprehensive discussion of the pertinent theories, which have been identified through an exhaustive literature review, with a specific focus on important viewpoints.

CHAPTER – 2

LITERATURE REVIEW

2.1 General

The purpose of the literature review in this chapter is to discover the factors that influence importer commitment and to develop a conceptual structure for the study. A review of the literature on waste generation, quantification, source identification, and prediction follow a discussion of relevant ideas. In addition, the review highlights important studies on prediction models. As a result, this chapter is divided into three sub-sections that investigate building industry practices, waste generation sources, and the quantification and prediction of construction waste. Below is a thorough examination of relevant studies.

2.2 Management of Construction Waste

Construction waste refers to all undesirable materials generated from construction or industrial operations, whether produced directly or indirectly. This category encompasses various types of waste, including concrete, steel, wood, and mixed site clearance materials. They are produced by projects like land excavation, building construction, demolition, roadwork, and building restoration [1]-[2]. The issue of building waste management is a worldwide environmental hazard that impacts every country. [3]-[4]. Following a review of the literature, 81 variables that affect building waste were identified. Seven categories were created to classify these factors, which encompassed design, workforce, administration, site circumstances, acquisition, and outside influences [5]. The building industry recognizes that material waste is a significant problem, this has a significant impact on the sector's efficiency as well as the environmental effects of building ventures. A waste management system that effectively controls and manages waste at the source throughout the construction project is required to solve this issue. The assessment of waste is crucial for evaluating the effectiveness of production processes. Within the realm of building project management, waste management holds significant importance due to the adverse impact the industry has on the environment, including resource depletion, waste generation, and pollution. [6]-[7].

In order to minimize the impact caused by construction activities, construction professionals should initially identify the primary factors contributing to waste generation. Prior to commencing construction, they can employ various methods to manage building waste effectively, which fall into categories like waste classification, waste management strategies, and waste disposal technologies. By implementing these methods, the detrimental environmental consequences of construction can be curbed, and the overall efficiency of construction projects can be enhanced. Notably, the building sector in India generates substantial waste throughout all stages of development, encompassing bricks, demolished building materials, and mild steel. Prioritizing waste reduction and recycling will lower expenses and increase economic and environmental benefits [8]. To avoid obstructing traffic and municipal governments, waste should be stored at the point of generation. To accomplish this objective, a hierarchical structure based on priority levels must be created. To manage construction waste effectively, construction companies should implement a waste management plan that includes waste reduction, reuse, and recycling strategies. The plan should begin during the design stage, where architects and engineers can specify materials that are recyclable, durable, and have minimal environmental impact [9]-[10].

During the construction stage, workers should sort and segregate waste materials and place them in designated collection areas. Construction companies can also reduce waste by using prefabricated materials and modular construction techniques that produce less waste on-site. Unwanted materials should be generously donated to charitable organizations or repurposed for other construction endeavours. To ensure efficient handling of construction waste, a well-rounded waste management plan is essential, integrating strategies for waste reduction, reuse, and recycling. Construction firms can diminish the ecological consequences of their activities, conserve natural resources, and decrease expenses linked to waste management by implementing sustainable approaches. Figure 2.1 represents the life cycles process of building.

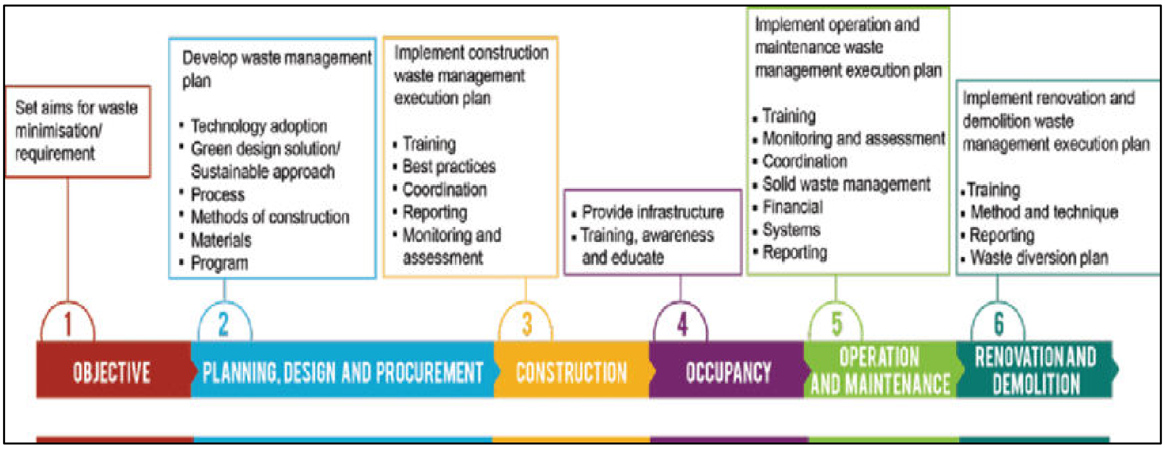


Figure 2.1: Systematic process for construction waste management through life cycle of a building. (Source: Ahmad Farhan Roslan et. Al, 2016)

2.3 Practices in Construction Industry

There are several ways to reduce waste in building projects, including adopting a zero-waste mindset, making wise choices during the planning stage, effectively managing the site, standardizing materials, and implementing waste management systems. To reduce waste generation, all project employees should work together. Implementing the waste rate estimation technique can result in improved material handling, reduced waste rates, and higher productivity. The 3R and 4R ideas (reduce, reuse, recycle, and recover) can also be useful in reducing building material waste throughout the product and service lifecycle. Preventing and reducing waste, reusing materials, recycling, recovering energy, treating waste, and disposing of garbage are all part of the waste hierarchy, which emphasizes resource efficiency. However, there are several practices that can be implemented to manage the generation of construction waste [33]-[35]. Firstly, the use of Building Information Modelling (BIM) technology can help optimize the design process to reduce waste generation. This technology can simulate the construction process and identify areas where materials can be saved or reused [22][36]. Furthermore, the incorporation of prefabrication and modular construction techniques presents a valuable opportunity to minimize on-site waste generation. By fabricating building components off-site and subsequently transporting them for assembly, a considerable reduction in waste can be achieved. Additionally, by establishing a well-designed waste management plan, we can further mitigate waste generation and ensure its appropriate disposal. This plan should include procedures for sorting, recycling, and disposing of waste. Additionally, training and educating construction workers on waste management practices can help improve their understanding of waste reduction and disposal. Lastly, using recyclable resources and behaviours can greatly reduce debris generation. This involves the use of materials that are eco-friendly, such as recycled materials or those that have a low carbon footprint [37]. Overall, the adoption of these practices can help reduce waste generation in the construction industry and promote sustainability. Figure 2.2 portray the Zero waste hierarchy structure adopted in construction industry to reduce the waste generation rate.

Figure 2.2 Zero waste hierarchy

Because it can visually show process flows in a clear, logical, and straightforward manner, the free-flow mapping presentation technique is a useful tool for investigating waste flow practices on building sites. Material flow analysis (MFA) plays a vital role in the field of industrial ecology as it assesses the input and output of process chains that involve materials. MFA has been used in waste management and recycling system planning and analysis, making it an efficient waste management decision-making tool. MFA, when combined with life cycle assessment (LCA), offers useful information to policymakers and decision-makers in assessing the environmental performance of waste management systems [38]-[40]. The MFA/SFA technique evaluates and compares all system inputs and outputs while monitoring waste flows and substances within the waste management model. MFA is also useful for mapping total waste movements and management procedures, as it provides transfer factors for all residue processes across multiple organizations, which can be used in LCA calculations. Using MFA as a foundation, it is feasible to build an input-dependent waste management model using LCAs. Overall, these techniques provide a thorough knowledge of waste management processes and aid in the identification of potential system improvements [41].

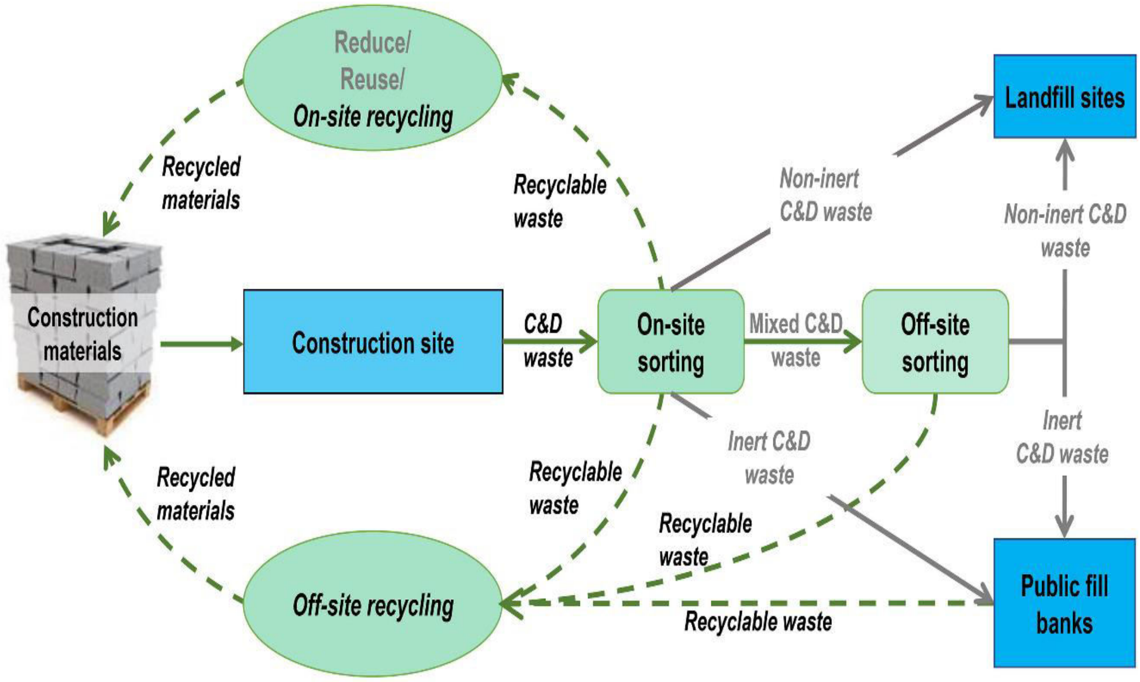


Figure 2.3: Material Flow on the construction site (Source: Amani Maalouf et. Al, 2023)

Waste flow prediction in construction can be modelled using building components during the construction phases. Reducing garbage generation, maximizing reuse and recycling, and minimizing mixed waste intake at landfills are all effective waste management methods. Additionally, it is possible to encourage the use of green building methods like large panel systems, prefabricated parts, and decreased wet trade applications [9]. In addition to sorting mixed construction debris and encouraging reuse and recycling whenever practical, a well-managed public filling program with adequate facilities and access can be beneficial [18]. Figure 2.3 shows the Material Flow on the construction site for the projects. Effective tactics include training construction workers, improving supervision, coordinating with stores to avoid over-ordering, and correctly storing and handling materials on-site [12]. Furthermore, strategies for reducing building and demolition waste can include standardizing designs, controlling stock to avoid over-ordering, and providing environmental education to employees. The government's introduction of the Construction Waste Disposal Charging Scheme (CWDCS) aims to incentivize construction and demolition companies to minimize their waste production and encourage the widespread adoption of recycling and reusing methods. This initiative aims to foster sustainable waste management approaches. To achieve a reduction in waste at building sites, the government can implement various policies, including a landfill tax, increased taxes on the use of new materials, and tax incentives for recycling efforts. [42]. Lean and Six Sigma methodologies can be used to identify and get rid of waste in the building industry. Construction waste illegally dumped poses a significant problem for the industry and has detrimental effects on the economy, ecology, and public health. Six Sigma aims to boost client satisfaction and profitability by lowering defects. Lean thinking and Six Sigma tools and techniques can also be useful to public and semi-public agencies. Research data can be analyzed through various techniques, including the Mean Score method, Ranking method, and Mann-Whitney U Test. [43]-[45]. A cost-benefit assessment is used to evaluate the economic viability of waste management on building sites, with a focus on economics. Benefit-cost analysis (BCA), a useful instrument for determining the economic viability of construction waste management, evaluates potential cost savings. Construction waste can be quantified using either the global index method or the component index approach, or by using a common construction model [46]. Often, the most efficient environmental solution is to reduce waste generation. If waste reduction is not an option, items and resources can be reused for the identical or another purpose. Waste can be recycled, composted, or used for energy recovery if reuse is not feasible. Disposal should only be used as a last measure, with the best available environmental option being used instead. According to research, increasing worker knowledge and education on construction waste management is critical for on-site waste minimization. Additional efficient strategies comprise the implementation of low-waste building technology, segregation of waste through designated waste skips based on material types, standardization of design and materials, and proper handling of construction materials. [19]-[20]. The Circular Economy (CE) offers a promising solution to mitigate the adverse consequences of construction and demolition activities. This innovative approach was devised as a response to the environmental repercussions caused by the waste generated from Construction and Demolition (C&D) processes. CE maximizes the use of raw materials, guarantees their value throughout their lifecycle, and reduces the production of excess waste. But there are many challenges involved in making the switch to CE in the construction and dismantling industries [47]. To ensure successful execution of CE, it is crucial to have a thorough understanding of multiple aspects such as societal, governmental, economic, behavioural, technological, and environmental dimensions. The CE principles call for reforming design standards, cutting back on the purchase of excess raw materials, and cutting, reusing, and recycling trash. By promoting recycling and reducing waste, these practices effectively stop environmental deterioration.[48]-[50]. The difference between two economies i.e., linear and a circular economy is shown in Figure 2.4. A novel strategy for reducing harmful environmental effects and fostering economic growth for long-term development is the use of CE in the building sector.

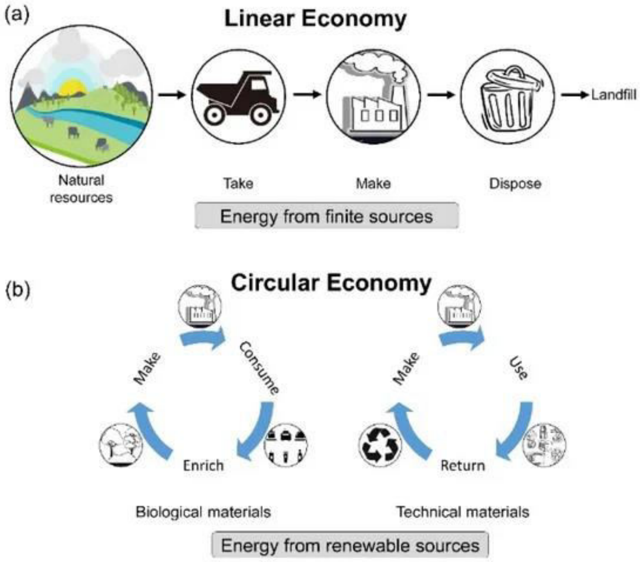


Figure 2.4: Recycling economy (Source: M Arena et. Al, 2021)

Implementing sustainable waste management practices in the construction industry encounters various potential limitations and barriers, spanning economic, regulatory, technological, and cultural dimensions. A primary challenge is the perceived or actual increase in costs associated with sustainable practices. The need for investments in new technologies, training programs, and waste sorting facilities can deter stakeholders in a cost-sensitive industry. Additionally, a lack of awareness and education regarding the long-term benefits of sustainable waste management poses a hurdle, with stakeholders potentially resisting or remaining indifferent due to inadequate information. Regulatory compliance, though advancing, faces issues of inconsistent frameworks and insufficient monitoring, impacting the widespread adoption of sustainable practices. Limited infrastructure for sorting, recycling, and disposing of construction waste is a substantial barrier, hindering effective diversion from landfills. Technological limitations, especially in regions lacking access to advanced recycling technologies, and the industry's resistance to adopting new technologies contribute to the challenges. The fragmented supply chain in the construction industry, with diverse stakeholder priorities, impedes coordinated waste management efforts. Overcoming inertia and fostering a culture of sustainability within a traditionally resistant industry require dedicated time, effort, and effective communication. The urgency of project timelines often takes precedence over considerations for sustainable waste management, leading to neglect of environmentally friendly practices. Moreover, the perceived inconvenience of sorting waste and adhering to new procedures can discourage the adoption of sustainable practices in construction projects. Addressing these multifaceted challenges is crucial for achieving meaningful progress in sustainable waste management within the construction sector [14][21][26].

2.4 Sources of Construction Waste

The initial and crucial phase in waste management is recognizing the primary origins of waste generation. There are thirty-four potential factors that contribute to waste production, which can be classified into seven main groups. These categories encompass procurement, handling, storage, workers, site management and supervision, design and contract documentation aspects, as well as external factors. Furthermore, researchers found that eight waste sources are significant. The process of converting materials contributes significantly to production uncertainty, resulting in to an increase in non-value-added activities. Decision-making can be improved and appropriate strategies for mitigating construction waste created by determining the contribution rates of various waste sources [51]-[54]. During the design, logistics, and physical building procedures, construction material waste can occur. In this research, construction waste refers to damaged materials that are destined for disposal, reuse, or recycling. These wastes are brought to the building site from a variety of sources, including design, procurement, material handling, operations, residuals, and others. Lack of current knowledge about on-site inventories is a common issue on big construction projects, which can result in the repeated purchase of the same materials, creating unnecessary waste. Waste can happen at any level of the structure and can come from both internal construction activities and external factors like theft and vandalism [55]-[56].

Ekanayake and Ofori (2000) classified garbage sources into four categories, including operational waste. (mistakes by laborers or skilled workers, accidents caused by carelessness, damage to completed work due to subsequent trades, use of wrong materials, unclear planning of required quantities, malfunctioning equipment, bad weather), Waste in design (inadequate attention given to dimensional coordination, design changes made during construction, lack of experience in construction method and sequence, lack of attention to market-available standard sizes, lack of knowledge about substitute goods, intricacy, mistakes, and inadequate contractual paperwork, as well as opting for inferior quality items., errors in construction method and sequence, complexity, errors, and incomplete contract documents. Material handling issues (damage during transportation, improper storage, supply of loose materials, use of whatever materials are available nearby, unfriendly behaviour on the part of the project team and workers, theft), and procurement loss (ordering mistakes, the failure to request or purchase limited amounts and obtaining goods that do not meet the required standards.) [57]-[60].

Table 2.1: Matrix of sources for generation of Construction waste [21][25][64]

Clusters	**Major Causes**	**Frequency of Occurrence**
DESIGNING RELATED		
	Frequent change in construction design	18
	Major errors in drawings and Design	11
	Insufficiency in design information’s	7
	Abysmal quality of design	5
	Incorrect layout for sites	4
	Complications in designs.	2
	Inexperience designer	2
	Communication barriers	2
MATERIAL HANDLING RELATED	Incorrect material storage	14
	Improper handling of materials	13
	Transportation damage to material	8
	Inferior quality of material	8
	Failure of equipment’s and tools	6
	Delay in allocation	5
	Use of non-suitable tools	3
HUMAN FACTOR RELATED	Human Error	10
	Incompetent and low skilled worker	6
	Deplorable attitude of workers	5
	Damage caused by negligence of workers	4
	Insufficient training for workers	3
	Lack of experience and skills	3
	Shortage of skilled workers	3
	Use of inappropriate materials	3
	Poor workmanship quality and methods	2
	Improper intent towards work	2
	Inappropriate use of safety gears	1

Clusters	**Major Causes**	**Frequency of Occurrence**
	Fatigue problems	1
PLANNING AND MANAGEMENT	Substandard planning	11
	Lamentable management of site	9
	Poor controlling	9
	Execrable supervision on site	7
	Inadvisable use of construction methods	7
	Coordination barriers amongst departments	7
	Inadequate information quality	7
	Shortfall in Communication	6
	Scarcity of construction equipment and tools	6
	Ineffective Resources allocation	4
	Frequent Rework	4
	Inefficient waste management strategies	3
	Lack of awareness among stakeholders	1
EXECUTION CONDITION RELATED	Materials residues on site	5
	Improper condition and layout of site	4
	Waste resulting from packaging	3
	Waste Congestion of the site	2
	Inadequate illumination on site	1
	Unwanted Crews interference	1
MATERIAL PROCUREMENT RELATED	Inaccurate procurement	11
	Careless Transportation	3
	Inappropriate quantity surveys	3
	Incorrect specifications and standards	2
MISCELLIONUS AND EXTERNAL	Unavoidable Weather effect	13
	Accidents on site	6
	Pilferage	4
	On site Vandalism	2
	Festivities	1

Clusters	Major Causes	Frequency of Occurrence
	Unpredictable local conditions	1
	Lack of legislative enforcement	1

Table 2.1 depicts a comprehensive mapping of the causative variables contributing to construction waste, as well as the frequency with which they appear, as cited in various study articles. These variables can be used as input parameters when creating pertinent questionnaires and models. Waste is produced throughout the entire construction process, starting from the initial planning phase and extending to the final stages. Understanding the various factors that contribute to this waste generation is essential for effectively managing and minimizing it. By addressing these fundamental causes, we can significantly reduce the overall amount of construction waste produced. Other major sources of building waste include incomplete information, poor material management, unskilled labour, and damage during transportation [61]-[62].

Construction waste creation has increased significantly as a result of the spike in construction activity, particularly in nations experiencing fast urbanisation and population growth. In response to this issue, a study was conducted to identify the key factors contributing to infrastructure waste in Thailand's construction sector. The article explains how construction waste is mainly generated by 28 important factors, which can be categorized into four groups: design, construction techniques, material sourcing, planning strategies, and human resources. They determined a significance level for each factor and designed a questionnaire to gather construction waste data. The findings demonstrate the primary classifications that are responsible for producing waste, and the elements within each group are arranged in order of their level of impact. Material administration, handling, transportation, storage, and site procedures were identified as common characteristics among the underlying causes. The identified underlying causes can help construction professionals reduce the waste generation in the early stages of the construction process [63]-[64].

Construction waste generation is influenced by a myriad of specific factors and challenges, leading to significant environmental impacts and resource depletion. One primary factor is the inherent complexity of construction projects, which often involve diverse materials, technologies, and stakeholders. The lack of standardized processes for waste management in the construction industry exacerbates the problem, as there is often insufficient coordination and communication among project participants. Additionally, the prevailing culture of overestimation in material quantities during project planning contributes to excess material procurement and subsequent waste generation. Inadequate recycling infrastructure and limited awareness of sustainable construction practices further compound the challenge. The cumulative effect of these factors underscores the need for comprehensive strategies to minimize construction waste and promote a more sustainable approach to building projects. [92][93][94].

2.5 Quantification of construction waste

Efficiently managing construction waste is essential for sustainable development and reducing its negative impact on the environment. A crucial aspect of this management involves accurately assessing the volume of waste generated throughout the construction process. [4][14]. There are different approaches to quantify construction waste, such as manual counting, weighbridge measurement, volume estimation, and modelling. Manual counting involves the physical counting of construction waste by workers or trained personnel. This technique is suitable for small-scale construction projects and can be used to determine the types and quantities of waste generated. However, it can be time-consuming and may not be accurate, especially when dealing with large volumes of waste. Weighbridge measurement involves weighing the construction waste using a weighbridge or scale. This technique is more accurate than manual counting and can be used to track the weight of waste generated over time. However, it may not be suitable for measuring bulky waste or waste with irregular shapes. Volume estimation involves estimating the volume of construction waste based on the size and shape of the waste. This technique can be used for waste with irregular shapes, and it is suitable for small-scale projects. However, it may not be accurate for bulky waste, and it may require trained personnel to estimate the volume correctly [56][60].

Modelling involves using computer programs to model the waste generated during the construction process. This technique can provide accurate data on the types and quantities of waste generated and can be used for large-scale construction projects. However, it may require specialized software and skilled personnel to develop the model. Regenerate response Determining how much is produced is the first step in efficiently managing construction and demolition (C&D) waste. A waste quantification model tailored to regional or national construction and demolition (C&D) waste generation is essential for achieving this goal. Accurate trash quantity estimation is critical in resolving building waste issues [68]. Waste quantification entails keeping detailed records of site accounting and waste characterization, which is necessary for determining the composition of building waste. It is feasible to quantify waste and determine the potential for waste reduction by estimating the volume of construction waste produced. Making educated decisions for minimizing and managing waste sustainably requires the use of quantification, which is a crucial technique for determining the actual magnitude of waste [67] A construction waste assessment or audit is required to acquire this critical data. This technique advances our understanding of the reasons, sources, volume, and composition of construction refuse generation. Accurate waste assessment data should be collected, so a method for recording quantitative data should be developed. Construction officials are accountable for this because they can create rules and rewards to promote eco-friendly construction methods and waste management procedures [65][69]. To reduce construction waste, standardized record-keeping methods and useful guidelines should be implemented. Enforcing requirements and norms are critical to ensuring compliance. For conventional buildings, a four-step waste quantification technique can be used, which entails identifying construction stages, selecting similar construction sites, sorting and weighing mixed waste, and thoroughly analysing the recorded amount [25][70].

Construction officials can evaluate the viability of C&D refuse recycling programs and estimate the lifespan of depleted landfill areas. Waste measurement is a useful technique for pinpointing inefficiencies and potential development areas in manufacturing systems. However, precisely measuring waste in various stages of construction projects can be difficult, making waste estimation difficult and unreliable [22][26]. As a result, precise waste measurement is critical for evaluating the performance of manufacturing processes. Various methods for quantifying building waste have been suggested in previous research, including the percentage method. The third and final point of discussion is waste quantification, which can be accomplished using a variety of techniques. One such approach is the use of a conversion factor [52]. A construction trash index can also be calculated using site audits, which include frequent visits, checklists, and the estimation of disposal records. Cutting and managing waste should be emphasized when it comes to addressing waste causes. As proposed by R., design interventions can help reduce cutting waste, while proper organization and supervision of site activities can help avoid management waste. Quantifying waste is a crucial step in understanding its true size and taking appropriate actions to minimize and manage it sustainably [51].

Waste characterization is the first and most important step of data collection in waste management. This procedure entails determining the kinds of waste that are produced. Several studies on the characterization of different types of construction waste materials have been performed. However, most studies have concentrated on the main kinds of C&D waste that account for a significant portion, such as concrete, bricks, wood, and steel. They also introduced the concept of "wastage level," which measures the proportion of building materials that are likely to be wasted by contrasting the quantity of materials used or completed with the quantity of materials actually purchased [68][70]. This idea is based on earlier work source 1 assessment and quantification of C&D waste. It is an excellent way to cut waste and assess performance on-site, particularly in material processing, storage, and transportation. The sources of building waste production, such as design, procurement, handling, operation, and residual refuse, are identified using waste generation-rate models. Estimate that 1 to 10% of the materials bought for construction projects in the Dutch industry are wasted, with the majority of this waste coming from leftover cut-offs, plan changes, and subpar workmanship. As a result, waste reduction at the source is critical for efficient waste management and productivity in construction initiatives [72]-[73]. Using waste indices to make calculations can help estimate the amount of waste that will be produced at different stages of a construction project. This can lead to increased awareness of waste reduction, better planning, and more efficient environmental management. In Hong Kong, this method has been applied to assess and standardize the environmental performance of construction projects, particularly in public housing. On average, construction waste generated by contractors in the building sector in Hong Kong ranges from 0.125 m3 to 0.25 m3 per gross floor area. (GFA) [52]. It is simpler to estimate waste in a unit amount/area of activity by using the "Global Index" as an indicator for a particular construction style and for projects of a similar nature in the future. This method can also be used to determine how much building waste is generated locally or nationally. In order to quantify the distribution of construction waste in a place, using a cutting-edge technique. They divided the layouts into four categories—stacked, gathered, scattered, and stockpiled—and then multiplied the expected volume by the estimated unit weight of each form to determine the weight of waste generated. A method for measuring the quantity of various waste products, such as 1 m2 of a partition wall, 1 kg of reinforcing steel, and 1 m3 of concrete [74]. Numerous surveys from various project sites were used to determine the fixed waste factors, along with soft measurement techniques like interviews, questionnaires, and statistical data estimation. Hard measurement techniques, on the other hand, included the Material Flow Analysis Approach (MFA) and sorting and weighing waste materials. Finally, waste quantification models are critical for identifying and reducing building waste production, with waste index calculations and the "Global Index" providing useful insights for efficient waste management. Furthermore, novel methods such as quantifying construction waste layout and developing detailed coded-classification systems can aid in accurately quantifying construction waste and informing future waste management practices [72].

2.6 Prediction of construction waste

Construction waste estimation is important in construction management because it allows project managers to establish effective waste control solutions. To achieve precise predictions regarding the waste produced during a construction project, a comprehensive grasp of the project's scope, materials employed, construction techniques, and potential waste sources becomes essential. This knowledge greatly aids in the effective planning and execution of waste reduction measures. Usually, project managers rely on historical data, such as waste records from prior projects or industry benchmarks, to anticipate the quantity of waste that will be generated. [27]. Moreover, digital tools like Building Information Modelling (BIM) software offer project managers the ability to pinpoint potential waste generation hotspots and optimize construction techniques, leading to waste reduction. Accurate predictions of construction waste amounts empower project managers to implement effective strategies like recycling, repurposing, and landfill diversion. These measures not only decrease the environmental impact but also lead to cost savings associated with waste disposal. [28]. Understanding current waste levels and accurately estimating future waste generation are critical components of waste from construction and demolition management. Although C&D waste output is decreasing in many places, accurate forecasting is still required to plan for waste treatment and recycling capacity. Forecasting C&D waste generation can provide valuable information for refuse disposal choices. Quantifying and forecasting waste is critical for effective trash management and should be investigated further. Future waste generation is inextricably linked to past waste generation because waste output is time-series data [29]. Using the ARIMA model and GRC method, a waste prediction system that relies on time-series can anticipate the generation of waste with a smaller amount of data. Based on the model's predictions, it appears that Sichuan is producing a greater amount of waste in general, but some specific sectors are generating an imbalanced proportion of it [30].

Several techniques are employed to predict and anticipate the generation of construction and demolition waste. Estimating building area, doing material circulation analysis, and utilizing geospatial data management techniques are among these ways. Various methodologies, such as grey models, regression using linearity, and the integrative autoregressive moving average model, are used to forecast waste output. [31]. These methods have been used in numerous studies to calculate and forecast the production of C&D garbage. Researchers have extensively used multiple regression analysis, BP neural network models, and Grey Model prediction methods to anticipate construction waste generation. Construction waste prediction methods are essential for efficient waste management in the construction industry [32]. There are several methods for predicting construction waste, including qualitative and quantitative approaches.

Qualitative methods rely on expert knowledge and experience to identify potential waste sources, such as identifying materials that are likely to generate waste, assessing construction site conditions, and evaluating project plans and specifications. The utilization of these techniques can furnish significant perceptions regarding the production of waste and can advise tactics for reducing waste. Conversely, quantitative approaches apply mathematical models to gauge the amount of waste produced while constructing [31]-[32]. These models can be based on data from previous construction projects or on statistical analysis of factors that affect waste generation. Other methods for predicting construction waste include waste audits, waste tracking systems, and construction waste management plans. By using these methods, construction companies can improve their waste management practices, reduce waste generation, and minimize the environmental impact of their operations [75]-[76].

In the past decade, there has been an increase in the use of machine learning and artificial intelligence (AI) approaches for construction waste prediction. These advanced methods utilize historical data from construction projects to create models facilitating precisely anticipating the amount of waste produced during specific endeavours. By analysing various key factors, including project type, size, location, and materials employed, these models can deliver highly accurate waste predictions. With the aid of machine learning algorithms, construction firms can identify patterns and trends in waste production over time. This valuable insight enables them to pinpoint areas where waste reduction strategies can be most effectively implemented to achieve maximum impact. AI methods can also be used to optimize construction processes to minimize waste generation, such as identifying the most efficient use of materials and reducing over-ordering. Overall, machine learning and AI methods provide a powerful tool for construction companies to reduce waste and improve their sustainability efforts [77]-[78]. The objective of this study was to forecast the yearly increase of C&D waste using three methodologies: quadratic exponential smoothing prediction, the Mann-Kendall trend test, and the building area estimation method. A comprehensive case study was conducted to achieve this aim. The results showed an increase in C&D trash. To forecast building end-of-life values and evaluate recoverable materials during the demolition stage, a machine learning algorithm was also developed. [79]-[80] The random forest and decision tree methods were used in the model, which was appropriate for a smaller dataset with categorical data. The use of these machine learning algorithms can help to enhance waste management systems and make accurate predictions about the production of construction waste. In general, accurate measurement and forecasting of C&D garbage generation are essential for efficient waste management. A number of techniques, such as time-series waste prediction frameworks, estimation and prediction techniques, and Machine learning algorithms have the ability to make predictions and projections about the production of construction and demolition waste. Figure 2.5 shows the typical Structure of the decision tree (DT) algorithm [28][29][82].

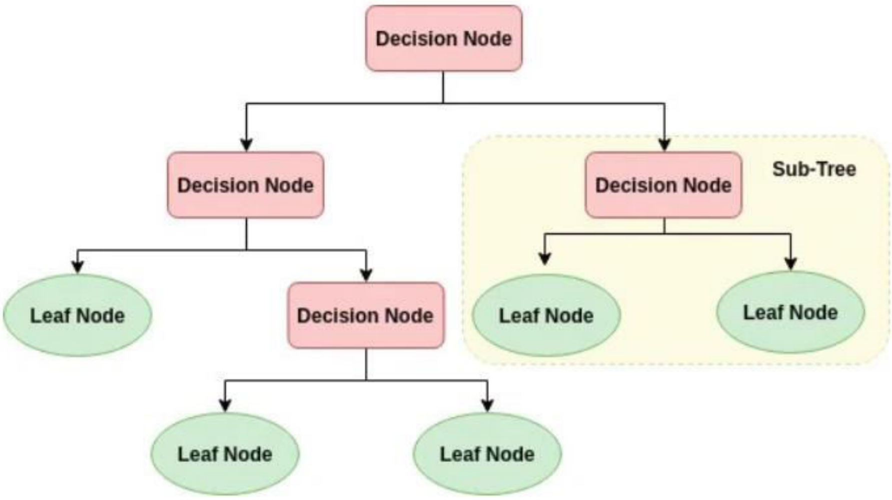


Figure 2.5: Structure of the decision tree (DT) algorithm

Several models, such as the neural network model known as BP network and the grey model prediction technique, are utilized to forecast the amount of waste produced. The former needs a large amount of data, whereas the latter depends on known data to generate a regular time series for prediction. Depending on the amount of data used for prediction, waste prediction models can be classified as macro or micro models. A few models that are frequently used are linear and regression models, S-curve and Artificial Neural Network models, waste design, and Big Data framework. Research has indicated that for GIS-based prediction models, it is necessary to have comprehensive data collection, with a greater emphasis on mid- and long-term forecasts. Accurately and efficiently estimating the production of Construction waste is crucial. This can be achieved by harnessing open data from statistical departments and creating practical prediction models to promote the optimal utilization of waste resources. Furthermore, there have been suggestions to leverage artificial intelligence and machine learning technologies for forecasting waste production. [27][31][32][75][76].

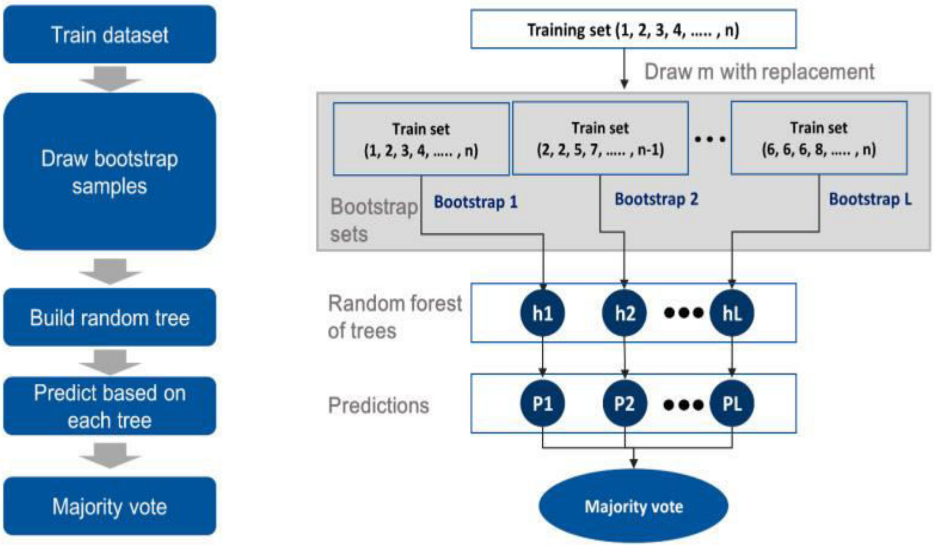


Figure 2.6: Structure of the random forest (RF) algorithm

The diagram above illustrates the typical framework of the random forest method, commonly employed for waste forecasting. When predicting C&D waste production, numerous studies have utilized machine learning models optimized for continuous data inputs. These models encompass adaptive neuro-fuzzy reasoning systems, support vector machines, decision trees, linear regression analysis, and artificial neural networks. However, when dealing with categorical data, these algorithms may not yield optimal results. Therefore, most approaches to predict C&D waste involve employing machine learning and statistical analysis techniques such as adaptive neuro-fuzzy inference systems, ANNs, SVMs, DTs, LR analysis, and GAs. Incorporating historical data, Algorithms based on machine learning can be programmed to recognize trends and anticipate future construction waste. For instance, decision trees, random forests, and neural networks can be used to forecast the quantity of waste produced based on factors such as project type, location, and construction materials used. Text data from construction documents and contracts can be analysed using Natural Language Processing approaches for identifying potential waste sources and estimating the quantity of debris that will be generated. This can help construction companies to optimize their waste management strategies [28][29][83]. By utilizing computer vision methods, it is possible to examine pictures and videos captured at construction sites in order to recognize discarded materials and make an approximation of the amount of waste produced. This can help construction companies to identify areas where waste reduction measures can be implemented. Internet of Things devices such as sensors can be deployed at construction sites to collect data on waste generation and monitor waste disposal practices. This data can be analysed using ML algorithms to identify trends and patterns that can be used to optimize waste management strategies. Forecasting the quantity of waste produced can be accomplished through the application of predictive analytics methods that consider different factors like construction activities, project schedules, and weather patterns. This can help construction companies to plan their waste management activities more effectively.

The burgeoning field of sustainable construction has increasingly turned to machine learning (ML) techniques to address the challenges associated with the prediction and management of construction waste. This literature explores and consolidate the existing knowledge on the potential applications of ML in enhancing sustainability within the construction industry. Various studies have demonstrated the efficacy of ML algorithms in predicting construction waste generation by analysing historical data, project specifications, and other relevant variables. Employed machine learning models to forecast construction waste generation based on project characteristics, highlighting the ability of these models to provide accurate estimates [95]. Additionally, Jones and Wang conducted a comparative analysis of different ML algorithms for predicting construction waste, emphasizing the versatility of these tools in adapting to various project scenarios [96]. Furthermore, the literature reveals the effectiveness of ML in optimizing waste management processes and resource allocation. Recent research by Chen and Li investigated the integration of ML algorithms into construction waste management systems, demonstrating improvements in efficiency and cost-effectiveness [97]. The potential of ML-based decision support systems in dynamically adjusting waste management strategies based on real-time data [98].

2.7 Research Gap Identified

1. To avoid high costs for both the client and contractor during all stages of construction, it is important to optimize resources and minimize waste throughout the construction project.
2. Extensive research has been conducted to identify alternative techniques that are necessary for environmental values, cost minimization, and waste detection, and which can be properly evaluated in a prescribed way.
3. Despite the availability of construction waste review and examination techniques, there is still a gap in accurately quantifying and predicting material waste, identifying its source, and incorporating sustainability principles into decision-making processes to reduce waste throughout an infrastructure construction project.
4. To address this gap, assessment methods must be updated thoroughly to create an efficient model for quantifying and identifying waste sources that incorporates sustainable development principles for waste reduction at the source into the decision-making process. Early prediction of waste during the planning stage can provide a superior solution for waste reduction.

2.8 Summary

In conclusion, to handle the generation of construction waste effectively, a thorough plan for managing waste is needed, which should include strategies for reducing, reusing, and recycling waste. By embracing sustainable practices, construction firms can reduce the ecological footprint of their operations, conserve natural resources, and reduce expenses related to waste management. Waste produced during construction arises at various stages of the process, beginning with the planning phase and ending with the final stage. The production of such waste has numerous underlying factors, and recognizing these factors is crucial to managing the quantity of waste produced. To minimize the amount of waste generated, it becomes crucial to tackle the root causes. Determining the quantity of construction waste will be influenced by factors like project scale, complexity, waste characteristics, and available resources. Employing a mix of techniques can yield precise data on waste generation, enabling the development of effective waste management strategies. In this regard, machine learning and AI techniques emerge as potent tools for construction companies to enhance sustainability by curbing waste and improving their eco-friendly practices.

CHAPTER - 3

WASTE MANAGEMENT PRACTICES IN CONSTRUCTION INDUSTRY

3.1 General

Building and construction work contributes significantly to worldwide trash generation, with considerable amounts of building and demolition waste produced yearly. Therefore, the effective management of construction waste has become increasingly important. The upcoming section will centre on the management of waste within the construction sector. It will cover various methods to reduce waste production, ways to sort and recycle waste, and the proper handling and disposal of dangerous substances. The chapter will also examine the benefits of sustainable waste management practices, such as reduced environmental impact, cost savings, and improved public health and safety. Moreover, examples of effective waste management methods in the construction sector will be showcased through case studies, demonstrating optimal strategies and creative solutions for minimizing waste and handling it efficiently.

Practices in construction Industry

Construction projects often underestimate the true cost of waste, as the expenses for materials and labour can exceed Rs.1,30000/tonne. Research shows that about 13% of acquired raw materials are unused and discarded, which presents an opportunity to improve purchasing efficiency by reducing waste and promoting reuse. To manage and monitor waste during the various stages of a construction site, careful planning and understanding of how waste occurs are essential [1]-[3] Waste management strategies should be customized to suit the site and construction phase. Efficient management of construction processes to minimize waste through reduction, reuse, recycling, and proper disposal can significantly impact the final price, standard, time, and ecological impact of the project. While infrastructure development has led to significant environmental implications globally, sustainable construction aims to balance the natural and built environments by implementing various waste management strategies [5][6][9]. This involves effectively using construction resources to minimize waste and maximize their potential rather than just disposing of them. The benefits of sustainable construction include reducing the impact on the environment. The primary objective of implementing a strategy for managing construction waste is to minimize the amount of materials generated by construction that end up being disposed of in landfills. This is achieved by diverting waste such as demolition debris, land clearing debris, and construction waste away from landfills, and instead, recycling materials that can be reused back into the manufacturing process or taking reusable materials to appropriate locations. In order to achieve efficient waste management, it is crucial to integrate a waste management plan right from the project's outset and maintain regular progress reports. The plan should encompass a comprehensive strategy to attain the desired recycling rate, involving the identification of specific materials earmarked for recycling or salvage, cost estimations comparing recycling and disposal fees, clear specifications for material handling, and a well-defined communication approach to disseminate the plan among the crew and subcontractors. [7][8][10]. The waste management plan recognizes waste management's crucial role in materials management and highlights the potential for waste from one project to become a valuable resource for another, thereby promoting an efficient waste management process. Integrating waste management in the preconstruction phase and consistently addressing it in job meetings are essential to ensure contractors and subcontractors fully comprehend the impact of these guidelines on their work from the beginning to the end of the construction process.

3.2 Methodology

To uncover the practices used in the construction and infrastructural industries, a framework depicted in Figure 3.1 was employed in this study. The method employed a comprehensive analysis of existing literature and a thorough investigation of ongoing construction projects to pinpoint exemplary practices that contribute positively to the industry, environment, and socio-economic aspects. Additionally, the study sought to identify areas that require more attention to reduce negative impacts on various elements. In Figure 3.1, the research methodology is depicted, comprising a comprehensive approach involving literature surveys, site visits, and structured interviews with stakeholders. The objective was to assess the construction industry's current practices in managing building construction material waste, covering all stages of the construction process, from planning and design to procurement, logistics, handling, subcontracting, and waste control. By employing these techniques, the research team identified challenging areas and highlighted effective waste management practices. Real-time construction projects were studied as case examples to examine various practices utilized on construction sites, specifically focusing on identifying processes and management techniques to control construction material waste. To achieve this, a combination of research methods was utilized, and the study evaluated the significance of material management and waste control in reducing project costs and duration. The parameters investigated were analysed, and the results were discussed and interpreted, leading to conclusions and recommendations.

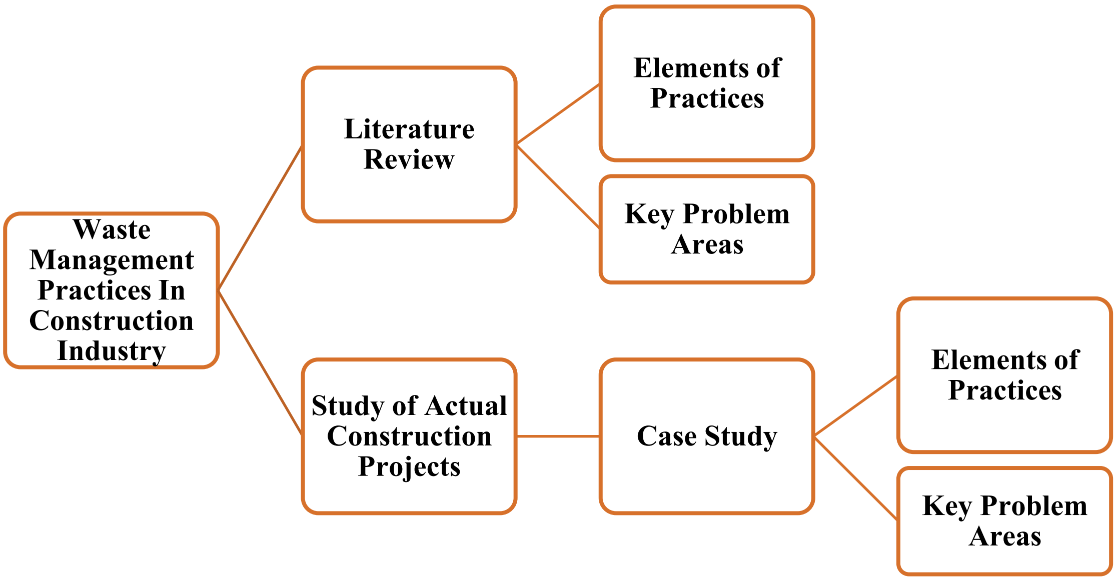


Figure 3.1: Methodology Flow Chart for Identification of Elements of Practices

3.3 Elements of good practices

The proper management of construction waste is crucial for the sustainable development of the construction industry. To achieve this, it is essential to adopt effective practices that focus on waste reduction, material recycling, and reusing, while minimizing landfill disposal. A pivotal component of these practices involves developing a comprehensive waste management plan that outlines specific strategies for waste reduction throughout the construction process. The waste management plan should encompass defined waste reduction targets, guidelines for waste segregation, options for recycling and reusing materials, and clearly assigned responsibilities for waste management.

Implementation of this plan requires the utilization of appropriate technologies and equipment for efficient sorting, transportation, and disposal of waste. However, several key concerns exist regarding construction waste management. One of the major concerns is the lack of awareness and inadequate education on waste reduction among stakeholders in the construction industry. Inadequate planning and coordination among stakeholders, as well as insufficient funding and inadequate enforcement of regulations, also contribute to poor waste management practices [12]. Another concern is the disposal of hazardous waste, which necessitates unique handling and disposal techniques in order to avoid damaging the environment and public health hazards. Finally, the lack of suitable infrastructure for waste management, including collection and disposal facilities, poses a significant challenge to effective construction waste management. Addressing these concerns requires a collaborative effort among stakeholders in the construction industry, waste management service providers, and government agencies to develop and implement effective waste management strategies. Figure 3.2 displays the elements of good practices adopted in construction industry for the curtailment of waste.

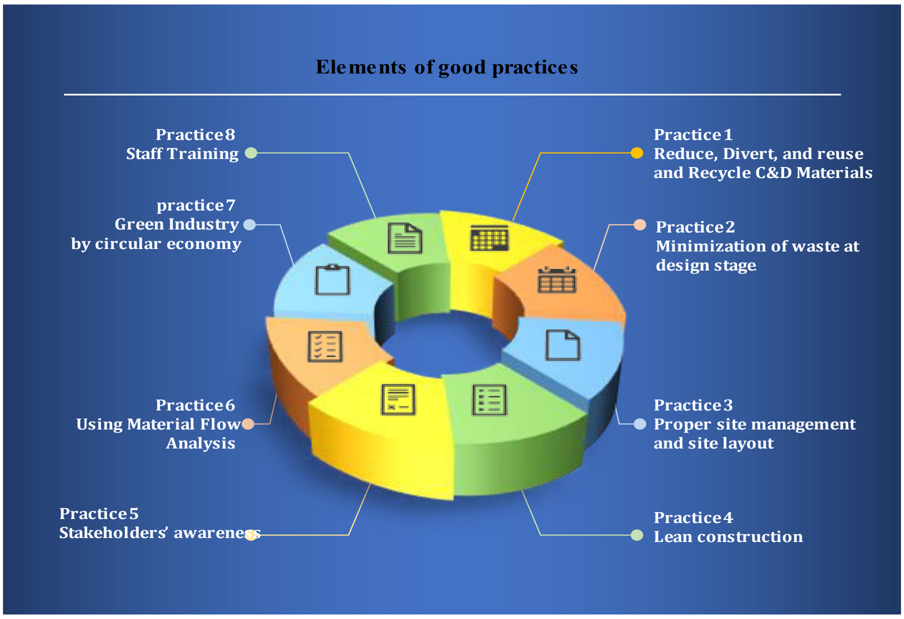


Figure 3.2: Elements of good practices

This approach includes evaluating a product throughout its entire lifecycle, not just the sum of its parts, to determine the balance of materials and energy used or discharged. Additionally, source reduction involves eliminating products that become waste after use. In the construction industry, source reduction of construction waste is essential for sustainability. Financial rewards are critical in deciding whether to execute this method, but few studies have examined the economic advantages and disadvantages of building waste source reduction from a system-wide changing standpoint. [86][89]. Figure 3.3 portray the priority and strategies set for the minimization of construction waste at site.

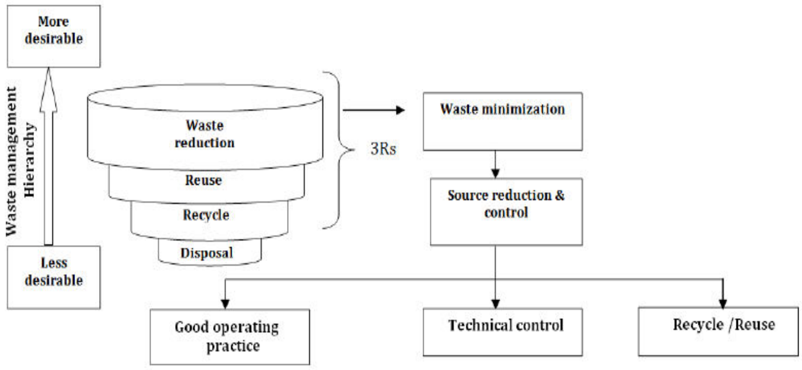


Figure 3.3: Waste minimization priority and strategies (Source: Shadi Kafi Mallak et al., 2015)

i. Divert and Reuse

The concept of reuse techniques involves utilizing materials again in their original application or in a lower-grade application when waste reduction is not possible or inevitable. In construction, there are various reusable and unused materials such as lumber, piping, plywood, and asphalt shingles. Utilizing these materials, which would otherwise be discarded as waste, brings about numerous advantages in social, economic, and environmental aspects. In renovation endeavours, it is possible to repurpose building materials, while raw construction materials can be effectively reused as valuable resources. This can provide potential value and contribute to the development of future projects while conserving natural resources [16]. Deconstruction is a method that can be used to salvage usable materials and reduce waste. The reuse of building materials is an increasingly important area of focus in many regions [33].

The building material waste management area is currently examining practices and trends from a cradle to reincarnation perspective, focusing on the building's entire life cycle [90]. The approach entails the incorporation of diverse strategies, including zero waste, integrated reusing, international cooperation, material reuse, resource optimization, waste reduction, and deconstruction. Adhering to the waste management hierarchy and thoroughly assessing the life cycle management of materials allows for the identification and comprehension of opportunities for reuse. Developing a comprehensive waste management plan for a particular project necessitates the consideration of cost, economic, social, and environmental factors. [85]. Reuse is considered an essential component of waste reduction efforts, and it is preferable to reduce and reuse before resorting to recycling. Reuse is different from recycling and involves keeping materials out of the waste stream by passing them on to others [34]. This approach promotes the well-being of local communities and social programs while offering tax benefits and reduced disposal fees to businesses that donate. The act of reusing serves as a vital strategy to prevent the accumulation of solid waste in landfills, leading to positive impacts on communities and fostering the overall well-being of citizens by facilitating access to useful items discarded by others and distributing them to those in need. In Figure 3.4, the plan for implementing waste material reuse at different stages of a construction project is illustrated. [7][11].

PLAN TO RE-USE CONSTRUCTION WASTE

Plan for Reuse of Construction Waste material Generated at Various Stages of construction projects.

1 Mapping the resource flow and waste generation.

2 Identifying the areas for growth and increase the balance between materials and waste management facilities

3 Preparing the Reuse strategies for the generated waste from the various stages of construction project

4 Implementation of suitable strategies to reuse the generated waste through certain activities at different phases of project

Figure 3.4: Reuse plan for waste material

ii. Recycle

One of the most commonly used techniques for reducing construction waste is recycling, which can be applied to many types of construction materials. This method is widely trusted and has been widely adopted in developed countries. Recycling involves reprocessing discarded materials into new materials or for new uses. According to solid waste management practices, recyclable materials are those that can be discarded but can undergo physical or chemical reprocessing and be reused [33]. Construction debris like concrete and rubble can be effectively recycled and transformed into useful aggregate and concrete products. Furthermore, wood from building components can be recycled to make engineered wood items like furniture. Furthermore, metals such as aluminium, copper, steel, and metal have high recyclability. [42]. Soil, stones, bricks, blocks, gypsum wallboard, concrete, steel, glass, plaster, lumber, shingles, plumbing, asphalt roofing, heating and electrical components are all common components of garbage. The effectiveness of recycling C&D waste hinges on several critical factors, encompassing regulatory policies, Specifications for contracts, economics, technological advances, and project management practices.

Besides disposal costs, multiple other factors contribute to the increasing enthusiasm for C&D waste recycling. One of these reasons is the decreasing availability of high-quality resources for building materials, which can be found at great distances from building projects, leading to increased transportation costs [11][34][35].

The rising cost of virgin materials used in building materials is also a motivation for recycling materials. The recycling process involves sorting the debris according to a hierarchy to achieve optimal results. The variability in the supply of recyclable materials and project-related barriers, such as economic and time constraints, are significant challenges to increasing C&D recycling [18]. To encourage contractors and waste processors to increase recycling, there are both direct and indirect incentives, which involve implementing strategies that directly contribute to achieving recycling goals. The project manager should also take into account the optimal management approach to maximize recycling in the project. This is crucial because the advantages of enhanced C&D recycling might not be immediately evident to the contractor. Figure 3.5 depicts the waste recycling action plan for the reduction of construction waste.

Figure 3.5: waste recycling action plan

iii. Recovery

Construction and demolition waste contains numerous valuable materials that can be reused, including bitumen, metals, wood, mineral wool, brick, concrete, cardboard, and reusable aggregates. These materials can either be sold directly or used in the production of new products, construction materials, or for energy generation. Ideally, this waste should be processed near the demolition site so that it can be continuously used for new roads, buildings, bridges, and urban landscape. Recovering as much material as possible from construction and demolition waste not only saves waste management costs but also reduces the expense of disposing of heavy and bulky waste in landfills or storage [19]. An alternative approach to landfilling involves harnessing the energy from residual materials by utilizing them as fuel for manufacturing processes or energy production equipment. A range of mechanical, biological, and caloric systems and technologies exist to convert, reprocess, or decompose waste into either new materials or usable energy. [35]. Figure 3.6 represent the Materials resource efficiency flow for the efficient recovery of waste materials.

Figure 3.6: Materials resource efficiency as part of sustainable construction. (Source: (WRAP (b), 2009))

B. Minimization of waste at design stage

The amount of waste generated can be significantly decreased by ensuring accurate design practices are employed during the initial stages of a project. Standardizing design can further decrease the number of off-cuts and enhance buildability. Incorporating design standardization in architectural and structural works can lower costs and reduce waste. Effective waste minimization is a crucial sustainable strategy for managing construction waste, and it is best achieved by reducing waste generation before it occurs [13]. Waste reduction plays a vital role in the construction process, with special emphasis on the planning phase due to its influence on crucial decisions. The choices made during project planning and design profoundly affect the amount of construction waste generated throughout the project's life cycle. Notably, the design stage holds immense significance, as decisions regarding building form, size, complexity, and materials can have a substantial impact on minimizing waste. By being mindful during the design process, waste can be minimized through rethinking before action is taken, refusing redundant waste, reusing potential waste, and preventing waste generation. Poor documentation of designs has also been linked to reworks and subsequent waste generation. [91] Emphasized the significance of adequate design documentation in decreasing construction waste. Despite this acknowledgment, methods for enhancing waste efficiency in design documents have not been explored thoroughly. Consequently, there is a pressing need to investigate and comprehend how design and its documentation can be optimized to effectively minimize construction waste [91].

C. Proper site management and site layout

Effective management of a construction site is essential for improving waste classification. Appropriate garbage skips can be given to minimise waste generation by properly forecasting the sorts of waste materials created at each step of the project. Precise planning of the site layout can also minimize the need to handle materials repeatedly, resulting in a reduction in waste. In addition, a tidy site layout enables proper stacking, storage, and transportation of valuable materials [4]. Proper site management and site layout play a crucial role in reducing construction waste. An effective site management plan should include measures for reducing waste throughout the construction process, from procurement to disposal. One way to minimize waste is by carefully planning the site layout to ensure efficient use of materials and equipment [7]. This can include setting up designated areas for storing and sorting waste, implementing recycling and reuse programs, and using materials that are easily recyclable or biodegradable. Proper site management can also involve training workers to be mindful of waste reduction and encouraging them to follow waste management procedures. By implementing these strategies, construction companies can significantly reduce the amount of waste generated on construction sites, resulting in cost savings, environmental benefits, and a more sustainable construction industry.

D. Lean construction

To "lean" means to increase value while using fewer resources, eliminating any non-value-adding activities. In construction, the "lean" approach involves minimizing the amount of materials stored on site for extended periods to reduce the risk of damage. Instead, materials are ordered and delivered in precise quantities and as close to the start of the work as possible. This technique reduces waste, improves productivity, and creates a safer working environment by minimizing the handling and storage of excess materials and avoiding damage due to weather and site limitations. Overall, lean construction is a recommended approach for material procurement that differs from conventional methods and delivers significant benefits [44].

The concept of Lean production revolves around eliminating non-value steps and enhancing valuable ones to enhance manufacturing design, supply, and assembly. A similar technique, known as Lean construction, concentrates on minimizing waste in materials, time, and effort while maximizing value with limited inputs like labor, machinery, and space. The main objective of Lean Construction is to reduce waste and optimize value by simultaneously designing construction facilities and processes. Accordingly, materials are made available on-site only when they are needed, avoiding unnecessary stockpiling. [45]. The adoption of Lean Construction in the construction process has numerous benefits, such as reducing costs by using precise materials and minimizing waste generation, shortening construction time through proper strategic planning, and enhancing productivity, profitability, and client satisfaction. The lean building concept also emphasises the two major kinds of construction process waste caused by the nature of operations and waste caused by tasks that do not add value.

E. Stakeholders' awareness

Proper knowledge and awareness of material waste generation and management among all stakeholders associated with a construction project are crucial in minimizing waste generation at every stage of the construction process. Nevertheless, the attainment of an integrated understanding concerning stakeholders' involvement in the project can only be realized during the project's implementation phase. It falls upon the project manager to foster this integrated understanding by ensuring that all stakeholders grasp the various project processes and the essential characteristics of the project's final product. Efficient management of stakeholder awareness is imperative, and it is crucial to identify those stakeholders whose awareness management will expedite the process of creating a cohesive understanding. To implement such management, the object to be influenced must be identified. In this case, it is the stakeholders' awareness of the project and product. The figure 3.7 shows the Stakeholder Engagement at various phases of the construction projects.

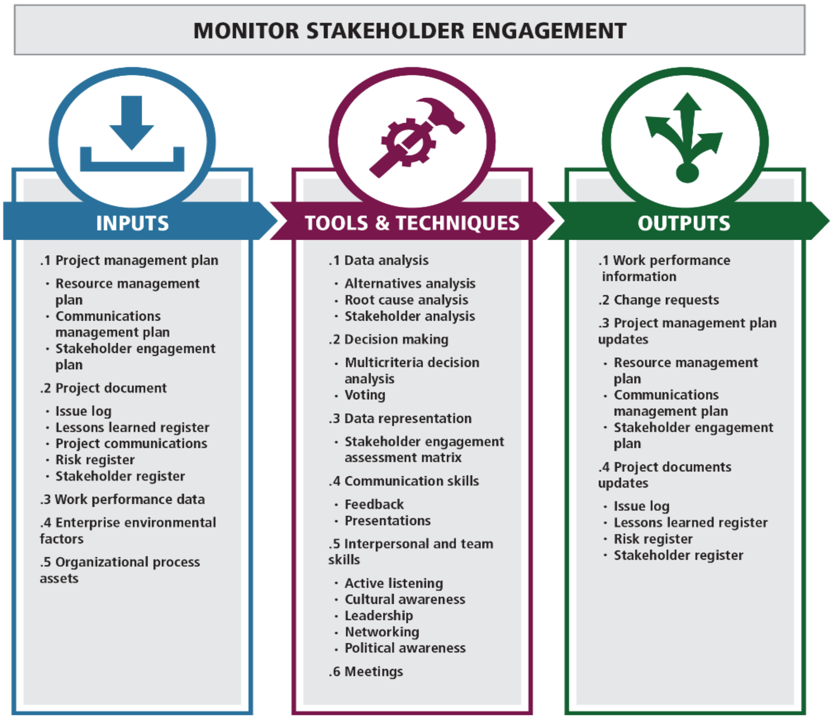


Figure 3.7: Stakeholder Engagement

F. Material Flow Analysis

Material flow analysis (MFA) is a methodical evaluation of the movement and distribution of materials within a specific system, considering both space and time. It establishes connections between the origins, pathways, and eventual disposal of these materials. Depending on the aim of the research, the level of detail in the model of the system may vary. An MFA system is always composed of a system boundary, one or more processes, material flows that occur between processes, and the stocks of materials present in these processes [38]. The analysis of the movement of materials through processes, such as extraction or harvest, chemical conversion, production, consumption, recycling, and disposal, is known as MFA. This technique is increasingly being used for waste management and recycling system planning. MFA quantifies both the quantities and stocks of substances and energy within a system. The prevalent topics in waste management are related to water and sewage management, waste reduction, energy conservation, and greenhouse gas emissions [39] Material flow analysis (MFA) is increasingly used to estimate and represent material flows, and it has become a mandatory tool for national and international policies. However, there is still potential for further expansion and integration of MFA in waste management. Integrated MFA and life cycle assessment (LCA) is recommended for decision-making in waste management systems [40]. MFA is helpful in analyzing and managing waste, secondary products, and residues by understanding the functioning and connections between processes. Environmental assessments of waste management should be based on the flows described by MFA to provide transparent information for decision-making. Urban metabolism research primarily employs three accounting methods: MFA, energy analysis, and the environmental impact approach are all examples of material flow analysis. MFA entails tracking all material flows, including input, storage, transformation, and output activities. It centres on classifying these flows and creating a balance sheet that effectively encompasses all material movements.

G. Green Industry by circular economy

The core principle of the circular economy is the seamless integration of cleaner production and industrial ecology within a comprehensive framework that encompasses industrial enterprises, interconnected chains of companies, eco-industrial parks, and regional infrastructure. This comprehensive approach aims to promote resource efficiencies [47]. To achieve this, the adoption of innovative products like renewable energy and recycling technologies is crucial, as they enhance the efficiency of conventional industries and supply chains. Implementing the circular economy has proven effective across various sectors, leading to optimized resource and energy utilization, reduced waste, and minimized environmental impacts in product cycles. Moreover, it opens up potential economic opportunities [48]. Though the construction industry holds significant potential for embracing the circular economy, the process is challenging and necessitates substantial changes in the industry's structure and societal practices, particularly in waste management and business operations [49]. Currently, much of the research in this area focuses on recovery options and specific circular principles, but there is a pressing need for integrative approaches that encompass circular economy strategies throughout the entire lifecycle of construction and demolition products. Figure 3.8 illustrates the widely adopted concept of circular economy by firms, aiming to reduce waste costs and mitigate environmental deterioration [50].

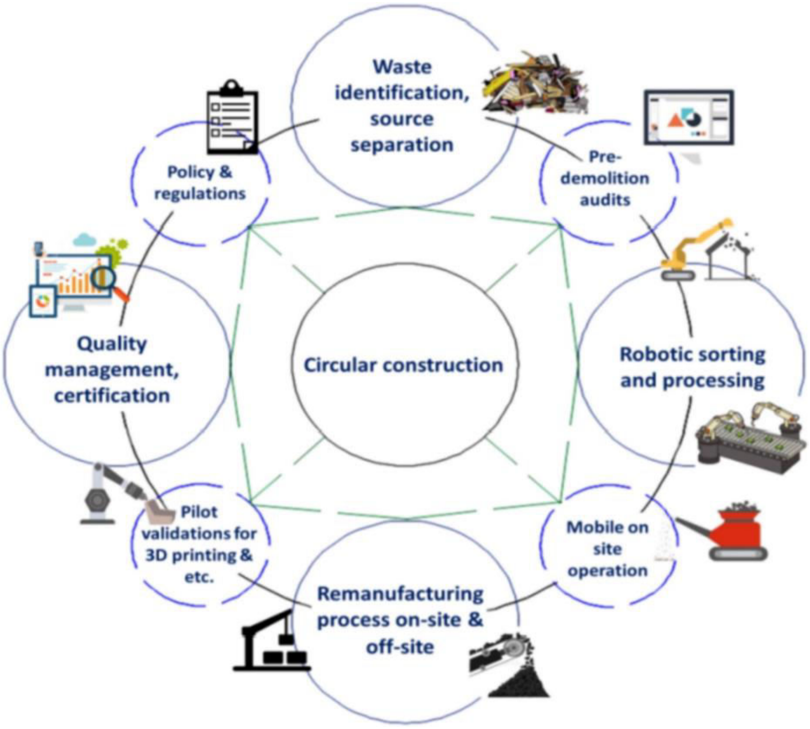


Figure 3.8: Concept of Circular Economy (Source: Seyed Hamidreza Ghaffar et al. 2020)

Construction waste management plays a crucial role in promoting sustainable construction practices, emphasizing the need for effective strategies to identify, quantify, and manage waste generated during construction projects. A key component of this process is the construction waste audit, which involves systematic data collection, analysis, and the development of strategies to minimize waste generation[6][14]. The study comprehensive overview various methodologies employed in conducting construction waste audits. One approach is On-Site Waste Sorting and Weighing, where construction waste is physically sorted and weighed at the construction site. Different materials, such as concrete, wood, metal, and plastic, are categorized and weighed using scales or other measuring devices. This method offers real-time data on the types and quantities of waste, facilitating prompt decision-making on waste reduction strategies. Quantitative Surveys and Sampling is another methodology that employs quantitative surveys and sampling techniques to estimate the composition and volume of construction waste. Random or systematic sampling is conducted to represent various areas of the construction site, and the collected data is extrapolated to estimate overall waste generation. This method proves efficient for large construction sites where on-site sorting may be challenging. The use of Waste Tracking Software and Technology represents a modern approach to construction waste audits. Here, waste tracking software and sensors are utilized to monitor and record waste generation in real-time throughout the construction process. The collected data can be analyzed to identify patterns, assess the effectiveness of waste management practices, and make informed decisions to optimize waste reduction efforts.[21][24][25]. Life Cycle Assessment (LCA) is a holistic methodology that involves analyzing the environmental impact of construction materials and processes throughout their life cycle, from extraction to disposal. By conducting LCAs, construction professionals can pinpoint the stages of the construction process that contribute most to environmental degradation. This comprehensive approach aids in designing more sustainable construction practices and reducing overall waste generation. In summary, these methodologies collectively contribute to a better understanding of construction waste, enabling the implementation of targeted measures for sustainable and responsible construction practices.[38]

3.4Key Problem Areas

A. Material contamination and Heterogeneity in waste materials

The varying level of the contamination as well as a larger degree of heterogeneity in the material waste complicate the process of recycling. The contamination in the material is observed due to the careless approach before disposing. The higher contaminated materials cannot be reused or diverted. Material contamination and heterogeneity are two important factors that can complicate waste management processes [18]. Material contamination and heterogeneity are also important factors that can impact the management of construction waste materials. Material contamination in construction waste can come from various sources, such as hazardous materials used during construction, discarded household items, and waste from adjacent sites. This can make it challenging to properly sort and dispose of construction waste, and can also pose safety risks for workers [15]. Contaminants such as asbestos, lead, and mercury require special handling to prevent their release into the environment and minimize exposure risks.

Heterogeneity in construction waste materials can arise from a range of factors, such as variations in building design and construction methods, as well as differences in the type and quality of materials used. This can make it difficult to develop effective waste management strategies, particularly for processes that require consistent and uniform feedstocks. The presence of heterogeneous materials can affect the quality and performance of recycled construction materials, leading to lower market demand and reduced economic value. To address these challenges, strategies such as improved waste segregation and source separation, enhanced training for workers and contractors, and the use of advanced sorting and processing technologies can be employed. Construction and demolition waste management plans can also be developed to help ensure that waste is properly managed throughout the construction process, from demolition through final disposal or recycling. Effective waste management strategies can help minimize the environmental impact of construction activities and support sustainable development practices.

B. Perception towards construction waste

It is one of the prominent reasons for the improper waste minimization. Practitioners in construction industry due to lack of understanding fail to understand the core concept of waste minimization, which probably lead to ineffective west minimization measures. The consequences of the poor perception towards the waste material have resulted in many cases of waste during the various stages in construction project. There are many misconceptions and improper perceptions about construction waste that can hinder effective waste management practices [59]. Some people may view construction waste as insignificant or inconsequential compared to other types of waste, leading to a lack of attention or resources devoted to managing it properly. Others may view construction waste as a necessary by-product of development and construction, failing to recognize the negative environmental impacts it can have if not properly handled. Additionally, some may assume that construction waste is inherently unrecyclable or unsalvageable, leading to low rates of diversion and high levels of landfill disposal [58].

This can be due to a lack of awareness or understanding about the types of materials that can be recycled or repurposed, as well as the technologies and processes that can enable their recovery. To overcome these improper perceptions, it is important to raise awareness about the environmental impact of construction waste and the benefits of effective waste management practices. Education and outreach efforts can help to increase public awareness about the types of materials that can be recycled or repurposed, as well as the importance of reducing waste generation through sustainable design and construction practices. Policy and regulatory measures can also play a significant role in improving the perception and management of construction waste [53]. For example, governments can establish mandatory waste diversion targets and incentivize sustainable construction practices, such as through tax credits or other financial incentives. By addressing improper perceptions and taking a comprehensive approach to construction waste management, we can reduce the environmental impact of construction activities and promote a more sustainable future.

C. Insufficient Knowledge and Training

The insufficient or inappropriate knowledge possessed by the stakeholders is one of the major barriers for the implementations of waste management strategies. Poorly trained or insufficiently trained person generally poses higher risk of generating the material waste from his working domain. Insufficient operator skills can lead to inadequate waste control. A proficiently trained operator, in contrast to a semi-skilled worker, will exhibit superior daily productivity. The importance of workmanship cannot be overstated as it significantly influences the final results. Throughout every stage of construction, careful attention must be given to workmanship allocation, since waste can arise at any point in the process, be it during the design, construction, or operation stages. Insufficient knowledge and training of construction stakeholders, including contractors, architects, engineers, and workers, can also hinder effective construction waste management. Without proper education and training, stakeholders may not be aware of the types of materials that can be recycled or repurposed, the hazards associated with certain waste streams, or the proper procedures for handling and disposing of waste [59].

This can lead to improper waste disposal practices, such as mixing hazardous and non-hazardous waste or improperly disposing of waste in landfills, which can have negative environmental impacts. Furthermore, investors may be unaware of the financial advantages of reducing waste and recycling, resulting in missed chances for savings in expenses and income generation. To address this issue, it is important to provide comprehensive education and training programs for construction stakeholders. These programs can include information on waste management best practices, hazard identification and mitigation, and the economic and environmental benefits of sustainable waste management practices. Training can also include practical skills such as waste segregation, recycling, and proper handling and disposal procedures. By investing in education and training for construction stakeholders, We can enhance waste management knowledge and awareness while also promoting a culture of sustainability in the building business. This can lead to improved waste diversion rates, reduced environmental impact, and increased economic benefits for stakeholders.

D. Laws and regulations

The one of the prominent obstacles in implying the waste management strategy in construction projects are insufficiency in regulations. The government authorities and agencies are very vital to monitor the construction waste management for the projects, considering its environmental impact and other relevant consequences. Nonetheless, the lack of government intervention in enforcing waste management laws has resulted in a standstill when it comes to adopting waste minimization practices. Inadequate laws and regulations concerning construction waste may give rise to numerous adverse outcomes, impacting both the environment and human health. The following are some of the potential issues that may emerge:

Increased pollution: Construction waste can contain hazardous materials, such as lead, asbestos, and chemicals. Improper laws and regulations can lead to improper disposal or handling of these materials, which can contaminate soil, air, and water, leading to health problems for people and animals.

Illegal dumping: When laws and regulations are weak, some construction companies may choose to illegally dump their waste in unauthorized locations. This can lead to eyesores, damage to natural habitats, and increased pollution.

Inefficient use of resources: When there are no clear guidelines on how to manage construction waste, it can lead to inefficiencies in resource use. For example, reusable materials that could be recycled or repurposed may end up in landfills.

Increased costs: Inefficient waste management practices can increase the costs of construction projects. Proper laws and regulations can help to ensure that waste is managed in an environmentally responsible and cost-effective way.

Negative impact on communities: Improperly managed construction waste can lead to negative impacts on nearby communities, including health problems, decreased property values, and reduced quality of life.

To avoid these negative consequences, it is important to have clear and enforceable laws and regulations in place to govern the management of construction waste. This can include requirements for proper disposal and recycling, as well as penalties for illegal dumping or other violations. Additionally, proper education and training for construction companies and workers can help to ensure that waste is managed in a safe and sustainable manner.

There are several barriers that can hinder the implementation of laws and regulations for construction waste management, including:

1. Lack of political will: Political leaders may not prioritize the issue of construction waste management, leading to a lack of support for new laws and regulations.
2. Resistance from industry: The construction industry may resist new laws and regulations that impose additional costs or require changes to their current practices.
3. Insufficient funding: Implementation of new laws and regulations may require significant financial resources, and without sufficient funding, it may be difficult to enforce compliance.
4. Lack of public awareness: A lot of individuals may be unaware of the significance of good construction waste management or the severe consequences of improper trash disposal. This can make gaining public approval for new laws and regulations challenging.
5. Inadequate infrastructure: Effective construction waste management requires infrastructure such as waste collection systems, recycling facilities, and disposal sites. In some areas, this infrastructure may be inadequate, making it difficult to implement and enforce new laws and regulations.
6. Limited enforcement capacity: Even if new laws and regulations are in place, there may be a lack of resources or capacity to enforce them effectively.
7. Complex regulatory frameworks: Complex regulatory frameworks can make it difficult for industry and other stakeholders to understand and comply with new laws and regulations. This can lead to confusion and non-compliance.

3.5 Case Study

3.5.1 General

The purpose of this case study is to assess the current methods for handling building materials inside the investigation zones. To achieve this, the study utilizes a structured questionnaire and personal interviews as the main methods of data collection. The structured questionnaire is a well-established and commonly employed approach for gathering information related to facts, opinions, and viewpoints. Its versatility makes it suitable for both descriptive and analytical surveys. Some of the key advantages associated with using this method include ensuring confidentiality, supporting internal and external validity, facilitating ease of analysis, and optimizing resource efficiency. The data in this study is obtained from a standardized sample of the population, allowing researchers to make statistical inferences, often aided by computers. However, using a questionnaire does have its limitations, such as the need for straightforward questions, lack of control over respondents, and the possibility of receiving generalized responses. The study's focus is confined to contracting companies categorized as first, second, and third degrees and registered in PCU (Prescribed Contractors' Union). Third-party suppliers and contracting firms in both the fourth and fifth classifications are left out due to their lesser size and lack of appropriate management of materials mechanisms.

3.5.2 Data Collection and Questionnaire Design

The case investigation collected data using a variety of methodologies, involving observing, recordings, interviews, and analysis of documentation. A well-designed questionnaire was crucial in achieving reliable results and a high response rate. The questionnaire was separated into two parts: Survey I, consisting of objective questions, and Survey II, consisting of subjective questions. The questions in the questionnaire were formulated based on three sources: a literature review, 18 interviews with contractors and managerial personnel to gather diverse perspectives, and the researcher's and engineers' experiences in construction management. Sample questionnaire is attached in Appendix-I. The poll was created primarily with closed questions and was separated into four different parts, which are as follows:

i) Section one: 07 elements are included in the organization's profile.

ii) Section two: 25 things are included in the implementation of construction materials management tools and procedures in building projects.

iii) Section three: The effects and the causes of waste and cost variance includes 03 items

iv) Section four: main hurdles and benefits in construction materials and waste management systems, which comprises two elements.

For the dissertation, a group of 50 contracting company representatives were given a questionnaire to complete during an interview. The researcher provided clear explanations and clarifications before the interview to ensure accurate answers. The contractors were given the opportunity to understand the questions before responding. The researcher also introduced themselves at the beginning of the interview to create a comfortable atmosphere and reassured the respondents that their data would only be used for research purposes and would not be shared with anyone else.

3.5.3 Population and Sample

The sample under investigation consists of contracting firms in a specific region, including those who have a valid contractor's registration and members of CREDAI. Due to the complexity of materials management, the focus was on the top contracting companies in the region. Based on the size of the city and the quantity of work needed, the projects were divided into three categories i.e., small, medium, and large. Projects with a construction cost of more than 5 crore were classified as large projects, those with a construction cost between 0.80 crore to 4.99 crore were considered medium projects, and those with a construction cost below 0.80 crore were categorized as small projects. There were an aggregate of 83 questionnaires distributed to contractors and employees of various construction companies, and 50 out of 83 responses were collected, resulting in a response rate of 60.25%.

3.5.4 Findings and Data Analysis

The questionnaire responses were entered in a methodical and efficient manner and were checked both manually and by computer to ensure accuracy. To analyse the data, it was categorized and the frequency distribution and percentage were used to determine the number of individuals or instances in each group. The research focused on companies in the construction and general contracting industry of various sizes (small, medium, and large) and utilized a statistical sampling approach. To protect the privacy of the participants and encourage honest responses about company practices, The responses to the questionnaire were kept private, and the outcomes were released in aggregate without disclosing any person or business-specific details that may jeopardise confidentiality. From the total fifty numbers of projects which were studied, some of them were completed in the recent years and remaining projects where on-going and at different integrated stages. Table 3.1 shows the status of the various projects.

Table 3.1: Status of Projects

Sr. no	Number of projects	Current status	status (%)
1	28	Completed	56
2	22	on-going	44

From these total numbers of projects some projects were pure residential apartments, some are residential cum commercial and, some projects were pure commercial projects. Table 3.2 presents various types of projects.

Table 3.2: Types of Projects

Sr. no	Type of projects	No. of projects	% Types
1	Residential	40	80
2	Commercial	5	10
3	Residential/commercial	5	10

Interviews were conducted with different stakeholders involved in several projects. These stakeholders included contractors, engineers, engineers involved in contracting, consultants, and supervisors, as outlined in Table 3.3. The interview questionnaire commenced with broad inquiries concerning the company's materials management personnel, organizational structure, and the different elements encompassed in materials management. Afterward, the questionnaire proceeded to more specific questions regarding various materials management functions. Conceptual buying, materials requirements strategy, making purchases, standard assurance/quality control logistics and transport, and site materials management were among these functions.

Table 3.3: Stakeholders Categories.

Sr. no.	Type of staff	No. of staff	% Types
1	Contractor	18	36
2	Engineers	13	26
3	engineers/contractors	16	32
4	Consultants	3	6

The initial segment of the questionnaire aimed to determine the extent of function implementation within the organization. It utilized a series of questions to gauge the diverse levels of implementation across different areas of the organization. Findings of first survey (Attached in Appendix-I). The data collected in the second phase involved questionnaires that consisted of both closed and open-ended questions. These questions covered a range of topics, such as material wastage, quantification methods, implementation barriers, and management. The data obtained was analysed using the Ranking method, which helped determine the significance and importance of factors related to material management, waste generation, and its management on the study sites. The responses of the participants were transformed into numerical scores during the analysis process.

A. Preferable Quantification Method

In questionnaire the respondents were asked to write the waste material quantification method which they prefer on site to estimate the amount of construction waste. The respondent had given the several methods which include volumetric method, numbering method, estimation method, and weighing method. For analysis these methods were bundled into 4 categories and their response rate is calculated to find out which method is mostly used. Out of 50 respondents only 29 were responded as 21 respondents do not quantify the amount of wastage. Table 3.4 shows the responses for preferable quantification methods.

Table 3.4: Preferable Quantification Method

Sr. No.	Methods	Responses out of 29	% Response
1	Volumetric	29	100
2	Numbering	12	41
3	Estimation	8	28
4	Weighing	16	55

B. Percentage Cost of Materials to the Cost of the Project

In this particular question the respondents were asked to give the per cent cost of required materials to the cost of given project. The various responses include different ranges of percentages starting from 40 to more than 70 percentages. The Table 3.5 shows the response for the various range's percentage cost of material to the total cost of project.

Table 3.5: Percentage Cost of Materials to the Cost of the Project

Sr. No.	Options in %	Response out of 50	% Response
1	40-50	3	6
2	51-60	15	30
3	61-70	30	60
4	Above 70	2	4

C. Effects of Material Waste at Site

In this question the respondents have given to write the various effects of construction material wastage at site, so as to analyse the important effects of material waste. The respondents have given various effects such as effect on total cost of project, delay in total duration affecting the scheduling, affecting the productivity of project, creating the problems for disposal of waste, also creating problems for storage of materials at site, reduction in workable area, environmental problems etc. All respondents had responded to this question. Table 3.6 shows the response for various effects of construction waste.

Table 3.6: Effects of Material Wastage

Sr. No.	Effects of Waste	Response out of 50	%Response
1	Project cost increment	50	100
2	Delay in completion	34	68
3	Material disposal problems	21	42
4	Reduction in productivity	15	30
5	Reduction in useable area	13	26
6	Material storage problems	9	18
7	Harmful to environment	5	10

D Causes of Material Waste

For this question respondent were asked to give the main causes of material wastage and cost variances for their sites. Respondents have given the various reasons for material waste at their site. These reasons includes improper planning techniques, improper supervision at site, more use of unskilled labours, frequent changes in designs, improper handling and transportation of materials, prone to use of materials not to specification, unawareness of relevant personals for different activities on site, negligence of site personals, faulty application practices, insufficient availability and use of equipment's at site, and improper storage practices which leads to wastage of materials at construction site. Table 3.7 shows the response for causes of material waste.

Table 3.7: Causes of Material Waste

Sr. No.	Causes of Waste	Response out of 50	% Response
1	Improper supervision	23	46
2	Improper handling & transportation	22	44
3	Use of unskilled labours	21	42
4	Improper planning	21	42
5	Change in designs	19	38
6	Unawareness of personals	16	32

Sr. No.	Causes of Waste	Response out of 50	% Response
7	Use of Material Not to Specifications	11	22
8	Insufficient equipment's	9	18
9	Faulty applications practices	8	16
10	Improper storage of materials	5	10
11	Negligence 0f Personals	5	10

E. Material Waste Minimisation Measures

In this question the respondents were asked to give the different waste minimizations measures or techniques which they use to control the amount of construction waste at site. The various responses from the respondent includes measures like proper procurement of materials, maintaining records for waste as well as materials, use of proper supervision techniques, proper application practices, physical auditing of materials, proper estimation of materials, proper planning techniques, proper communications between site personals, use of specified materials, and proper inventory control practices. Table 3.8 shows the response for material waste minimization measures.

Table 3.8: Material Waste Minimisation Measures

Sr. No	Measures/Techniques	Response out of 50	% Response
1	Reuse of materials	37	74
2	Proper supervision	22	44
3	Proper planning	17	34
4	Proper procurement	9	18
5	Accurate estimation	8	16
6	Proper communication	6	12
7	Inventory control	6	12
8	Auditing of materials	5	10
9	Proper application practices	3	6
10	Use of specified materials	2	4
11	Record maintenance	1	2

F. Major Barriers in Implementation of Material and Waste Management Plans

For these question respondents were asked to give the major barriers which they faced in implementing the material and waste management plan at their corresponding sites. Their reasons include barriers like insufficient finance, unskilled labour, time constraints, government rules and regulations, unfavourable site conditions, insufficient knowledge about the plans, and environmental barriers. Table 3.9 presents the responses for the barriers for implementation of waste management plans.

Table 3.9: Barriers in Implementation of Waste Management Plans

Sr. No.	Implementation Barriers	Response out of 42	% Response
1	Financial	24	57.14
2	Labours	19	45.23
3	Government rules & regulations	14	33.34
4	Unfavourable site conditions	10	23.8
5	Improper knowledge	6	14.3
6	Time	2	4.76
7	Logistics	2	4.76

I. Materials Safety Measures

Respondents were asked to give the measures which they use for materials safety at site in this particular question. The various measures which they use are proper storage and handling of site materials, use of warehouses for materials storage, and use security systems including security personals. Table 3.10 shows the responses for material safety measures.

Table 3.10: Materials Safety Measures

Sr. No.	Security Measures	Response	% Response
1	Security systems	50	100
2	Proper storage	29	58
3	Use of warehouses	23	46

J. Benefits of Material Waste Minimisation

For this question particularly the respondents were asked to state the benefits of material waste minimization. They have stated the various benefits such as reduction in total cost of project; time bound completion of project, increment in project productivity, quality benefits, proper inventory control, consumer's satisfaction, environmental benefits, reduction in total amount of wastage, and storage benefits. Table 3.11 shows the responses for benefits of material waste minimization.

Table 3.11: Benefits of Material Waste Minimisation

Sr. No.	Benefits	Response	% Response
1	Cost	48	96
2	In time completion	25	50
3	Waste reduction	13	26
4	Quality maintenance	12	24
5	Productivity	9	18
6	Inventory control	8	16
7	Proper storage	8	16
8	Environmental	5	10
9	Consumer satisfaction	3	6

3.5.5 Result and Discussion

The poll's first portion is divided into three sections: major contracting organizations, moderate contracting organizations, and minor contracting organizations. Initially, it was determined if the materials management group would be included in project strategy. In this regard, the survey results revealed that a median of 65% of respondents stated that materials management was a component of the strategy plan in which the vast majority of large contracting companies participated was there about 80% and medium and small contributing 68% and 46% respectively. About 84% total respondents don't have materials management computer system for management, only large organizations have most of it that too only 60%. Medium and small organizations have less than 10%. Majority of respondents periodically audit their material management processes. In an average 66% organizations audit their process including 90% large organizations, 60% medium organizations, and 47% small organizations.

It was observed that majority do not outsource the material management functions. On average only 22% organizations do outsourcing including 30% large, 24 medium, and 14 % small organization. In average about 63% of the respondents have surplus reducing programs which include 80% large organizations, 48 and 60% medium and small organizations respectively. 84% organizations on an average have warehouse for materials. In which major share was of large organizations, contributing 100% and remaining medium and small organization contributing 84% and 64% respectively. Only 29% respondents in an average have material tracking systems. In which only 14% small organizations, 24% medium, and 50% large organizations have such kind of systems. About 67% organizations have system for systematic inventory control in average. Again the 90% of respondents concern with the issues related to environment. About 92% concerns are from medium, 90% from large, and remaining small organizations concerns 87%. All organizations have a formal procedure for evaluating a supplier's quality systems. On an average 80% of organizations had seen implementing modularization. About 87% small organization, 80% large and, 72% medium size organizations implement modularization. The survey also showed that respondent relies on third-party providers for equipment's. About 82% respondents use equipment's for material handling including majority 90% of medium organizations. Small and large organizations use 60% and 90% respectively. Less than 25% of the responding organizations tend to plan yearly operation spares. Also 76% of them don't create routing guide for material transportation.

It is also interesting to note that 98% of the respondents were having provisions for disposal of construction waste. This includes 100% large and small organizations. Average 60% of the respondents quantify the amount of waste materials. About 80% large, 60% medium, and 40% small organizations do the quantification. Almost same number of organizations maintains the records of waste. The following figure represents the percentage response for the survey one results. On an average 50% organizations maintain it.

However, less than 40% of organizations conduct the educational programmes for their employees and labours. In this about 40% of large organizations, 40% small, and 36% medium provides it. It was also interesting to see that 90% organizations have close coordination between material management and procurement team. 100% positive response is from large organization, 96% from medium and 73% from small organization. Average 96% of respondent organization prefers negotiation for buying the materials including 100% small, 96% medium and 90% large organizations. All respondents believe in good buyer seller relationship for smooth operation on site. And nearly average 78% of organization use material substitutions for reducing the total cost of materials. This includes 96% large, 80% small, and 65% medium organizations. In Figure 3.9 percentage response for survey one result is shown.

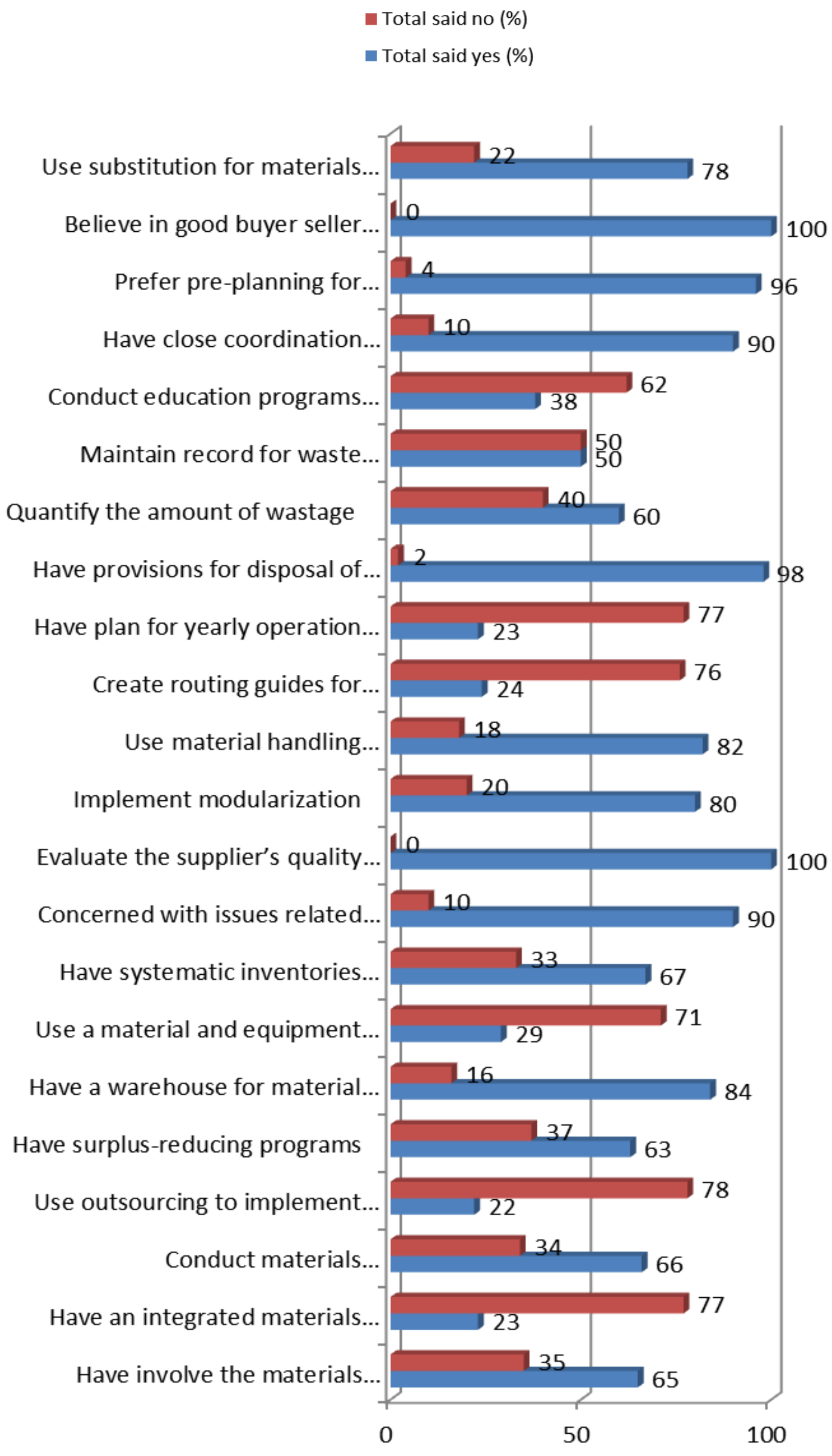


Figure 3.9 Percentage Response of Survey One Result.

In second phase all descriptive questions were analysed and the results were computed. For preferable quantification methods given in by various respondents were analysed so as to get the most preferable method for waste quantification and it was found that about 42% of respondent do not quantify the amount of wastage. And out of remaining 58% respondent all respondents use volumetric method, 41% respondent use numbering method, 28% estimation method and 55% quantify by weighing the amount of waste. So based on the frequency of responses these methods are ranked. Volumetric method had got highest response so it has been ranked first, numbering, estimation, and weighing are ranked second third and fourth respectively as per their response rate. Figure 3.10 shows the percentage of responses for the preferable quantification methods.

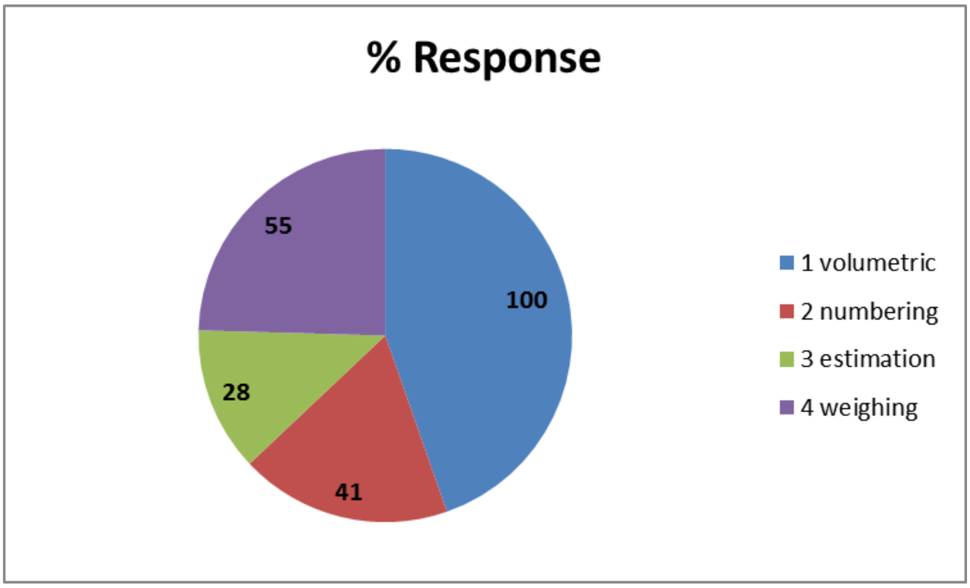


Figure 3.10: Responses for Preferable Quantification Method.

The causes of material wastage are found out and analysed from the received responses given to identify the most important causative factors of waste generation. Eleven causes have been identified which contribute to the waste generation on various studied sites. Among these eleven causes improper supervision has highest response frequency of 46% so it is ranked first. The other causes such as improper handling & transportation has 44% it is ranked second, use of unskilled labours and improper planning has 42% they are ranked third, change in designs has 38% it is ranked fifth, unawareness of site personals has 32% had ranked sixth, use of material which is not to specifications has 22% had ranked seventh, insufficient availability of equipment's has 18% and had ranked eight, faulty applications practices on construction site has 16% had ranked ninth, improper storage of materials and negligence of site personals towards work has 10% had been ranked least i.e. eleventh. Ranking of all these eleven causes generating the waste on construction site has been ranked according to their frequency of occurrences and responses. Response rate of waste generation causes in percentage had given in Figure no 3.11.

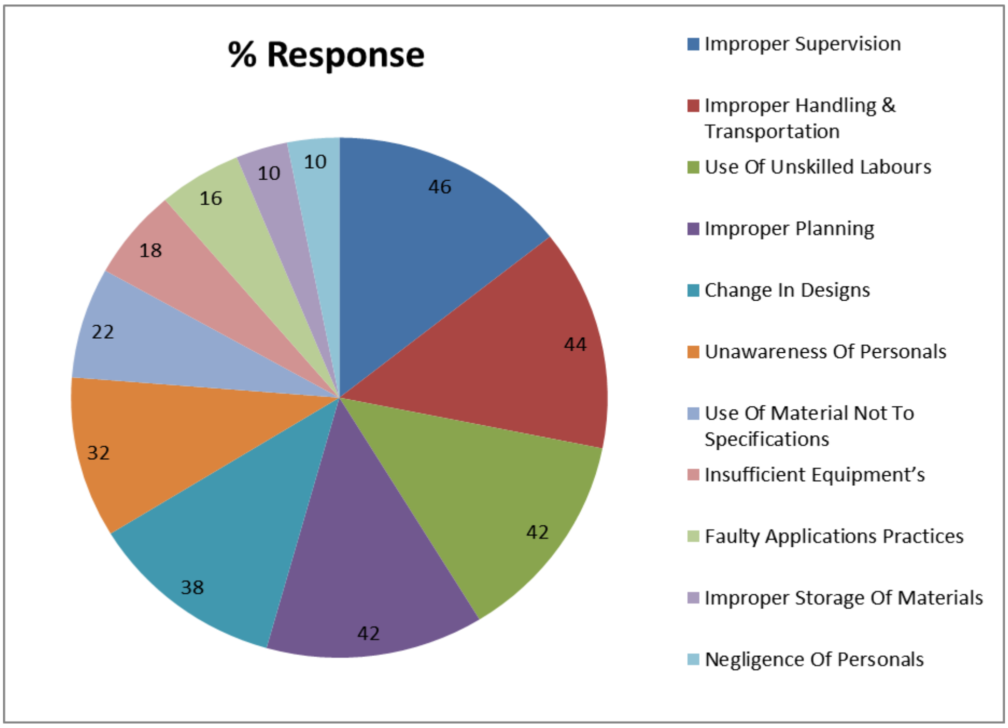


Figure 3.11: Responses for Causes of Material Waste

The effects of material waste given has been analysed to find out the generous effects of wastage of materials on construction site. Among the various responded effects, the most important effect of waste is on total cost of project. So, the cost increment has got the highest response rate of cent percentage and has ranked first. The material wastage also effects the duration of project. The delay in completion has got 68% response and has ranked second. Respondents suffering from disposal problems making it one of the vital effects of material waste. A material disposal problem got the response 42% and has been ranked third. The effect also includes reduction in productivity of the project and has response of 30% and reduction of useable space i.e., the workable area has response rate 26% and has been ranked fourth and fifth respectively. There is also material storage problem adding to the effects of material waste has response rate of 18% and has ranked sixth. Threat to environment is also one of the effects of material waste having the response rate of 10% and has been ranked seventh in the ranking process. Percentage rate of response for effects of material waste is shown in Figure 3.12.

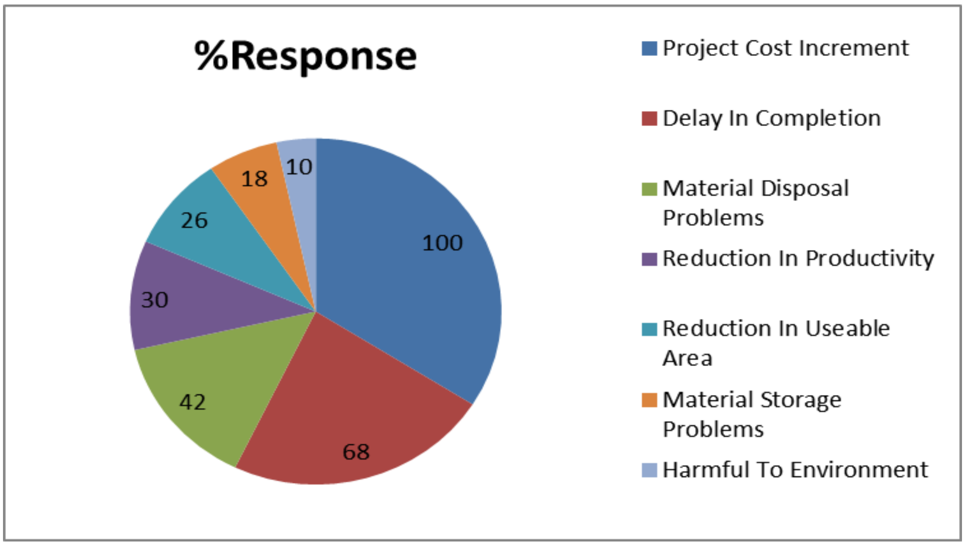


Figure 3.12: Responses for Effects of Material Waste

The percentage cost of materials in relation to the total cost of the project has been analysed to determine the contributions made by materials towards the overall project cost. This analysis helps in assessing the extent of cost variations attributed to the materials. The findings are presented in Table 3.13, revealing that 60% of the respondents reported the materials' percentage cost to be within the range of 61% to 70%, while 30% indicated a range of 51% to 60%. Only 6% of the respondents quoted a percentage cost of materials between 40% and 50%, and merely 4% mentioned a percentage cost above 70%. A graphical representation of the responses can be observed in Figure 3.13.

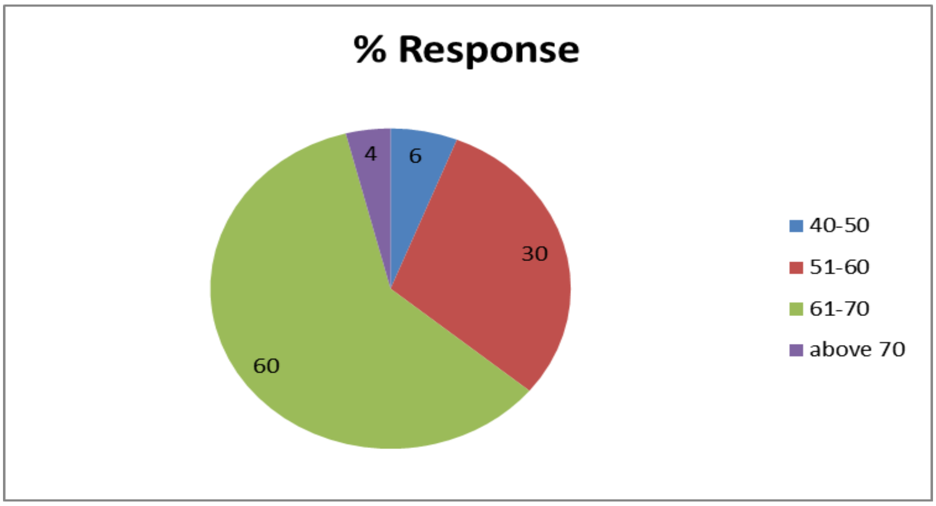


Figure 3.13: Responses for Percentage Cost of Materials to the Cost of the Project

On material waste minimisation measures, Table 3.14 shows the responses of the various measures used by respondent to minimize the material waste on construction site. The reuse of construction materials has been done by majority of respondent to minimize the waste. The quoted percentage response for reuse of materials is 74% so it is ranked first in the group. The response for proper supervision practices was 44% and was ranked second. Proper planning got the percentage response of 34% so ranked third. Proper procurement of materials got the response of 18% and was ranked fourth. Accurate estimation received the response of 16% and was ranked fifth. Proper communication and inventory control measures got the response of 12% each so it was ranked sixth. Auditing of materials got the response of 10% and was ranked eighth. Proper application practices on site received the response of 6%, use of specified materials received 4%, and record maintenance received only 2%. They are ranked ninth tenth and eleventh respectively. Figure 3.14 show the quoted percentage responses of waste minimisation measures.

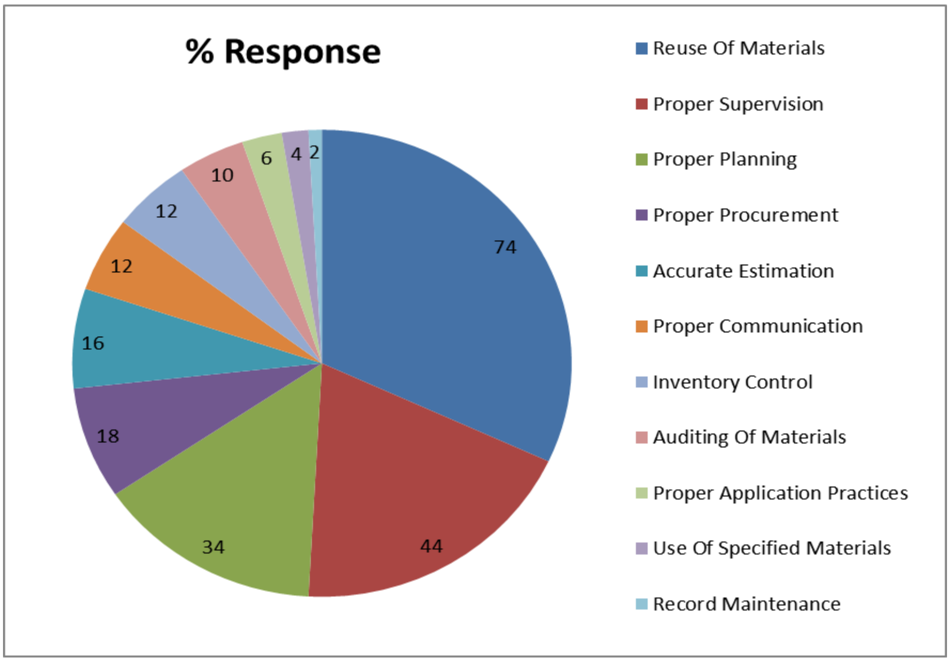


Figure 3.14: Responses of Waste Minimisation Measures

The major barriers in implementation of material and waste management plans encountered by the respondents were given in Table 3.15 was analysed to get the most important barriers for implementations. By knowing such barriers appropriate actions for eliminations can be taken. 57.14% of respondent has quoted finance as barrier for implementations of plans so it has been ranked first. About 45% of respondent believe labours as a barrier so it has ranked second. 34% of the respondent encountered government rules & regulations as barrier so it has ranked third on the list. About 24% respondent quoted unfavourable site conditions as barrier so it has been ranked fourth. 15% respondent faced improper knowledge about subject as barrier so it has ranked fifth. Only about 5% of respondent believe time and logistics as a barrier so it has ranked sixth on the list. Figure 3.15 shows the percentage responses for major barriers in implementation of material and waste management plans.

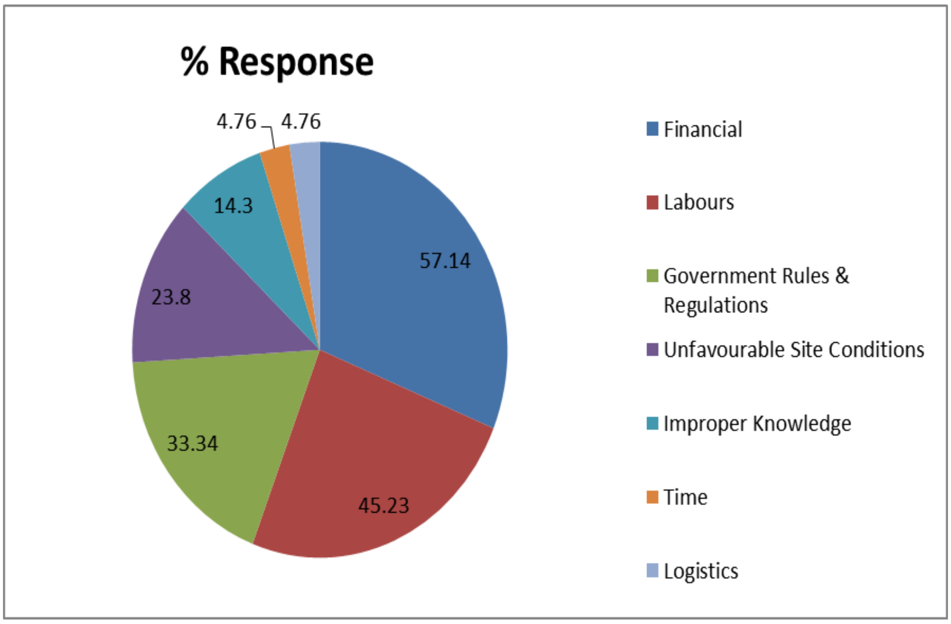


Figure 3.15: Responses for Major Barriers in Implementation of Material and Waste Management Plans

Materials safety measures which were taken by the various respondents for ensuring safety of their materials is given in Table 3.16. According to that cent percentage of the quoted responses is for security systems and was ranked first in the list. About 58% respondent has quoted proper storage practices that help them to keep their materials safe, so it was ranked second. 46% respondent believes in use of warehouses for ensuring safety of materials and so was ranked third. Figure 3.16 represents percentage responses for materials safety measures ensuring the safety of materials.

In Table 3.17 benefits of material waste minimisation by the respondents has been given. These are those benefits which the respondents get after doing minimization of waste on construction site. 96% of majority respondents got the Cost benefits by waste minimization, so it has been ranked first in the order. 50% of the respondents encountered the in-time completion of their project so it has ranked second. 26% respondents have quoted waste reduction as a benefit of waste minimization so was ranked third.

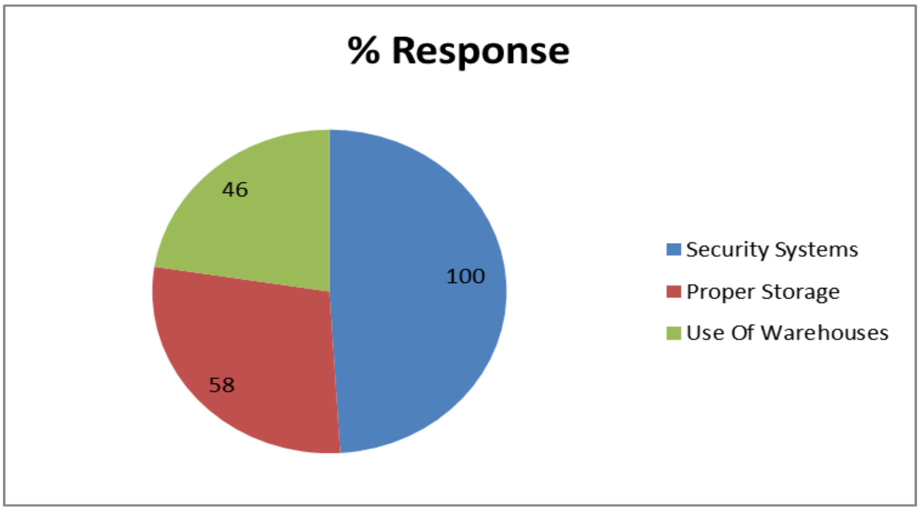


Figure 3.16: Responses for materials safety measures

About 24% respondent mentioned overall quality maintenance of the project as a benefit and was ranked fourth. 18% of respondent stated productivity as benefit so was ranked fifth. 16% of respondent quoted benefits include inventory control and proper storage of materials so it was ranked sixth. 10% respondent stated that minimization of waste helps the environmental and it was ranked eight. And only 6% respondent believe waste minimization leads to Consumer Satisfaction so it was ranked least on the table. Figure 3.17 shows the percentage responses for the benefits of material waste minimisation.

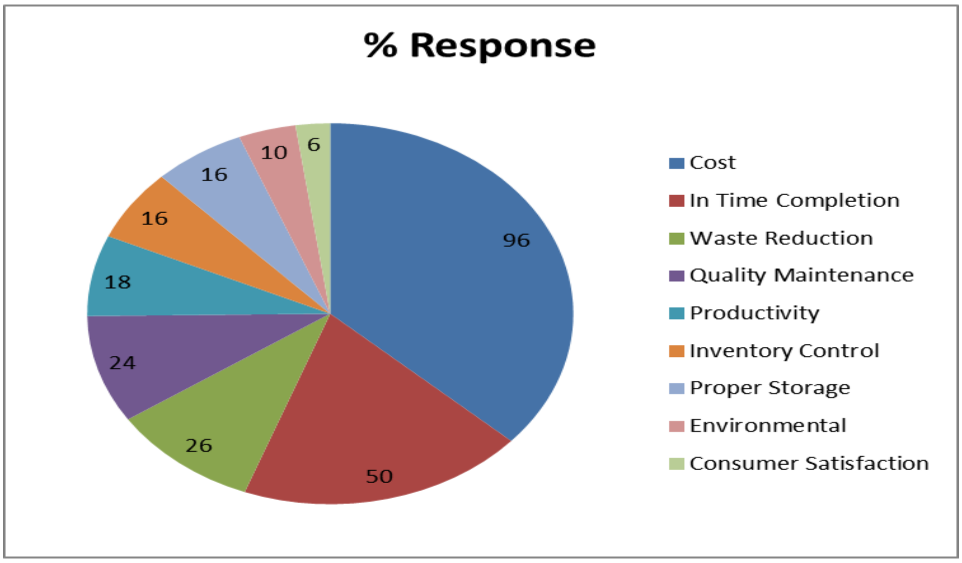


Figure 3.17: Responses for The Benefits of Material Waste Minimisation.

Civil contracting firms often face significant challenges in managing construction waste, posing environmental concerns and financial burdens. One potential solution lies in the implementation of comprehensive waste management plans. These plans should be devised at the project inception, outlining strategies for waste reduction, recycling, and responsible disposal. By conducting a thorough waste audit, firms can identify key areas for improvement and set realistic waste reduction targets. Additionally, integrating technology such as waste tracking software can enhance monitoring and reporting capabilities, ensuring compliance with regulations and promoting transparency. Collaboration with waste management partners and local recycling facilities is another crucial aspect. Establishing strong partnerships allows firms to streamline the disposal process, increasing the likelihood of materials being recycled or repurposed. Furthermore, promoting a culture of sustainability within the organization and among subcontractors can foster a collective commitment to responsible waste management practices.

Another essential solution involves the adoption of innovative construction techniques and materials that minimize waste generation. Prefabrication and modular construction methods, for example, can significantly reduce on-site waste by optimizing material usage and decreasing the need for excessive cutting and modifications. Implementing Building Information Modeling (BIM) technology can enhance project planning and design, enabling a more accurate estimation of materials needed and reducing overordering. Additionally, the use of eco-friendly and recycled materials not only decreases the environmental impact but also contributes to a circular economy. Civil contracting firms can also explore alternative waste-to-energy technologies, such as waste incineration or anaerobic digestion, to harness energy from construction waste that cannot be recycled. By investing in research and development for sustainable construction practices and materials, firms can not only address waste management challenges but also position themselves as leaders in environmentally responsible construction, attracting clients who prioritize sustainable development.

3.6 Summary

The chapter on "Waste Management Practices in Construction Industry" discusses the challenges faced by the construction industry in managing waste, which is a significant contributor to environmental pollution. The chapter explores various strategies and practices that can be adopted to reduce waste generation, promote reuse and recycling, and manage hazardous waste. The chapter discusses the benefits of waste management, including cost savings, reduced environmental impacts, and enhanced corporate image. It also highlights the regulatory framework and the need for compliance with environmental regulations and standards. The chapter discusses various waste management practices, such as waste minimization, source segregation, recycling and reuse, and disposal of hazardous waste. It also highlights the importance of waste audits and monitoring to track waste generation and identify areas for improvement. Overall, the chapter emphasizes the need for a holistic and integrated approach to waste management in the construction industry, which involves the adoption of sustainable practices and the collaboration of all stakeholders.

i) The survey findings indicate that while most contractors are interested in involving the management team in project planning for managing construction materials, some contractors failed to include this step in their planning.

ii) The majority of contracting firms did not utilize any software or computerized systems to support project materials management due to a shortage of suitable construction materials management software and a lack of qualified personnel to use such systems.

iii) Most respondents conduct periodic audits of their material management processes, have surplus reducing and systematic inventory control programs, and ensure the proper flow of materials on construction sites. However, they do not outsource material management functions to maintain the flow.

iv) To ensure material safety, most organizations use warehouses, security systems, proper storage practices, and evaluate supplier quality systems. However, many of them do not use material tracking systems.

v) A majority of organizations are concerned with environmental issues and have provisions for the disposal of construction waste.

vi) The majority of organizations use modern substitute materials to reduce project costs and believe in modularization.

vii) Although material handling may not add value to the product, it increases the cost of the product. Therefore, organizations should optimize material handling on construction sites to achieve safe and efficient operations. Most organizations rely on third-party providers for equipment.

viii) Some organizations quantify the amount of waste and maintain records, while others do not due to a lack of awareness. The preferred quantification method is the volumetric method.

ix) Most organizations believe in management team coordination, negotiation during purchasing, and good buyer-seller relationships. However, they do not conduct educational programs for employees and labour, which could improve their productivity.

x) Material waste on construction sites can be primarily attributed to several factors. These include inadequate supervision, workers' lack of awareness, improper handling and transportation, leading to excessive off-cuts, rework, variations, material contamination, and ineffective laws and regulations. The consequences of such wastage are reflected in increased total project costs and prolonged project duration.

xi) Contractors implement various practices to minimize material waste on construction sites, including proper planning, communication, procurement, and supervision. They also practice material waste recycling and implement reuse of materials, waste minimization at the source, circular economy concepts, and material flow analysis. However, the cost is a significant barrier to implementing material and waste management plans.

xii) Most contracting organizations in prioritize cost savings and increasing profits as the most important benefits and incentives for material waste minimization, while environmental benefits are neglected and considered less important.

CHAPTER – 4

IDENTIFICATION AND ANALYSIS OF SOURCES GENERATING CONSTRUCTION WASTE

4.1 General

The chapter concerning the identification and analysis of sources that produce building waste is critical in resolving the growing issues about managing waste in the building industry. Its primary focus lies in recognizing and comprehending the origins of waste during construction processes, ultimately leading to the formulation of effective waste reduction strategies. This chapter encompasses an array of construction waste sources, ranging from design and planning to construction materials, activities, and demolition. Detailed insights into the types of waste produced by each source and their environmental impact are also provided.

4.2 Identification and Analysis of Sources Generating Construction Waste

Construction waste is a significant issue worldwide, and proper management is essential to mitigate its environmental impact. The technique for determining the origins of waste produced during building activities is referred to as source identification of construction waste. The identification of the source of construction waste can provide valuable information to develop waste reduction strategies and improve waste management practices. The source identification process involves tracking and documenting the type and quantity of waste generated, as well as the location and stage of construction activities where the waste is produced. Various techniques can be used to identify the sources of construction waste, including waste audits, waste tracking, and material flow analysis [53]. Waste audits involve sorting, weighing, and analysing the waste generated at a construction site to determine the types and quantities of waste. Waste tracking involves monitoring and recording the movement of waste from the construction site to the final disposal site. Material flow analysis involves analysing the entire process of material flow from the production stage to the disposal stage to identify areas where waste can be reduced. Building waste source identification is a vital step towards ecologically sound building practises. By identifying the sources of waste, construction companies can develop waste reduction strategies, increase recycling rates, and minimize the environmental impact of their activities [57]-[58].

Building waste source recognition and evaluation is a critical component of sustainable construction practises. It involves analysing the materials and waste generated during construction activities to identify areas where waste can be reduced and recycled. The source identification process begins with waste audits, which provide valuable information on the type and quantity of waste generated. This information can then be used to develop waste reduction strategies, such as reducing the use of certain materials, implementing waste segregation practices, and increasing recycling rates. Material flow analysis can also be used to identify areas where waste can be minimized, such as reducing the transportation of materials, optimizing inventory management, and reducing packaging waste [38]. By identifying the sources of construction waste and implementing effective waste reduction strategies, Construction firms may lessen the impact on the environment and help to ensure an environmentally friendly future. [58]. It is essential to properly manage and dispose of construction waste to minimize its environmental impact and promote sustainable construction practices. Source identification of construction waste can help construction companies identify areas where waste can be reduced and develop strategies to increase recycling and reuse of materials.

4.3 Factor categories for Construction waste

Construction waste poses a significant environmental problem, accounting for a substantial portion of the world's waste. Numerous factors contribute to its generation, encompassing deficient planning, inadequate design, and outdated building codes. Other factors that contribute to construction waste include material overordering, packaging and transport waste, and demolition waste from renovation or remodelling projects. Additionally, improper construction practices, lack of skilled labour, and insufficient investment in waste management infrastructure can also lead to increased construction waste. As the construction industry continues to grow, it is crucial to address these factors and develop sustainable practices to reduce construction waste and promote environmental sustainability. Following are the predominant factors categories responsible for generation of construction waste.

A. Designing and Documentation in project

Designing and Documentation play a crucial role in reducing construction waste generation. During the designing phase, architects and engineers can incorporate sustainable and green building practices that can minimize waste generation. This includes designing buildings that use renewable energy sources, use materials that are easily recyclable, and designing efficient building systems that can reduce energy and resource consumption. Furthermore, during the designing phase, construction teams can plan the construction process and identify potential sources of waste that can be reduced or eliminated. By focusing on designing for sustainability and waste reduction, the project can minimize waste generation and promote a more sustainable building process.

Metadata is also important in avoiding building waste. Proper building process documentation can assist in identifying waste-related issues and locations where waste can be reduced or avoided. This documentation includes tracking materials and waste streams, and documenting the use of sustainable building practices. The project can discover places where waste can be reduced and resources conserved by carefully recording the development process. Additionally, proper documentation can provide a reference for future projects, enabling teams to learn from past successes and mistakes, and continually improve their waste reduction strategies. Overall, designing and documentation are essential tools for reducing construction waste generation and promoting sustainable building practices. The Designing and Documentation cluster includes Change in the infrastructure design, Inappropriate project Documents, Error in Infrastructural design, Architectural or structural drawing errors and Complications in the design factors. One prevalent issue is inadequate communication between architects, engineers, and contractors during the design phase. When design documents lack clarity or fail to provide detailed specifications, it can lead to misunderstandings and misinterpretations by construction teams. For example, vague instructions on material specifications or assembly methods may result in contractors making incorrect choices or assumptions, leading to the generation of construction waste as errors are rectified. Additionally, changes in design during the construction phase, commonly known as design changes or variations, can lead to the disposal of partially completed work and materials that no longer align with the revised design. Poorly coordinated designs may also result in excess materials being ordered, as uncertainties in quantities and specifications prompt contractors to over-purchase, contributing further to unnecessary waste. Documentation-related issues can also arise during the procurement process. Inaccurate quantity takeoffs, discrepancies in bills of quantities, or mistakes in project specifications can lead to overordering or underordering of materials. Overordering contributes to surplus materials that may not find use in the project, leading to disposal as waste. On the other hand, underordering can result in delays and the need for rush deliveries, often involving expedited shipping with increased environmental impact. In both cases, the lack of accurate documentation can exacerbate construction waste issues. Furthermore, the absence of clear guidelines on the recycling or reuse of construction materials in project specifications may lead to a default disposal approach, where materials that could be salvaged end up being discarded. Overall, a comprehensive and well-coordinated approach to design and documentation is essential to minimize construction waste and promote sustainable building practices.

B. Construction Materials handling, procurement, and storage related factors.

Handling, purchasing, and stockpiling of construction materials are significant elements when assessing the quantity of waste produced during the course of a building project. Inefficient handling of materials can lead to damage, excessive waste, and increased costs. Poor procurement practices such as over-ordering materials or ordering materials that do not meet the project requirements can result in unnecessary waste. Similarly, improper storage of materials can lead to spoilage, damage, and increased waste. To reduce construction waste, it is essential to adopt efficient material handling practices.

This can be achieved by ensuring that materials are carefully handled and transported to the construction site to prevent damage or waste. Proper training of workers on how to handle and transport materials can also minimize waste. For procurement, it is crucial to have an accurate estimate of the required materials and to order only what is needed. Working with trusted vendors who can offer the correct amount and quality of products at the right time can help you achieve this. Materials should be stored in a safe and secure location that is safeguarded from the elements to avoid damage or spoiling. Finally, effective material handling, procurement, and storage are essential aspects that can dramatically impact the quantity of trash generated during a building project. Construction organisations may reduce waste, save money, and reduce the environmental effect of their projects by implementing efficient practises. Improper storage of construction materials, insufficient material quality, insufficient material quantity ordered, insufficient material handling, insufficient material transportation, insufficient material packaging, and insufficient material packaging comprise the Construction materials handling, procurement, and storage cluster.

C. Methods in construction and Project management

Effective waste management is of utmost importance in construction projects due to the significant concern surrounding construction waste generation. Minimizing its adverse effects on the environment and public health is vital. The incorporation of suitable methods in construction and project management can play a pivotal role in reducing waste generation. An example of such a method involves adopting a life cycle approach, wherein the entire project, from design to disposal, is carefully considered. This approach allows for the identification of potential waste sources and helps to develop effective waste management strategies to minimize waste generation. Another method is to incorporate sustainable design and construction practices that promote resource efficiency and reduce waste generation. For instance, utilizing prefabrication techniques, designing for disassembly, and using recycled materials can significantly reduce waste generation and improve the sustainability of the project.

Effective project management is also essential to minimize construction waste generation. A well-planned project management strategy that incorporates waste reduction goals and targets can significantly minimize waste generation. This includes proper planning, communication, and coordination among all stakeholders to ensure that waste management practices are implemented effectively. Additionally, regular monitoring and tracking of waste generation and disposal can provide valuable feedback for improving waste management practices in future projects. Effective project management can not only reduce waste generation but also improve the overall project efficiency, cost-effectiveness, and sustainability. The Methods in construction and Project management clusters includes following factors Improper Activity Coordination, Inefficient Control and supervision of activities, Inappropriate use of Construction methods, Poor waste management planning & techniques, Tools and equipment (Wrong handling /malfunctioning), Misuse of construction materials., Frequent Rework in activity, Wrong teams /subcontractors' selection, Ineffective Process/ Wrong choice of construction process, Error in execution, Ineffective planning and scheduling of activities.

D. Human Resources related factors

Construction projects can generate significant amounts of waste, and human resources related factors can play a critical role in the amount of waste generated. One important factor is the level of employee training and education regarding waste management practices. When construction workers are not adequately trained on proper waste management practices, they may unintentionally create waste by using incorrect materials or discarding waste improperly. Additionally, if workers are not aware of the environmental impact of construction waste, they may not prioritize waste reduction efforts. Another important human resources factor is the culture and values of the construction company. If a company prioritizes sustainability and waste reduction, this mindset will be reflected in the attitudes and behaviours of employees. However, if a company places more emphasis on speed and efficiency, waste reduction may not be given as much importance. Therefore, companies should prioritize creating a culture that values sustainable practices and waste reduction in order to encourage employees to take proactive steps to minimize waste generation. This cluster includes the following factors Use of Incompetent workers, Lack of experience of designer, Inattentive working attitudes and behaviours, Lack of suppliers' involvement for project.

4.4 Methodology

The purpose of the methodology concerning the identification and analysis of construction waste sources is to establish a well-organized approach to pinpoint the origins of construction waste and examine the factors contributing to its creation. The methodology is designed to systematically explore the construction activities, processes, and materials utilized in a construction project, thus identifying the waste streams generated throughout the project's lifecycle. By gaining insights into the sources of construction waste, the methodology can aid in devising strategies to minimize waste through reduction, reuse, and recycling, thereby promoting more sustainable construction practices. Moreover, the methodology plays a crucial role in identifying areas within the construction industry where process improvements and innovative practices can be applied to curtail waste generation. Figure 4.1 illustrates the flow of the adopted methodology for identifying and analysing the sources responsible for construction waste.

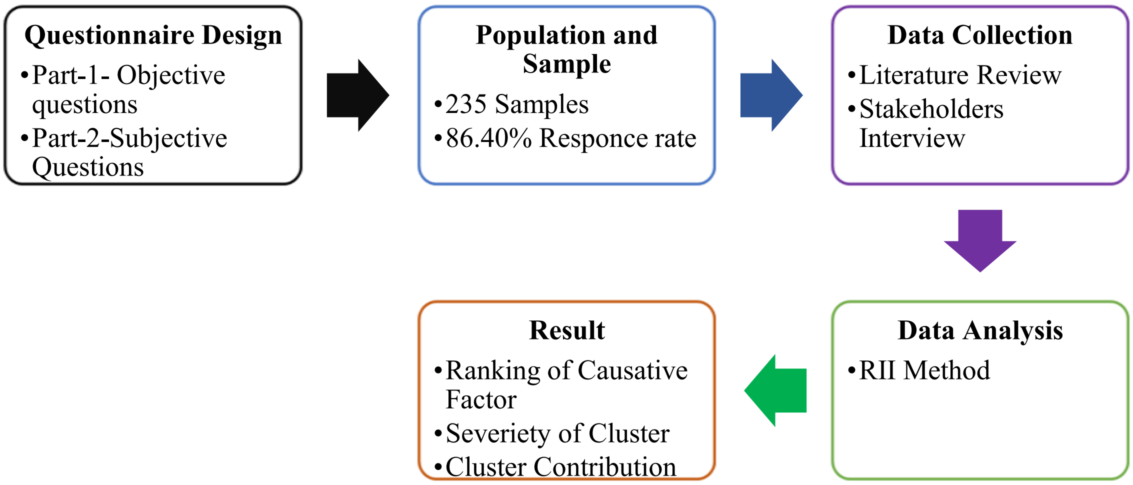


Figure 4.1: Methodology Flow chart for Identification of Factors causing waste

4.4.1 Questionnaire Design

In this study, a precise structured questionnaire method is adopted. In view to achieve the high rate of return and accuracy in results it is important to have good questionnaire design. The questionnaire is divided into two parts first one is survey I i.e., inclusive of informative type questions and second one survey II i.e., inclusive of ranking type questions. The question in the questionnaire framed based on review of literature structured interviews with stakeholders, which can be useful for creating questions. When designing a questionnaire to identify the factors responsible for construction waste, it was essential to ask targeted questions that provide actionable insights.

Designing a RII (Relative Importance Index) based questionnaire for material waste data requires a systematic approach to ensure that the questionnaire captures all relevant factors. The first step was to identify the key variables that affect material waste in the context of interest. These variables include factors such as production processes, material handling procedures, equipment design, and employee behaviour. Next, the questionnaire was designed to elicit responses from experts or stakeholders who are knowledgeable about the specific context. The questionnaire includes questions that help to identify the relative importance of each variable, as well as questions that elicit specific information about each variable. Sample questionnaire is attached in Appendix-II. Finally, the responses were analysed using RII to determine the most important variables that influence material waste. This process can help to identify areas where improvements can be made to reduce material waste and improve overall efficiency.

4.4.2 Population and Sample

Population and sampling are two important concepts in statistics that are essential for collecting and analysing data. The population represents the complete set of individuals, objects, or events that are relevant to a researcher's study. Conversely, a sample is a smaller, carefully chosen subset of the population, used for the purpose of conducting a study or experiment. In this particular research, 51 site surveys were conducted, and 235 stakeholders were interviewed and asked to fill out a questionnaire. Before conducting the structured interviews, the questionnaire was thoroughly explained to ensure accurate responses. However, the selection of a sample can be a complex process, and researchers must ensure that their sample is representative of the population in order to draw accurate conclusions. Total 272 numbers of questionnaire were distributed to stakeholders of different construction companies. 235 out of 272 Reponses were collected (response rate is 86.40 %).

4.4.3 Data collection and Analysis

The factors responsible for the generation of construction waste has been identified from the literature review as well as from the stakeholders by structured interview and questionnaire method. For analysis RII method has been used. The Relative Importance

Index (RII) method is a popular technique used to evaluate the relative importance of different factors that contribute to a particular phenomenon. The RII method involves asking a group of experts or stakeholders to rank a set of factors based on their perceived importance in contributing to the phenomenon being studied. The RII for each factor is then calculated by dividing the mean rank given by the experts for that factor by the sum of the mean ranks for all factors. The resulting RII value provides a measure of the relative importance of that factor compared to the other factors. The RII method is a simple and effective way to evaluate the relative importance of different factors and can be used in a variety of fields, including business, healthcare, and social sciences. One of the strengths of the RII method is its simplicity and ease of use. It does not require any specialized knowledge or software, and can be easily implemented by researchers or practitioners in the field. Additionally, the RII method can provide valuable insights into the relative importance of different factors that contribute to a particular phenomenon. This information can be used to prioritize resources and efforts towards the most important factors, and can help to guide decision-making in a variety of contexts. However, it is important to note that the RII method does have some limitations, including the potential for biases or inconsistencies in the expert rankings, and the fact that it does not provide information about the direction or strength of the relationships between factors and the phenomenon being studied. By using the equation 1.0 the contribution of each factor leading to generation of construction waste was evaluated and ranked according to their relative importance.

$$\mathbf{RII = \Sigma W/(A \times N), \ (0 < RII < 1) \ \ldots\ldots\ldots\ldots\ldots\ldots \ (1.0)}$$

Where (W) is the weightage that respondents give to the component on a scale of 1 to 5, (1 being strongly disagree and 5 being strongly agree), (A) indicates the maximum weight (i.e., 5 in this case), and (N) is the total number of respondents. To interpret the RII value, it is important to keep in mind that the RII only indicates the relative importance of the factors within the specific context and sample used in the study. Therefore, the results cannot be generalized to other populations or situations.

- **Project status**

Construction project status refers to the current state of a construction project, including its schedule of completion. It involves monitoring and reporting on various aspects of the project, such as the status of construction work, completion of activities and milestones. The project status may be communicated through various means, such as progress reports, site visits, or meetings with stakeholders. Proper oversight of building project status is crucial to ensure that the project is finished on schedule, within budget, and to the appropriate quality standards. Regular monitoring and reporting on the project status also enable project managers to identify and address issues as they arise, minimizing potential delays and cost overruns. In the presented study, from the total fifty one numbers of projects which were visited and studied, some of them were completed in the recent years and remaining projects where on-going and at different integrated stages. The status of those project is given in table no. 4.1.

Table 4.1: Status of Projects

Sr. no	Number of projects	Current status	Status (%)
1	28	Completed	56
2	22	on-going	44

- **Stakeholders Characteristics**

In the context of a construction project, stakeholders refer to any individuals or groups who have a vested interest in the project's success or failure. Stakeholders within the organisation and external stakeholders are the two primary groups of stakeholders in building ventures. Internal stakeholders include the project owner, investors, project managers, and employees, while external stakeholders include government regulators, local communities, customers, suppliers, and contractors. Characteristics of stakeholders in construction projects can vary widely, but typically include a combination of financial, social, and environmental interests. For example, project owners and investors may prioritize financial returns and timelines, while government regulators and local communities may prioritize safety, environmental impact, and community engagement. Effective stakeholder management is critical for ensuring the success of a construction project, as it can help to build support, identify risks, and manage conflicts throughout the project lifecycle. For study all the stakeholder age group, gender, educational qualification, experience in domain and position in their respective firms' characteristics are taken into consideration so as to cover the respondents of all categories. For the purpose of analysis 235 responses were selected based on predetermined selection parameters, which assures the impartiality and transparency in procedure. Following table precisely shows the characteristics of respondents with respect to the projects that were visited during the data collection. Particularly the residential construction projects were taken for the study. Survey included around Fourth five percent of the projects are under construction and fifty five percent are completed. Table 4.2 shows the characteristics of the respondents who has responded to the shared questionnaire

Table 4.2: Stakeholders Characteristics

Characteristic		**Frequency**
Gender	Male	189
	Female	46
Age group	Under 30	41
	30 to 40	62
	41 to 50	94
	50 and over	38
Position	Managing director	12
	Project manager	58
	Project engineering	38
	Project director	28
	Assistant project manager	12
	Site engineering	30
	Project architecture	12
	Site architecture	5
	Foreman	40
	<5 years	38

Characteristic		Frequency
Experience in construction	5–10 years	52
	11–15 years	86
	16–20 years	39
	20 years<	20
Education	Vocational	46
	Bachelor	99
	Master	86
	Ph.D.	4

- **Factor categories**

The formation of clusters is a useful approach to understanding the factors that contribute to construction waste with similar nature and characteristics. Construction waste is a complex problem that involves a range of factors, including materials, design, construction methods, and waste management practices. By identifying and clustering these factors based on their similarities, it becomes easier to analyse and address them more effectively. From the literature review and responses collected from the stakeholders 28 per dominant factors were listed out which were prominently contributing to the construction waste, from about 143 total factors these factors are chosen depending on suitability for specific projects and tasks, as well as combination of factors falling under the category. The root causes are clubbed in four primary groups. The causative factors generating the construction waste are shown in Table 4.3 below. Additionally, cluster formation can help stakeholders to identify common solutions and strategies that can be applied to a group of factors, leading to more efficient and effective waste management practices in the construction industry.

Table 4.3: Factor categories

Factor Clusters	**Factor Name**
Design and Documentation in Project	Change in the infrastructure design
	Inappropriate project Documents
	Error in Infrastructural design.
	Architectural or structural drawing errors
	Complications in the design
Construction Materials handling, procurement, and storage related factors.	Improper storage of construction materials
	Inappropriate Material quality
	Improper quantity of Material ordering
	Improper handling of materials
	Improper Material transportation
	Improper Packaging of materials
	Defective delivered materials
	Damaged materials used
Methods in construction and Project management	Improper Activity Coordination
	Inefficient Control and supervision of activities
	Inappropriate use of Construction methods
	Poor waste management planning & techniques
	Tools and equipment (Wrong handling /malfunctioning)
	Misuse of construction materials.
	Frequent Rework in activity.
	Wrong teams /subcontractors’ selection
	Ineffective Process/ Wrong choice of construction process
	Error in execution

Factor Clusters	Factor Name
	Ineffective planning and scheduling of activities.
Human Resources related factors.	Use of Incompetent workers
	Lack of experience of designer.
	Inattentive working attitudes and behaviors
	Lack of suppliers' involvement for project

- **Ranking of Factors**

The ranking of factors contributing to construction waste is crucial for several reasons. Firstly, identifying the primary factors responsible for generating waste can help construction companies and policymakers prioritize their efforts to minimize waste generation. This, in turn, can lead to more efficient use of resources, cost savings, and reduced environmental impact. Secondly, analysing the factors contributing to waste generation can help identify areas of improvement in the construction process, such as materials selection, design, and construction methods. Finally, understanding the factors contributing to construction waste can inform the development of waste management strategies and policies, enabling the industry to move towards more sustainable practices.

Overall, the ranking of factors contributing to construction waste is essential for effective waste management and promoting sustainability in the construction industry. Table 4.4 precisely shows the evaluation of the responses from the selected respondents. The RII technique has been used to rank the responses according to their relative importance and to compute the most influencing factors responsible for the generation of the construction waste.

Table 4.4: Ranking of factors and RII (n = 235).

SR. NO	FACTORS	1	2	3	4	5	RII	RANK
1.	Inattentive working attitudes and behavior's	8.00	35.00	72.00	71.00	49.00	0.701	1
2.	Inefficient Control and supervision of activities	17.00	47.00	62.00	51.00	58.00	0.673	2
3.	Ineffective planning and scheduling of activities	21.00	39.00	63.00	58.00	54.00	0.672	3
4.	Improper handling of materials	23.00	40.00	56.00	64.00	52.00	0.669	4
5.	Change in the infrastructure design	10.00	44.00	85.00	56.00	40.00	0.661	5
6.	Complications in the design	19.00	47.00	63.00	57.00	49.00	0.660	6
7.	Improper storage of construction materials	24.00	48.00	51.00	69.00	43.00	0.650	7
8.	Frequent Rework in activity.	24.00	55.00	59.00	53.00	44.00	0.632	8
9.	Error in Infrastructural design.	26.00	56.00	52.00	61.00	40.00	0.628	9
10.	Use of Incompetent workers	26.00	50.00	67.00	52.00	40.00	0.625	10
11.	Architectural or structural drawing errors	30.00	56.00	42.00	46.00	61.00	0.624	11
12.	Lack of experience of designer.	29.00	52.00	60.00	52.00	42.00	0.622	12
13.	Improper quantity of Material ordering	28.00	52.00	60.00	58.00	37.00	0.620	13
14.	Improper Material transportation	30.00	52.00	61.00	49.00	43.00	0.619	14

SR. NO	FACTORS	1	2	3	4	5	RII	RANK
15.	Poor waste management planning & techniques	25.00	58.00	56.00	63.00	33.00	0.618	15
16.	Ineffective Process/ Wrong choice of construction process	30.00	45.00	65.00	65.00	30.00	0.617	16
17.	Inappropriate use of Construction methods	38.00	55.00	56.00	49.00	37.00	0.615	17
18.	Defective delivered materials	38.00	47.00	56.00	49.00	45.00	0.614	18
19.	Tools and equipment (Wrong handling /malfunctioning)	31.00	50.00	63.00	55.00	36.00	0.613	18
20.	Wrong teams/subcontractors' selection	29.00	66.00	52.00	38.00	50.00	0.611	20
21.	Inappropriate project Documents	38.00	52.00	54.00	44.00	47.00	0.608	21
22.	Error in execution	38.00	58.00	49.00	45.00	45.00	0.600	22
23.	Improper Activity Coordination	49.00	52.00	50.00	57.00	27.00	0.567	23
24.	Improper Packaging of materials	40.00	63.00	64.00	36.00	32.00	0.563	24
25.	Misuse of construction materials.	48.00	52.00	59.00	50.00	26.00	0.561	25
26.	Inappropriate Material quality	43.00	63.00	52.00	51.00	26.00	0.560	26
27.	Damaged materials used	44.00	67.00	53.00	41.00	30.00	0.554	27
28.	Lack of suppliers' involvement for project	42.00	65.00	60.00	45.00	23.00	0.493	28

- **Severity of categories**

In order to effectively address the issue of construction waste, it is important to conduct a thorough severity analysis of the factors contributing to its generation. This analysis involves identifying the various stages of the construction process where waste is generated and examining the underlying causes of waste production at each stage. Factors that may contribute to construction waste include improper design, inaccurate forecasting of material needs, inadequate construction planning, poor project management, lack of efficient waste management systems, and a general lack of awareness and education about waste reduction strategies. By identifying and analysing these factors, construction companies and project managers can develop effective Waste minimization measures are being implemented to reduce the environmental impact of construction activities and enhance sustainability. The severity analysis of factors contributing to construction waste is of utmost importance in the construction industry. Construction waste has significant economic, environmental, and social impacts, including cost overruns, resource depletion, and increased pollution. Therefore, identifying the severity of the factors that contribute to construction waste helps to prioritize efforts to reduce waste and improve efficiency. This analysis can provide valuable information about the root causes of waste, which can inform decision-making and lead to more effective waste reduction strategies. By addressing the most severe factors contributing to construction waste, the industry can reduce waste generation, increase resource efficiency, and minimize environmental impacts, all while improving the bottom line. Depending on the score of RII the severity of each factor has been assigned. The causative factors generating the construction waste with severity are shown in Table 4.5 below. With reference to the score of RII the severity of each factor has been assigned. H stand for higher degree of severity. M stands for moderate degree of severity and L stands for lower degree of severity.

Table 4.5: Severity of Factor

Factor Clusters	Factor Name	SEVERITY
Designing and Documentation in project	Change in the infrastructure design	H
	Inappropriate project Documents	L
	Error in Infrastructural design.	H
	Architectural or structural drawing errors	M
	Complications in the design	H
Construction Materials handling, procurement, and storage related factors.	Improper storage of construction materials	H
	Inappropriate Material quality	L
	Improper quantity of Material ordering	M
	Improper handling of materials	H
	Improper Material transportation	M
	Improper Packaging of materials	L
	Defective delivered materials	L
	Damaged materials used	L
Methods in construction and Project management	Improper Activity Coordination	L
	Inefficient Control and supervision of activities	H
	Inappropriate use of Construction methods	M
	Poor waste management planning & techniques	M
	Tools and equipment (Wrong handling /malfunctioning)	L
	Misuse of construction materials.	L
	Frequent Rework in activity.	H
	Wrong teams /subcontractors' selection	L
	Ineffective Process/ Wrong choice of construction process	M

Factor Clusters	Factor Name	SEVERITY
	Error in execution	L
	Ineffective planning and scheduling of activities.	H
Human Resources related factors.	Use of Incompetent workers	H
	Lack of experience of designer.	M
	Inattentive working attitudes and behavior’s	H
	Lack of suppliers’ involvement for project	L

4.4.4 Result and Discussion.

The Results and Discussion chapter is a critical component of the thesis. This chapter presents the findings of the study and interprets their meaning in light of the research questions. The Discussion section then explores the implications of the findings, placing them in the context of previous research and identifying any limitations or areas for future study.

- **Stakeholders Characteristics**

235 responses were chosen for analysis and the data presented provides information on the respondents involved in residential construction projects. The survey consisted of 45% of projects that were still under construction, and 55% that had already been completed. Figure 4.2 illustrates the gender distribution of stakeholders involved in the studied projects, with 80.42% of respondents being male and 19.58% being female.

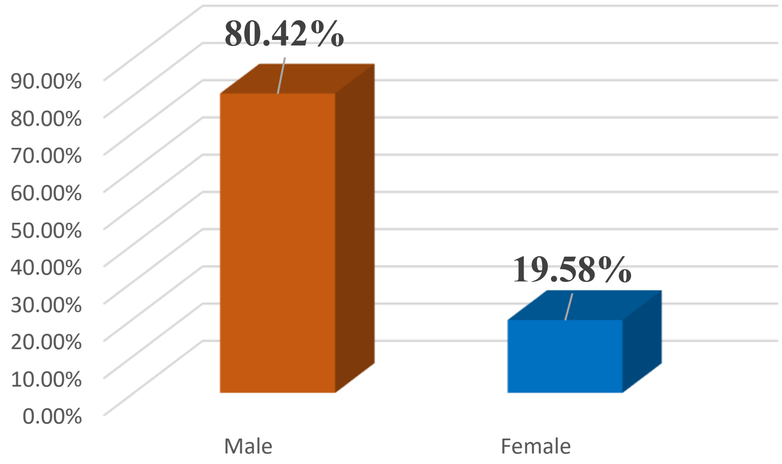


Figure 4.2: Gender of Stakeholders

Stakeholders can be of any age group, as anyone who is affected by or has an interest in a particular project, organization, or issue can be considered a stakeholder. To ensure that the diverse needs and perspectives of stakeholders of all age groups are taken into account and adequately addressed, consideration is given to all possible age groups of stakeholders. The data presented in Figure 4.3 illustrates the distribution of respondents across different age groups. 15.56% of the respondents were under 30 years old, 23.70% belonged to the age group between 30 and 40 years old, 40% were between 40 and 50 years old, and 20.74% were over 50 years old.

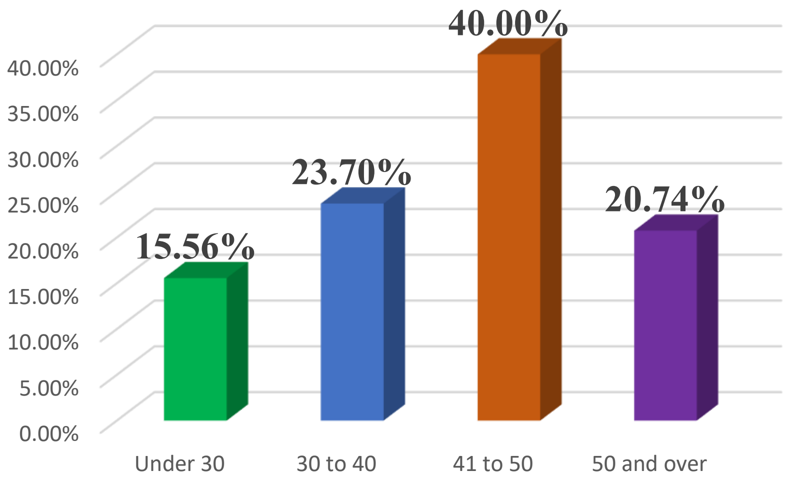


Figure 4.3: Age Groups of Stakeholders

Stakeholders play a critical role in the success of a construction firm. They are individuals or groups with a vested interest in the company's activities, and they can impact or be impacted by the firm's operations. Stakeholders in a construction firm typically include owners, shareholders, employees, contractors, suppliers, customers, local communities, government agencies, and regulatory bodies. Each stakeholder has a unique position and set of expectations that the company must address to maintain its relationships and reputation. Effective stakeholder management requires open communication, transparency, and a commitment to ethical business practices. By engaging with stakeholders and understanding their needs, a construction firm can build strong partnerships and achieve sustainable growth. The diagram 4.4 illustrates the different roles held by those surveyed in their respective companies. Approximately 5.10 percent were in top positions as Managing Directors and Chief of Operations, while 24.68 percent worked as Project Managers. Project Engineers made up 16.17 percent of the respondents, and 11.91 percent were Project Directors. Assistant to Project Managers accounted for 5.10 percent, Site Engineers made up 12.76 percent, Project Architects were 5.10 percent, Site Architects were 2.12 percent, and 17.02 percent were Foremen.

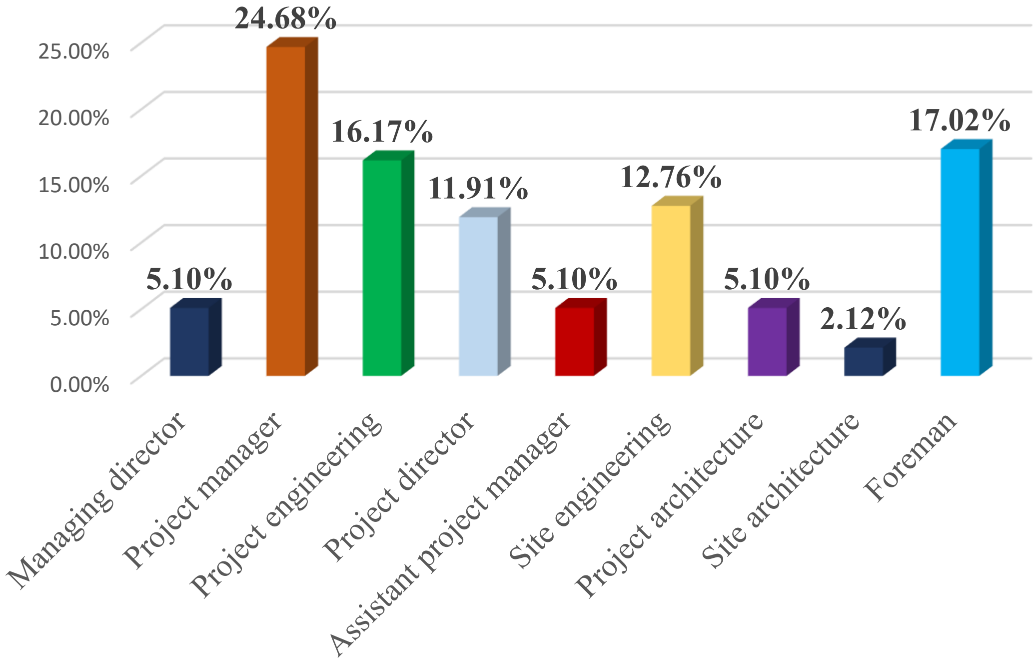


Figure 4.4: Positions of Stakeholders in Firms

Construction projects involve a wide range of stakeholders who have different experiences throughout the project lifecycle. Some of the key stakeholders include owners, architects, engineers, contractors, suppliers, and subcontractors. Each of these stakeholders has unique perspectives and experiences based on their roles, responsibilities, and interactions with other stakeholders. The construction industry is complex, involving a wide range of stakeholders such as architects, engineers, contractors, and clients, who all bring different perspectives and experiences to a project.

The importance of these stakeholders' experiences cannot be overstated, as they play a crucial role in the success of construction projects. Their experiences provide a wealth of knowledge that can inform decisions and guide project outcomes. For example, architects and engineers bring technical expertise, which is essential for designing buildings that meet safety standards and functional requirements. Contractors bring experience in project management, scheduling, and cost estimation, which is crucial for delivering projects on time and within budget. Clients bring their unique needs and expectations, which must be incorporated into the design and construction process to ensure customer satisfaction. By leveraging the collective experiences of all stakeholders, construction projects can be completed efficiently, effectively, and to the satisfaction of all involved parties. The diagram 4.5 illustrates how stakeholders in the construction industry perceive their overall experience. 16.17 percent of these stakeholders had a minimum of five years of background, 22.12 percent had 5 to 10 years of experience, 36.30 percent had 11 to 15 years of experience, 16.60 percent had 16 to 20 years of expertise, and 8.51 percent had more than 20 years of involvement.

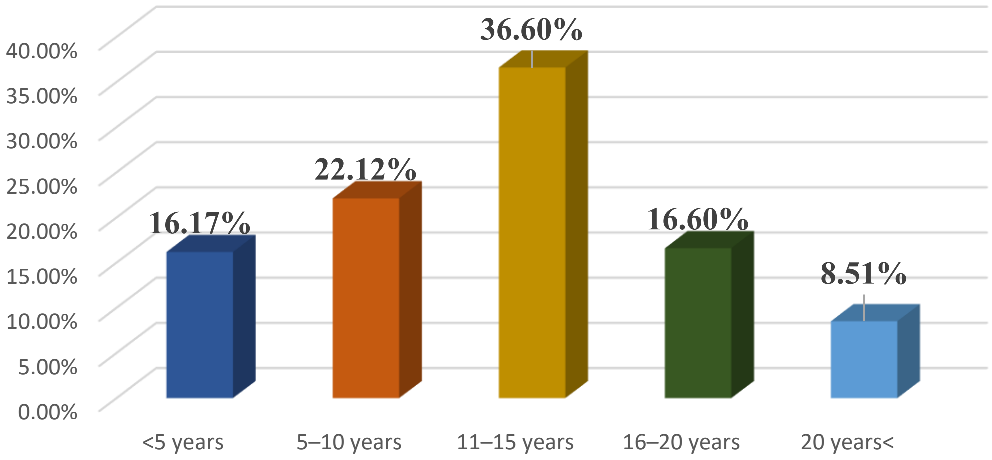


Figure 4.5: Experience of Stakeholders

The education of stakeholders is an essential parameter in any construction project. Stakeholders refer to individuals or groups who have a vested interest in the project's success or failure. These can include clients, investors, project managers, contractors, subcontractors, government officials, and the general public. Educating stakeholders about the project's objectives, timelines, risks, and challenges is crucial to ensure smooth and efficient execution. Proper education can help stakeholders understand their roles and responsibilities, anticipate potential issues, and provide valuable input to improve project outcomes. It can also help build trust and confidence among stakeholders, foster collaboration, and enhance the project's overall reputation. In short, education of stakeholders is an indispensable aspect of any successful construction project. Figure 4.6 depicts the educational backgrounds of the stakeholders. 19.57% had finished vocational training, whereas 42.13% had an undergraduate degree associated with building or a related sector. Around 36.60% held a master's degree and 1.70% had a doctoral degree in their respective fields.

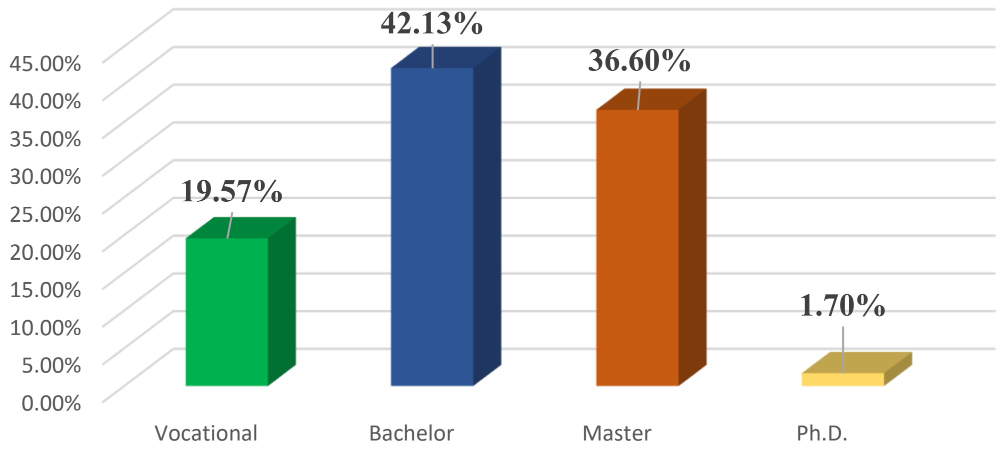


Figure 4.6: Educational qualification of Stakeholders

- **Factor contribution**

Table 4.7 provides a detailed summary of the assessment of feedback received from various stakeholders. The Relative Importance Index (RII) methodology has been applied to prioritize the responses based on their significance in generating construction waste. A total of 28 factors were selected and divided into 4 categories based on their attributes. The analysis revealed that the highest RII score and rank were attributed to the Inattentive working attitudes and behaviours, followed by Inefficient Control and supervision of activities, Ineffective planning and scheduling of activities, Improper handling of materials, Change in the infrastructure design, Complications in the design, Improper storage of construction materials, Frequent Rework in activity, Error in Infrastructural design, Use of Incompetent workers, Architectural or structural drawing errors, Lack of experience of designer, Improper quantity of Material ordering, Improper Material transportation, Poor waste management planning & techniques, Ineffective Process/ Wrong choice of construction process, Inappropriate use of Construction methods, Defective delivered materials, Tools and equipment (Wrong handling /malfunctioning), Wrong teams/subcontractors' selection, Inappropriate project Documents, Error in execution, Improper Activity Coordination, Improper Packaging of materials, Misuse of construction materials, Inappropriate Material quality, Damaged materials used and lastly, Lack of suppliers' involvement in the project.

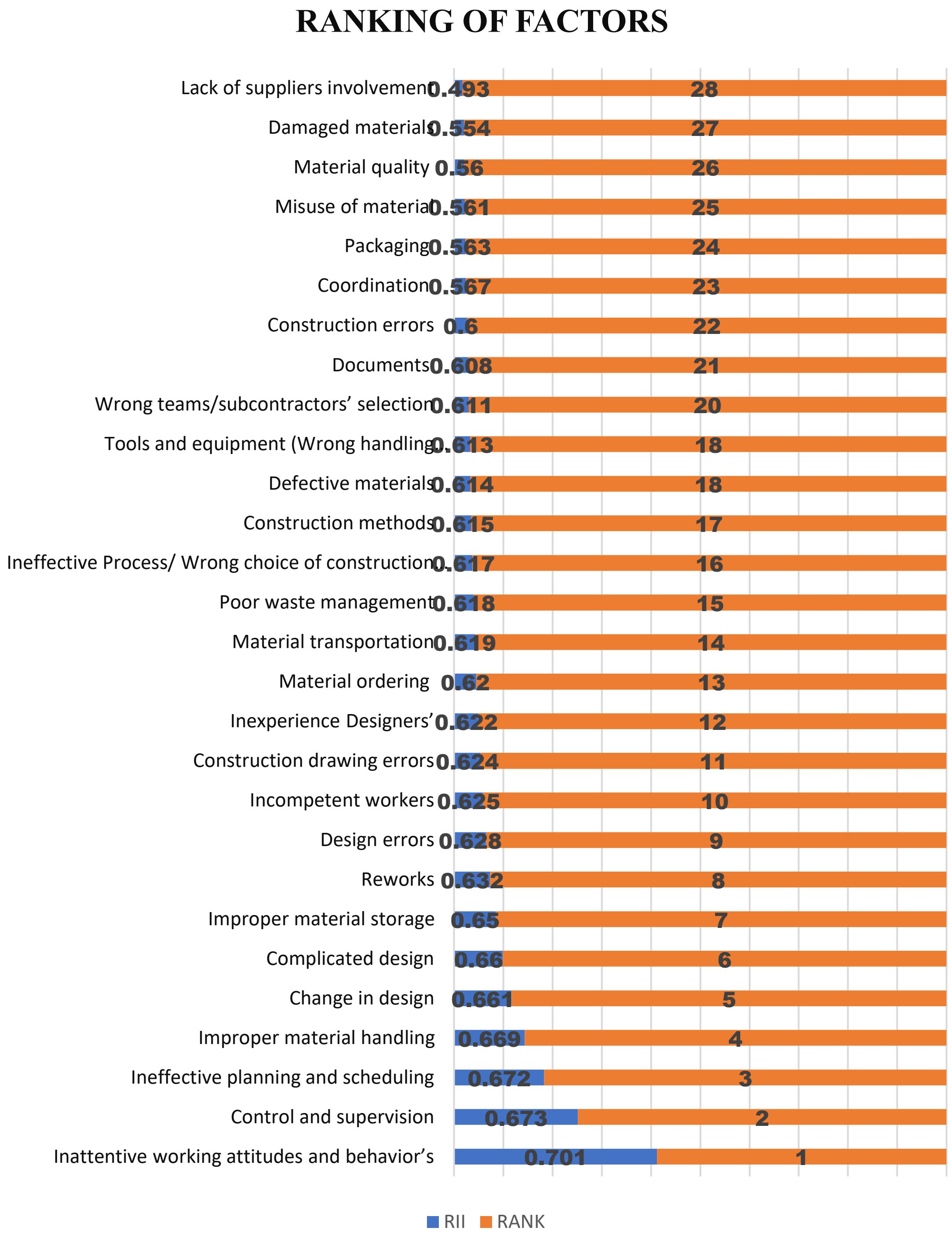


Figure 4.7: Ranking of Factors

- **Cluster Contribution**

Cluster contribution analysis is a methodology employed to pinpoint the primary origins of construction waste in a project or its specific elements/parameters. This approach involves categorizing the construction waste into various clusters, followed by an in-depth analysis of each cluster. This analysis helps determine the quantity of waste produced, its source, and the potential for waste reduction. The main goal of cluster contribution analysis is to enable construction companies and policymakers to devise effective strategies for waste reduction and promote sustainable practices within the construction industry. As a result, this approach facilitates more resource-efficient operations, cost savings, and a diminished environmental impact from construction activities. Figure 4.8 illustrates the contribution of each cluster to the overall generation of construction waste.

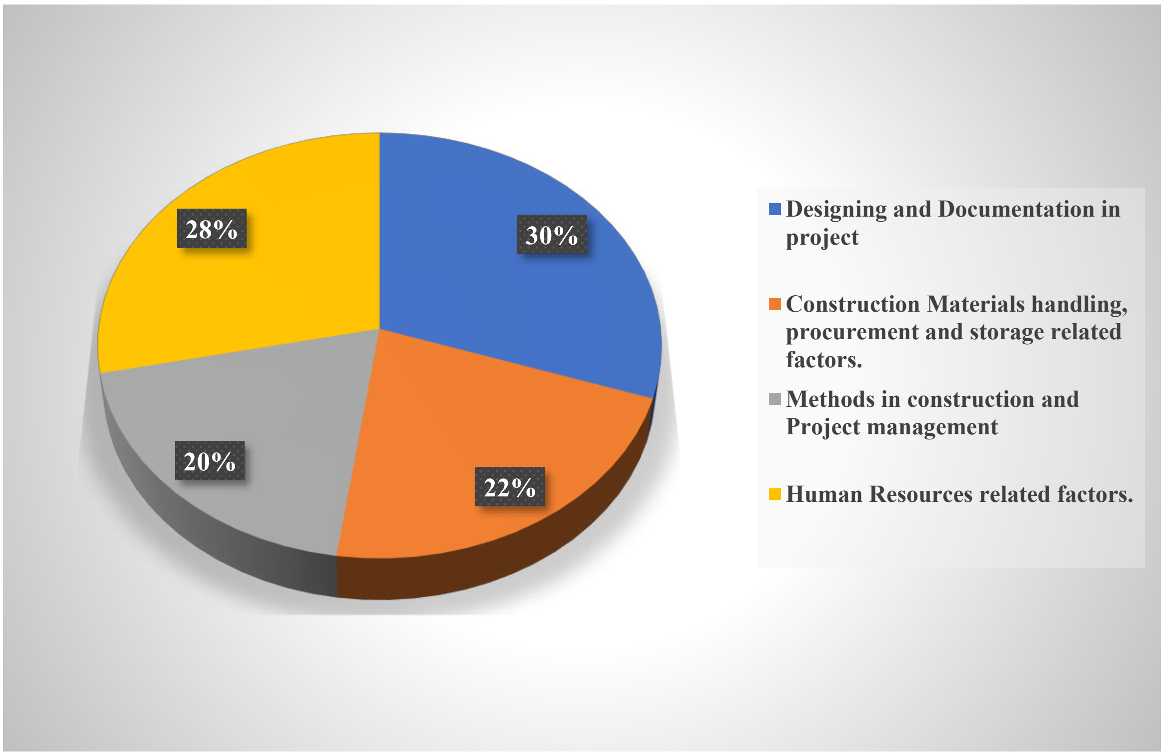


Figure 4.8: Cluster Contribution

A. Designing and Documentation in project

Among all the listed factors under the categories design and documentation Change in the infrastructure design is the most ranked cause of waste having the RII of 0.661. The particular factor significantly contributes towards the waste generation. This cluster contributes about 30 percent of the total generated amount of waste.

B. Human Resources related factors

Table 4.4 displays the RII and ranks of factors categorized under the group "Human Resources" contributing to construction waste. The factor "Inattentive working attitude and behaviors" holds the top rank with an RII value of 0.789, signifying its significant impact on construction waste generation. This factor stands out among all others, indicating its potential to generate a substantial amount of waste. The cluster of factors within "Human Resources" collectively contributes approximately 28 percent of the total waste generated.

C. Methods in construction and Project management

Table 4.4 shows the position and relative importance of components classified as building methods and planning. Ineffective activity scheduling and planning appears as the second most impactful driver to residential project waste generation., with an RII (Relative Importance Index) of 0.672. The factor has the overall third ranking among all considered factor which show the importance of correct methodology adoption and perfect and precise planning. The cluster is responsible for contributing about 20 percent of the total waste generation.

D. Construction Materials handling, procurement, and storage related factors

Total eight factors fall under the material and procurement group and are shown in table 4.4 In this particular group Improper storage of construction materials factor has been rank as the most responsible factor for generation of construction waste, having RII of 0.650. The particular factor is having overall seventh rank among all the selected factors. As one of the most influencing factor material procurement and storage should have been done more accurately as per requirement. The cluster contributes around 22 percent of total waste generation.

- **Severity of Factors**

The results and analysis of the severity of factors causing construction waste indicate that there are several key factors that contribute significantly to the generation of waste in construction projects. These factors include poor design and planning, inadequate material management practices, and lack of awareness and training among workers. Additionally, the use of non-renewable materials, such as concrete and steel, also contribute significantly to the environmental impact of construction activities. By addressing these factors through the implementation of effective waste management strategies, such as improved planning and design, better material selection and management, and increased awareness and training, construction companies can significantly reduce the amount of waste generated during construction activities while also reducing the environmental impact of their projects. The severity of factors is categorised into three categories high, medium and low. Figure 4.9 indicates the count for the factors according to severity. Out of 28 factors 10 are the very critical factors responsible for the construction waste fall under the highly severe factor, 11 factors contribute moderately to the generation of waste and categorises under low severe category, and lastly 7 factors who are responsible for production of less amount of wastage as compare to other two is considered under less severe category.

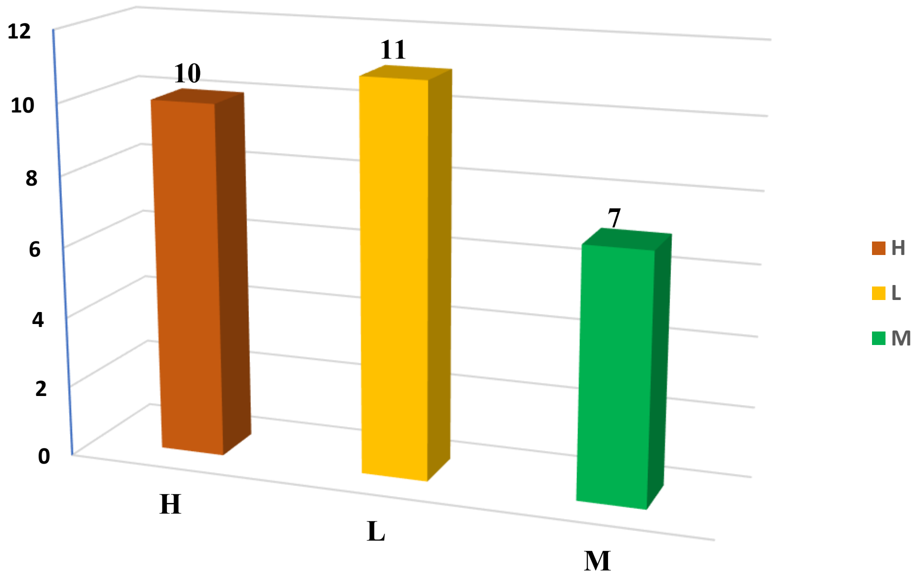


Figure 4.9: Count of Factors According to Severity

Minimizing construction waste necessitates a comprehensive and multifaceted approach, beginning with addressing inattentive working attitudes and behaviours. Implementing rigorous training programs and safety protocols can foster a culture of responsibility and awareness among construction workers. Simultaneously, improving control and supervision of activities is crucial. Utilizing advanced project management tools and technologies, such as Building Information Modelling (BIM), can enhance real-time monitoring and control, ensuring that every aspect of the construction process aligns with efficiency and waste reduction goals. Effective planning and scheduling are integral to waste minimization. Employing lean construction principles and collaborative planning methods can streamline workflows, reduce downtime, and minimize unnecessary material use. Proper handling of materials, along with changes in infrastructure design, necessitates a collaborative effort between architects, engineers, and construction teams. Encouraging interdisciplinary communication and adopting sustainable design principles can lead to optimized material usage and waste reduction. Rework, often a significant source of waste, can be mitigated through stringent quality control measures and advanced project tracking systems. Additionally, addressing the issue of incompetent workers involves investing in training programs and certification processes to ensure a skilled and knowledgeable workforce. Improving the accuracy of architectural and structural drawings involves leveraging advanced design and simulation tools to catch errors before construction begins. Efficient waste management planning and techniques are essential components of a sustainable construction process. Implementing on-site recycling facilities, promoting the reuse of materials, and adopting waste-to-energy technologies can significantly reduce the environmental impact of construction projects. Collaborative efforts with suppliers, including their active involvement in project planning, can enhance material procurement processes, reducing the likelihood of overordering or poor-quality materials. Finally, addressing issues related to tools, equipment, and subcontractor selection requires a rigorous evaluation of suppliers and subcontractors, emphasizing their commitment to sustainability and waste reduction. Comprehensive project documentation, including clear execution plans and guidelines, can further support waste minimization efforts by providing a structured framework for the entire construction process.

4.5 Summary

Identification of the factors generating the construction waste at primary stage help to draft the waste reduction plan, as the nature of waste is dynamic. The study determines and identify the predominant ranking among the twenty-eight factors responsible for the generation of waste from residential projects. The factors which were identified are further classified under four categories, (1)Designing and Documentation in project, (2) Construction Materials handling, procurement, and storage related factors (3) Methods in construction and Project management, and (4) Human Resources related factors. The findings of this study show that human resource and construction method and planning related factors are the major contributor to construction waste generation in residential projects.

Changes in the design of infrastructure, design complications, and infrastructure design errors are also among the most significant factors in the category. Human resources are scored higher on the scale since they are one of the most significant factors in the thorough creation of building trash. Inattentive working attitudes and behaviours, as well as control and supervision, are the top two factors in this group, ranking fifth overall. To minimize the waste generation at source the elements like Attitude toward task, behaviour of the human work force, and precise planning as well as correctly executed waste management plan at site plays a crucial role. Construction Materials handling, procurement and storage related factors and Methods in construction and Project management are ranked third and last, respectively. Amongst all the cluster the designing and documentation contributes the most for the waste generation. For precise and efficient minimization of waste for residential building projects, it is important that all the relevant stakeholders, should properly address all the above factors at each stage of project in aim to minimize the generation of waste.

CHAPTER - 5

QUANTIFICATION ANALYSIS AND PREDICTION MODEL FOR CONSTRUCTION WASTE

5.1 General

Quantification analysis and prediction modelling are essential aspects of managing construction waste, which is a significant environmental concern globally. In this chapter, our primary emphasis lies on the advancement and utilization of these models within the construction industry. Initially, we delve into the significance of quantifying construction waste and comprehending the underlying factors that contribute to its generation. Subsequently, the chapter delves into an exploration of various prediction models employed in construction waste management. These models encompass statistical approaches, artificial intelligence methodologies, and cutting-edge machine learning algorithms. The chapter will also delve into the challenges associated with developing and implementing these models and provide strategies for overcoming these challenges. Finally, the chapter will conclude by highlighting the benefits of using quantification analysis and prediction modelling in construction waste management and its potential for improving sustainability in the construction industry.

5.2 Quantification Analysis and Prediction Model for Construction Waste

Building waste quantification on-site is critical for managing and minimising the negative environmental effects of building activities. Construction waste includes materials that are not needed for the project, such as packaging, excess materials, and demolition debris. By quantifying the waste generated, the project team can identify the main sources of waste and implement measures to reduce it [24]-[25]. Quantification also helps in monitoring the progress of waste reduction efforts and identifying areas for improvement. This can save money by lowering the volume of waste that must be carried and cleaned of. Moreover, quantification of waste can also contribute to meeting sustainability goals and regulatory requirements related to waste management [26]. In summary, building waste quantification is critical in achieving efficient and sustainable construction practices. Estimating the amount of construction trash produced at every phase of a project adequately is crucial for assessing the total quantity generated. In addition to the necessity for precision in waste computation and the ability to identify the characteristics of the waste generated, this work is challenging to do. Accurate segregation of construction waste is of utmost importance in determining the precise volume of generated waste. The dynamic nature of construction activities poses a challenge in accurately identifying and quantifying the waste produced. Furthermore, the lack of sufficient documentation, particularly regarding debris generation, makes data collecting for building waste management a difficult process. [52][54]. Construction waste generation and composition exhibit variability across different project stages, depending on the efficient adoption and execution of on-site waste management policies. Precise waste estimation, along with proper identification and segregation, is essential for monitoring and quantifying the total waste output. This calculated waste quantity plays a vital role in evaluating waste management practices at any construction site. Notwithstanding the limitations, it is reasonable to predict the waste production pattern of a building project. In essence, precisely estimating the quantity of building waste generated throughout every stage of the project is crucial for waste management efficiency. However, achieving this goal demands precision, accurate identification of waste characteristics, and proper segregation, which can be challenging due to the dynamic nature of construction activities and a lack of documentation. Nonetheless, precise trash generation tracking can assist set benchmarks for waste management practises and predict prospective waste generation trends. Forecasting construction waste is critical to developing sustainable building practises. Building organisations acquire the ability to plan and implement efficient waste reduction initiatives by properly forecasting the quantity of trash generated, resulting in a considerable reduction in their total environmental impact. It is possible to employ resource-efficient procedures, significantly minimise landfill waste, and eventually achieve improved cost-effectiveness by properly forecasting the quantity and composition of waste generated during construction. Moreover, precise waste prediction fosters compliance with environmental regulations and enhances a positive corporate reputation. By prioritizing waste prediction, construction companies showcase their dedication to environmental responsibility and play a crucial role in shaping a sustainable future. [27]-[28]. Accurate calculation of waste in construction projects can be achieved through effective estimation and prediction techniques. Redefining waste management in construction projects, estimation focuses on assessing waste generated in past endeavours, while prediction leverages historical data to foresee waste output in future projects. Accurate waste prediction plays a pivotal role in effective planning, strategic waste treatment, and optimizing resource utilization. Construction waste management encompasses all materials produced during the construction process that go unused for their intended purposes. By forecasting waste amounts in a construction project, project managers can proactively strategize for efficient waste handling, curtail overall waste generation, and trim project expenses. A number of variables can influence the amount of trash from construction generated, including the scale of the project, the nature of the building job, material selection, and site management practices. Building waste can be estimated by analysing previously collected information from comparable endeavours, trash generation rates for various construction operations, and decrease in waste objectives. Furthermore, the incorporation of Machine Learning and Artificial Intelligence technology might help predict waste. This enables architects and constructors to mimic methods of construction and identify possible waste-generating activities prior to beginning actual construction. Accurate construction waste forecasting enables project managers to discover waste reduction possibilities, improve project sustainability, and optimise their waste management plan. [31]. Preventing trash from construction is critical to the successful management of building projects. Project managers can create precise estimates regarding the volume of waste generated during construction by analysing previous records, waste production rates, and technology improvements. Effective waste management not only reduces costs but also improves project sustainability by promoting a simplified and ecologically responsible building procedure. Particularly in residential projects, early detection of possible waste is critical for reducing its impact in later phases. Machine learning is a new topic with enormous opportunities in a variety of fields, particularly data from industries processing. Project managers can use machine learning approaches to create strong prediction models that accurately forecast the quantity of trash produced in building endeavours. Machine learning's key role in waste management has the potential to revolutionise the construction industry, opening up new avenues for a more environmentally friendly and economical approach to building endeavours. As evident from recent studies [75][76], machine learning is increasingly gaining importance in predicting construction waste generation. The issue of construction waste poses significant challenges worldwide, impacting the environment negatively and burdening companies with increased costs. By harnessing the capabilities of machine learning models, construction companies can analyse their historical project data, enabling them to predict waste quantities and pinpoint opportunities for waste reduction. This strong technique enables these businesses to improve their planning, optimise resource allocation, reduce costs, and drastically minimise their environmental impact. Furthermore, machine learning enables real-time waste monitoring, allowing for timely interventions and modifications throughout the construction process. In essence, machine learning's game-changing potential in the construction sector resides in its ability to improve waste management practises and build a culture of environmentalism.

5.3 Quantification of construction waste

The process of measuring and calculating the amount of waste generated throughout the construction process is referred to as quantification of building materials. This entails identifying and categorising various sorts of waste materials, such as concrete, lumber, metal, and polymers, as well as estimating the quantities of each. The quantification of construction waste is important for several reasons, including compliance with environmental regulations, reducing project costs, and improving sustainability practices. By accurately quantifying and tracking construction waste, builders and contractors can identify areas for improvement, implement waste reduction strategies, and promote a more environmentally responsible construction industry. This process can also help to ensure that waste is disposed of safely and efficiently, reducing the impact on the environment and surrounding communities [56]. Waste quantification involves measuring and tallying the total amount of waste produced by a specific project at various stages and presenting it as statistical data. It is a performance indicator for waste management plans and helps in monitoring project implementation. Accurate waste quantification data is crucial for strategic development and predictive modelling. Data regarding estimated and actual consumption of fundamental and major construction materials, such as cement, reinforcement steel, bricks, sand, and coarse aggregate, is gathered and meticulously examined. Through this analysis, negative variances or wastages are identified for each project, impacting project productivity. Such scrutiny aids in quantifying the waste generated for specific construction materials, facilitating the identification of areas for waste reduction. The choice of waste quantification techniques can significantly influence project outcomes. Here are some practical guidance and examples: Manual Sorting and Weighing: Technique: Workers manually sort and weigh construction waste on-site. Influence: This method provides accurate data but can be time-consuming and labor-intensive. Example: In a demolition project, workers separate materials like wood, metal, and concrete, weigh each category, and record the quantities for proper disposal or recycling. BIM (Building Information Modeling): Technique: Utilize BIM to estimate and track material quantities throughout the project lifecycle. Influence: BIM can enhance accuracy and efficiency in waste quantification, enabling real-time tracking of materials and waste generation Example: During the design phase, BIM can estimate the amount of excess materials, facilitating better procurement planning and waste reduction. RFID (Radio-Frequency Identification): Technique: Attach RFID tags to construction materials for automated tracking Influence: RFID streamlines the data collection process, providing real-time information on material usage and waste generation. Example: RFID tags on pallets of bricks can help track the number of bricks used in construction, reducing the likelihood of overordering and minimizing waste. Waste Tracking Software: Technique: Implement specialized software for waste tracking and reporting Influence: Software tools streamline data collection, analysis, and reporting, improving overall waste management. Example: A construction project manager uses waste tracking software to monitor and analyse waste generation patterns, identifying opportunities for waste reduction and recycling. Lean Construction Practices: Technique: Apply Lean principles to minimize waste through efficient planning and execution. Influence: Lean practices focus on reducing unnecessary activities and materials, directly impacting waste generation. Example: Implementing just-in-time delivery to reduce excess material stockpiles on-site, thereby minimizing potential waste. Supplier Collaboration: Technique: Collaborate with suppliers to optimize packaging and delivery processes. Influence: Improved communication with suppliers can lead to reduced packaging waste and more efficient use of materials.

Example: Work with suppliers to minimize the use of excessive packaging and explore options for returning or recycling packaging materials. Life Cycle Assessment (LCA): Technique: Conduct a life cycle assessment to understand the environmental impact of materials used. Influence: LCA helps identify materials with lower environmental impact, contributing to sustainable construction practices. Example: Compare the environmental impact of using traditional concrete versus alternative materials with lower carbon footprints.

5.3.1 Methodology

The process of quantifying construction waste involves several essential steps. Initially, a waste audit is carried out to identify the various types and quantities of waste produced during the construction project. Subsequently, the waste is sorted into distinct categories, such as wood, metal, concrete, and other materials. Accurate measurements of weight and volume are taken using scales and other measuring equipment. Lastly, the collected data is analysed to pinpoint opportunities for waste reduction and recycling. Additionally, this analysis aids in setting benchmarks and monitoring progress over time. The primary objective behind this methodology is to equip construction companies with a comprehensive understanding of their waste generation. Figure 5.1 shows the Methodology flow chart for quantification of construction waste

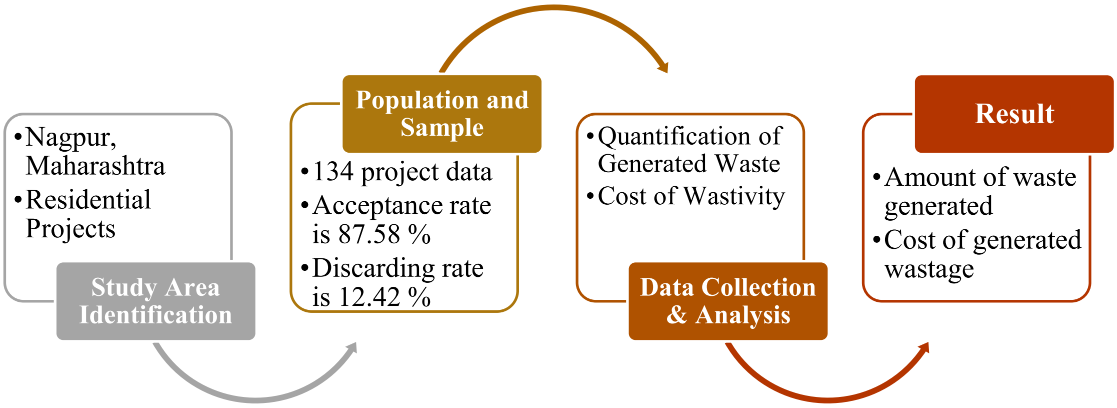


Figure 5.1: Methodology Flow Chart for Quantification of Construction Waste

A. Study Area

Nagpur is the third largest city in India's Maharashtra state and acts as the state's winter capital. It is also known as a prospective smart city and is located in the country's geographic centre. While it ranks as the fourteenth largest city in terms of population, it has high potential for development due to its abundant resources. With a total area of 227.36 km2, Nagpur is a prime city for investment in infrastructure projects, as it boasts an unbeatable location. The city is currently undergoing many residential projects, with more in the queue. Nagpur is growing in both directions as a result of its enormous territory, and people from all sectors are investing in projects that fit within their financial means. There is a range of residential projects, from single dwelling units to high-rise buildings. The city is expanding in all possible directions, thanks to the availability of high-quality public transport like the metro rail. This has enabled the growth of the residential sector throughout the city, from the central business district to the outskirts.

Nagpur, located in the state of Maharashtra, is a rapidly developing city with a growing population and increasing demand for housing. As a result, there has been a significant rise in the number of residential construction projects in the city in recent years. The development of such projects has been instrumental in meeting the housing needs of the city's residents, and has also contributed to the overall growth and progress of Nagpur. With a favourable investment climate, improved infrastructure, and a skilled workforce, Nagpur offers numerous opportunities for developers and investors to launch successful residential construction projects in the city. As the city continues to grow and modernize, the demand for housing is only expected to increase, making Nagpur an attractive destination for residential real estate development. Overall, the infrastructural development of Nagpur has been a significant step towards making the city more liveable, sustainable, and competitive. Figure 5.2 shows the detail map for the chosen study area.

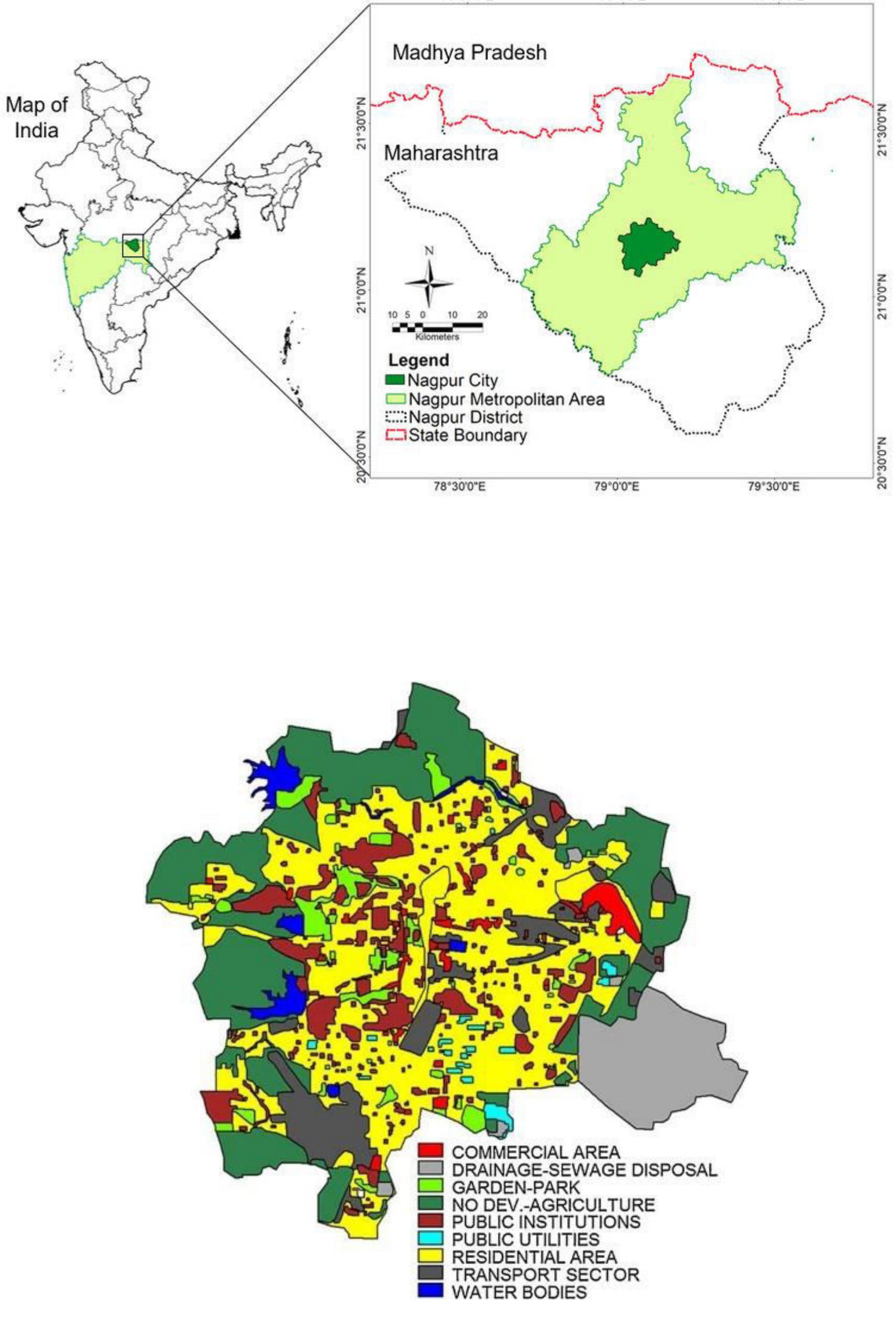


Figure 5.2: Study Area

B. Population and Sample

To collect statistics on construction waste, 153 building ventures were investigated. A total of 134 were used for assessment, with a favourable acceptance percentage of 87.58%. The remainder of 19 initiatives were discarded, resulting in a 12.42% waste rate. To ensure consistency and accuracy in data collection, a simultaneous approach to waste investigation was employed due to the dynamic and variable nature of construction activities and projects, which often have short and varying compilation periods. Large, medium, and small residential constructions were separated into three groups, with about equal shares retained. Categorizing construction projects based on their area of construction has been done for accurate quantification covering maximum types of residential projects. Small projects are considered those that require a construction area of up to 84 square meters. These types of projects are often simple and can be completed within a short time frame, usually less than six months. Examples of small construction projects include home, small residential buildings, and small-scale infrastructure projects. Medium projects selection, on the other hand, considered a construction area of 84 to 130 square meters. These projects are often more complex and require a higher level of expertise, as well as a longer construction time frame. Examples of medium construction projects include mid-sized residential buildings, medium to larger residential buildings, and small to mid-sized infrastructure projects. Larger projects have been considered having construction area more than 130 square meter. Categorizing construction projects into these different sizes based on their area of construction helps in better understanding the project requirements, scope, and management, and can assist in more effective project planning and execution.

Data was collected from projects at different stages of construction, including substructural, superstructural, and finishing stages. Collecting waste data from various stages of construction projects is an essential aspect of studying the impact of construction activities. The data collected provides valuable insights into the types and amounts of waste generated during the construction process. Sample data collection is attached in Appendix-II. By analysing this data, identification of the areas where waste generation is prominent is determined. Furthermore, waste data collected at different stages help in making decisions about material selection, recycling and reuse options, and waste disposal methods. Collecting data at different stages of the construction process allows for a comprehensive understanding of the entire lifecycle of construction waste, from production to disposal. Ultimately, the collection and analysis of waste data from construction projects can lead to more sustainable construction practices and a reduced environmental impact. Construction projects can be broadly categorized into three stages: substructure, superstructure, and finishing stage. Each stage involves a set of specific activities that are necessary for the completion of the construction project. Studying these stages helps in understanding the different components and the sequence of events that take place during construction.

The substructure stage is the first stage of construction and involves the preparation of the site for the construction of the building. This stage involves the excavation of the ground and the construction of the foundation, which supports the building. The substructure stage also includes the installation of drainage systems, utility lines, and any other underground structures required for the project. The superstructure stage is the second stage of construction and involves the construction of the main building structure above the ground. This stage includes the construction of walls, floors, and roofs, and the installation of doors, windows, and other components of the building envelope. The superstructure stage also involves the installation of mechanical, electrical, and plumbing systems that are essential for the functioning of the building. The finishing stage is the final stage of construction and involves the installation of finishes and fixtures that give the building its final appearance. This stage includes the installation of flooring, wall finishes, and ceiling finishes, as well as the installation of fixtures such as lighting, cabinets, and plumbing fixtures. The finishing stage is critical as it is the stage where the building is completed and made ready for occupancy. In conclusion, categorizing construction projects into substructure, superstructure, and finishing stages is essential for the study of construction. Each stage involves specific activities that are necessary for the completion of the construction project. Understanding these stages helps in planning and executing construction projects effectively.

C. Data Collection and Analysis for construction waste.

Estimation-based building waste data collecting entails applying mathematical equations and statistical approaches to approximate the amount of waste generated during a building project. This method entails gathering data from all of the researched project standards in order to predict the quantity of waste that will be generated at three distinct times during a certain project. This estimate is based on variables such as the project's size and scope, the materials used, and the building methods used. Gain a better and more precise measurement of the quantity of waste produced at various stages of the project by gathering data in this manner. One of the advantages of using estimation-based techniques for collecting construction waste data is that it is relatively quick and easy to implement. Since this method involves using existing data and industry standards, it does not require extensive data collection or analysis. Additionally, this method can be used to estimate waste production for a variety of different construction projects, making it a flexible and versatile tool.

- **Amount of Wastage**

This study focuses on analysing the estimated material requirements and actual consumption for various construction projects, including materials like cement, bricks, reinforcement steel, sand, coarse aggregate, floor finishes, and wall finishes. The aim is to identify negative variances or wastages in significant materials for each project. The floor size of each project is derived using the principal building plan to validate the anticipated material demands. The waste generated during construction is meticulously quantified and analysed at every stage. Calculating waste is crucial for effective waste management, as it helps determine the amount of material lost due to inefficiencies in the system. The waste calculation formula is straightforward, involving subtracting the estimated material consumption from the actual consumption to obtain the wasted amount. To determine the total amount of wastage for a specific item, Equation 1 is applied.

Amount of waste = [Actual consumption – Estimated consumption]

To gather information for a project, data is collected on various aspects such as the type of construction, its current stage, and measurements including floor area, plinth area, foundation area, and volume. To determine the required number of materials, an estimate is made based on the bill of quantities, and the actual procurement amount is calculated by referring to the procurement book and books of accounts. The quantities estimated and used throughout all stages are recorded and analysed to keep track of the project's progress.

The exact amount of wastage is computed particularly the amount of waste generated for small project in substructure stage, total 30 projects were considered for the selected categories of project. The selection of the cluster of small projects was done by the area of construction. The selected area of plinth is kept in between 53 to 84 square meters. The estimation has been done for the quantum of construction done in the selected project, as well as the actual consumption or the procured quantity has been studied and the amount of waste generated for the major civil materials has been calculated by using Equation 1. The waste generated during the substructure stage for medium-sized projects, which was compiled from data collected from 40 projects in this category. Selection of medium projects was based on their plinth area, which was limited to between 84 and 130 square meters. The amount of construction work carried out in each selected project was estimated, and the actual consumption and procured quantity were analysed to calculate the amount of waste generated for major civil materials, using Equation 1. The data pertains specifically to waste generation in the substructure stage of larger projects. The selection of the projects was based on their plinth area falling within a specific range of 130 to 372 square meters. The analysis involved evaluating both the actual consumption and the quantity of construction carried out in each project, and then applying Equation 1 to determine the amount of waste generated by the key civil materials.

The superstructure stage, the second part of the construction project, entails determining the amount of waste generated. Civil engineering materials are the primary materials considered during this phase. The number of storeys were considered from ground floor till seventh storey residential projects. The computation of waste generated during the superstructure stage of 30 small projects that were selected based on their construction area. The number of storeys were single storey projects. The slab area of construction for the selected projects ranges from 56 to 167 square meters. The waste generated for major civil engineering materials has been calculated using Equation 1, which involved estimating the amount of construction done, examining the actual consumption, or procured quantity, and determining the waste generated. The amount of waste produced during the superstructure phase of 40 medium-scale projects that were chosen on the basis of their construction area. The slab area of construction for these projects varies from 167 to 517 square meters. The number of storeys included were from ground till three storey projects. To calculate the waste generated for significant civil engineering materials, Equation 1 was employed. This equation entailed estimating the quantity of construction work completed, examining the actual consumption, or procured quantity, and determining the resulting waste. The waste produced during the superstructure stage of 64 large-scale projects, selected based on their construction area. These projects have a construction slab area that ranges from 517 to 2973 square meters. The number of storeys considers from ground till seventh storey. To determine the amount of waste produced for important civil engineering materials, Equation 1 was utilized. The equation involves calculating the quantity of construction work completed, evaluating the actual amount consumed or procured, and determining the waste that results from it.

The final stage of the construction project is known as the finishing stage, where all the necessary materials for finishing are utilized. During this stage, the calculation of wastage is performed for all the materials used in the finishing work of the structure. The measurement of the slab area is taken into account for determining the quantity of wastage. A total of 30 small projects were chosen based on their slab area, all of which were single storey. Using Equation 1 for the primary building materials, the amount of waste produced during the finishing stage was then estimated. The construction slab areas of the selected projects ranged from 56 to 167 square meters, and the calculation involved estimating the amount of construction work done, analysing the actual consumption or procured quantity, and finally determining the amount of waste generated. An investigation was carried out to quantify the amount of waste produced during the finishing phase of 40 medium-scale building projects selected depending on their slab area. The plinth area of these projects ranged from 167 to 517 square meters, and they consisted of buildings ranging from a single storey to three storeys. To calculate the amount of waste generated for important civil engineering materials, Equation 1 was used. This equation involved estimating the amount of construction work completed, analysing the actual consumption or procurement quantity, and then determining the resulting waste. To determine the quantity of waste generated during the finishing stage of 64 large-scale projects, chosen based on their construction area, an equation (Equation 1) was utilized. The projects have a construction plinth area that ranges from 517 to 2973 square meters and spans up to seven storeys. The equation involves assessing the amount of construction work completed, the actual number of materials used or procured, and calculating the resulting waste generated from these factors. Sample data is attached in Appendix-II.

- **Wastivity**

Wastivity, in the context of waste management, represents the overall effectiveness of waste management practices. It is gauged by comparing the waste material produced by a project to the projected material consumption. Lowering the wastivity percentage becomes crucial for optimizing the efficiency of any undertaking. The calculation of wastivity involves employing mathematical Equation 2. This concept finds significant application within the construction industry, where it measures the proportion of waste generated during a construction project relative to the total weight of materials utilized. The computation of wastivity is important because it helps contractors and builders to identify areas where they can reduce waste and save costs. By calculating wastivity, construction professionals can track the amount of waste generated during a project and use this information to optimize their processes and improve their environmental sustainability. Significantly, the computation of wastivity has several benefits for construction projects. First, it helps contractors to identify areas where they can reduce waste and save costs. By minimizing waste, they can reduce the amount of materials needed and save money on disposal fees. Second, the computation of wastivity can help to improve the environmental sustainability of a project. By reducing the amount of waste generated, construction professionals can reduce the carbon footprint of their projects and promote sustainable building practices. Finally, calculating wastivity can help to improve the efficiency of a project. By identifying areas where waste can be reduced, contractors can optimize their processes and save time and money. Overall, the computation of wastivity is an essential tool for construction professionals looking to improve their bottom line and their environmental impact.

$$\mathbf{Wastivity} = \frac{\mathbf{wastage \times 100}}{\mathbf{estimated\ consumption}} \qquad \mathbf{\ldots\ldots\ (2)}$$

Each stage of the construction project has been assessed for wastage, and the total wastage has been determined for each stage. Sample wastivity data is attached in Appendix-II. Determining the amount of wastage for substructure, superstructure as well as the finishing stage the wastivity for each material considered at every stage has been computed, comprehensively for each floor or storey the computation of wastivity has been done to achieve higher degree of accuracy.

- **Cost of Wastage**

Construction materials play a vital role in shaping our built environment. However, the production, transportation, and disposal of these materials come at a cost, both financially and environmentally. The cost of waste in construction materials is significant, with up to 30% of construction materials being wasted during the construction process. This waste can result in increased costs for the construction project, as the excess materials need to be disposed of, leading to additional disposal fees and transportation costs. Moreover, the environmental impact of this waste is significant, as it can contribute to greenhouse gas emissions, landfills, and pollution. Therefore, minimizing construction waste is crucial to reducing the overall cost of construction projects and preserving the environment. In addition to the direct costs of waste in construction materials, there are also indirect costs associated with this waste. For example, the production of construction materials requires significant energy and resources, including water, fuel, and raw materials. When construction materials are wasted, these resources are also wasted, resulting in higher energy and resource consumption.

Moreover, the disposal of construction waste can also result in additional costs, such as pollution and environmental damage. Therefore, minimizing waste in construction materials not only reduces the direct costs of construction but also leads to a more sustainable and efficient use of resources. The cost of building is an important consideration in establishing the viability of any project. The amount of waste generated during the construction process is a significant contributor to the cost of construction. It is therefore essential to manage waste effectively to minimize the overall cost of the project. The cost associated with waste generation can be calculated by multiplying the current SSR (State schedule rate) by the amount of wastage generated. This equation helps in estimating the cost incurred due to waste generation and can aid in making informed decisions about waste management strategies that can reduce costs and improve the sustainability of construction projects. Sample coast analysis is attached in Appendix-II. Therefore, it is important to factor in the cost of waste generation when making decisions about construction projects.

5.3.2 Results and Discussion

A. Wastivity

The graph below depicts the median amount of waste produced throughout the three stages of a building endeavour. The primary phase, known as the substructure stage, involves activities such as casting the foundation, plinth, and ground columns, and is responsible for a wastage range of 12 to 14 percent for bricks, 11 to 13.5 percent for aggregates, 10 to 14.5 percent for sand, 10 to 12.6 percent for cement, and 4 to 8.5 percent for steel reinforcement. The results are applicable to projects of all sizes. The second phase, referred to as the superstructure stage, involves casting structural elements such as beams, columns, and slabs, and also includes brickwork. This phase produces the largest amount of waste. The average wastage during this stage ranges from 12 to 12.25 percent for bricks, 11 to 12.25 percent for aggregates, 10 to 11.5 percent for sand, 12 to 12.2 percent for cement, and 6 to 6.2 percent for steel reinforcement.

The last phase, commonly known as the finishing stage, also adds substantially to the project's waste stream. Plastering, wall finishes, and floor finishes are all part of this phase of construction. The wastage percentage for cement during this stage ranges from 11 to 13.7 percent, while the wastage range for sand is 10 to 12.4 percent. Internal and external wall finish wastage proportions fluctuate between 10 to 11.3 percent and 10 to 11.8 percent, respectively, while floor finish wastage runs from 9 to 10.3 percent.

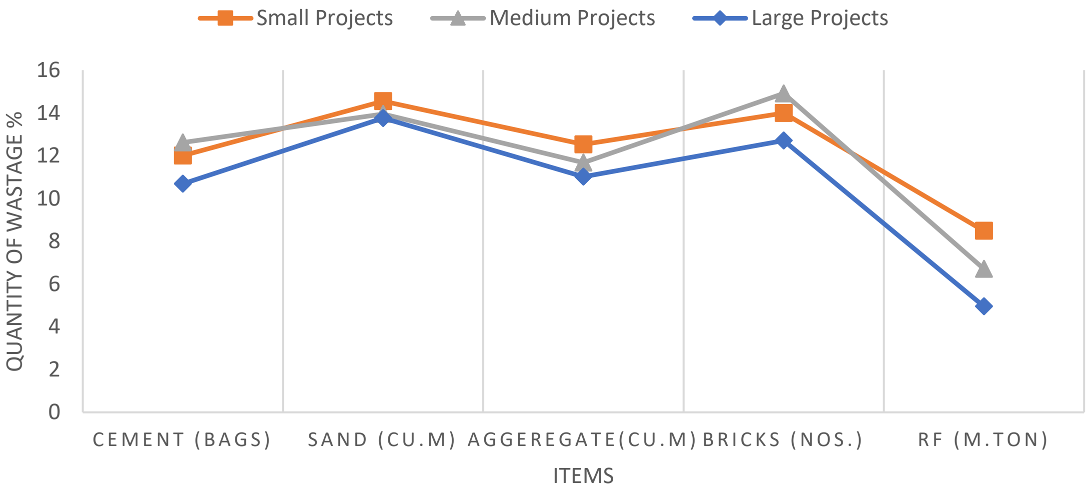


Figure 5.3: Average Wastivity % For Projects in Substructure Stage

Figure 5.3 depicts the waste produced throughout the substructure stage of building ventures, divided into three sizes (small, medium, and large). In minor projects, cement waste accounted for around 12% of total waste, whereas sand waste accounted for approximately 14.5% of total waste. Bricks accounted for around 14% of waste, aggregates 13.5%, and reinforcement 8.5%. Wastage rates for medium-sized projects were slightly higher, with cement waste accounting for 12.5%, sand waste accounting for 13.7%, brick waste accounting for 15%, and aggregate waste accounting for 11%. Reinforcement waste was about 6.7%. For larger projects, the wastage rate decreased for all materials. Cement wastage was about 10.6%, sand wastage was 10.7%, while brick, aggregate, and reinforcement wastage were 12.7%, 11%, and 5%, respectively.

The study indicates that wastage during the substructure stage of construction projects is a significant concern, with varying rates depending on the project size. While larger projects have lower wastage rates, there is still a considerable amount of waste produced. It is essential to develop strategies to reduce wastage during this stage of construction to minimize the environmental impact and improve the efficiency of the construction process. By identifying areas of high wastage and implementing targeted measures, construction projects can become more sustainable and cost-effective.

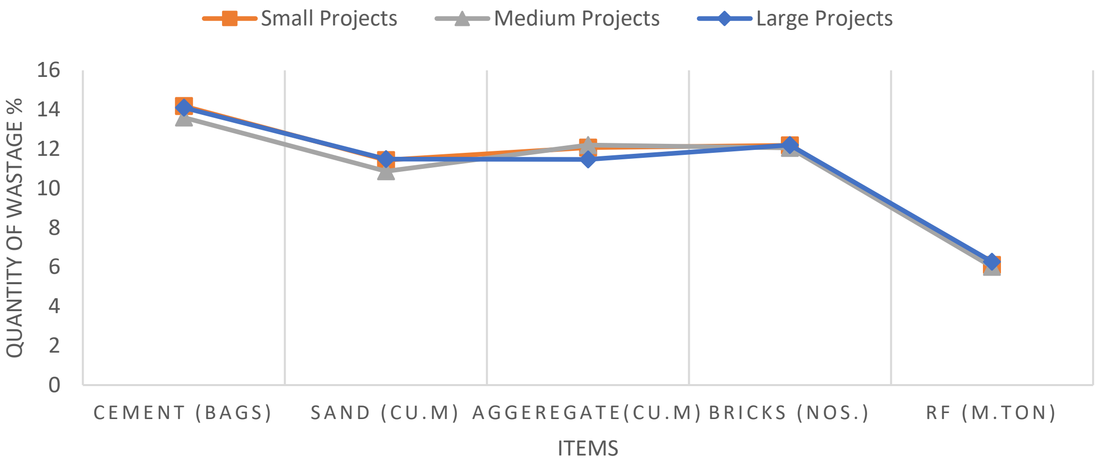


Figure 5.4: Average Wastivity % For Projects in Superstructure Stage

Figure 5.4 depicts the amount of waste produced during the superstructure stage in small, medium, and large-scale construction projects. The percentages of waste for bricks, sand, coarse aggregate, cement, and reinforcing vary depending on the scale of the project. The percentages of waste for minor projects were 12.19% for bricks, 11.4% for sand, 12% for coarse aggregate, 12.1% for cement, and 6.1% for reinforcing. Wastage percentages for medium projects were 12.06% for bricks, 10.8% for sand, 12.2% for coarse aggregate, 12.06% for cement, and 6.01% for reinforcing. Wastage percentages for large-scale projects were 12.2% for bricks, 11.49% for sand, 11.47% for coarse aggregate, 10.6% for cement, and 4.9% for reinforcing, all computed as a percentage of total expected material. These statistics show that waste percentages vary depending on the size of the construction project. For all project sizes, the highest wastage percentage was observed for bricks, with the small project generating the highest wastage percentage of 12.19% and the large project generating a slightly lower percentage of 12.2%. The wastage percentages for sand and coarse aggregate were similar for all project sizes, with the medium project generating the lowest percentage of 10.8% for sand and the large project generating the lowest percentage of 11.47% for coarse aggregate. The wastage percentages for cement and reinforcement were also similar for all project sizes, with the large project generating the lowest percentage of 10.6% for cement and 4.9% for reinforcement. Overall, the wastage percentages presented in Figure 5.4 highlight the need for efficient material management during construction projects of all sizes. By identifying the materials that have the highest wastage percentages, project managers can take steps to minimize waste and reduce costs. Furthermore, the data presented can serve as a benchmark for future projects, allowing for more accurate estimations of material requirements and wastage.

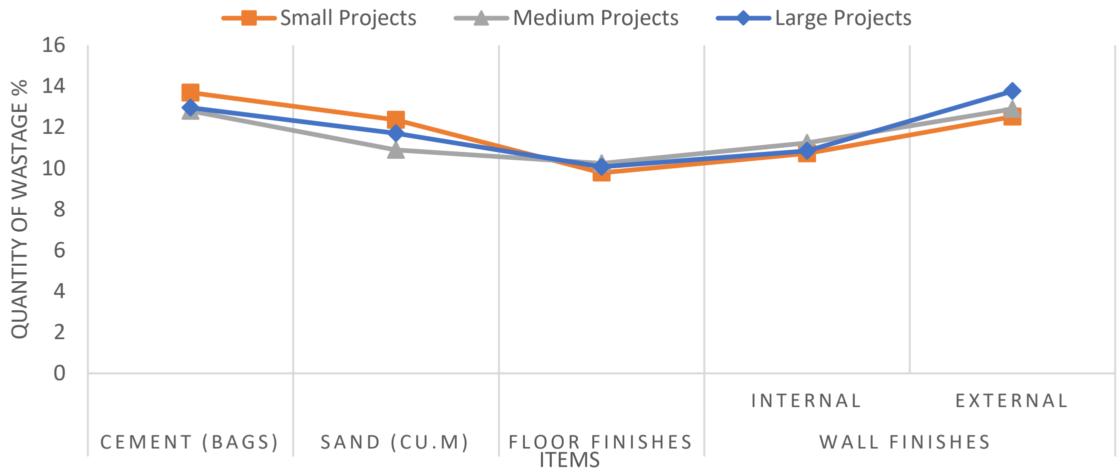


Figure 5.5: Average Wastivity % For Projects in Finishing Stage

Figure 5.5 depicts data on waste produced during the last finishing stage of building assignments. The data demonstrates differing wastage rates for different products based on the size of the projects. Smaller projects had higher wastage rates, with 13.6% and 12.3% for cement and sand, and 11.5% and 9.7% for external and internal wall finishes, respectively. In smaller endeavours, the waste rate for floor finishes was 9.7%. Medium-scale projects, on the other hand, showed significantly lower wastage rates of 12.4% and 10.8% for cement and sand, respectively, as well as 11.2% and 10.8% for internal and external wall finishes, and 10.2% for floor finishes. Larger projects, on the contrary conjunction, boasted even more efficient use, with wastage rates of 11.9% and 11.7% for cement and sand, respectively, 10.8% and 11.7% for internal and external wall finishes, and 10.07% for floor finishes. These data highlight how the size of the project influences the quantity of waste generated during the finishing stage, with smaller projects producing more garbage than medium and large-scale equivalents. The highest wastage rates were observed for cement and sand, which are key materials used in construction. Wall finishes, both internal and external, also generated significant amounts of waste. Floor finishes had lower wastage rates compared to cement, sand,

and wall finishes. In conclusion, the data from Figure 5.5 emphasises the significance of minimising waste formation during the completion stage of construction projects, particularly for smaller projects. Efforts should be made to reduce wastage rates for cement and sand, as well as wall finishes. This can be accomplished by improved planning, more effective material utilisation, and proper waste management practises. By reducing waste generation, construction projects can become more sustainable and cost-effective.

B. Cost of wastage

The cost is a critical parameter when it comes to decision-making and strategy development. A formula is used to assess the cost of a project that takes into consideration the total amount of waste generated at various stages of the project, such as the substructure, superstructure, and finishing stages. This formula involves multiplying the waste amount with the current state scheduled rates of major civil engineering materials for the year 2022 in the study area. This calculation is used for all residential infrastructure projects, regardless of their scale, including small, medium, and large projects.

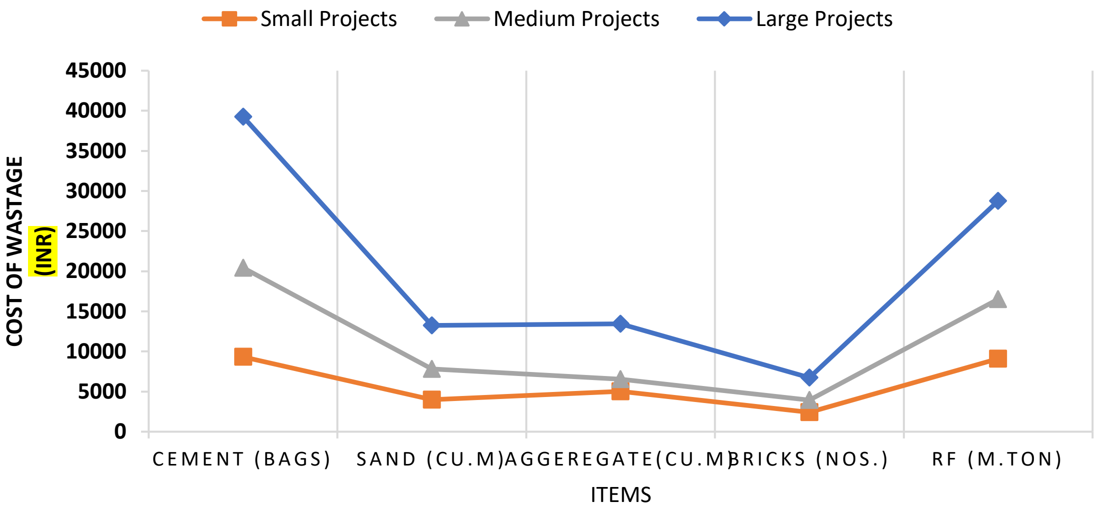


Figure 5.6: Average Cost of Wastage for Projects in Substructure Stage

The cost of wastage in construction projects was analysed for substructure and superstructure stages across different project sizes, and the findings are presented in

Figures 5.6 and 5.7. According to Figure 5.6, the substructure stage wastage cost was 6 percent for smaller projects, 5.8 percent for medium-sized projects, and 5 percent for large-scale projects. Furthermore, Figure 5.7 shows that the cost of wastage at the superstructure stage was 8% for smaller projects, 7.5% for medium-sized projects, and 7% for large-scale projects. Figure 5.6 depicts the cost of waste produced during the substructure stage of construction projects. The analysis shows that the cost of waste decreases as the project size grows. Smaller initiatives, in particular, had a higher wastage cost of 6%, while large-scale projects had a cost of 5%. Figure 5.7 investigates the cost of wastage for the superstructure stage, revealing that the cost lowers as the project size grows. For instance, smaller projects had a wastage cost of 8 percent, while larger projects had a cost of 7 percent. In conclusion, the study analysed the cost of wastage for substructure and superstructure stages in different construction project sizes. Figure 5.6 and 5.7 present the findings for the wastage cost generated in each stage for smaller, medium, and large projects. The results demonstrate that wastage costs decrease as the project size increases, with larger projects exhibiting a lower percentage of wastage cost in both substructure and superstructure stages.

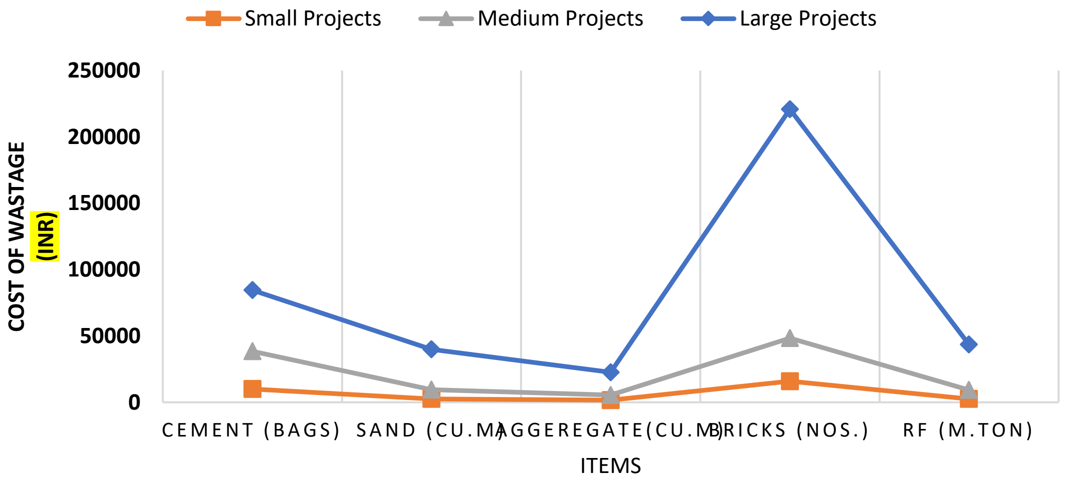


Figure 5.7: Average Cost of Wastage for Projects in Superstructure Stage

Figure 5.8 presents information on the cost of waste produced during the finishing stage in various construction projects. Small, medium, and large projects are taken into consideration. According to the data findings, the wastage cost during the finishing stage varies across different project scales. Wastage contributes to around 4.5% of the overall project cost for small-scale projects. Meanwhile, medium-scale projects have a significantly smaller percentage terms, around 4%, credited with finishing-stage waste expenses. In the context of large-scale projects, waste costs are specifically equivalent to 4% of the entire cost of materials used during the project.

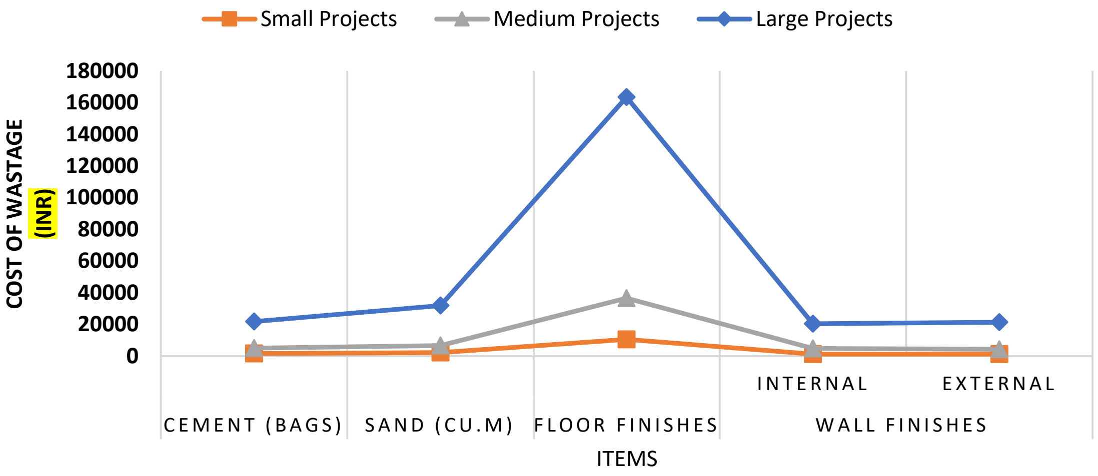


Figure 5.8: Average Cost of Wastage for Projects in Finishing Stage

5.4 Prediction Model for Construction Waste

The accurate prediction of construction waste plays a vital role in promoting sustainable building practices. Construction waste encompasses any materials resulting from construction or demolition that are not intended for reuse or recycling. To ensure effective waste management and resource preservation, it is crucial to estimate the amount of waste generated. This prediction can be achieved through methods like waste audits or the analysis of construction plans and material specifications. By gaining insights into the types and quantities of materials utilized, it becomes possible to make informed estimates of waste generation and implement effective measures to minimize it. The anticipation of construction waste holds significant importance in advancing the sustainability of the construction industry. It aims to curtail the environmental consequences of construction operations and safeguard valuable resources. Machine learning is a useful tool for forecasting the amount of waste generated on building sites

[78]. Machine learning models can be taught to accurately predict the amount of waste produced for a specific project by using historical data from previous projects. This information includes the types of construction materials used, the project schedule, and the project's magnitude and scope. Machine learning models can provide precise projections of building waste through meticulous analysis and the use of advanced algorithms. As a result, project managers may make better informed decisions concerning waste management and disposal, resulting in more efficient and sustainable construction practises and a lower environmental effect of such projects.

Decision trees and k-nearest neighbors (KNN) stand as valuable machine learning tools with applications that significantly enhance decision-making processes in the realm of construction waste management. In the case of decision trees, a pivotal application lies in Waste Sorting Optimization. Here, decision trees prove instrumental in classifying various construction waste types by considering attributes such as material composition, size, and recyclability, ultimately streamlining the sorting process at waste collection sites. This optimization not only augments recycling endeavours but also mitigates landfill contributions. Another notable use involves Predictive Modelling for Waste Generation, where decision trees leverage historical data and project specifics to forecast construction waste output, empowering construction companies to devise effective waste management strategies. Furthermore, decision trees play a crucial role in Risk Assessment for Waste Management Strategies, enabling decision-makers to evaluate and choose strategies that strike a balance between cost-effectiveness, environmental impact, and regulatory compliance.

On the other hand, KNN finds practical applications in Similarity-Based Waste Disposal Planning, contributing to efficient waste management by identifying analogous construction projects based on waste characteristics. This information aids in planning waste disposal strategies that have proven successful in comparable contexts. KNN also proves valuable in Dynamic Bin Allocation for Waste Collection, dynamically assigning waste collection bins based on current waste compositions at construction sites. This adaptability optimizes resource utilization by ensuring bins are strategically placed to address evolving waste patterns. Additionally, KNN serves in Monitoring and Anomaly Detection, offering real-time insights into waste generation patterns. It identifies anomalies in waste composition or generation rates, enabling early intervention to mitigate improper waste disposal or unforeseen environmental impacts. In a holistic approach, a Combined Approach integrates decision trees and KNN into an Integrated Decision Support System for construction waste management. Decision trees guide high-level decisions, while KNN provides fine-grained insights based on similarity to past cases. This synergy yields a comprehensive and adaptive decision-making framework, leveraging the strengths of both algorithms and offering a holistic approach to construction waste management. Through the integration of these machine learning algorithms, organizations can make more informed decisions, optimize resource allocation, and contribute to sustainable and environmentally friendly construction practices.

Effective construction waste management plays a pivotal role in advancing sustainability objectives within the construction industry. The integration of sophisticated, data-driven models like decision trees and K-nearest neighbors (KNN) into sustainable waste management strategies is a key avenue for enhancing decision-making processes and minimizing environmental impact. Decision trees emerge as potent tools in construction waste management, offering predictive capabilities to optimize decision-making. Through the analysis of historical data related to waste generation, disposal, and recycling rates, decision trees discern patterns, enabling predictions about future waste streams. This insight aids construction project managers in efficiently planning waste management strategies. Integration with sustainability strategies involves predictive planning, resource allocation optimization, and a commitment to continuous improvement through regular model updates. In parallel, K-nearest neighbors (KNN), a machine learning algorithm for classification and regression tasks, proves valuable in construction waste management. Applied here, KNN analyses similarities between different waste types and recommends recycling or disposal methods based on historical data. The integration with sustainability strategies includes waste classification, real-time decision support, and fostering collaboration and knowledge sharing. To maximize the impact of decision trees and KNN models, integration with broader sustainability strategies is essential. Circular economy principles, emphasizing the reuse, recycling, or repurposing of materials, align with the goals of reducing waste. Stakeholder engagement, involving contractors, suppliers, and local communities, fosters a collaborative approach to waste management. Additionally, technological innovation, such as sensors and smart waste management systems, enhances data accuracy for decision trees and KNN models, improving overall waste management efficiency. The integration of decision tree and KNN models with sustainability strategies in construction waste management represents a forward-thinking approach to improving environmental outcomes in the construction industry. By leveraging data-driven insights and combining them with broader sustainability initiatives, construction projects can achieve higher efficiency, reduce waste, and contribute significantly to a more sustainable future.

When selecting an algorithm for developing a machine learning model, several critical factors have been carefully considered to ensure optimal performance and results. Firstly, understanding the nature of the problem at hand is crucial as different algorithms are designed for specific tasks, such as classification, regression, or clustering. Assessing the size and complexity of the dataset has been treated equally important, as some algorithms may be more suitable for large datasets, while others are more efficient with smaller ones. Additionally, the interpretability of the model and the ease of implementation have been taken into account, especially in applications where model transparency is essential. Consideration of computational resources is paramount, as some algorithms may require significant processing power or memory. Furthermore, evaluating the algorithm's robustness to outliers and its ability to handle missing data can impact the model's overall reliability. Finally, staying informed about the latest advancements in machine learning and understanding the strengths and limitations of various algorithms are also considered to make informed decisions in aligning the chosen algorithm with the specific requirements of the task at hand.

5.4.1. Methodology

Creating a machine learning model for prediction requires a number of critical processes. The first emphasis is on data collection and pre-processing to ensure data cleanliness, uniformity, and proper formatting. Subsequently, the process involves feature selection and engineering to pinpoint essential variables and transform them into a usable format for the model. Following the important features have been discovered, the next step is to choose an appropriate approach based on the nature of the problem and the available data, that includes logistic regression, decision tree models, or artificial neural networks. After selecting a method, the chosen model is trained using a subset of the data, while the remainder is utilised for validation to guarantee generalizability and minimise excessive overfitting. Furthermore, parametric adjustment is carried out to improve the model's performance and produce better outcomes. Finally, the real-world performance of the model is assessed by evaluating it on a separate test set. It is crucial to recognize that the development of machine learning models is an iterative process. Adjustments and fine-tuning may be required to enhance accuracy and reliability, making it a continuous journey towards achieving the best possible outcomes.

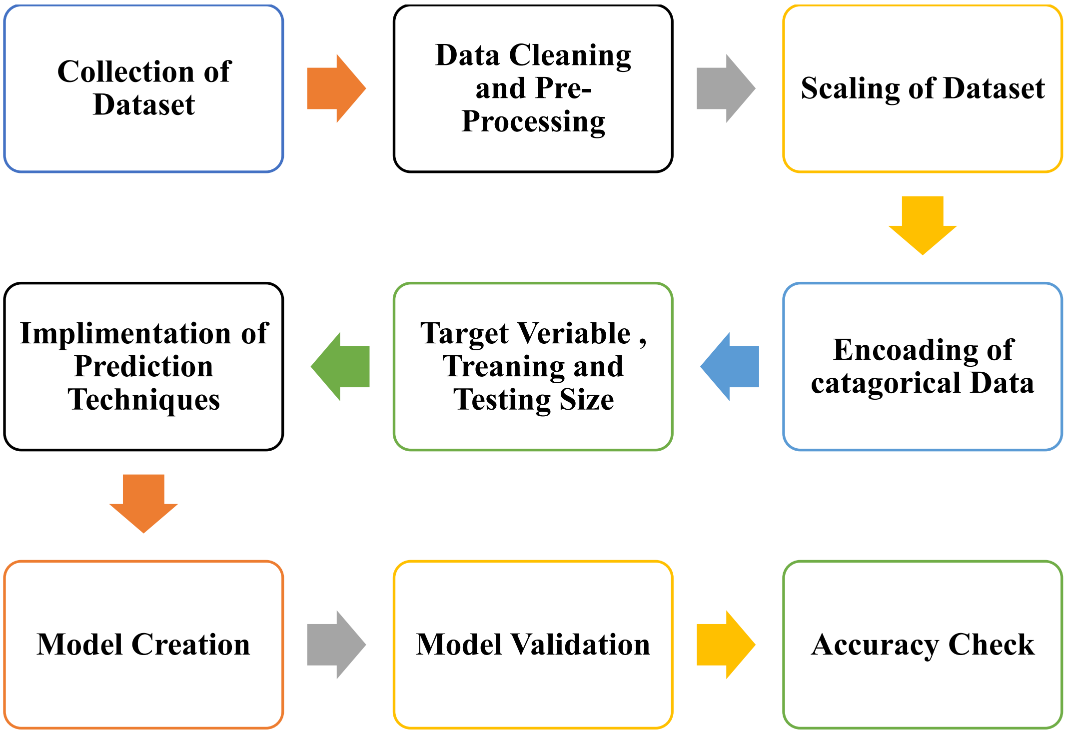


Figure 5.9: Flow Chart of Steps for ML Prediction

The flow chart depicted in Figure 5.9 outlines the various steps involved in the process of machine learning prediction. In the realm of machine learning, a dataset represents a cohesive collection of data treated as a single entity by a computer, serving as the foundation for analysis and prediction. To ensure comprehensibility to machines, the data is structured accordingly. In this specific scenario, the dataset originates from diverse construction projects sharing common traits and utilizing similar construction materials. The raw data was gathered from a total of 153 construction sites, encompassing details concerning the waste production during three distinct construction stages: substructure, superstructure, and finishing stages. Because the majority of the independent variables determining the outcome of the model were classified in nature, thoughtful choice of suitable machine learning methods was required. To ensure the dataset's reliability, a thorough data cleaning process was executed, eliminating any duplications or errors present in the collected information. Moreover, the data underwent transformation to conform to a particular scale. The process of data cleaning and pre-processing holds immense significance in readying the data for machine learning models, particularly predictive ones. Data cleaning encompasses the identification and rectification or elimination of errors, missing values, or discrepancies within the dataset. Additionally, it is crucial to detect and eliminate outliers that could distort the outcomes of a predictive model. After the data has been cleaned, pre-processing comes into play, involving the conversion of the data into a suitable format that can be utilized by the machine learning algorithm. This includes feature scaling, which involves scaling the data to a range that is suitable for the algorithm, and feature selection, which involves selecting the most relevant features for the model. Additionally, data normalization, where data is transformed into a standard format to make it easier to compare across different variables or datasets, is another important pre-processing step. Categorical data is a type of data that represents categories or labels instead of numerical values. In machine learning, categorical data needs to be encoded into numerical values so that algorithms can process it. Encoding data that is categorical can be accomplished using a variety of strategies, including one-hot encoding, label encoding, and target encoding. One-hot encoding entails creating a single binary column for every grouping, whereas label encoding assigns every classification a unique integer value. In contrast, target encoding utilizes the target variable to encode the categorical variable. Each of these methods offers distinct advantages and can be chosen based on the specific requirements of the data analysis or machine learning task. The selection of an appropriate encoding method relies on the nature of the dataset and the machine learning algorithm being employed. Accurate encoding of categorical data is vital to ensure precise and effective training and prediction of machine learning models. Therefore, it is imperative to meticulously carry out these encoding steps to enhance data quality and model performance. In this study, a supervised learning approach was adopted to train the model, utilizing about 70% of the dataset for this purpose. The trained model was then evaluated against the target values for each input vector in the training dataset. To fine-tune the model's hyperparameters, validation was employed to obtain a clear assessment. Following this, an unbiased evaluation of the final model was performed using a hold-out dataset, which represented 30% of the total data. This test dataset was used to gauge the model's accuracy in the final stage. Figure 4.3 depicts the comprehensive flowchart illustrating the step-by-step process involved in machine learning prediction. The dataset employed in this study was a collection of data from construction projects exhibiting similar characteristics and materials. Prior to training the model, the data underwent cleaning and transformation to fit a specific scale suitable for the analysis. Ultimately, the supervised learning method was used to train the model for the prediction task. Using machine learning approaches, a leading-edge prediction model has been developed to determine the quantity of waste produced at multiple phases of building operations. For the purpose of data mining and statistical evaluation, the model integrates decision tree-based techniques and the K-Nearest Neighbour (KNN) algorithm, revealing undetected trends and patterns in the information being analysed. Decision trees are very useful for multi-variable assessment because they segregate the data into branch-like frameworks, allowing for accurate waste forecasts at each building stage. The modular tree structure of the decision tree method comprises of branches, root nodes, internal nodes, and leaf nodes. This algorithm constructs an accurate model for training by learning from the information gathered and employing fundamental decisions to predict the value of the target variable. The KNN algorithm, on the other hand, is a simple and easy-to-implement supervised machine learning technique that covers both classification and regression problems. It uses a proximity-based prediction strategy, and the elbow method is used to calculate the appropriate k-value for the dataset. The calculation of the Euclidean distance, as indicated in Equation 3, is critical in this method.

$$d = \sqrt{\{(x22 - x11)^2 + (y22 - y11)^2\}} \qquad \text{……………………} \; \textbf{(3)}$$

The decision tree algorithm serves as a popular and versatile technique in machine learning, applicable to classification and regression tasks alike. It builds a tree-like structure where internal nodes make decisions based on features or attributes, while leaf nodes hold the corresponding input data point's class label or numerical value. Throughout the construction process, the algorithm carefully chooses the most informative feature to split the data, considering an impurity measure like entropy or Gini index. This recursive process continues until certain stopping criteria, such as reaching a maximum depth or minimum number of data points in a leaf node, are met. To produce predictions, raw points of data follow the decisions at every node within the node as they transit the decision tree from the root to the leaf node. Finally, the class label or numerical value allocated to that particular leaf node determines the final result that is generated. The decision tree algorithm is interpretable and versatile, capable of handling both categorical and numerical data. As a result, it serves as a powerful tool for data analysis and predictive modelling. Figure 5.10 presents the flowchart of the decision tree algorithm, which showcases its working methodology for prediction.

Step 1: Data Preparation: The first step is to collect and pre-process the data. This includes cleaning and transforming the data into a format that can be used for training the model.

Step 2: Attribute Selection: The next step is to select the attributes that are most relevant to the prediction task. The objective is to choose the attributes that will best segregate the data into various categories.

Step 3: Building the Tree: Following the selection of the attributes, the decision tree is constructed by recursively partitioning the data into subsets based on the most significant attribute. The property chosen for separating is the one that best divides the data into distinct classes.

Step 4: Determining the Splitting Criteria: There are different criteria that can be used to determine the best split. One common approach is to use information gain, which measures how much information the split provides about the class label.

Step 5: Assigning Predictions to Leaf Nodes: Once the tree has been built Based on the vast majority class of the data used for training that fits into that leaf, an assumption is assigned to each leaf node.

Step 6: Evaluation of the Model: Subsequently, the model undergoes assessment employing an independent test dataset to ascertain its accuracy and performance. This step is crucial in verifying that the model does not suffer from overfitting to the training data and exhibits strong generalization capabilities when faced with new data.

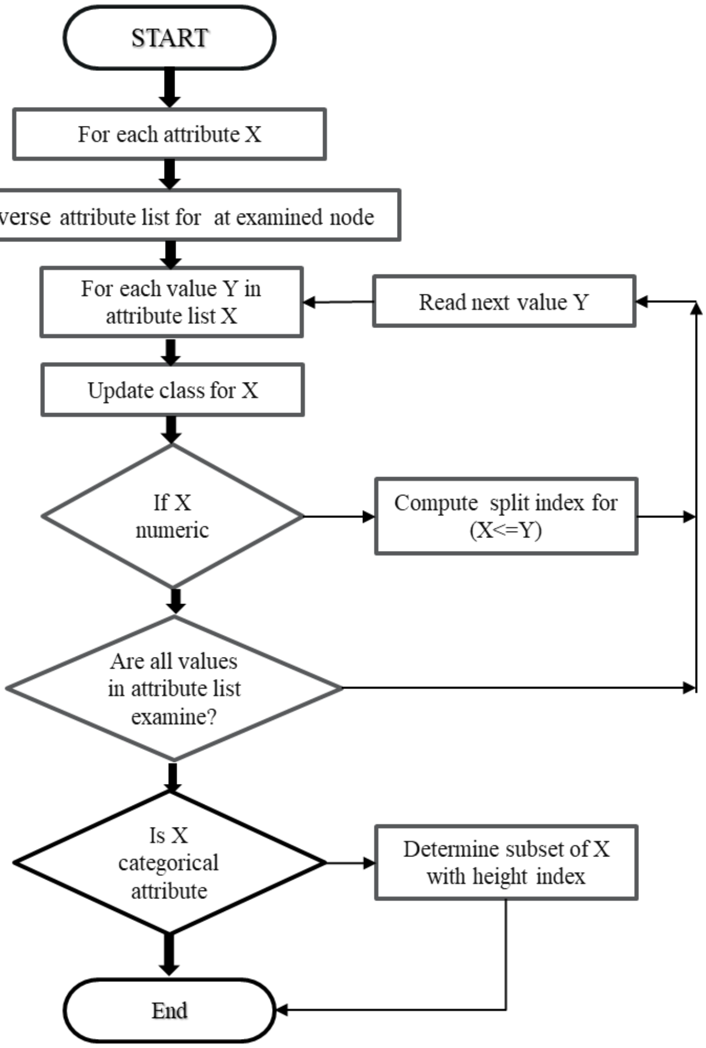


Figure 5.10: Flow Chart for Decision Tree Algorithm

The decision tree is a hierarchical construction that illustrates a sequence of decisions and their potential consequences. It originates from a single node, called the root, and extends into multiple internal nodes, each representing a decision point. These internal nodes connect to corresponding leaf nodes, which signify the possible outcomes. As the decision-making process progresses, different branches of the tree depict the various choices or actions taken. This structure provides a logical and visual representation of the decision-making process, simplifying comprehension and interpretation. Figure 5.11 displays a standard hierarchical structure for the decision tree algorithm.

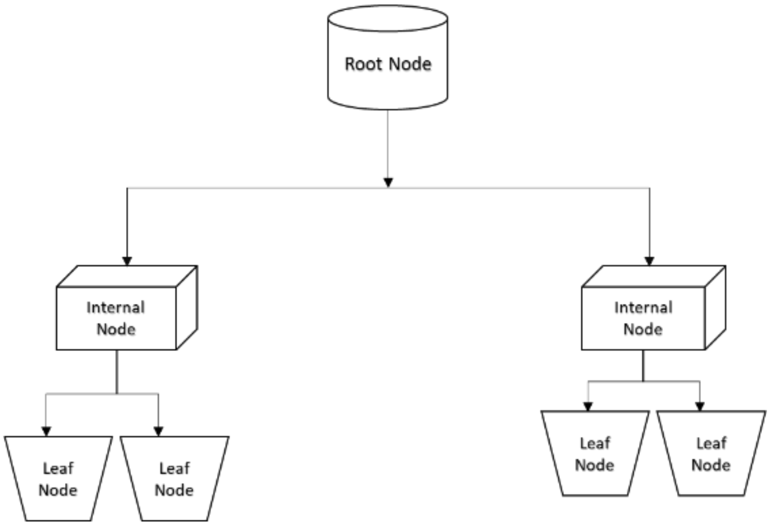


Figure 5.11: Decision Tree Hierarchical Structure

K-Nearest Neighbors (KNN) serves as a supervised machine learning technique, applied to both classification and regression endeavours. Functioning as a non-parametric approach, it compares the input data point to the k-nearest data points available in the training set. The value of k serves as a crucial hyperparameter, determining the number of neighbors considered when making predictions. Utilizing distance metrics like Euclidean distance or Manhattan distance, the algorithm identifies the k-nearest neighbors. Subsequently, for classification tasks, it bases its prediction on the majority class of the neighbors, while for regression tasks, it relies on the average value of the nearest neighbors. KNN is simple to understand and implement, making it a popular algorithm in the machine learning community. The K-Nearest Neighbors (KNN) algorithm has several strengths and limitations. While it is effective for prediction tasks, it can become computationally expensive when dealing with large datasets. Additionally, the choice of the parameter k, which represents the number of nearest neighbors considered, has a significant impact on the algorithm's performance. KNN's versatility lies in its ability to handle non-linearly separable data, where no clear relationship exists between the input features and the target variable. Moreover, it proves beneficial when dealing with noisy data or missing values, as it relies solely on the closest neighbors without making assumptions about the data distribution.

However, KNN's performance might suffer in high-dimensional spaces due to the curse of dimensionality, where meaningful distances between data points become challenging to determine. In summary, KNN stands as a straightforward and adaptable algorithm for accurate predictions across various machine learning tasks. Nonetheless, thoughtful consideration is necessary when selecting the appropriate value for k and when dealing with high-dimensional data. For a visual representation of the KNN algorithm's typical structure, refer to figure 5.12.

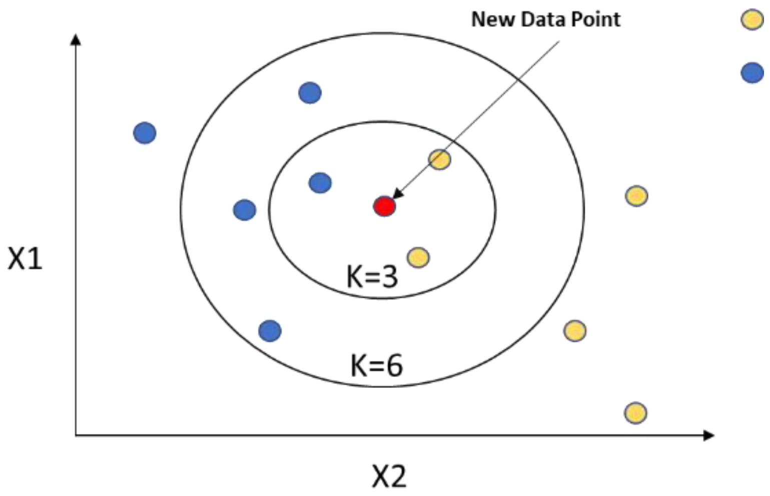


Figure 5.12: KNN structure

The K-Nearest Neighbors (KNN) algorithm serves as a supervised learning technique in machine learning, applied to both classification and regression tasks. At its core, the algorithm revolves around assessing the similarity among data points. The KNN algorithm can be broken down into the subsequent steps:

Step 1: Determine the value of K - This step involves selecting the value of K, which is the number of nearest neighbors that will be used to make predictions. The value of K is usually selected through cross-validation or some other method.

Step 2: Calculate distances - In this step, the distance between the test instance and all the training instances is calculated. The distance can be Euclidean, Manhattan, or any other distance metric.

Step 3: Find K nearest neighbors - The next step is to find the K nearest neighbors to the test instance based on the calculated distances. The neighbors are determined by selecting the K instances with the smallest distances to the test instance.

Step 4: Make predictions - For classification and regression tasks in machine learning, the K-nearest neighbours (KNN) algorithm is simple and effective. It works by selecting a value for K, calculating distances between test and training data, finding the K nearest neighbors, and making predictions based on their majority class or average value.

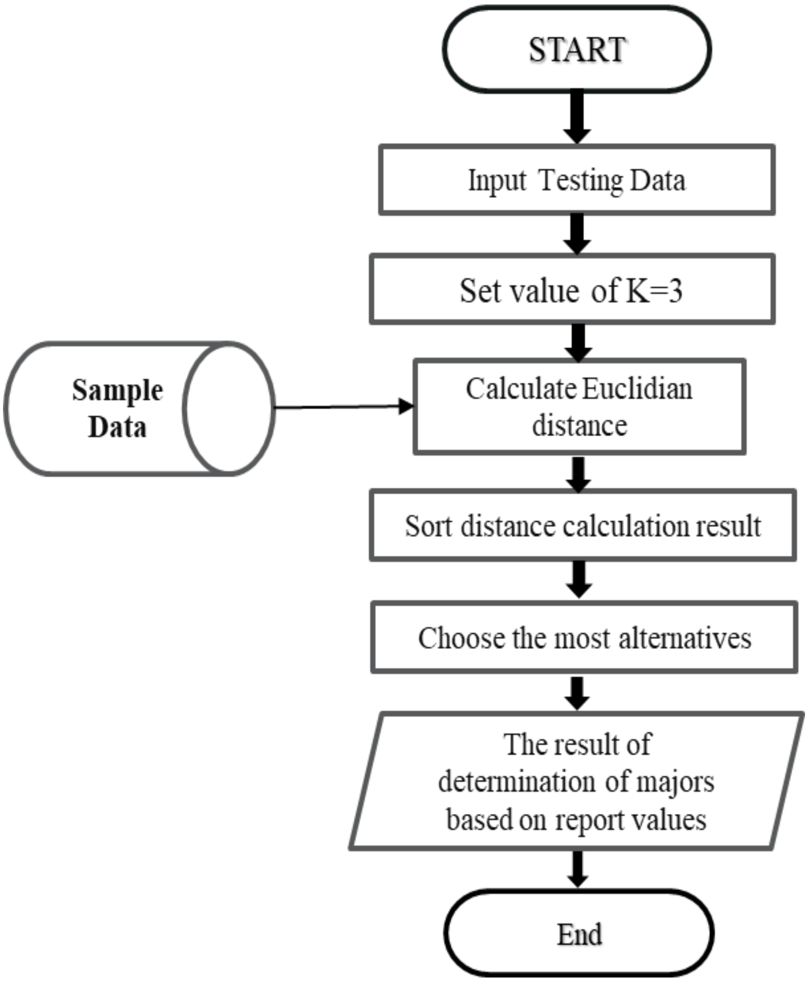


Figure 5.13: Flow Chart for KNN Algorithm

Validation was used to evaluate the model's performance during the hyperparameter modification procedure. To ensure the impartial assessment of the final model, a separate dataset was used for evaluation from the training dataset used to fit the model. The validation step plays a crucial role in guaranteeing the accuracy and dependability of the machine learning model's predictions by testing it on data that was not previously utilized during training. This method is used to assess the model's capacity to generalise to new data. The supplied data was separated into two sets: one for model training and one for performance evaluation. The root mean square error (RMSE) is critical when measuring the model's performance since it quantifies the difference between anticipated and actual values in the data set being studied. The square root of the RMSE is determined by averaging the squared discrepancies between expected and actual results. A lower RMSE indicates greater forecast accuracy. As a result, utilising the RMSE approach to validate a machine learning model for prediction is critical to ensuring it meets the appropriate level of accuracy. The quadratic mean or standard deviation of these disparities is represented by the square root of the second moment of the differences between expected and actual values. It calculates the residuals' deviation from the regression line, where residuals are the discrepancies between actual and anticipated values. A lower RMSE suggests better data fit and higher predicting accuracy. Notably, RMSE is always a non-negative statistic that may be calculated using Sama Azadi et al. (2015)'s Equation 4. Furthermore, RMSE is a useful technique for comparing forecasting errors among different models on a single dataset.

$$\mathbf{RMSE} = \sqrt{[}\sum (\mathbf{Pi} - \mathbf{Oi})/\boldsymbol{n}] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \mathbf{(4)}$$

where:

is an abbreviation for "sum"

Pi is the anticipated value for the dataset's ith observation.

The observed value for the ith observation in the dataset is Oi, and the sample size is n.

The precision of a machine learning model is an important indicator of its ability to properly anticipate unknown data. It is calculated as a percentage of the number of right guesses divided by the total number of forecasts. Higher accuracy values signify better performance, indicating the model's ability to generalize effectively and make accurate predictions on new data. Nevertheless, it's essential to recognize that accuracy alone may not be enough to assess a model's overall performance. In certain cases, additional metrics like Mean Absolute Percent Error are considered, depending on the nature of the problem being addressed. Furthermore, various factors have the potential to impact the accuracy of a model. These factors include the data quality, algorithm and hyperparameter selection, as well as the size of the training dataset. To attain the appropriate level of reliability for a certain activity, the machine learning model must be carefully selected and fine-tuned. A test dataset comprising 30% of the total data was used to evaluate the model's accuracy during the secondary stage. The precision of a machine learning model is critical since it impacts the dependability of its forecasts. The Mean Absolute Percent Error (MAPE) method is an excellent methodology for assessing the precision of predictions. MAPE is a percentage variance between expected and actual results. For the calculation of the % error, take the absolute difference between the forecasts and the actual values, divide it by the actual value, and multiply the result by 100. The maximum possible error score is calculated by averaging these percentage mistakes. A lower number of MAPE signifies improved precision, while a larger number indicates decreased accuracy. As a result, MAPE is a useful tool for evaluating machine learning model performance, particularly when precision is crucial and the prediction values span a large range. Absolute error in machine learning refers to the difference between a predicted value and the true value of an observation. MAPE, or Mean Absolute Percent Error, is a popular loss function for regression situations. It computes the average of absolute errors for a series of forecasts and observations, revealing the overall size of errors in the predictions. MAPE also aids in the formulation of learning problems as optimisation challenges.

The Mean Absolute Percent Error is an easy to understand metric that is frequently used in machine learning for regression situations. Its major use is to evaluate the accuracy of a regression model by calculating the average difference between predicted and actual values. MAPE, unlike some other accuracy measures, considers the magnitude of the observations, resulting in a more relevant score. The mean of the absolute values of individual prediction errors is computed over all instances in the test set to determine MAPE for a model. The difference between the true and expected values is represented by each prediction error. Equation 5 is used to calculate MAPE, while Equation 6 is used to calculate model correctness.

$$\textbf{Mean Absolute Percent Error} = \left\{\left[\frac{\mathbf{1}}{\boldsymbol{n}}\right] \times \sum(\boldsymbol{abs}(\boldsymbol{yi} - \boldsymbol{xi})/\boldsymbol{xi})) \times \mathbf{100}\right\} \quad \text{...............} \ \textbf{(5)}$$

were,

Σ : summation

yi: Actual observed value for the i th observation

xi: Calculated value for the i th observation

n: Total number of observations

$$\textbf{Accuracy} = \textbf{(100- MAPE)} \quad \text{..................} \quad \textbf{(6)}$$

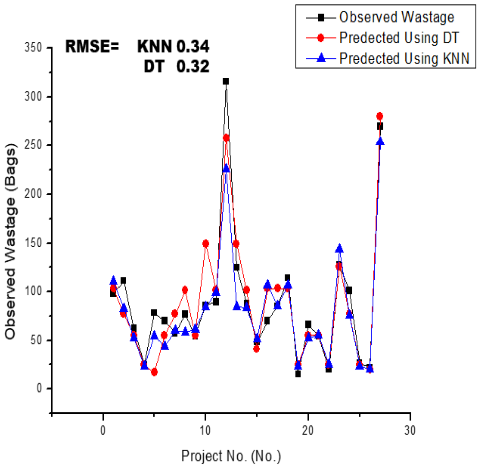
5.4.2 Results and discussion

A. Waste prediction

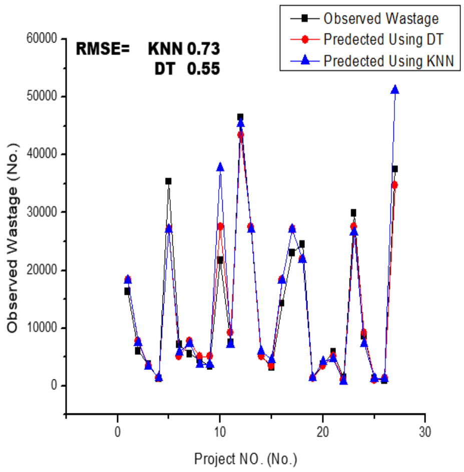
The research project concentrated on predicting waste from construction in the allocated area and using this estimate to predict waste output during various phases of construction projects. The decision tree and k-nearest neighbour algorithms were used by the investigators to accomplish this. The estimated waste amounts were then assessed against actual data collected from building sites and visually shown through graphs for each project stage. These graphs' X-axis reflected the overall number of projects, while the Y-axis depicted the observed waste of certain resources at their individual building sites. The analysis results showed an important correlation between projected and actual trash creation, as proven by a median root mean square error (RMSE) of 0.49, which was less than one. This low RMSE number implies that the models used are accurate. In broad terms, the models predicted waste from building effectively, especially for predictions in the short term. However, when projecting waste during longer time periods, accuracy decreased marginally. Overall, the study demonstrated the efficacy of the decision tree and k-nearest neighbour algorithms in predicting construction waste at various stages of building ventures.

The models exhibited a high level of accuracy when compared to real-world data from construction sites. As a result, the study suggests that these models are suitable for short-term projections of construction waste but may experience decreased accuracy when forecasting waste over an extended period.

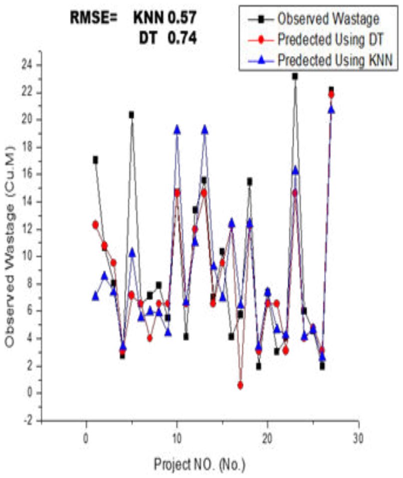
Figures 5.14 and 5.15 show the efficiency of two machine learning methods, KNN and decision tree, respectively, in forecasting waste produced throughout multiple phases of fundamental civil engineering building materials. The average root mean square error for the substructure stage, which included materials such as cement, bricks, coarse aggregates, sand, and steel reinforcement, was 0.63 for KNN and 0.60 for the decision tree method. The observed and predicted values for the superstructure stage are shown in figure 5.15, with average root mean square errors of 0.48 and 0.50 for the KNN and decision tree, respectively. The results show that the two different KNN and decision tree algorithms efficiently estimate the production of waste during the construction stages, with the KNN performing somewhat better in the superstructure stage. The aforementioned results have important repercussions for the building industry's waste reduction and sustainability initiatives. Accurate trash generation prediction at various stages enables construction companies to apply waste-reduction strategies and encourage sustainable practises. This method not only saves money but also adds to a more ecologically friendly construction procedure.



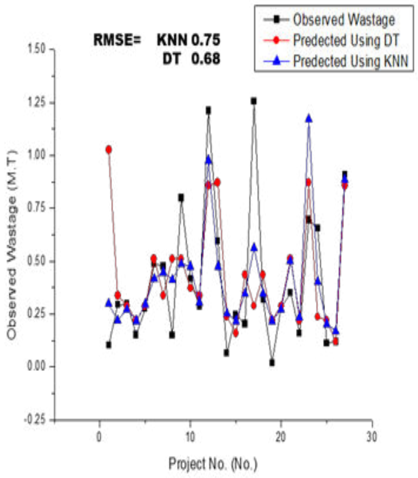
Waste prediction for Cement in Sub-structure Stage



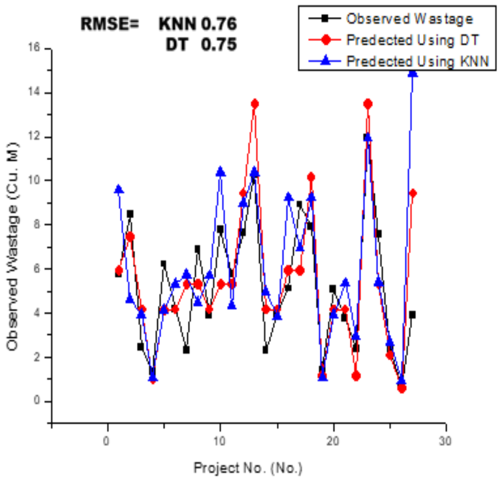
Waste prediction for Bricks in Sub-structure Stage



Waste prediction for Aggregate in Sub-structure Stage

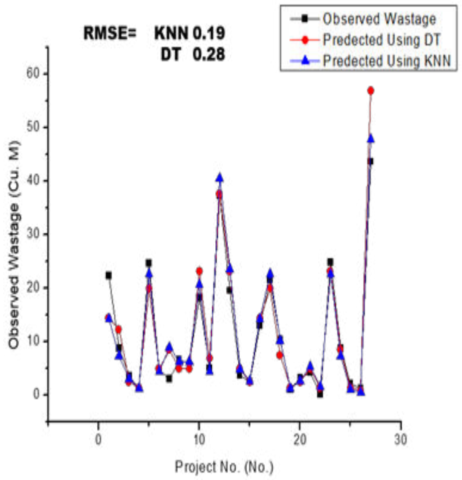


Waste prediction for Reinforcement in Sub-structure Stage

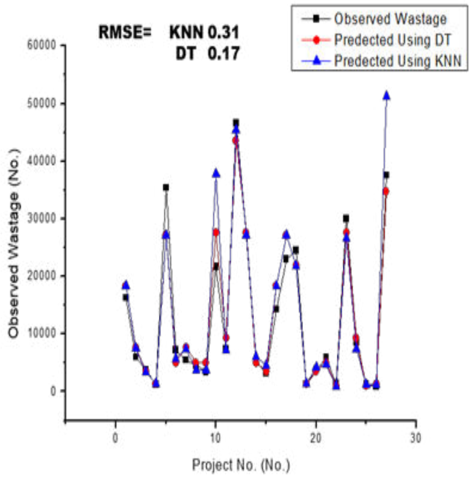


Waste prediction for Sand in Sub-structure Stage

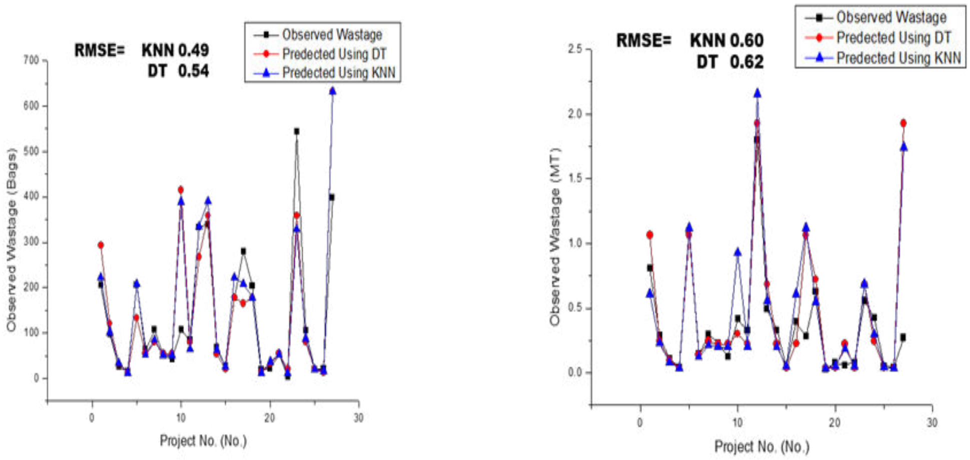
Figure 5.14: Waste Prediction for Substructure Stage



Waste prediction for Aggregate in Super-structure Stage

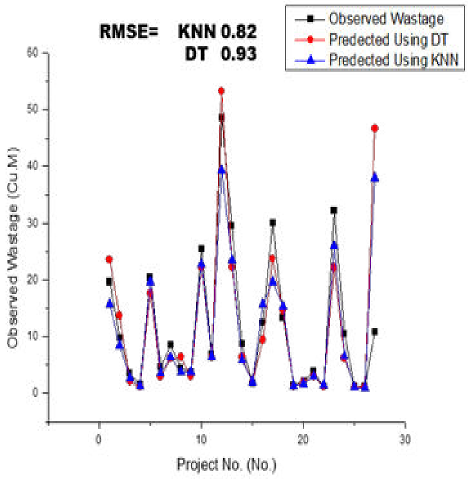


Waste prediction for Bricks in Super-structure Stage



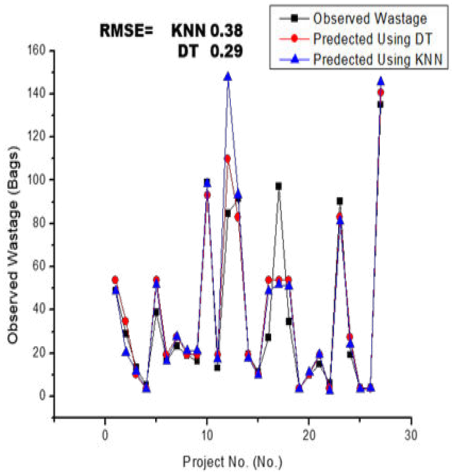
Waste prediction for Cement in Super-structure Stage

Waste prediction for Reinforcement in Super-structure Stage

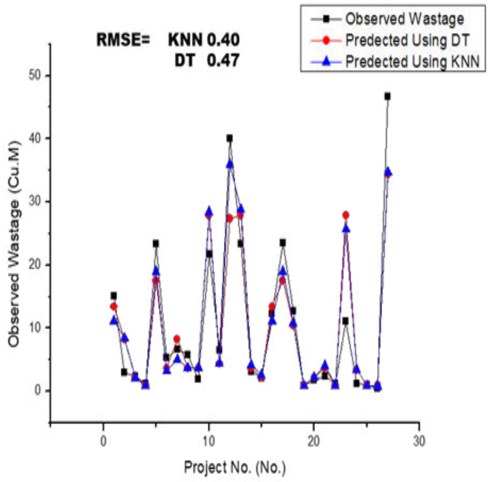


Waste prediction for Sand in Super-structure Stage

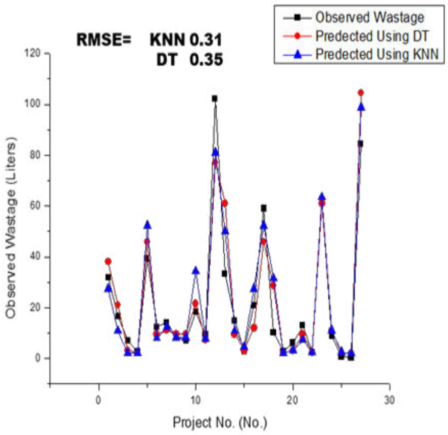
Figure 5.15: Waste Prediction for Superstructure Stage



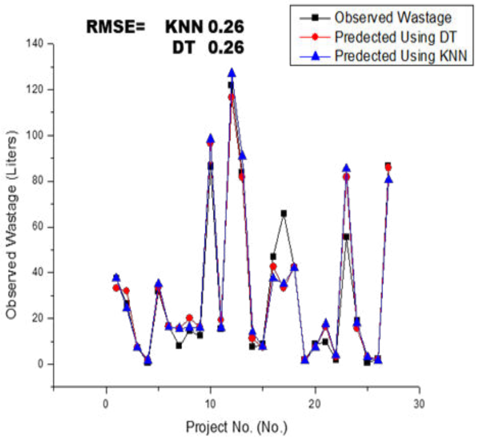
Waste prediction for Cement in Finishing Stage



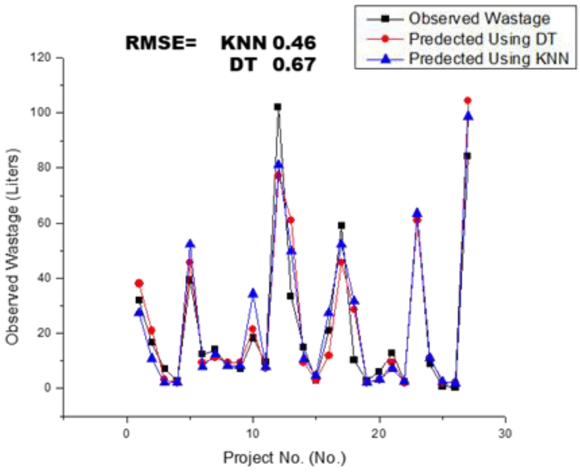
Waste prediction for Sand in Finishing Stage



Waste prediction for External Wall Finishes in Finishing Stage



Waste prediction for Internal Wall Finishes in Finishing Stage



Waste prediction for Floor Finishes in Finishing Stage

Figure 5.16: Waste Prediction for Finishing Stage

Figure 5.16 depicts the results of a study that used KNN and decision tree models to forecast waste produced throughout the building project's concluding stage. According to the results, the KNN model had an average root mean square error of 0.36, whereas the decision tree model had a slightly higher error of 0.40. These results indicate that the KNN model outperformed the decision tree model in terms of reliability. The two models, however, performed admirably well, as their projected values closely corresponded to the observed values, indicating a high level of accuracy for both. These positive results give strong support for the feasibility and usefulness of using KNN and decision tree models to predict waste in building projects, particularly during the finishing stage.

The accurate patterns observed between the predicted and observed values suggest that these models may be useful tools for project managers in the construction industry. By accurately predicting wastage, managers can take proactive steps to reduce waste and increase efficiency, ultimately saving time and money on construction projects.

B. **Verification and Performance Evaluation**

The average Root Mean Square Error (RMSE) values for three distinct building stages are shown in Figure 5.17, which are typically used to measure the reliability of models for prediction. The substructure stage has an initial average RMSE value of 0.62, indicating that the prediction models utilised at this level have relatively more mistakes than the future stages. However, as construction progresses to the superstructure stage, there is a significant improvement, The median RMSE value has dropped to 0.49. This shows that the precision of the prediction models has significantly improved in this stage relative to the substructure stage. Ultimately, the lowest average RMSE value of 0.38 is seen in the concluding stage of building, showing the improved accuracy of the prediction models used in this step. In terms of prediction model accuracy, these findings confirm the finishing step as the most dependable of the three building phases.

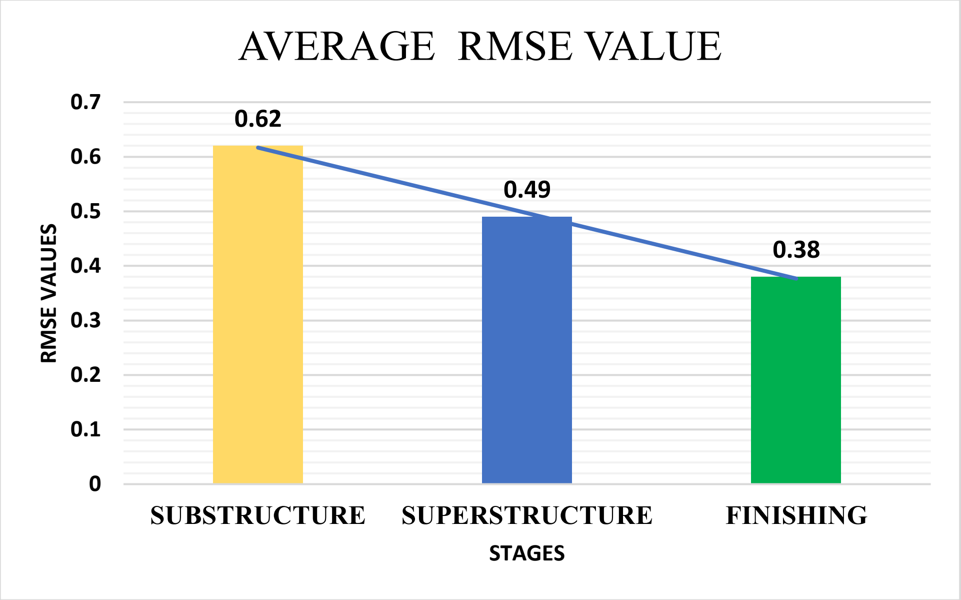


Figure 5.17: Average RMSE Values at Three Stages

It is important to emphasize that lower RMSE values indicate higher accuracy for prediction models. As a result, the finishing stage of construction exhibits the highest accuracy among the three stages, followed by the superstructure stage, while the substructure stage demonstrates the least accuracy. The conclusions offered in Figure 5.17 are extremely valuable to building professionals because they allow them to identify areas where prediction model accuracy needs to be improved. Prioritising prediction model accuracy throughout the substructure stage can be advantageous for building professionals. This enhancement ensures a strong start to the construction process with a high level of precision, which ultimately has a favourable impact on the overall accuracy of the construction method.

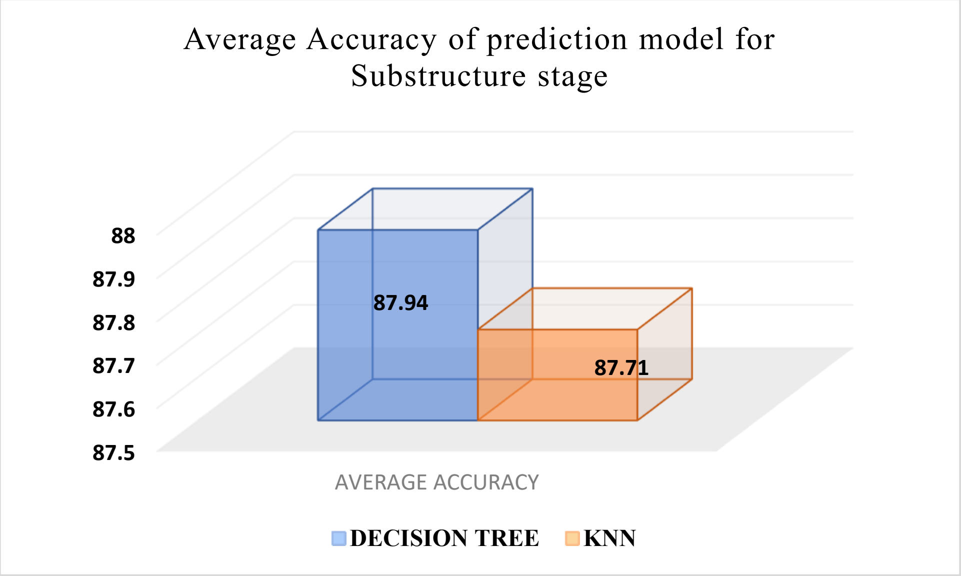


Figure 5.18: Average Accuracy at Substructure Stages

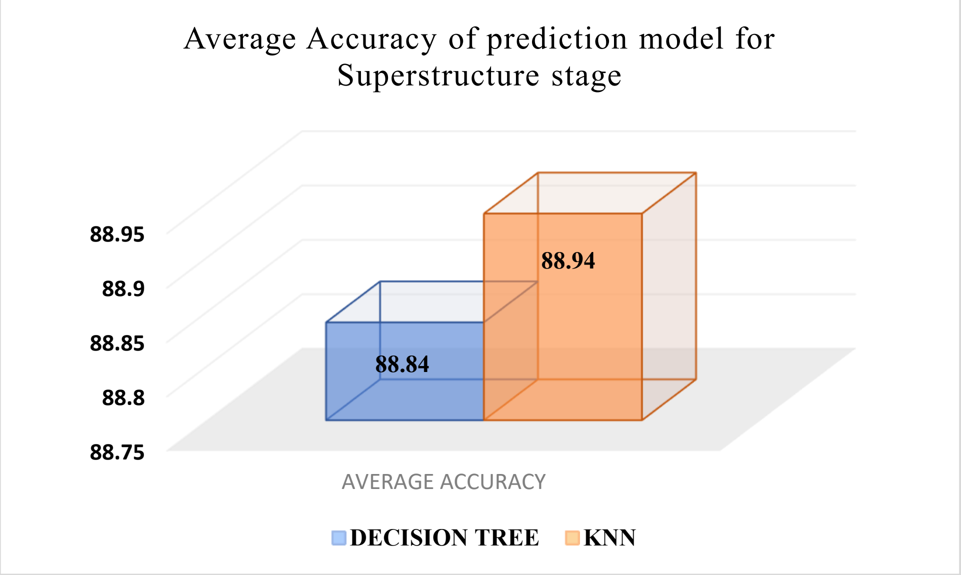


Figure 5.19: Average Accuracy at Superstructure Stages

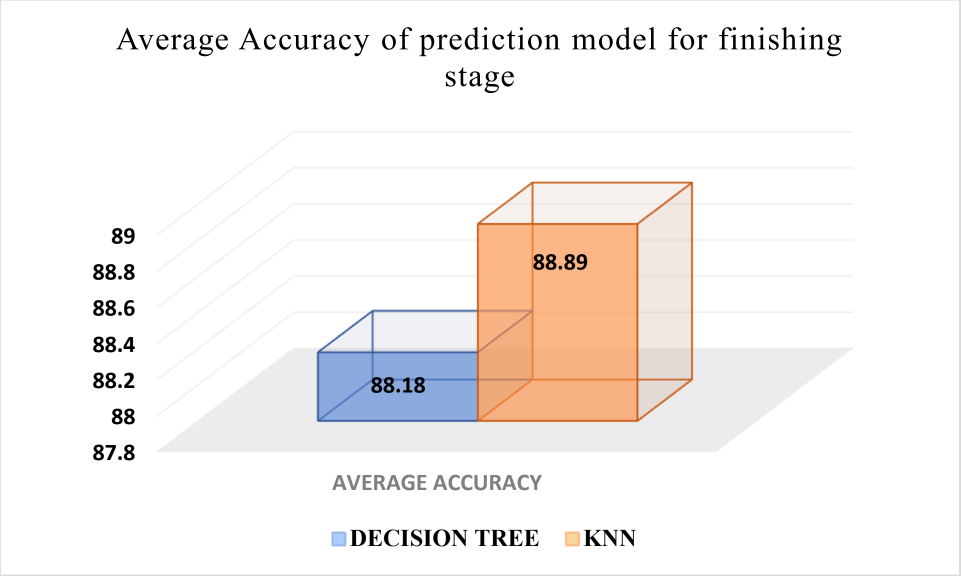


Figure 5.20: Average Accuracy at Finishing Stages

The figures (5.18, 5.19, and 5.20) exhibit data demonstrating the performance of models based on the Decision Tree and KNN algorithms at various stages of a construction project. The Decision Tree approach has an amazing average accuracy of 87.94% at the substructure stage, whereas the KNN algorithm has a slightly less impressive average accuracy of 87.71%. During the superstructure stage, however, the KNN approach outperforms the Decision Tree technique, achieving an average accuracy of 88.94% versus 88.84%. Similarly, at the final stage, the KNN model has a higher average accuracy of 88.89% than the Decision Tree algorithm, which has an average accuracy of 88.18%. These statistics show the variation in accuracy between the Decision Tree and KNN algorithms contingent upon the stage of the construction project. The Decision Tree algorithm performs better during the substructure stage, whereas the KNN algorithm performs better throughout the superstructure and finishing phases. As a result, when choosing an algorithm for modelling building projects, it is critical to consider the individual project stage under consideration.

Figures 5.21 and 5.22 show the accuracy results of the decision tree and KNN models, respectively. These numbers demonstrate the models' prediction performance for various construction materials throughout the three stages of the building process. Prediction accuracy varied dependent on the particular construction material and stage of construction. Analysing the Mean Absolute Percent Error revealed that both models fared better in estimating the cement, sand, and aggregate requirements. This is due to the fact that these materials have a proportionate relationship, which makes them more predictable. However, when it came to anticipating the requirements for reinforcement materials, which belong under the supreme category and have considerably lesser demands, both models' accuracy dropped significantly.

Estimates for brick requirements, on the other hand, were pretty accurate, with both models continuously exhibiting a higher quartile trend in their brick estimates. Furthermore, at the finishing stage, the accuracy of predictions for floor and internal wall finishes was significantly higher than the accuracy of predictions for external wall finishes.

The decision tree model attained an average accuracy of 87.94% throughout the substructure stage, whereas the KNN model earned an accuracy of 87.17%. The decision tree model obtained 88.84% accuracy in the superstructure stage, which was slightly less than the KNN model's accuracy of 88.94%. Finally, both of the models achieved the same accuracy of 87.94% during the completion stage. In summary, the results show that both models predicted construction material requirements similarly. However, the KNN model outperformed the decision tree model in predicting superstructure demands, whereas the decision tree model outperformed it in predicting substructure and finishing stage requirements. As a result, the appropriate model is determined by the stage of the construction project and the type of construction material under consideration.

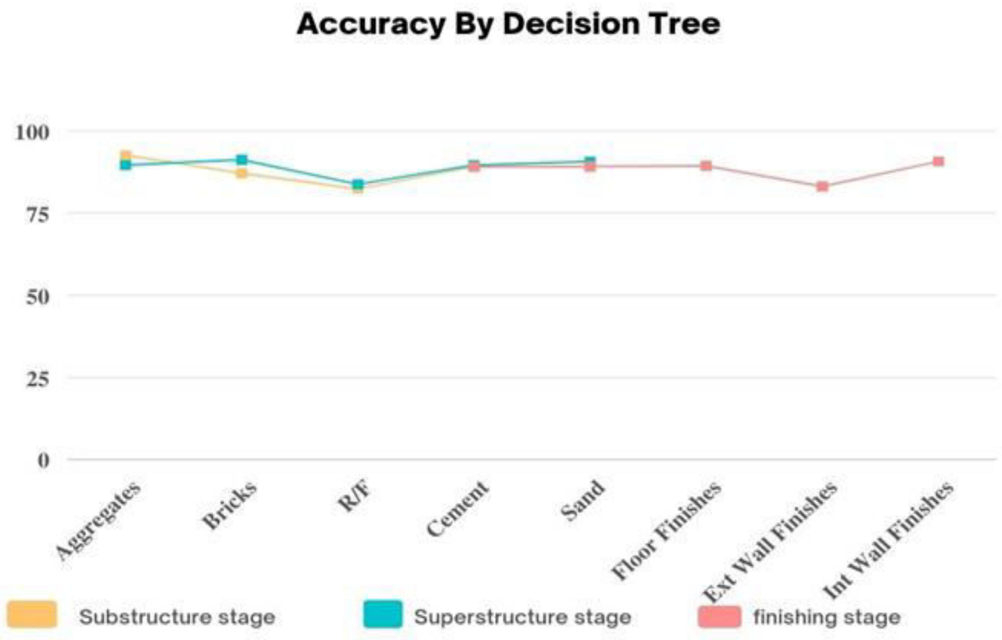


Figure 5.21: Accuracy by Decision Tree Model for All Stages

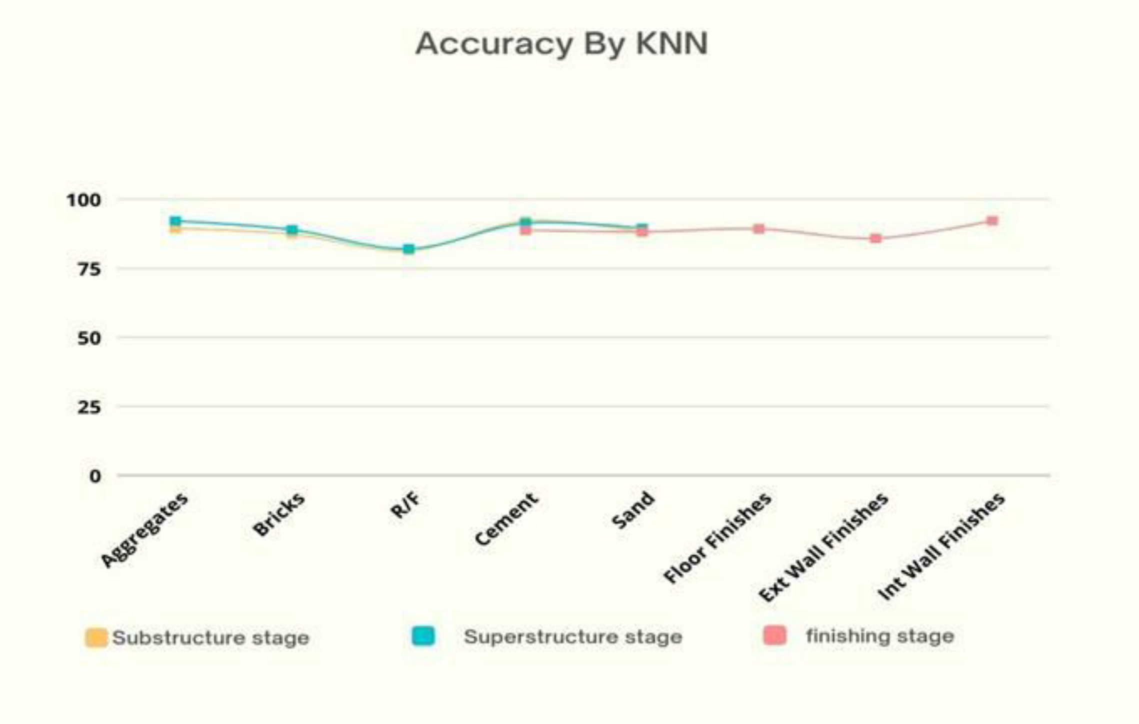


Figure 5.22: Accuracy by KNN Model for All Stages

A detailed comparison of the median accuracy of decision tree and KNN models in forecasting the production of waste during various phases of building endeavours - foundation, superstructure, and finishing is provided in Figure 5.23. The decision tree model attained an average accuracy of 88.32 percent, while the KNN model did slightly better at 88.51 percent, according to the data. These degrees of accuracy are deemed adequate for projecting trash creation at various project phases. Nonetheless, the study had some shortcomings. Firstly, the dataset used was relatively small and restricted to real construction sites, limiting the study's scope without a synthetic dataset covering multiple construction projects. Both models also had their own drawbacks. Overfitting was a danger in decision tree learning, resulting in complicated trees that might not generalise effectively with fresh data. Furthermore, correctly sorting nodes may make the process computationally expensive. The KNN model, on the other hand, had slower prediction speeds with larger datasets and required a substantial amount of memory capacity for data used for training and testing. Regarding these constraints, the study indicated that both the decision tree and the KNN models were able to forecast construction waste relatively well. However, when evaluating the results, it is critical to keep the model limitations, as well as the dataset's size and origin, in mind.

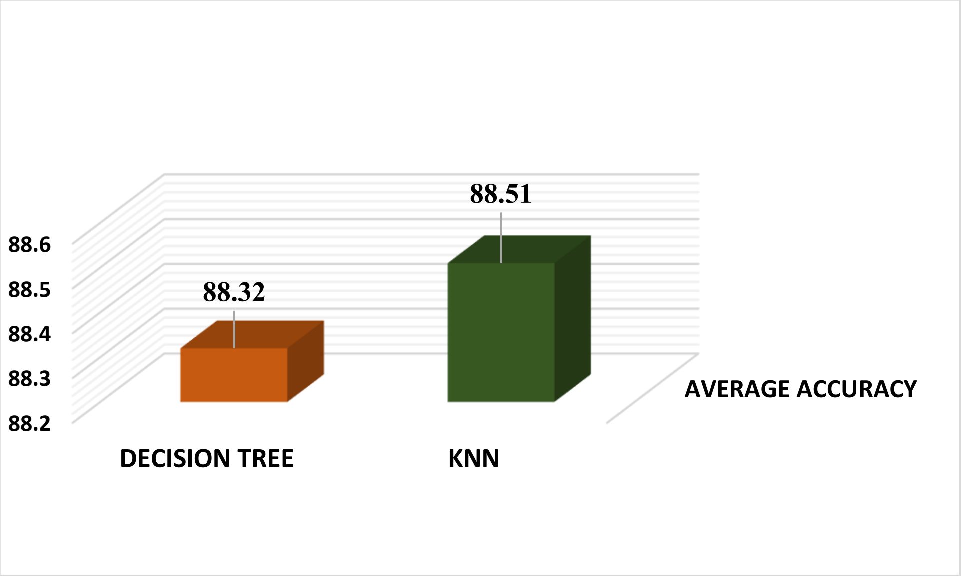


Figure 5.23: Combined Average Accuracy of Prediction Model for All Stages

5.5 Summary

The chapter discussing quantification analysis and prediction models for construction waste offers a comprehensive exploration of the diverse methods and strategies employed in forecasting and analysing construction waste. Commencing with an overview of construction waste and its environmental implications, the chapter then proceeds to examine the various categories of generated construction waste. The chapter then delves into the various methods used for quantification analysis of construction waste, including direct measurement, volumetric analysis, and estimation method. The chapter then moves on to prediction models for construction waste, starting with the traditional regression model, and then progressing to the machine learning techniques using decision tree and KNN algorithm. The chapter provide a comparative analysis of these models, highlighting the advantages and limitations of each. They also emphasize the importance of using accurate input variables and the need for continuous improvement of the models. Finally, the chapter concludes with a discussion on the applications of quantification analysis and prediction models in construction waste management, including waste reduction, recycling, and disposal. The chapter also highlight the need for a holistic approach to construction waste management, integrating these models with other sustainability strategies. Overall, the chapter provides valuable insights into the complex field of construction waste management and emphasizes the need for continual research and innovation to develop more effective and sustainable solutions

CHAPTER - 6

CONCLUSION AND FUTURE SCOPE

6.1 General

The conclusion chapter serves as the final section of a written work, providing a summary of the main points and ideas presented throughout the piece. It offers a synthesis of the key arguments and findings, highlighting their significance and implications for the reader. A well-crafted conclusion is provided for reinforcing the importance of the work and its contribution to the field. Overall, the conclusion chapter is a critical component of any written work, providing a powerful conclusion to the author's message.

6.2 Research Conclusions

1. Waste produced during construction arises at various stages of the process, beginning with the planning phase and ending with the final stage.
2. The technique used to quantify construction waste will be determined by the project's size and complexity, the type of waste generated, and the availability of resources.
3. A combination of techniques may be used to achieve accurate data on the waste generated, which can inform effective waste management strategies.
4. The building industry requires a holistic and integrated strategy to waste management that includes the adoption of sustainable practises and the involvement of all stakeholders.
5. The key contributors to construction waste production in residential projects are human resources, building methods, and planning.
6. The highest wastage rates were observed for sand and bricks, which are key materials used in substructure stage of construction for all types of studied projects and on other side the lowest wastage rate was observed for the

reinforcement. At superstructure stage the highest rate of waste was observed for the cement and bricks, again the lowest wastage rate was observed for the reinforcement. For the finishing stage the highest rate of wastage is generated from the cement and external wall finishes and the lowest waste generation is from the floor finishes, portraying that the amount and material wastage varies with the variation in stages of construction.

7. Wastage during the substructure and Superstructure stage of construction projects is a significant concern, with varying rates depending on the project size. While larger projects have lower wastage rates, there is still a considerable amount of waste produced
8. wastage costs for the cement and reinforcement are higher at substructure stage whereas at superstructure stage cost of cement and bricks is higher and at the finishing stage cost of sand and floor finishes is higher indicating if the stage change cost of wastages also varies accordingly.
9. The projected values were compared to real building site data and found to be quite close, with a high level of accuracy for the models. The study suggests that these models are suitable for short-term predictions of construction waste, but their accuracy may decrease when predicting waste over a longer period.
10. KNN and decision tree algorithms can effectively predict the waste generated during construction stages, with KNN showing slightly better performance in the superstructure stage.
11. It is important to notice that the lower the RMSE number, the greater the prediction models' accuracy. Therefore, the finishing stage of construction is the most accurate among the three stages, followed by the superstructure stage, and the substructure stage has the least accuracy
12. The precision of the Decision Tree and KNN algorithms used in the models changes depending on the stage of the construction project. The Decision Tree algorithm works better at the substructure stage, while the KNN algorithm performs better at the superstructure and finishing stages. Therefore, the choice of algorithm for modelling construction projects should consider the stage of the project in question.

13. Mean Absolute Percent Error study demonstrated that the two models were more accurate in estimating sand, cement, and aggregate specifications, as these materials are proportionally related.
14. Both models exhibited a notable decline in their ability to predict the reinforcement material requirements, which belong to the highest category and have lower quantified demands compared to other construction materials.
15. The brick requirements' predictions exhibited a commendable accuracy, with both models consistently predicting a higher quartile for the brick usage pattern.
16. During the final phase, the accuracy of predictions regarding floor and internal wall finishes surpassed that of external wall finishes.
17. Both models displayed similar accuracy levels, with the KNN model performing slightly better in predicting superstructure requirements, while the decision tree model exhibited slightly better accuracy in predicting substructure and finishing stage requirements
18. The accurate patterns observed between the predicted and observed values suggest that these models may be useful tools for project managers in the construction industry.
19. The analysis suggests that both models are suitable for predicting construction material requirements, and the selection of the model can be based on the specific stage of the construction project and the construction material being considered.

6.3 Future Scope

The application of machine learning approaches to the management of building-related residential waste has created new prospects for waste management efficiency. In the future, the application of these techniques will continue to evolve, and there will be an increased focus on the integration of real-time data collection and analysis tools. This will enable the development of more accurate and robust predictive models for Waste produced can be used to improve waste management techniques and lessen the overall environmental impact of construction activities. Additionally, with the growing emphasis on sustainability in the construction industry, there will be an increased need for the implementation of circular economy principles in waste management. Machine learning techniques can play a critical role in facilitating the transition towards circular economy practices, by enabling the identification of new waste streams and potential reuse and recycling opportunities.

In addition, the invention of sophisticated analytical instruments for the management of residential building construction waste has the potential to result in the creation of new business models that include waste reduction as a key performance indicator. By leveraging machine learning techniques, construction companies can identify opportunities for waste reduction, implement measures to reduce waste, and measure the effectiveness of their waste management strategies. This can create new revenue streams for construction companies that are able to achieve significant waste reduction, as well as incentivize other companies to adopt similar practices. In the future, the integration of machine learning techniques in waste management can have a transformative impact on the construction industry, enabling the industry to move towards a more sustainable and circular future.

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APPENDICES

Appendix-I

A. Questionnaire for Case Study

Name of on-going/completed project:	
Type:	
Location:	**Duration:**
Current status:	**Cost:**
Staff interviewed:	

1) Do you involve the materials management group in the project planning?

YES NO

2) Do you have an integrated materials management computer system?

YES NO

3) Do you conduct materials management process audits?

YES NO

4) Do you use outsourcing to implement some materials management functions?

YES NO

5) Do you have surplus-reducing programs?

YES NO

6) Do you have a warehouse for material and equipment?

YES NO

7) Do you use a material and equipment tracking system?

YES NO

8) Do you have systematic inventories management system?

YES NO

9) Do you concerned with issues related to the environment?

YES NO

10) Do you evaluate the supplier’s quality systems?

YES NO

11) Do you implement modularization?

YES NO

12) Do you use material handling equipment's and systems?

YES NO

13) Do you create routing guides for material transportation?

YES NO

14) Do you have plan for yearly operation spares?

YES NO

15) Do you have provisions for disposal of construction waste from the project?

YES NO

16) Do you quantify the amount of wastage?

YES NO

17) Which quantification method do you prefer?

i).

ii).

18) Do you maintain record for waste materials?

YES NO

19) Do you conduct education programs for employees and labours?

YES NO

20) Do you have close coordination between the materials manager teams and procurement teams?

YES NO

21) According to you what are the effects of material wastage at site?

i).

ii).

22) What is the Percentage Cost of Materials to the Cost of the Project?

23) Do you prefer pre-planning for negotiation for purchasing materials?

YES NO

24) Do you believe in good buyer seller relationship?

YES NO

25) What are the causes of material waste and cost variance?

i).

ii).

26) What kind of waste minimization measures or techniques do you use?

i).

ii).

27) According to you what are the major barriers for implementation of waste management plans?

i).

ii).

28) Do you use substitution for materials to reduce the cost?

YES NO

29) What are the measures do you use for material safety?

i).

30) What kind of benefits does u have after implementing material and waste management plans?

i).

ii).

Remarks:

Date: **Signature**

B. Results For Survey-I (Case Study)

Sr. no	Practice, concept, and issue	Large organization said yes (%)	Medium organization said yes (%)	Small organization said yes (%)	Large organization said no (%)	Medium organization said no (%)	Small organization said no (%)	Average said yes (%)	Average said no (%)
1	Have involve the materials management group in the project planning	80	68	46.67	20	32	53.32	65	35
2	Have an integrated materials management computer system	60	8	0	40	92	100	23	77
3	Conduct materials management process audits	90	60	46.67	10	40	53.33	66	34
4	Use outsourcing to implement some materials management functions	30	24	13.33	70	76	86.67	22	78
5	Have surplus-reducing programs	80	48	60	20	52	40	63	37
6	Have a warehouse for material and equipment	100	84	66.67	0	16	33.33	84	16
7	Use a material and equipment tracking system	50	24	13.33	50	76	86.67	29	71
8	Have systematic inventories	70	72	60	30	28	40	67	33

Sr. no	**Practice, concept, and issue**	**Large organization said yes (%)**	**Medium organization said yes (%)**	**Small organization said yes (%)**	**Large organization said no (%)**	**Medium organization said no (%)**	**Small organization said no (%)**	**Average said yes (%)**	**Average said no (%)**
	management system								
9	Concerned with issues related to the environment	90	92	86.66	10	8	13.34	90	10
10	Evaluate the supplier's quality systems	100	100	100	0	0	0	100	0
11	Implement modularization	80	72	86.66	20	28	13.34	80	20
12	Use material handling equipment's and systems	90	96	60	10	4	40	82	18
13	Create routing guides for material transportation	20	24	26.66	80	76	73.34	24	76
14	Have plan for yearly operation spares	40	16	13.33	60	84	86.66	23	77
15	Have provisions for disposal of construction waste from the project	100	96	100	0	4	0	98	2
16	Quantify the amount of wastage	80	60	40	20	40	60	60	40
17	Maintain record for waste materials	70	48	33.33	30	52	86.66	50	50
18	Conduct education programs for	40	36	40	60	64	60	38	62

Sr. no	Practice, concept, and issue	Large organization said yes (%)	Medium organization said yes (%)	Small organization said yes (%)	Large organization said no (%)	Medium organization said no (%)	Small organization said no (%)	Average said yes (%)	Average said no (%)
	employees and labours								
19	Have close coordination between the materials manager teams and procurement teams	100	96	73.33	0	4	26.67	90	10
20	Prefer pre-planning for negotiation for purchasing materials	90	96	100	10	4	0	96	4
21	Believe in good buyer seller relationship	100	100	100	0	0	0	100	0
22	Use substitution for materials to reduce the cost	90	64	80	10	36	20	78	22

Appendix-II

A. Questionnaire for Source Identification of Construction Waste.

Name of on-going/completed project:	
Type:	
Location:	**Duration:**
Current status:	**Cost:**
Staff interviewed:	
Gender:	
Age:	**Experience (Yrs.):**
Position in Firm:	
Educational Qualification:	

SR. NO	**FACTORS**	**1**	**2**	**3**	**4**	**5**
1.	Inattentive working attitudes and behavior's					
2.	Inefficient Control and supervision of activities					
3.	Ineffective planning and scheduling of activities					
4.	Improper handling of materials					
5.	Change in the infrastructure design					
6.	Complications in the design					
7.	Improper storage of construction materials					
8.	Frequent Rework in activity.					
9.	Error in Infrastructural design.					
10.	Use of Incompetent workers					
11.	Architectural or structural drawing errors					
12.	Lack of experience of designer.					
13.	Improper quantity of Material ordering					

SR. NO	FACTORS	1	2	3	4	5
14.	Improper Material transportation					
15.	Poor waste management planning & techniques					
16.	Ineffective Process/ Wrong choice of construction process					
17.	Inappropriate use of Construction methods					
18.	Defective delivered materials					
19.	Tools and equipment (Wrong handling /malfunctioning)					
20.	Wrong teams/subcontractors' selection					
21.	Inappropriate project Documents					
22.	Error in execution					
23.	Improper Activity Coordination					
24.	Improper Packaging of materials					
25.	Misuse of construction materials.					
26.	Inappropriate Material quality					
27.	Damaged materials used					
28.	Lack of suppliers' involvement for project					

B. Wastivity calculations

1. Substructure Stage

CODE	Project Type	Construction stage	Plinth area	Floor Area	Area of foundation	Volume	Estimated				
			SQ.MT	SQ.MT	SQ.MT	(CU.M)	Cement (Bags)	Sand (CU.M)	Aggeregate (CU.M)	Bricks (NOS.)	RF (M.TON)
RSP_001	RES. Small Project	Substructure	55.76	50.19	17.28	18.58	167	7.76	20.00	1553	1.48
RSP_002	RES. Small Project	Substructure	57.62	51.86	17.86	18.60	167	7.74	19.85	1605	1.47
RSP_003	RES. Small Project	Substructure	58.06	52.26	18.00	18.75	168	7.80	20.01	1618	1.48
RSP_004	RES. Small Project	Substructure	58.53	52.68	18.14	18.90	170	7.87	20.17	1630	1.49
RSP_005	RES. Small Project	Substructure	59.46	53.51	18.43	19.20	172	7.99	20.49	1656	1.52
RSP_006	RES. Small Project	Substructure	60.85	54.77	18.86	19.65	176	8.18	20.97	1695	1.55
RSP_007	RES. Small Project	Substructure	62.24	56.02	19.30	20.10	180	8.37	21.46	1734	1.59
RSP_008	RES. Small Project	Substructure	63.92	57.53	19.81	20.64	185	8.59	22.03	1781	1.63
RSP_009	RES. Small Project	Substructure	64.57	58.11	20.02	20.85	187	8.68	22.26	1799	1.65
RSP_010	RES. Small Project	Substructure	65.03	58.53	20.16	21.00	188	8.74	22.42	1812	1.66
RSP_011	RES. Small Project	Substructure	67.81	60.15	22.00	24.92	225	16.83	31.14	2085	1.99
RSP_012	RES. Small Project	Substructure	68.75	61.87	23.24	25.23	228	16.86	31.43	2109	1.99
RSP_013	RES. Small Project	Substructure	69.21	62.29	23.39	25.40	229	16.97	31.65	2123	2.01
RSP_014	RES. Small Project	Substructure	69.68	62.71	23.55	25.58	231	17.08	31.86	2138	2.02
RSP_015	RES. Small Project	Substructure	70.23	63.21	23.74	25.78	233	17.22	32.11	2155	2.04
RSP_016	RES. Small Project	Substructure	70.98	63.88	23.99	26.05	235	17.40	32.45	2177	2.06
RSP_017	RES. Small Project	Substructure	72.00	64.80	24.34	26.43	239	17.65	32.92	2209	2.09
RSP_018	RES. Small Project	Substructure	73.21	65.89	24.74	26.87	243	17.95	33.47	2246	2.12
RSP_019	RES. Small Project	Substructure	73.39	66.05	24.81	26.94	243	18.00	33.56	2252	2.13
RSP_020	RES. Small Project	Substructure	73.95	66.56	24.99	27.14	245	18.13	33.81	2269	2.14
RSP_021	RES. Small Project	Substructure	74.35	66.91	25.12	43.15	372	24.28	54.03	2245	3.45
RSP_022	RES. Small Project	Substructure	76.18	68.56	25.75	43.46	375	24.35	54.33	2296	3.43
RSP_023	RES. Small Project	Substructure	76.64	68.98	25.91	43.73	377	24.50	54.66	2310	3.45
RSP_024	RES. Small Project	Substructure	77.29	69.57	26.12	44.10	380	24.71	55.12	2330	3.48
RSP_025	RES. Small Project	Substructure	78.04	70.23	26.38	44.52	384	24.95	55.65	2352	3.52
RSP_026	RES. Small Project	Substructure	79.43	71.49	26.85	45.32	391	25.39	56.65	2394	3.58
RSP_027	RES. Small Project	Substructure	79.90	71.91	27.00	45.58	393	25.54	56.98	2408	3.60
RSP_028	RES. Small Project	Substructure	81.48	73.33	27.54	46.48	401	26.05	58.10	2456	3.67
RSP_029	RES. Small Project	Substructure	82.68	74.41	27.95	47.17	407	26.43	58.96	2492	3.73
RSP_030	RES. Small Project	Substructure	83.61	75.25	28.26	47.70	411	26.73	59.63	2520	3.77

Actual Consumption					Amount of waste =Actual consumption – Estimated consumption					Wastivity Wastivity=wastage*100/estimatedconsumption				
Cement (Bags)	Sand (CU.M)	Aggeregate (CU.M)	Bricks (NOS.)	RF (M.TON)	Cement (Bags)	Sand (CU.M)	Aggeregate(CU.M)	Bricks (NOS.)	RF (M.TON)	Cement (Bags)	Sand (CU.M)	Aggeregate(CU.M)	Bricks (NOS.)	RF (M.TON)
180	8.8	22.55	1800	1.6	13	1.05	2.55	247	0.12	8	13.48	12.75	16	8.11
187	9	22	2000	1.5	20	1.26	2.15	395	0.03	12	16.26	10.81	25	2.08
190	8.5	22	1700	1.6	22	0.70	1.99	83	0.12	13	8.92	9.92	5	8.02
190	9	22	1800	1.7	20	1.13	1.83	170	0.21	12	14.41	9.05	10	13.86
200	8.6	24	1850	1.7	28	0.61	3.51	194	0.18	16	7.62	17.10	12	12.08
195	9	25	1900	1.7	19	0.82	4.03	205	0.15	11	10.04	19.19	12	9.51
210	9.5	25	2000	1.75	30	1.13	3.54	266	0.16	16	13.56	16.52	15	10.21
200	10	24	2000	1.65	15	1.41	1.97	219	0.02	8	16.41	8.93	12	1.19
212	10	25	1900	1.8	25	1.32	2.74	101	0.15	13	15.23	12.33	6	9.28
210	10	25	2000	2	22	1.26	2.58	188	0.34	11	14.41	11.53	10	20.55
245	19.23	35.22	2400	2.15	20	2.40	4.09	315	0.16	9	14.26	13.12	15	8.04
250	20	35	2400	2.2	22	3.14	3.57	291	0.21	10	18.65	11.34	14	10.36
255	20	36	2500	2.25	26	3.03	4.35	377	0.24	11	17.85	13.75	18	12.11
250	20.5	35	2500	2.25	19	3.42	3.14	363	0.23	8	19.99	9.86	17	11.36
260	20	37	2450	2.3	27	2.78	4.89	295	0.26	12	16.14	15.21	14	12.93
255	19.5	38	2500	2.2	20	2.10	5.55	323	0.14	8	12.05	17.09	15	6.89
265	20	37.5	2300	2.2	26	2.35	4.58	91	0.11	11	13.29	13.91	4	5.38
270	19	36.5	2550	2.35	27	1.05	3.03	304	0.23	11	5.85	9.04	14	10.70
275	20	38	2600	2.35	32	2.00	4.44	349	0.22	13	11.14	13.23	15	10.42
275	22	40	2500	2.2	30	3.87	6.19	231	0.06	12	21.33	18.30	10	2.60
410	27.88	60	2800	3.6	38	3.60	5.97	555	0.15	10	14.83	11.06	25	4.35
420	28	60	2700	3.6	45	3.65	5.67	404	0.17	12	14.97	10.44	18	4.85
425	28.5	65	2600	3.7	48	4.00	10.34	290	0.25	13	16.32	18.92	13	7.11
450	28	65	2800	3.75	70	3.29	9.88	470	0.27	18	13.32	17.92	20	7.65
450	30	63	2850	3.8	66	5.05	7.35	498	0.28	17	20.25	13.20	21	8.04
430	30	62	2750	3.8	39	4.61	5.35	356	0.22	10	18.14	9.45	15	6.15
455	28	65	2800	3.9	62	2.46	8.02	392	0.30	16	9.63	14.08	16	8.31
450	30	65	2800	4	49	3.95	6.90	344	0.33	12	15.18	11.87	14	8.93
460	30	70	2850	4	53	3.57	11.04	358	0.27	13	13.50	18.72	14	7.34
475	32	70	2900	4	64	5.27	10.37	380	0.23	16	19.72	17.40	15	6.15

2. Superstructure Stage

CODE	Project Type	Construction stage	NO. of Storey	Floor Area	Slab Area	Area of column	Area of beam	Area of brickwork	Volume for RCC	Volume for Brickwork	Estimated					Actual Consumption				
				SQ.MT	SQ.MT	SQ.MT	SQ.MT	SQ.MT	(CU.M)	(CU.M)	Cement (Bags)	Sand (CU.M)	Aggeregate (CU.M)	Bricks (NOS.)	RF (M.TON)	Cement (Bags)	Sand (CU.M)	Aggeregate (CU.M)	Bricks (NOS.)	RF (M.TON)
RSP_001	RES. Small Project	Superstructure	G	55.76	55.76	0.63	4.17	10.51	8.91	17.98	105	8.79	8.43	9000	0.53	116	10.00	9.55	10500	0.55
RSP_002	RES. Small Project	Superstructure	G	57.62	57.62	0.65	4.26	10.85	9.18	18.60	109	9.09	8.69	9000	0.55	120	10.00	10.00	10000	0.60
RSP_003	RES. Small Project	Superstructure	G	58.06	58.06	0.66	4.30	10.94	9.25	18.75	109	9.16	8.76	9300	0.56	130	10.45	10.00	10200	0.60
RSP_004	RES. Small Project	Superstructure	G	58.53	58.53	0.66	4.33	11.03	9.32	18.90	110	9.24	8.83	9372	0.56	128	10.50	9.75	10000	0.58
RSP_005	RES. Small Project	Superstructure	G	59.46	59.46	0.67	4.40	11.20	9.47	19.20	112	9.38	8.97	9446	0.57	129	10.00	9.00	11000	0.62
RSP_006	RES. Small Project	Superstructure	G	60.85	60.85	0.69	4.50	11.46	9.69	19.65	115	9.60	9.18	9596	0.58	130	10.75	10.00	11000	0.61
RSP_007	RES. Small Project	Superstructure	G	62.24	62.24	0.70	4.61	11.73	9.92	20.10	117	9.82	9.39	9821	0.59	132	11.00	11.00	11300	0.62
RSP_008	RES. Small Project	Superstructure	G	63.92	63.92	0.72	4.73	12.04	10.18	20.64	121	10.09	9.64	10046	0.61	140	11.55	10.75	11400	0.64
RSP_009	RES. Small Project	Superstructure	G	64.57	64.57	0.73	4.78	12.16	10.29	20.85	122	10.19	9.74	10316	0.62	138	11.75	11.00	11550	0.66
RSP_010	RES. Small Project	Superstructure	G	65.03	65.03	0.73	4.81	12.25	10.36	21.00	123	10.26	9.81	10421	0.62	130	12.00	11.20	12000	0.68
RSP_011	RES. Small Project	Superstructure	G	69.06	69.06	0.78	5.11	12.78	10.80	21.90	128	10.70	10.23	10496	0.65	132	11.90	10.50	12000	0.73
RSP_012	RES. Small Project	Superstructure	G	68.75	68.75	0.78	5.09	12.95	10.95	22.20	130	10.85	10.37	11146	0.66	140	12.00	12.00	11500	0.70
RSP_013	RES. Small Project	Superstructure	G	69.21	69.21	0.78	5.12	13.04	11.03	22.35	131	10.92	10.44	11096	0.66	150	12.25	12.25	11700	0.72
RSP_014	RES. Small Project	Superstructure	G	69.68	69.68	0.79	5.16	13.13	11.10	22.50	131	11.00	10.51	11171	0.67	155	12.30	12.00	12000	0.70
RSP_015	RES. Small Project	Superstructure	G	70.23	70.23	0.79	5.20	13.23	11.19	22.68	132	11.08	10.59	11246	0.67	150	12.40	11.00	12500	0.68
RSP_016	RES. Small Project	Superstructure	G	70.98	70.98	0.80	5.25	13.37	11.31	22.92	134	11.20	10.71	11336	0.68	155	12.50	12.45	12700	0.73
RSP_017	RES. Small Project	Superstructure	G	72.00	72.00	0.81	5.33	13.56	11.47	23.25	136	11.36	10.86	11456	0.69	156	12.50	13.00	12750	0.74
RSP_018	RES. Small Project	Superstructure	G	73.21	73.21	0.83	5.42	13.79	11.66	23.64	138	11.55	11.04	11621	0.70	158	12.00	12.50	12800	0.77
RSP_019	RES. Small Project	Superstructure	G	73.39	73.39	0.83	5.43	13.83	11.69	23.70	138	11.58	11.07	11816	0.70	160	13.00	12.00	13000	0.71
RSP_020	RES. Small Project	Superstructure	G	73.95	73.95	0.84	5.47	13.93	11.78	23.88	139	11.67	11.15	11846	0.71	160	13.50	12.45	13400	0.74
RSP_021	RES. Small Project	Superstructure	G+1	74.35	148.70	2.07	11.12	27.88	24.98	49.76	265	23.30	20.80	25000	1.50	290	26.55	23.65	30000	1.58
RSP_022	RES. Small Project	Superstructure	G+1	76.18	152.36	2.12	11.38	28.49	25.60	50.89	271	23.85	21.27	25567	1.54	290	25.00	23.00	30000	1.56
RSP_023	RES. Small Project	Superstructure	G+1	76.64	153.29	2.13	11.45	28.66	25.75	51.20	273	23.99	21.40	25723	1.55	300	25.80	24.00	29000	1.59
RSP_024	RES. Small Project	Superstructure	G+1	77.29	154.59	2.15	11.55	28.91	25.97	51.63	275	24.20	21.58	25941	1.56	310	26.00	25.00	30000	1.60
RSP_025	RES. Small Project	Superstructure	G+1	78.04	156.08	2.17	11.66	29.19	26.22	52.13	278	24.43	21.79	26190	1.57	300	26.55	25.00	30000	1.65
RSP_026	RES. Small Project	Superstructure	G+1	79.43	158.86	2.21	11.87	29.71	26.69	53.06	283	24.87	22.18	26658	1.60	340	27.00	25.00	31000	1.70
RSP_027	RES. Small Project	Superstructure	G+1	79.90	159.79	2.22	11.94	29.88	26.85	53.37	285	25.01	22.31	26814	1.61	310	28.50	26.00	30500	1.72
RSP_028	RES. Small Project	Superstructure	G+1	81.48	162.95	2.27	12.17	30.47	27.38	54.43	290	25.51	22.75	27344	1.64	300	29.55	25.50	29000	1.75
RSP_029	RES. Small Project	Superstructure	G+1	82.68	165.37	2.30	12.35	30.92	27.78	55.23	294	25.89	23.09	27749	1.67	330	30.00	24.00	30000	1.80
RSP_030	RES. Small Project	Superstructure	G+1	83.61	167.22	2.32	12.49	31.27	28.09	55.85	298	26.18	23.35	28060	1.69	325	28.00	26.00	31500	1.85

Amount of waste = Actual consumption – Estimated consumption					Wastivity Wastivity=wastage*100/estimatedconsumption				
Cement (Bags)	Sand (CU.M)	Aggeregate(CU.M)	Bricks (NOS.)	RF (M.TON)	Cement (Bags)	Sand (CU.M)	Aggeregate(CU.M)	Bricks (NOS.)	RF (M.TON)
11	1.21	1.12	1500	0.02	10	13.77	13.29	17	3.00
11	0.91	1.31	1000	0.05	10	10.01	15.10	11	8.98
21	1.29	1.24	900	0.05	19	14.04	14.17	10	8.11
18	1.26	0.92	628	0.02	16	13.67	10.44	7	3.68
17	0.62	0.03	1554	0.05	15	6.57	0.35	16	9.09
15	1.15	0.82	1404	0.03	13	11.94	8.95	15	4.88
15	1.18	1.61	1479	0.03	12	11.98	17.16	15	4.21
19	1.46	1.11	1354	0.03	16	14.50	11.50	13	4.76
16	1.56	1.26	1234	0.04	13	15.31	12.94	12	6.94
7	1.74	1.39	1579	0.06	6	16.92	14.17	15	9.40
4	1.20	0.27	1504	0.08	3	11.18	2.64	14	12.61
10	1.15	1.63	354	0.04	8	10.60	15.72	3	6.53
19	1.33	1.81	604	0.06	15	12.15	17.34	5	8.83
24	1.30	1.49	829	0.03	18	11.86	14.17	7	5.11
18	1.32	0.41	1254	0.01	13	11.87	3.83	11	1.29
21	1.30	1.74	1364	0.05	16	11.59	16.29	12	7.60
20	1.14	2.14	1294	0.05	15	10.01	19.70	11	7.53
20	0.45	1.46	1179	0.07	14	3.87	13.20	10	10.04
22	1.42	0.93	1184	0.01	16	12.24	8.39	10	1.21
21	1.83	1.30	1554	0.03	15	15.67	11.61	13	4.69
25	3.25	2.85	5000	0.08	9	13.95	13.70	20	5.33
19	1.15	1.73	4433	0.02	7	4.83	8.13	17	1.58
27	1.81	2.60	3277	0.04	10	7.52	12.14	13	2.90
35	1.80	3.42	4059	0.04	13	7.45	15.83	16	2.68
22	2.12	3.21	3810	0.08	8	8.67	14.73	15	4.88
57	2.13	2.82	4342	0.10	20	8.58	12.72	16	6.16
25	3.49	3.69	3686	0.11	9	13.94	16.54	14	6.79
10	4.04	2.75	1656	0.11	3	15.85	12.09	6	6.54
36	4.11	0.91	2251	0.13	12	15.90	3.95	8	7.99
27	1.82	2.65	3440	0.16	9	6.97	11.37	12	9.75

3. Finishing stage

CODE	Project Type	Construction stage	NO. of Storey	Slab Area	Area of Wall Internal	Area of Wall External	Estimated					Actual Consumption				
				SQ.MT	SQ.MT	SQ.MT	Cement (Bags)	Sand (CU.M)	Floor Finishes	Wall Finishes		Cement (Bags)	Sand (CU.M)	Floor Finishes	Wall Finishes	
									SQ.MT	Internal	External				Internal	External
RSP_001	RES. Small Project	Finishing	G	55.76	136	85	25	6.5	55.76	22	15	28	7.1	62	25	17
RSP_002	RES. Small Project	Finishing	G	57.62	141	88	26	6.71	57.62	23	15	30	7.25	64	24	18
RSP_003	RES. Small Project	Finishing	G	58.06	142	88	26	6.76	58.06	23	16	30	7.3	65	25	16
RSP_004	RES. Small Project	Finishing	G	58.53	143	89	26	6.82	58.53	23	16	29	7.75	64	26	17
RSP_005	RES. Small Project	Finishing	G	59.46	145	91	27	6.93	59.46	23	16	31	8	62	24	18
RSP_006	RES. Small Project	Finishing	G	60.85	148	93	27	7.09	60.85	24	16	30	7.8	66	25	18
RSP_007	RES. Small Project	Finishing	G	62.24	152	95	28	7.25	62.24	24	17	30	8	68	26	19
RSP_008	RES. Small Project	Finishing	G	63.92	156	97	29	7.45	63.92	25	17	32	8.45	65	27	20
RSP_009	RES. Small Project	Finishing	G	64.57	158	98	29	7.52	64.57	25	17	34	8.75	67	26	20
RSP_010	RES. Small Project	Finishing	G	65.03	159	99	29	7.57	65.03	26	17	34	9	69	28	20
RSP_011	RES. Small Project	Finishing	G	69.061	169	105	31	8.04	69.06	27	19	37	9.2	72	29	21
RSP_012	RES. Small Project	Finishing	G	68.75	168	105	31	8.01	68.75	27	18	34	9	77	30	22
RSP_013	RES. Small Project	Finishing	G	69.21	169	105	31	8.06	69.21	27	19	32	9.22	78	31	21
RSP_014	RES. Small Project	Finishing	G	69.68	170	106	31	8.12	69.68	27	19	35	9	80	32	20
RSP_015	RES. Small Project	Finishing	G	70.23	171	107	31	8.18	70.23	28	19	37	9.3	79	30	21
RSP_016	RES. Small Project	Finishing	G	70.98	173	108	32	8.27	70.98	28	19	34	9.5	78	30	22
RSP_017	RES. Small Project	Finishing	G	72.00	176	110	32	8.39	72.00	28	19	36	9.45	78	29	20
RSP_018	RES. Small Project	Finishing	G	73.21	179	112	33	8.53	73.21	29	20	38	9.25	80	32	21
RSP_019	RES. Small Project	Finishing	G	73.39	179	112	33	8.55	73.39	29	20	36	9.4	81	33	23
RSP_020	RES. Small Project	Finishing	G	73.95	180	113	33	8.61	73.95	29	20	39	9.55	84	31	22
RSP_021	RES. Small Project	Finishing	G+1	148.70	363	227	67	17.32	148.70	58	40	75	20	160	65	45
RSP_022	RES. Small Project	Finishing	G+1	152.36	372	232	68	17.75	152.36	60	41	77	20	164	67	46
RSP_023	RES. Small Project	Finishing	G+1	153.29	374	234	69	17.86	153.29	60	41	80	20	168	69	44
RSP_024	RES. Small Project	Finishing	G+1	154.59	377	236	69	18.01	154.59	61	41	82	21	171	70	45
RSP_025	RES. Small Project	Finishing	G+1	156.08	381	238	70	18.18	156.08	61	42	80	20	177	70	48
RSP_026	RES. Small Project	Finishing	G+1	158.86	388	242	71	18.50	158.86	62	43	83	20	178	68	44
RSP_027	RES. Small Project	Finishing	G+1	159.79	390	244	72	18.61	159.79	63	43	85	21	180	70	50
RSP_028	RES. Small Project	Finishing	G+1	162.95	398	248	73	18.98	162.95	64	44	84	21	183	71	45
RSP_029	RES. Small Project	Finishing	G+1	165.37	403	252	74	19.26	165.37	65	44	84	22	187	70	50

Amount of waste Actual consumption – Estimated consumption					Wastivity Wastivity=wastage*100/estimatedconsumption				
Cement (Bags)	Sand (CU.M)	Floor Finishes	Wall Finishes		Cement (Bags)	Sand (CU.M)	Floor Finishes	Wall Finishes	
			Internal	External				Internal	External
3	0.6	6.238	3	2	12	9.23076923	11.18682974	13.6363636	13.3333333
4	0.5384224	6.38	1.3645592	2.54493312	16	8.0222927	11.07254426	6.02841894	16.4666587
4	0.53671498	6.93608324	2.19017094	0.42586399	15	7.93571429	11.9456	9.60187354	2.73443092
3	0.9326087	5.471571906	3.00769231	1.3012709	11	13.6798469	9.348571429	13.0812981	8.28902069
4	1.07439614	2.542549238	0.64273504	2.05208473	16	15.5133929	4.27625	2.75175644	12.8674168
3	0.71207729	5.149015236	1.09529915	1.67830546	10	10.0463468	8.461679389	4.5819404	10.2826668
2	0.74975845	5.755481234	1.54786325	2.3045262	8	10.3411514	9.246567164	6.33017582	13.8032992
3	1.00497585	1.083240431	1.89094017	2.85599108	12	13.4986244	1.694767442	7.5309079	16.6588287
5	1.22922705	2.432924563	0.63547009	2.68156076	18	16.3444245	3.768057554	2.50534935	15.4838477
5	1.42512077	3.968413229	2.45299145	2.55696767	17	18.8137755	6.102285714	9.60187354	14.6589631
6	1.15577472	2.939	1.87007676	2.47618234	20	14.3677567	4.255658041	6.8930411	13.3675594
3	0.99227053	8.252322557	2.99316239	3.56022297	10	12.3914093	12.00378378	11.0829799	19.3072994
1	1.15816425	8.787811223	3.81068376	2.43562988	3	14.3660115	12.69691275	14.0153718	13.1199166
4	0.88405797	10.32329989	4.62820513	1.31103679	12	10.8928571	14.816	16.9086651	7.01503221
6	1.11913043	8.765886288	2.40923077	2.16152508	18	13.6798469	12.48095238	8.7320174	11.4739919
2	1.23256039	7.022668153	2.11726496	2.96217614	7	14.9086107	9.894240838	7.59346224	15.5594261
4	1.06352657	6.000743218	0.71581197	0.68807135	12	12.6814516	8.334451613	2.53078492	3.5629344
5	0.72285024	6.79301375	3.24136752	1.36412932	16	8.47704405	9.279187817	11.2709376	6.94712927
3	0.85120773	7.607209216	4.16837607	3.31429208	9	9.95705244	10.36506329	14.4576527	16.836032
6	0.93628019	10.04979562	1.94940171	2.16478038	18	10.8696384	13.58994975	6.71036682	10.9138211
8	2.67965696	11.302	6.58547768	5.11562765	13	15.4711541	7.600640224	11.2736994	12.8261455
9	2.2531401	11.64028242	7.14700855	5.13346711	13	12.695993	7.64	11.9409379	12.561543
11	2.14492754	14.71125975	8.78205128	2.88428094	16	12.012987	9.597090909	14.5837769	7.01503221
13	2.99342995	16.41062802	9.27111111	3.53542029	18	16.6240986	10.615625	15.2663934	8.52636229
10	1.82028986	20.92419175	8.68717949	6.13672241	14	10.0127551	13.40642857	14.1686183	14.6589631
12	1.49565217	19.13712375	5.59230769	1.38916388	17	8.08270677	12.04631579	8.96092691	3.2601188
13	2.38743961	20.20810108	7.22735043	7.1399777	19	12.8270349	12.64651163	11.5135341	16.6588287
11	2.01951691	20.04942401	6.98649573	1.2927447	15	10.6399658	12.30399088	10.9140967	2.95773481
10	2.73816425	21.63396507	5.03760684	5.64486065	13	14.2154896	13.08247191	7.75465095	12.7265087

C. Rate Calculation

1. Substructure Stage

RATE					COST OF WASTAGE				
Cement (Bags)	Sand (CU.M)	Aggeregate(CU.M)	Bricks (NOS.)	RF (M.TON)	Cement (Bags)	Sand (CU.M)	Aggeregate(CU. M)	Bricks (NOS.)	RF (M.TON)
280	1575	996	8	47000	3640.00	1645.88	2539.80	1976.00	5640.00
280	1575	996	8	47000	5644.24	1982.19	2137.22	3163.52	1438.20
280	1575	996	8	47000	6107.50	1096.36	1977.74	660.00	5581.25
280	1575	996	8	47000	5730.76	1785.53	1818.27	1356.48	9724.30
280	1575	996	8	47000	7777.28	958.87	3491.32	1549.44	8610.40
280	1575	996	8	47000	5247.06	1293.88	4008.90	1638.88	6939.55
280	1575	996	8	47000	8316.84	1786.40	3530.48	2128.32	7618.70
280	1575	996	8	47000	4160.58	2219.91	1960.37	1755.65	913.68
280	1575	996	8	47000	6993.14	2082.25	2733.11	810.72	7183.95
280	1575	996	8	47000	6056.40	1983.92	2573.63	1507.20	16027.00
280	1575	996	8	47000	5600.00	3780.00	4068.66	2520.00	7520.00
280	1575	996	8	47000	6219.55	4951.39	3551.09	2328.00	9706.16
280	1575	996	8	47000	7188.60	4772.01	4335.54	3014.00	11423.09
280	1575	996	8	47000	5357.65	5380.12	3128.00	2900.00	10790.03
280	1575	996	8	47000	7640.51	4377.36	4866.14	2363.20	12380.35
280	1575	996	8	47000	5551.00	3302.85	5523.66	2580.80	6667.44
280	1575	996	8	47000	7402.91	3695.71	4560.26	730.00	5274.69
280	1575	996	8	47000	7682.44	1654.32	3014.24	2433.60	10678.72
280	1575	996	8	47000	8910.06	3157.56	4423.62	2788.00	10425.49
280	1575	996	8	47000	8392.92	6092.30	6161.77	1851.20	2615.81
280	1575	996	8	47000	10640.00	5670.00	5949.11	4440.00	7050.00
280	1575	996	8	47000	12692.78	5743.30	5650.35	3232.00	7833.02
280	1575	996	8	47000	13453.10	6296.91	10300.42	2320.00	11549.08
280	1575	996	8	47000	19557.55	5181.98	9838.50	3763.20	12521.55
280	1575	996	8	47000	18534.06	7957.77	7318.60	3984.00	13297.24
280	1575	996	8	47000	11015.03	7256.12	5332.79	2848.00	10345.41
280	1575	996	8	47000	17375.35	3872.24	7990.86	3136.00	14061.46
280	1575	996	8	47000	13800.44	6227.04	6869.07	2755.20	15416.05
280	1575	996	8	47000	14937.28	5618.94	10991.24	2864.00	12857.79
280	1575	996	8	47000	17857.92	8301.18	10331.36	3040.00	10889.90

List of Publication

Paper Title	Name of Journal	Indexing	Publisher	DOP
Quantification analysis and prediction model for residential building construction waste using machine learning technique.	Asian Journal of Civil Engineering	Scopus & UGC-CARE List (India)	Springer Nature Switzerland AG	31 January 2023
Performance analysis of machine learning-based prediction models for residential building construction waste	Asian Journal of Civil Engineering	Scopus & UGC-CARE List (India)	Springer Nature Switzerland AG	18 May 2023
A formal evaluation of KNN and decision tree algorithms for waste generation prediction in residential projects: A comparative approach	Asian Journal of Civil Engineering	Scopus & UGC-CARE List (India)	Springer Nature Switzerland AG	21 June 2023

Asian Journal of Civil Engineering
https://doi.org/10.1007/s42107-023-00580-x

RESEARCH

Quantification analysis and prediction model for residential building construction waste using machine learning technique

Akshay Gulghane[1,2] · **R. L. Sharma**[1] · **Prashant Borkar**[3]

Received: 14 December 2022 / Accepted: 18 January 2023

Abstract

Prediction of construction waste is one of the successful techniques to reduce the amount of waste generation at source. Estimation of construction waste at each stage or phase of project is very essential to accurately compute and predict the total waste generation. The study aims to quantify the amount of construction waste at different stages of construction project so as to develop a machine learning model to accurately predict the amount of generated waste at various stages and from variable sources. About 134 construction sites were inspected to collect the generated waste data. As the construction activities are very dynamic in nature, it is very important to precisely compute the waste generation, to analyze the data prediction model, and enable to predict the sources and the amount of waste likely to generate. The decision tree and the *K*-nearest neighbors algorithm are used for analyzing, and the neural networks performance was studied by providing gross floor area and material estimation. The results indicate that an appreciable amount of waste is generated at every stage of project having considerable high cost, and a particular pattern has been observed for waste materials at typical stages of projects. The model has average RSME values of 0.49 which indicates the accuracy of model is satisfactory for use to perform the predictions. The combined average accuracy of the decision tree and KNN was found to be 88.32 and 88.51, respectively. These findings can provide basic data support and reference for the management and utilization of construction waste.

Keywords Construction waste management · Quantification of waste and waste minimization · Machine learning · Prediction model

Introduction

One of the main contributors to the environmental burden and consuming the appreciable amount non-renewable resources as well as causing waste streams is the construction and infrastructural industry. The industry plays paramount role in economical contribution as well as the social development world-wide but also responsible for diminution about 40% natural resources, greenhouse gas emission of 18% and global waste of 25% (Ali and Rahmat 2010; Suk et al., 2016). The residential building sector uses a significant amount of resources and thus it is one of the biggest contributors to the environmental deterioration. Management of construction waste has become a critical issue around the globe due to rapid urbanization in living areas. (Coskuner et al., 2020) Construction waste is primarily generated at each stage of construction project; the amount of the generated waste mainly depends upon the type of project, quantum of work, degree of complexity, accuracy of design, adopted working methodology, communication and the quality of workmanship (Markandeya Raju et al., 2015; Parsamehr et al., 2022). Residential construction project mostly generates the waste between 0.95 and 1.15 kg of solid waste per square foot. In particular, the amount of construction waste generation is steadily increasing with respect to forward transition of construction stages (Ruibo et al., 2021). The reduction of such high

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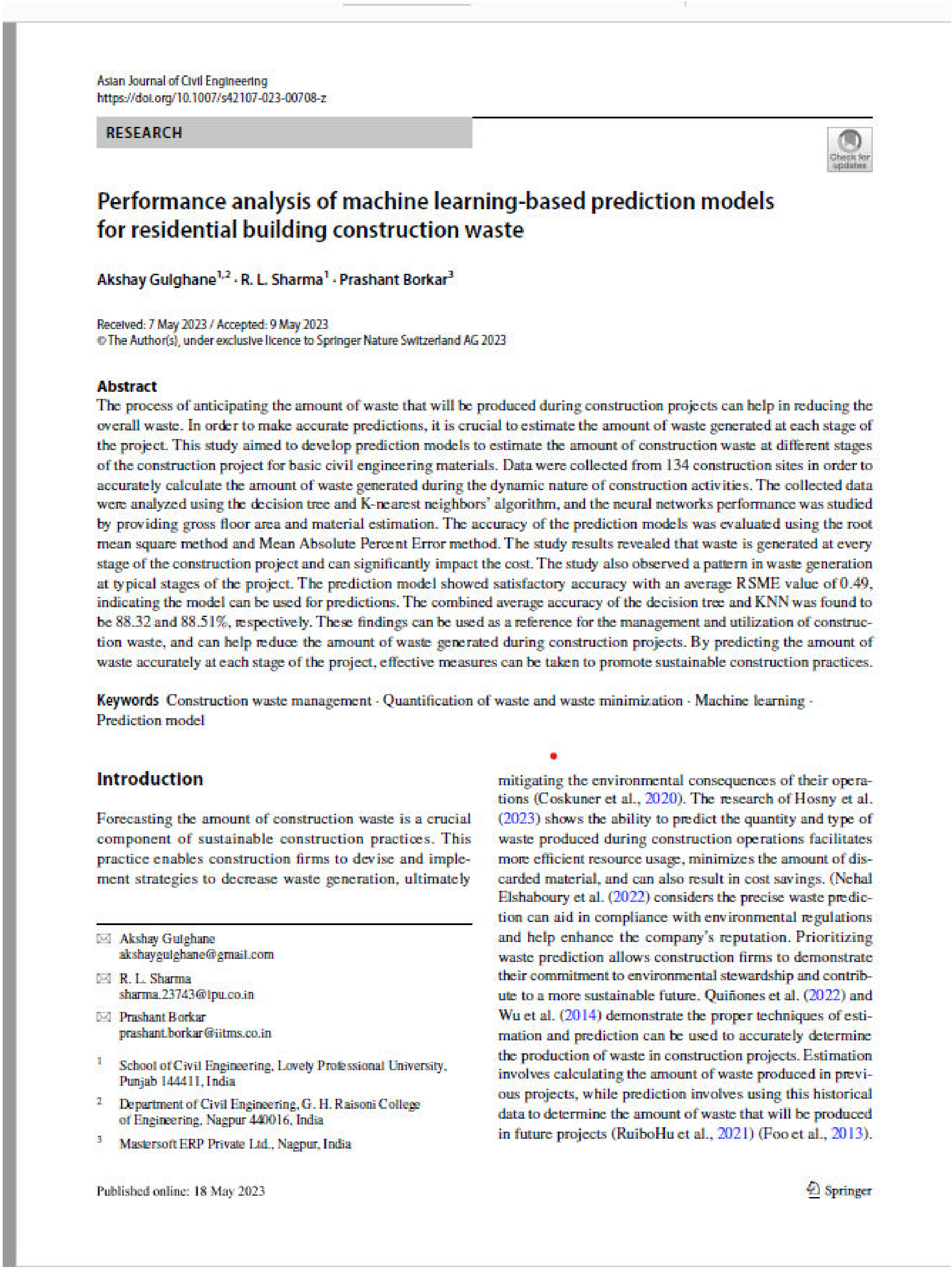

Asian Journal of Civil Engineering
https://doi.org/10.1007/s42107-023-00708-z

RESEARCH

Performance analysis of machine learning-based prediction models for residential building construction waste

Akshay Gulghane[1,2] · R. L. Sharma[1] · Prashant Borkar[3]

Received: 7 May 2023 / Accepted: 9 May 2023

Abstract

The process of anticipating the amount of waste that will be produced during construction projects can help in reducing the overall waste. In order to make accurate predictions, it is crucial to estimate the amount of waste generated at each stage of the project. This study aimed to develop prediction models to estimate the amount of construction waste at different stages of the construction project for basic civil engineering materials. Data were collected from 134 construction sites in order to accurately calculate the amount of waste generated during the dynamic nature of construction activities. The collected data were analyzed using the decision tree and K-nearest neighbors' algorithm, and the neural networks performance was studied by providing gross floor area and material estimation. The accuracy of the prediction models was evaluated using the root mean square method and Mean Absolute Percent Error method. The study results revealed that waste is generated at every stage of the construction project and can significantly impact the cost. The study also observed a pattern in waste generation at typical stages of the project. The prediction model showed satisfactory accuracy with an average RSME value of 0.49, indicating the model can be used for predictions. The combined average accuracy of the decision tree and KNN was found to be 88.32 and 88.51%, respectively. These findings can be used as a reference for the management and utilization of construction waste, and can help reduce the amount of waste generated during construction projects. By predicting the amount of waste accurately at each stage of the project, effective measures can be taken to promote sustainable construction practices.

Keywords Construction waste management · Quantification of waste and waste minimization · Machine learning · Prediction model

Introduction

Forecasting the amount of construction waste is a crucial component of sustainable construction practices. This practice enables construction firms to devise and implement strategies to decrease waste generation, ultimately mitigating the environmental consequences of their operations (Coskuner et al., 2020). The research of Hosny et al. (2023) shows the ability to predict the quantity and type of waste produced during construction operations facilitates more efficient resource usage, minimizes the amount of discarded material, and can also result in cost savings. (Nehal Elshaboury et al. (2022) considers the precise waste prediction can aid in compliance with environmental regulations and help enhance the company's reputation. Prioritizing waste prediction allows construction firms to demonstrate their commitment to environmental stewardship and contribute to a more sustainable future. Quiñones et al. (2022) and Wu et al. (2014) demonstrate the proper techniques of estimation and prediction can be used to accurately determine the production of waste in construction projects. Estimation involves calculating the amount of waste produced in previous projects, while prediction involves using this historical data to determine the amount of waste that will be produced in future projects (RuiboHu et al., 2021) (Foo et al., 2013).

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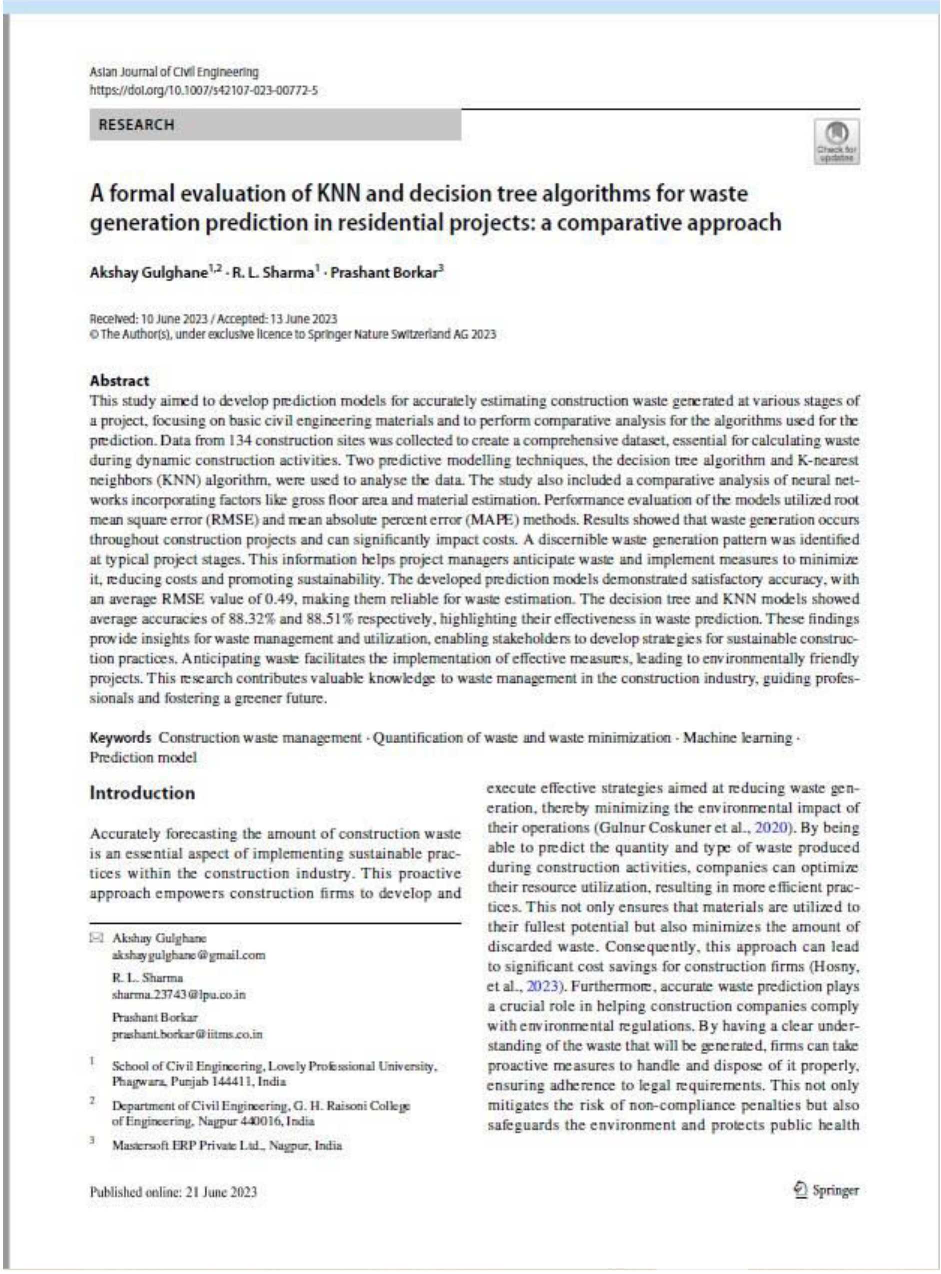

Asian Journal of Civil Engineering
https://doi.org/10.1007/s42107-023-00772-5

RESEARCH

A formal evaluation of KNN and decision tree algorithms for waste generation prediction in residential projects: a comparative approach

Akshay Gulghane[1,2] · **R. L. Sharma**[1] · **Prashant Borkar**[3]

Received: 10 June 2023 / Accepted: 13 June 2023

Abstract
This study aimed to develop prediction models for accurately estimating construction waste generated at various stages of a project, focusing on basic civil engineering materials and to perform comparative analysis for the algorithms used for the prediction. Data from 134 construction sites was collected to create a comprehensive dataset, essential for calculating waste during dynamic construction activities. Two predictive modelling techniques, the decision tree algorithm and K-nearest neighbors (KNN) algorithm, were used to analyse the data. The study also included a comparative analysis of neural networks incorporating factors like gross floor area and material estimation. Performance evaluation of the models utilized root mean square error (RMSE) and mean absolute percent error (MAPE) methods. Results showed that waste generation occurs throughout construction projects and can significantly impact costs. A discernible waste generation pattern was identified at typical project stages. This information helps project managers anticipate waste and implement measures to minimize it, reducing costs and promoting sustainability. The developed prediction models demonstrated satisfactory accuracy, with an average RMSE value of 0.49, making them reliable for waste estimation. The decision tree and KNN models showed average accuracies of 88.32% and 88.51% respectively, highlighting their effectiveness in waste prediction. These findings provide insights for waste management and utilization, enabling stakeholders to develop strategies for sustainable construction practices. Anticipating waste facilitates the implementation of effective measures, leading to environmentally friendly projects. This research contributes valuable knowledge to waste management in the construction industry, guiding professionals and fostering a greener future.

Keywords Construction waste management · Quantification of waste and waste minimization · Machine learning · Prediction model

Introduction

Accurately forecasting the amount of construction waste is an essential aspect of implementing sustainable practices within the construction industry. This proactive approach empowers construction firms to develop and execute effective strategies aimed at reducing waste generation, thereby minimizing the environmental impact of their operations (Gulnur Coskuner et al., 2020). By being able to predict the quantity and type of waste produced during construction activities, companies can optimize their resource utilization, resulting in more efficient practices. This not only ensures that materials are utilized to their fullest potential but also minimizes the amount of discarded waste. Consequently, this approach can lead to significant cost savings for construction firms (Hosny, et al., 2023). Furthermore, accurate waste prediction plays a crucial role in helping construction companies comply with environmental regulations. By having a clear understanding of the waste that will be generated, firms can take proactive measures to handle and dispose of it properly, ensuring adherence to legal requirements. This not only mitigates the risk of non-compliance penalties but also safeguards the environment and protects public health

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List of Conferences

Paper Title	**Name of conference**	**Indexing**	**Publisher**	**DOC**
Management of Construction waste in Building Architecture: A case study	International Conference on Advance in Sustainable Construction Material.	(AIP Series Conference Indexed by SCOPUS.	ELSEVIER	18-19 MARCH 2022
Identification And Analysis of Construction Waste Sources in Residential Building Architecture.	"Recent advancement Infrastructural Development, Water Management & Climate Change"	(IOP Conference Series (Earth and Environmental Science) Indexed by SCOPUS	Thomson Reuters	10-11 JUNE 2022

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