

**DEVELOPMENT OF A FRAMEWORK FOR CONSTRUCTION  
AND DEMOLITION WASTE MANAGEMENT IN INDIA  
USING BUILDING INFORMATION MODELING**

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**NOVEMBER 2024**

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USING BUILDING INFORMATION MODELING**

*by*

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*Submitted*

*in fulfillment of the requirements of the degree of*

*Doctor of Philosophy*

*to the*



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**NOVEMBER 2024**

## CERTIFICATE

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This is to certify that the thesis entitled “**Development of a Framework for Construction and Demolition Waste Management in India using Building Information Modeling,**” being submitted by **Ms. Sakshi Gupta, 2017CEZ8089**, to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work carried out by her under our supervision and guidance. In our opinion, the thesis work has reached the requisite standard, fulfilling the requirements for the degree of Doctor of Philosophy.

The contents of this thesis, in whole or in parts, have not been submitted to any other University or Institute for the award of any degree or diploma.

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## ACKNOWLEDGEMENTS

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First and foremost, I would like to thank God for guiding and helping me to complete this thesis.

I would like to extend my sincere gratitude to my guides, Prof. Kumar Neeraj Jha, Department of Civil Engineering, IIT Delhi, and Dr. Gayatri Vyas, Department of Civil Engineering, College of Engineering Pune (COEP) Technological University, Pune, for their constant support, encouragement, consistent and inspiring guidance, and utmost cooperation at every stage throughout the duration of the study. It was a highly educative and memorable experience working under their supervision. I am grateful that their mentorship, active participation, constant encouragement, and ‘never give up’ perspective, especially during my difficult times, have made me a good researcher.

I thank my student research committee members, Prof. Dhanya C.T. and Prof. Shashank Bishnoi of the Department of Civil Engineering, IIT Delhi, and Prof. Sushil, Department of Management Studies, IIT Delhi, for providing me with their valuable input throughout my study.

I wish to take this opportunity to extend my sincere thanks to the faculty members of IIT Delhi with whom I interacted occasionally. I also thank all the Department of Civil Engineering, IIT Delhi staff members, especially Mr. Randheer Kumar Jha and Mr. Rajeev Aggarwal, for their possible help during my research work.

As with any empirical research, the respondents and interviewees played a major role in providing me with significant input. I am grateful to all the respondents and interviewees who contributed by filling in the questionnaire, sparing their valuable time, and giving insight into my research problem.

I have earned magnificent souls as friends during these years at IIT Delhi. During my coursework, I cherish the moments spent with Dr. Nivea, Mr. Vinayak, and many M. Tech students. I thank my research group colleagues Dr. Dilip Patel, Dr. K.K. Tripathi, Dr. Prachi Sohoni, Dr. Satish Kumar V, Dr. Ratnesh Kumar, Dr. Sreenivas, Dr. Sparsh Johari, Dr. Santu Kar, Dr. Abhilasha Panwar, Dr. O. P. Tripathi, Ravindranadh Chowdary Kamma, Aman, Sakshi, Murali Krishna, Purva, Shikha, Garima and others with whom I have spent time in technical discussions at various stages of my research.

I am grateful to the management of Amity University Haryana, and it would be unfair on my part if I do not thank my colleagues at Amity University Haryana, Dr. Rashi Koul, Mr. Avinash Dholiwal, Dr. R K Malik, Dr. Sandeep Phogat, and many others for providing all possible constant support and helping me in my official duties, which has enabled me to focus on the present work.

I would like to extend my deepest gratitude to my parents, Mr. Ajay Gupta (Father) and Mrs. Kamna Gupta (Mother), for their constant support and encouragement throughout my study at IITD. Whatever I have achieved in my professional life is all because of them and I cannot express in words the efforts and encouragement they gave to nurture me. I wholeheartedly thank my loving brother, Mr. Sankul Gupta, for his unconditional love and cooperation, without which this study would not have been possible at all. I would also like to thank my husband, Mr. Ashish Verma, for the constant support during thesis writing and submission days of my work.

Last but not least, I thank the Almighty for giving me the strength and patience to complete this work in all aspects, leading to the path of success.

**Sakshi Gupta**  
**Gurugram**

## ABSTRACT

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In recent years, infrastructure growth has substantially increased due to people's increased disposable income worldwide, notably in nations like India, China, Brazil, South Africa, and Vietnam. The resource requirement will keep growing due to spurt needs for housing, commercial and industrial establishment, and road, railway, and airport infrastructures. Over time due to rapid development, the management of construction projects has continuously become more challenging. Additionally, there is increased pressure to construct intelligent and sustainable buildings. More construction will lead to more wastage of materials and other resources. Therefore, due to the environmental damage it causes, waste produced during building and demolition has become a significant obstacle to sustainable development. Construction and demolition waste management (C&DWM) is a complicated process involving much analytical thinking and is the prime reason for the success of any construction project.

India is awakening to the problem and potential of C&DW. As more and more cities recognize this stream and formulate strategies for managing it, they face challenges in the sector that must be addressed comprehensively for on-ground impact. Even though several studies have examined various aspects of C&DWM, there is still a sizable gap in integrating strategic tools. Advanced technological solutions are the answers to the problems related to C&DW and building information modeling (BIM) is one of them. BIM has developed as a cutting-edge technology with several applications in different construction areas. It demands utilizing some strategies and tools for minimizing waste, which has been reported in the literature. However, several challenges and complexities have been encountered, some of which have been addressed in this work. The study aims to address the pressing issue of

C&DWM in India by leveraging BIM technology. To achieve the aim of the work, the following four objectives have been set out:

- i. To assess the factors causing construction and demolition wastes in the Indian construction industry.
- ii. To investigate the BIM strategies for C&DWM and propose a BIM-based C&DWM theoretical framework.
- iii. To quantify the amount of construction waste using BIM technology.
- iv. To identify the factors affecting BIM for deconstruction (BIM-D) and develop a conceptual model for BIM-D in the Indian construction industry.

Despite the rapid growth of the construction industry, C&DW remains a significant challenge, prompting the need for efficient waste management strategies. Through comprehensive literature review, this research identifies existing gaps and explores the root causes of C&DW, setting the stage for the development of innovative frameworks that integrate BIM into the waste minimization and deconstruction processes.

An extensive literature survey was carried out to achieve the first objective, which intended to find the variables producing C&DW in India's construction sector and recognize the parameters that warrant a decrease in a construction project based on their importance level. Based on the data obtained through the questionnaire survey, the significance of each attribute was evaluated. A conceptual framework for assessing the C&DW in the Indian construction industry was proposed using the eight factors and 44 attributes identified after the factor analysis. This laid the groundwork for the investigation into BIM strategies tailored for effective C&DWM.

After identifying factors affecting the C&DW generation in the Indian construction industry, it was necessary to explore the C&DWM strategies and tools. Utilizing the BIM

platform could help minimize the C&DW at the source and design stage. The limitations of the tools based on BIM for C&DWM were identified to ensure a comprehensive understanding and outline the future needs for developing the tools to address the constraints. A pivotal component of this research involves proposing a BIM-based theoretical C&DWM framework, including strategies for economic and logistic analyses, to revolutionize C&DWM practices.

A questionnaire-based study was conducted to assess the BIM implementation for construction waste minimization to ascertain the strategies and understand the use of BIM for tackling construction waste. Additionally, the study endeavours to quantify construction waste using BIM technology, offering precise data to inform waste reduction efforts. It was further supplemented by a case study using the BIM approach to quantify concrete waste. It aided in developing knowledge on BIM in CWM, especially concrete waste, and catered to the third research objective of the study. Minimizing waste will create a more modest benefit for stakeholders in the construction sector, particularly project owners, contractors, sub-contractors, and real estate developers.

The deconstruction process to reduce C&DW is gaining popularity due to its importance in end-of-life (EOL) performances in the construction sector. Many organizations have started paying attention to building information modeling for deconstruction (BIM-D) practices, but the BIM for deconstruction approach is still in the inception stage in India. Although there are a few elementary studies in India, the actual BIM practices face several barriers, and the basic knowledge about the factors affecting BIM-D implementation is still missing. Another critical aspect of this research is the exploration of BIM for deconstruction (BIM-D). By identifying the factors influencing BIM-D using interpretive structural modeling (ISM) and developing a conceptual model, the study aims to enhance the sustainability of the construction industry in India. This proposed model not only addresses the environmental concerns associated with C&DW but also promotes the reuse and recycling of materials, aligning with

global sustainability goals. The results showed that the hierarchical BIM-D implementation architecture would support and enhance deconstruction processes in the Indian construction industry.

The results of this study demonstrated that effective waste prediction and minimization at the design stage depend on the integration of C&DWM into BIM. Further, it can be stated that the findings from this research will aid the construction authorities, experts, and stakeholders in managing C&DW more efficiently. It is, therefore, acknowledged that BIM technology will enhance a project's capabilities from its initiation to the EOL of the structure.

Thus, this research influences the field of construction management by catering the needs of a comprehensive framework for C&DWM using BIM, with the potential to significantly reduce waste and promote sustainable practices within the Indian construction industry.

**Keywords:** Building Information Modeling; Construction Waste; Construction and Demolition Waste; Construction Industry; Deconstruction; Framework; India; Strategies; Sustainability; Waste Management.

## सारांश

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हाल के वर्षों में, लोगों की वृद्धि हुई विश्वव्यापी वित्तीय आय के कारण अधिकतम मात्रा में अधिक प्रभावी रूप से बढ़ी है, खासकर भारत, चीन, ब्राजील, दक्षिण अफ्रीका, और वियतनाम जैसे राष्ट्रों में। संसाधन आवश्यकता निवास, वाणिज्यिक और औद्योगिक स्थापना, और सड़क, रेलवे, और हवाई अड्डा बुनियादों के लिए उम्मीदवार आवश्यकता के कारण लगातार बढ़ती रहेगी। समय के साथ तेजी से विकास के कारण, निर्माण परियोजनाओं का प्रबंधन लगातार अधिक चुनौतीपूर्ण होता जा रहा है। इसके अलावा, बुद्धिमान और सतत इमारतें निर्मित करने के लिए बढ़ी दबाव है। अधिक निर्माण सामग्रियों और अन्य संसाधनों की अधिक बर्बादी की ओर ले जाएगा। इसलिए, जलवायु नुकसान के कारण, निर्माण और विध्वंस के दौरान उत्पन्न कर्ष को सतत विकास के लिए महत्वपूर्ण बाधा बना दिया है। निर्माण और विध्वंस के कार्य प्रबंधन (सी एंड डीडब्ल्यूएम) एक जटिल प्रक्रिया है जिसमें अधिकांश विश्लेषणात्मक विचार शामिल होता है और यह किसी भी निर्माण परियोजना की सफलता का प्रमुख कारण है।

भारत सी एंड डीडब्ल्यू की समस्या और संभावनाओं की ओर जाग रहा है। जैसे-जैसे अधिक से अधिक शहर इस धारा को पहचानते हैं और इसे प्रबंधित करने के लिए रणनीतियाँ बनाते हैं, वे क्षेत्र में चुनौतियों का सामना करते हैं जिन्हें जमीनी प्रभाव के लिए समग्र रूप से संबोधित किया जाना चाहिए। हालांकि कई अध्ययनों ने सी एंड डीडब्ल्यूएम के विभिन्न पहलुओं का परीक्षण किया है, रणनीतिक उपकरणों को एकीकृत करने में अभी भी एक बड़ा अंतर है। उन्नत तकनीकी समाधान सी एंड डीडब्ल्यू से संबंधित समस्याओं का उत्तर हैं, और बिल्डिंग इंफॉर्मेशन मॉडलिंग (बीआईएम) उनमें से एक है। बीआईएम ने विभिन्न निर्माण क्षेत्रों में कई अनुप्रयोगों के साथ एक अग्रणी प्रौद्योगिकी के रूप में विकसित किया है। इसमें कचरे को कम करने के लिए कुछ रणनीतियों और उपकरणों का उपयोग करने की मांग की गई है, जिसे साहित्य में बताया गया है। हालांकि, कई चुनौतियों और जटिलताओं का सामना किया गया है, जिनमें से

कुछ का इस कार्य में संबोधन किया गया है। यह अध्ययन भारत में सी एंड डीडब्ल्यूएम की गंभीर समस्या को बीआईएम प्रौद्योगिकी का उपयोग करके संबोधित करने का लक्ष्य रखता है। इस कार्य के उद्देश्य को प्राप्त करने के लिए, निम्नलिखित चार उद्देश्य निर्धारित किए गए हैं:

- i. भारतीय निर्माण उद्योग में निर्माण और विध्वंस कचरे का कारण बनने वाले कारकों का मूल्यांकन करना।
- ii. सी एंड डीडब्ल्यूएम के लिए बीआईएम रणनीतियों की जांच करना और एक बीआईएम -आधारित सी एंड डीडब्ल्यूएम सैद्धांतिक ढांचा प्रस्तावित करना।
- iii. बीआईएम प्रौद्योगिकी का उपयोग करके निर्माण कचरे की मात्रा को मापना।
- iv. बीआईएम - डी को प्रभावित करने वाले कारकों की पहचान करना और भारतीय निर्माण उद्योग में बीआईएम - डी के लिए एक सैद्धांतिक मॉडल विकसित करना।

निर्माण उद्योग के तीव्र विकास के बावजूद, सी एंड डीडब्ल्यू एक महत्वपूर्ण चुनौती बना हुआ है, जिससे कचरा प्रबंधन रणनीतियों की कुशलता की आवश्यकता होती है। व्यापक साहित्य समीक्षा के माध्यम से, यह शोध मौजूदा अंतरालों की पहचान करता है और सी एंड डीडब्ल्यू के मूल कारणों का पता लगाता है, जिससे कचरा न्यूनीकरण बीआईएम - डी को एकीकृत करने वाले नवीन ढांचों के विकास के लिए मंच तैयार होता है।

पहले उद्देश्य को प्राप्त करने के लिए एक व्यापक साहित्य सर्वेक्षण किया गया, जिसका इरादा भारत के निर्माण क्षेत्र में सी एंड डीडब्ल्यू उत्पन्न करने वाले चरों को खोजना और उन मापदंडों को पहचानना था जो उनके महत्व स्तर के आधार पर एक निर्माण परियोजना में कमी की वारंटी देते हैं। प्रश्नावली सर्वेक्षण के माध्यम से प्राप्त डेटा के आधार पर, प्रत्येक विशेषता का महत्व मूल्यांकन किया गया। कारक विश्लेषण के बाद पहचाने गए आठ कारकों और 44 विशेषताओं का उपयोग करके भारतीय निर्माण उद्योग में सी एंड डीडब्ल्यू का मूल्यांकन करने के लिए एक सैद्धांतिक ढांचा प्रस्तावित किया गया। इसने प्रभावी सी

एं ड डीडब्ल्यूएम के लिए अनुकूलित बिल्डिंग इन्फॉर्मेशन मॉडलिंग रणनीतियों की जांच के लिए आधारभूत काम तैयार किया।

भारतीय निर्माण उद्योग में सी एंड डीडब्ल्यू उत्पादन को प्रभावित करने वाले कारकों की पहचान के बाद, सी एंड डीडब्ल्यूएम रणनीतियों और उपकरणों का पता लगाना आवश्यक था। बीआईएम प्लेटफॉर्म का उपयोग स्रोत और डिज़ाइन चरण में सी एंड डीडब्ल्यू को कम करने में मदद कर सकता है। सी एंड डीडब्ल्यूएम के लिए बीआईएम आधारित उपकरणों की सीमाओं की पहचान की गई ताकि एक समग्र समझ सुनिश्चित की जा सके और बाधाओं को संबोधित करने के लिए उपकरणों को विकसित करने की भविष्य की आवश्यकताओं की रूपरेखा तैयार की जा सके। इस शोध का एक महत्वपूर्ण घटक बीआईएम -आधारित सैद्धांतिक सी एंड डीडब्ल्यूएम ढांचे का प्रस्ताव करना शामिल है, जिसमें आर्थिक और लॉजिस्टिक विश्लेषणों की रणनीतियाँ शामिल हैं, जो सी एंड डीडब्ल्यूएम प्रथाओं में क्रांति लाने के लिए है।

एक प्रभावली-आधारित अध्ययन किया गया था ताकि निर्माण कचरे को कम करने के लिए बीआईएम कार्यान्वयन का मूल्यांकन किया जा सके, रणनीतियों की पहचान की जा सके और निर्माण कचरे से निपटने के लिए बीआईएम के उपयोग को समझा जा सके। इसके अतिरिक्त, अध्ययन ने बीआईएम प्रौद्योगिकी का उपयोग करके निर्माण कचरे की मात्रा का निर्धारण करने का प्रयास किया, जिससे कचरे को कम करने के प्रयासों को सूचित करने के लिए सटीक डेटा प्रदान किया जा सके। इसे बीआईएम दृष्टिकोण का उपयोग करके कंक्रीट कचरे की मात्रा का निर्धारण करने वाले एक मामले के अध्ययन द्वारा और समर्थन किया गया था। इससे डीडब्ल्यूएम में बीआईएम पर ज्ञान विकसित करने में मदद मिली, विशेष रूप से कंक्रीट कचरे के बारे में, और अध्ययन के तीसरे शोध उद्देश्य को पूरा किया। कचरे को कम करने से निर्माण क्षेत्र में हितधारकों के लिए अधिक मामूली लाभ होगा, विशेष रूप से परियोजना मालिकों, ठेकेदारों, उप-ठेकेदारों और रियल एस्टेट विकासकर्ताओं के लिए।

निर्माण क्षेत्र में अंत-जीवन (ईओएल) प्रदर्शनों में इसके महत्व के कारण सी एंड डीडब्ल्यू को कम करने की प्रक्रिया लोकप्रिय हो रही है। कई संगठनों ने बीआईएम - डी प्रथाओं पर ध्यान देना शुरू कर दिया है, लेकिन भारत में विध्वंस के लिए बिल्डिंग इन्फॉर्मेशन मॉडलिंग दृष्टिकोण अभी भी आरंभिक चरण में है। हालांकि भारत में कुछ प्राथमिक अध्ययन हैं, वास्तविक बीआईएम प्रथाओं का सामना कई बाधाओं से होता है, और बीआईएम - डी कार्यान्वयन को प्रभावित करने वाले कारकों के बारे में मूल ज्ञान अभी भी अनुपलब्ध है। इस शोध का एक अन्य महत्वपूर्ण पहलू बीआईएम - डी का अन्वेषण है। व्याख्यात्मक संरचनात्मक मॉडलिंग (आईएसएम) का उपयोग करके बीआईएम - डी को प्रभावित करने वाले कारकों की पहचान करने और एक सैद्धांतिक मॉडल विकसित करने के द्वारा, यह अध्ययन भारत में निर्माण उद्योग की स्थिरता को बढ़ाने का लक्ष्य रखता है। यह प्रस्तावित मॉडल न केवल सी एंड डीडब्ल्यू से जुड़ी पर्यावरणीय चिंताओं को संबोधित करता है बल्कि सामग्रियों के पुनः उपयोग और पुनर्चक्रण को भी बढ़ावा देता है, जो वैश्विक स्थिरता लक्ष्यों के अनुरूप है। परिणामों से पता चला कि पदानुक्रमिक बीआईएम - डी कार्यान्वयन वास्तुकला भारतीय निर्माण उद्योग में विध्वंस प्रक्रियाओं का समर्थन और सुधार करेगी। इस अध्ययन के परिणामों ने दिखाया कि डिज़ाइन चरण पर प्रभावी कचरा पूर्वानुमान और न्यूनीकरण सी एंड डीडब्ल्यूएम को बीआईएम में एकीकृत करने पर निर्भर करता है। आगे, यह कहा जा सकता है कि इस शोध से प्राप्त निष्कर्ष निर्माण प्राधिकरणों, विशेषज्ञों, और हितधारकों को सी एंड डीडब्ल्यू को अधिक कुशलतापूर्वक प्रबंधित करने में सहायता प्रदान करेंगे। इसलिए, यह माना जाता है कि बीआईएम प्रौद्योगिकी एक परियोजना की क्षमताओं को इसकी शुरुआत से संरचना के ईओएल तक बढ़ाएगी। इस प्रकार, यह शोध बीआईएम का उपयोग करके सी एंड डीडब्ल्यूएम के लिए एक व्यापक ढांचे की आवश्यकताओं को पूरा करके निर्माण प्रबंधन के क्षेत्र पर प्रभाव डालता है, जिसमें भारतीय निर्माण उद्योग के भीतर कचरे को काफी कम करने और स्थायी प्रथाओं को बढ़ावा देने की क्षमता है।

**कुंजीशब्द:** बिल्डिंग इन्फॉर्मेशन मॉडलिंग; निर्माण कचरा; निर्माण और विध्वंस कचरा; निर्माण उद्योग;  
विध्वंस; ढांचा; भारत; रणनीतियाँ; स्थिरता; कचरा प्रबंधन।

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## LIST OF ABBREVIATIONS

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AEC	Architecture, Engineering and Construction
AECO	Architecture, Engineering, Construction, and Operations
ANOVA	Analysis of Variance
ASHRAE	American Society of Heating, Refrigerating, And Air-Conditioning Engineers
BIM	Building Information Modeling
BIM-D	Bim For Deconstruction
BIM-DAS	Bim-Based Deconstructability Assessment Score
BMTPC	Building Material And Technology Promotion Council
BOQ	Bill Of Quantities
BREEAM	Building Research Establishment Environmental Assessment Method
BWAS	Building Waste Assessment Score
C&DW	Construction And Demolition Waste
C&DWM	Construction And Demolition Waste Management
C2C	Cradle-To-Cradle
CAD	Computer-Aided Drawing
CAGR	Compound Annual Growth Rate
CBA	Cost/Benefit Analysis
CFA	Confirmatory Factor Analysis
CFP	Carbon Foot Printing
COBie	Construction-Operations Building Information Exchange
CW	Construction Waste
CWM	Construction Waste Management

D&R	Demolition And Renovation
DAS	Deconstructability Assessment Score
DfD	Design For Deconstruction
DOI	Degree Of Importance
DoWT-B	Design Out Waste Tool For Buildings
DRWE	Demolition And Renovation Waste Estimation
EFA	Exploratory Factor Analysis
EIA	Environmental Impact Assessment
EOL	End-Of-Life
EPS	Environmental Performance Score
EWS	Economically Weaker Section
gbXML	Green Building Xml
GDP	Gross Domestic Product
GFA	Gross Floor Area
GIS	Geographic Information Systems
ICT	Information And Communications Technology
IDM	Information Delivery Manuals
IFD	Industry Foundation Dictionaries
ISM	Interpretive Structural Modelling
JIT	Just-In-Time
KMO	Kaiser-Meyer-Olkin
LCD	Life Cycle Design
MICMAC	Matrice D'impacts Croises-Multiplication Appliquée A Classement Classification And Categorization
MoEFCC	Ministry Of Environment, Forests, And Climate Change

MSA	Measures Of Sampling Adequacy
MSW	Municipal Solid Waste
MVD	Model View Definitions
NBIMS	National Building Information Modelling Standards
NWT	Net Waste Tool
O&M	Operation and Maintenance
PCA	Principal Component Analysis
QTO	Quantity Take-Off
RIBA	Royal Institute of British Architects
RII	Relative Importance Index
RM	Reachability Matrix
SMARTWaste	Site Methodology to Audit, Reduce, And Target Waste
SPSSV26	Statistical Package for Social Sciences Version 26
SSIM	Structural Self-Interaction Matrix
SWMP	Site Waste Management Plan
TIFAC	Technology, Information, Forecasting and Assessment Council
WCWES	Web-Based Construction Waste Estimation System
WMMM	Waste Management Mapping Model
WMP&G	Waste Management Plans and Guides
WMPAT	Waste Management Performance Assessment Tool