OPTIMIZING SELECTIVE DEMOLITION WITH BIM:
A PATH TOWARD SUSTAINABLE CONCRETE RECYCLING

MUSTAFA CAN ALP

ÖZYEĞİN UNIVERSITY

SEPTEMBER, 2025

OPTIMIZING SELECTIVE DEMOLITION WITH BIM: A PATH TOWARD SUSTAINABLE CONCRETE RECYCLING

by
Mustafa Can Alp

Thesis
Submitted in Partial Fulfillment of the
Requirements for the Degree of

Master of Science

in
Civil Engineering

Advisor: Assoc. Prof. Zeynep Başaran Bundur
Co-advisor: Asst. Prof. Gürşans Güven Işın

Graduate School of Science and Engineering
Özyeğin University
İstanbul

September, 2025

OPTIMIZING SELECTIVE DEMOLITION WITH BIM: A PATH TOWARD SUSTAINABLE CONCRETE RECYCLING

Approved by:

Assoc. Prof. Zeynep Başaran Bundur,
Advisor
Department of Civil Engineering
Özyeğin University

Assoc. Prof. Semra Çomu Yapıcı
Department of Civil Engineering
Boğaziçi University

Asst. Prof. Gürşans Güven Işın,
Co-Advisor
Department of Civil Engineering
University of Monitoba

Assoc. Prof. Çağla Meral Akgül
Department of Civil Engineering
Middle East Technical University

Asst. Prof. Taner Yılmaz
Department of Civil Engineering
Özyeğin University

Approval Date: August 06, 2025

In memory of my father, Atilla Alp

DECLARATION OF ORIGINALITY

I hereby declare that I am the sole author of this thesis and that this is the true copy of my thesis, including the final revisions, approved by my thesis committee. All data and information have been obtained, produced, and presented in accordance with the rules of research ethics and principles of academic honesty. As required by these rules, to the best of my knowledge I have acknowledged ideas, thoughts, and any copyrighted material in accordance with the standard referencing rules. I certify that any part of this thesis has not been submitted for a degree or diploma in another educational institution.

Mustafa Can Alp

ABSTRACT

The construction industry contributes roughly 39% of the annual global Carbon dioxide (CO_2) emissions and is responsible for 35% of global waste generation in landfills due to the demolition of structures. To improve sustainability and material circularity in society, the construction and demolition sector holds a prominent position, particularly in recycling. With the release of EN 197-6 “Recycled Concrete”, recycling of construction demolition waste (CDW) becomes more important. An essential step in recycling CDW is the efficiency of selective demolition techniques to maximize resource efficiency. However, major limitations of selective demolition includes increased duration of demolition, labor demand, and cost. This necessity underscores the importance of integrating selective demolition techniques with Building Information Modeling (BIM). This study aims to demonstrate the economic and operational and environmental perspective of selective demolition processes by using a BIM-based approach. A six-story residential building was modeled in Autodesk Revit to simulate the selective demolition scenarios. This study aims to compare the efficiency of two selective demolition techniques: a hydraulic breaker excavator and a mini excavator, from economic, operational, and environmental perspectives using a BIM-based approach. Assuming that the materials (concrete, brick) resulting from the demolition would be recycled and substituted, the amount of carbon emissions produced was calculated. The results showed that selective demolition increases recycling potential and contributes to the environment in terms of emissions, but it was concluded that selective demolition is not a viable option for contractors without incentives and subsidies.

Keywords: BIM (Building Information Modeling); Circular economy; Selective demolishing; Recycled Aggregates (RCA); CDW(Construction and Demolition Waste)

ÖZET

İnşaat sektörü, yıllık küresel CO_2 emisyonlarının yaklaşık %39'unu oluşturmakta ve yapıların yıkılması nedeniyle çöp sahalarında oluşan küresel atıkların %39'inden sorumludur. Toplumda sürdürülebilirliği ve malzeme döngüselliğini iyileştirmek için, inşaat ve yıkım sektörü, özellikle geri dönüşüm alanında önemli bir konuma sahiptir. EN 197-6 "Geri Dönüştürülmüş Beton" standardının yayınlanmasıyla birlikte, inşaat yıkıntı atıklarının (İYA) geri dönüşümü daha çok önem kazanmıştır. İYA'nin geri dönüşümünde önemli bir adım, kaynak verimliliğini en üst düzeye çıkarmak için seçici yıkım tekniklerinin verimliliğidir. Ancak, seçici yıkımın başlıca sınırlamaları arasında yıkım süresinin uzaması, işgücü talebi ve maliyet artışı bulunmaktadır. Bu gereklilik, seçici yıkım tekniklerinin Yapı Bilgi Modellemesi (BIM) ile entegre edilmesinin önemini vurgulamaktadır. Bu çalışma, BIM tabanlı bir yaklaşım kullanarak seçici yıkım süreçlerinin ekonomik, operasyonel ve çevresel perspektifini göstermeyi amaçlamaktadır. Autodesk Revit'te altı katlı bir konut binası modellenerek seçici yıkım senaryoları simüle edildi. Bu çalışma, BIM tabanlı bir yaklaşım kullanarak ekonomik, operasyonel ve çevresel açıdan iki seçici yıkım tekniğinin (hidrolik kırıcı ekskavatör ve mini ekskavatör) verimliliğini karşılaştırmayı amaçlamaktadır. Yıkımdan elde edilen malzemelerin (beton, tuğla) geri dönüştürüleceği ve ikame edileceği varsayımıyla, üretilen karbon emisyon miktarı hesaplandı. Sonuçlar, seçici yıkımın geri dönüşüm potansiyelini artırdığını ve emisyonlar açısından çevreye katkıda bulunduğunu göstermiştir, ancak seçici yıkımın teşvikler ve sübvansiyonlar olmadan müteahhitler için uygulanabilir bir seçenek olmadığı sonucuna varılmıştır.

Anahtar Kelimeler: BIM (Yapı Bilgi Modellemesi); Döngüsel ekonomi; Seçici yıkım; Geri dönüştürülmüş agregalar (RCA); CDW (İnşaat ve Yıkım Atıkları)

ACKNOWLEDGEMENTS

First of all, I would like to express my deepest gratitude to my advisor, Associate Professor Zeynep Başaran Bundur, and my co-advisor, Assistant Professor Gürşans Güven Işın, for their constant support throughout this study.

I am also grateful to my thesis committee, Asst. Prof. Taner Yılmaz, Assoc. Prof. Semra Çomu Yapıcı, and Assoc. Prof. Çağla Meral Akgül, for their time and valuable comments.

Additionally, I would like to express my deepest gratitude to my team members Ilgın Sandalcı, Shanghayeg Sadeghzadeh Benam, Tolga Aydın, Sami Berat Tever, and Mahmut Kerem Sarıkaya, for the information and constant support.

I want express my gratitude for the time and hospitality of industry stakeholders Ender Bozkurt, Mustafa Akkaya, and Ali Çimen, who provided the information about demolition and made this study possible.

Finally I would like to express my deepest gratitude to my family members, who have always supported me: my father Atilla Alp, my mother Tülin Alp, my brother Tacettin Taylan Alp, and my sister-in-law Selin Alp, for their unwavering support throughout this process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

CDW	Construction Demolition Waste
RCF	Recycled Concrete Fine
RCA	Recycled Concrete Aggregate
BIM	Building Information Modeling
ADR	Advanced Dry Recovery
HAS	Heating Air Classification System
RCP	Recycled Concrete Paste
BF-BOF	Blast Furnace-Basic Oxygen Furnace
RBP	Recycled Brick Powder
CO_2	Carbon dioxide

1. INTRODUCTION

The world climate is changing rapidly due to increasing urbanization and industrialization activities, and this causes problems related to climate change. Excessive consumption of natural resources, such as unlimited concrete production, raw material extraction, waste storage, as well as greenhouse gas emissions caused by construction activities are among the main problems that accelerate climate change and environmental degradation. When these adverse effects of cement production are combined with the consumption of raw materials required for concrete production, like aggregate, water, and chemicals; the negative impact of construction activities on the environment increases even more.As a result of factors such as new building and infrastructure construction, demolition, reconstruction or renovation works, expansion of existing buildings, and maintenance activities, a large amount of CDW is emerging, such as concrete, brick, ceramics, glass, and wood.

CDW represent the most significant waste volume, one-third of the waste generated in the European Union [2]. Approximately 800 million tons of CDW are produced in Europe every year, and this figure is expected to increase further due to the increasing urban population, the continuous development of economies, and industrialization activities [2][3]. As a developing country, Türkiye anticipates demolishing or reconstructing 8.2 million buildings over the next two decades [4]. Moreover, with the addition of population growth and increased infrastructure needs, CDW volume will be much more than expected. For instance, in the city of Istanbul, many buildings located in different districts of the city need to undergo urban transformation, and all the waste that will be generated due to the demolition of these buildings will be sent to landfills if they are not recycled or reused.

As CDW continues to pose environmental and logistical challenges, strategies such as selective demolition and on-site waste separation have emerged as effective approaches to improve material recovery and reduce landfill use. This way, the performance of waste after recycling can be improved and the recovery of valuable materials such as Recycled Concrete Aggregate (RCA) and Recycled Concrete Fine (RCF) becomes possible. In England, Portugal, and Japan, RCA can be substituted for 20% of the aggregates for new construction [5]. Thus, it contributes to the circular economy and creates landfill space [6]. Recycling of concrete at the end of the life of a structure can also potentially reduce the depletion of virgin aggregate materials [6]. While RCF, generated through concrete recycling, carbon dioxide can be captured under certain conditions through a process known as carbon capture or carbon sequestration. This transformation results in a high value-added material which can be used as a supplementary cementitious material, that contributes to more sustainable construction practices [3].

For successful selective demolition, detailed planning, scheduling, and waste quantification are required. These make selective demolition more environmentally friendly and cost-effective. The efficiency of selective demolition also depends on having a skilled team and using the right equipment. In the selective demolition approach first non-bearing elements (brick walls and insulation material) can be manually dismantled with demolition drills, followed by the dismantling of the walls and insulation, and the concrete elements (structural walls, columns, floors, stairs) can be dismantled starting from the top floor with a jaw excavator and continuing down to the lowest floor [7].

To address the growing demands for sustainable construction practices and the limitations of traditional demolition methods; this study proposes to use Building Information Modeling (BIM) to apply selective demolition approaches for optimum material recovery from buildings with two different demolition scenarios. This work investigates the economic benefits of selective demolition practices in construction, through a case study of a six-story residential building located in Istanbul.

1.1 Goal and Objectives

This study aims to simulate selective demolition cases using a BIM-based method. This hypothetical model helps with determining the volume of recycled material generated from the resulting waste and the cost of associated logistics. The information was gathered from industry professionals regarding the type of excavator that would be used for demolishing the case study building, as well as the fuel consumption of these excavators. The insights gained from this information highlights the environmental and economic benefits of selective demolition. The proposed approach enhances the efficiency, traceability, and sustainability of concrete recycling practices within circular construction systems. The specific objectives of this study are as follows:

- To simulate selective demolition in a BIM-based workflow and determining how much material can be recycled.
- To evaluate demolition scenarios from operational, labor, machinery, and logistics perspective.
- To determine how much carbon emissions are generated by materials and methods used in each demolition scenario.
- To examine the contribution of potential financial returns from the recycling of concrete, steel, and brick as part of circular economy practices.
- To develope a BIM-based demolition planning and reference model for the industry to promote more sustainable demolition practices.

1.2 Outline of the Thesis

This thesis study is established as follows:

- **Chapter 1.** introduction and problem statement.
- **Chapter 2.** reviews existing literature, assessments of CDW management in Türkiye, selective demolition, recycling of materials and BIM integration to demolition and CDW management.
- **Chapter 3.** outlines the materials and methods, providing a comprehensive explanation of the simulation process, cost analysis for demolition and carbon emission.
- **Chapter 4.** presents and discusses the results from Scenario 1 and 2 as well as comparison in terms of carbon emissions.
- **Chapter 5.** concludes the study by summarizing key findings and their significance.

2. LITERATURE REVIEW

Raw material uses and production lines designed for the construction industry generate significant carbon emissions. Because carbon emissions generated during the production of materials (especially cement) are the primary cause of environmental pollution [8], there is a global search for substitutes for these materials. It has been proven that materials recycled through selective demolition can be reused in the industry, and it is known that the resulting materials from concrete recycling are used in the industry to a certain extent. Furthermore, the high rate of construction and demolition waste generated in landfills will be significantly reduced by repurposing these materials and contributing them to the industry, emptying landfill space and reducing raw material consumption. Because this study concerns the management and recycling of waste resulting from the selective demolition of a building, it has been examined under four subheadings. These are waste management in Türkiye, selective demolition, material recycling, and BIM integration. The study brings together these four topics to assess the environmental and economic aspects of recycling and logistics for waste generated by the selective demolition of a building in Istanbul.

2.1 CDW Management in Türkiye

Various administrative regulations and government policies are implemented in many countries to recycle construction and demolition waste. In Türkiye, low disposal and landfill fees, coupled with inadequate oversight of the waste disposal process, negatively impact recycling rates[9]. In Istanbul, the fee for the landfilling of demolition trash is 105.26 TL($3,73/ton)[10]. While the fee for demolition waste disposal in Japan is $359/ton, in the United States, one of the countries with a high recycling rate, this fee is $60/ton[4]. In these countries, not only economic incentives, but also legal regulations support recycling processes. In Japan, the "Recycling Society Law" and the "Construction Materials Recycling Law," enacted in 2000, and the "Green Purchasing Law" of 2001 require the participation of all stakeholders in the recycling process.

Although relevant Turkish regulations require waste to be reduced at the source and selective demolition methods to be applied, field data and information from industry representatives show that these practices are rarely followed.

The existing construction and demolition waste rule in Türkiye, the "Excavation Soil, Construction and Demolition Waste Regulation," was published in 2004 and has not been revised, making it ineffective under current conditions. Furthermore, while excavation soil should not be considered waste, its inclusion in the law usually results in the mixing of construction and demolition waste with excavation soil, which impedes appropriate waste separation. In Türkiye, recycling and recovery efforts are limited due to a lack of broad selective demolition and a failure to sort waste at the source[11].

Also, there is no official data on the amount of waste released after construction and demolition in Türkiye. Considering the existing reinforced concrete building stock between the years before 1980 and 2000, 63% of these buildings are on the European side and 37% are on the Anatolian side. It is thought that the resulting CDW will be distributed according to these rates.

Table 2.1: *Number of Buildings Expected to Undergo Urban Transformation on the European Side [1]*

EUROPEAN SIDE DISTRICTS	1980 ÖNCESİ	1980–2000 ARASI	1980 ÖNCESİ–2000 ARASI	BETONARME BİNA YÜZDESİ	1980 ÖNCESİ–2000 ARASI BETONARME BİNA SAYISI PROJEKSİYONU
ARNAVUTKÖY	96	19,203	19,299	76.00%	14,667
AVCILAR	2,596	14,847	16,883	94.10%	15,887
BAĞCILAR	6,072	28,546	34,618	95.00%	32,887
BAHÇELİEVLER	3,892	15,483	19,375	97.00%	18,794
BAKIRKÖY	4,869	5,092	9,961	91.60%	9,124
BAŞAKŞEHİR	814	13,620	14,434	75.00%	10,826
BAYRAMPAŞA	8,295	10,240	18,535	77.50%	14,365
BEŞİKTAŞ	7,272	4,195	12,467	81.00%	10,098
BEYLİKDÜZÜ	6,491	6,221	12,712	89.12%	11,329
BEYOĞLU	17,052	7,490	24,992	64.00%	15,995
BÜYÜKÇEKMECE	2,303	13,662	14,925	91.00%	13,582
ÇATALCA	1,863	9,266	11,129	73.00%	8,124
ESENLER	6,582	11,738	18,320	96.00%	17,587
ESENYURT	14,884	23,302	38,186	95.00%	36,277
EYÜP	11,966	10,171	22,137	70.00%	15,496
FATİH	31,899	7,887	39,786	66.80%	26,577
GAZİOSMANPAŞA	12,786	8,375	21,161	81.90%	17,331
GÜNGÖREN	2,513	7,287	9,800	96.34%	9,441
KAĞITHANE	11,813	11,877	23,690	87.67%	20,769
KÜÇÜKÇEKMECE	7,535	20,621	28,156	88.05%	24,791
SARIYER	11,898	21,170	33,068	83.31%	27,549
SİLİVRİ	1,338	25,292	26,630	83.00%	22,103
SULTANGAZİ	4,502	18,421	22,923	81.92%	18,779
ŞİŞLİ	10,601	8,487	19,088	73.56%	14,041
ZEYTİNBURNU	2,594	10,103	12,697	92.00%	11,681
TOPLAM:	103,509	334,591	438,100	-	**438,100**

Table 2.2: *Number of Buildings Expected to Undergo Urban Transformation on the Anatolian Side [1]*

ANADOLU YAKASI İLÇELER	1980 ÖNCESİ	1980–2000 ARASI	1980 ÖNCESİ–2000 ARASI	BETONARME BİNA YÜZDESİ	1980 ÖNCESİ–2000 ARASI BETONARME BİNA SAYISI PROJEKSİYONU
ADALAR	3,584	1,741	5,325	45.50%	2,423
ATAŞEHİR	7,735	10,297	18,032	81.00%	14,606
BEYKOZ	15,981	18,352	34,333	68.42%	23,491
ÇEKMEKÖY	529	13,813	14,342	89.95%	12,901
KADIKÖY	12,816	5,611	18,427	84.00%	15,479
KARTAL	9,211	14,491	23,702	85.06%	20,161
MALTEPE	6,541	18,144	24,685	80.72%	19,926
PENDİK	6,703	27,889	34,592	81.65%	28,244
SANCAKTEPE	460	15,873	16,333	89.04%	14,543
SULTANBEYLİ	458	22,817	23,275	88.00%	20,482
ŞİLE	6,762	11,923	18,685	73.53%	13,739
TUZLA	2,882	11,139	14,021	81.00%	11,357
ÜMRANİYE	5,448	28,279	33,727	82.00%	27,656
ÜSKÜDAR	13,864	21,489	35,353	87.00%	30,757
TOPLAM:	–	–	–	–	**255,764**

2.1.1 Identified Gaps in the Literature with a Focus on Türkiye

When studies on construction and demolition waste in Türkiye are examined, it is evident that although various contributions have been made, there are still significant gaps. In one study, dust dispersion in demolition scenarios was examined, and the environmental impacts were compared, with the most suitable scenario selected from among five different scenarios[12]. In another study, the potential for using geopolymer concrete and disassembled prefabricated materials in value-added applications was investigated. Additionally, the amount of waste expected to be generated after an earthquake was estimated, and its management was examined from environmental, economic, and social perspectives, highlighting the importance of waste management[13]. In a study conducted on urban transformation projects in Izmir, it was revealed that waste should be separated at the source, recycling facilities should be established, and recycling should be made attractive through government incentives[14]. In addition, it was noted that renovation projects generate a significant amount of construction debris and that material quality, design quality, and workmanship are important[15]. Despite numerous studies focusing on these issues, there are gaps in the literature regarding waste management, demolition methods, and related topics in Türkiye. In particular, it has been observed that studies are limited in terms of the integration of BIM-based digital planning tools into demolition and separation processes, and the adaptation of preventive design strategies at the urban transformation scale. Therefore, in the context of construction waste management studies in Türkiye, there is a need for research that combines sustainability, value-added reuse of waste, and the integration of digital technologies to address both economic and environmental dimension.

2.1.2 Key Challenges in Türkiye and Opportunities for BIM

Selective demolition in Türkiye faces many challenges, which BIM can help address through improved planning, coordination and data management. If material connections are specified in advance within BIM, the most suitable demolition or disassembly methods and equipment can be identified. Another challenge is the lack of documentation needed to create as-built models of older buildings. In such cases, point clouds can be generated through laser scanning can be converted into BIM models to provide accurate digital representation. Tight demolition schedules, which often limit oppurtunities for material recycling, can also be optimized through 4D simulation, allowing the process to be previewed and planned more efficiently. Furthermore, BIM can support economic assessments by linking demolition data with projected values in the recycled materials market. For example, by separating and tracking lower-strength concrete from higher-strength concrete.

2.2 Selective Demolition

The separation of waste generated during demolition is subject to selective demolition according to the Regulation on the Control of Excavation, Construction, and Demolition Waste. Selective demolition can be carried out using the same equipment used in conventional demolition. A strategy is developed by determining the materials to be removed from the building beforehand. Selective demolition involves the separation of asbestos and other hazardous waste, as well as doors, windows, plumbing, metal, wood, plaster-derived materials, non-load-bearing elements, glass, insulation materials, asphalt, concrete, etc. [4]

The purpose of selective demolition is to reduce waste by isolating useable items. While selective demolition may appear to be a more time- and cost-intensive procedure than conventional demolition, the economic benefits of using recycled construction demolition waste should not be underestimated.

Steps of Selective Demolition[4]

1. Determining strategic priorities
2. Planning
3. Selection of equipment to be used
4. Isolation of the work area
5. Building Statics
6. Environmental Impact Assessment

Selective Demolition Planning[4]

Structural Assessment: Impact on the structural system and risk-bearing components of the structure needs to be analyzed.

Plumbing Layout Mapping: Plumbing layout can be complicated in buildings. For this reason, the installation must be mapped to ensure efficient recovery of recyclable materials

Environmental Analysis: Environmental analysis should be performed to minimize the damage to the environment that may occur during demolition.

2.2.1 Challenges in Selective Demolition

One of the main problems that arise during selective demolition is the strong connection between materials. Structural and non-structural materials are connected to each other during concrete pouring, mortar bonding, and mechanical connections. These connections ensure that the structure maintains its integrity during its service life, but they also make it difficult to separate the elements during demolition. For example, additional breaking operations are required to sever the connection between concrete and steel. Additionally, the mortar used to bond brick elements together, such as the paint applied over plaster, can serve as an example. These strong connections increase the need for labor, prolong the demolition process, and require equipment that consumes more energy. This translates to higher costs and less material being recycled. To overcome these challenges, specialized equipment, skilled workers, and sometimes partial demolition of certain areas of the building may be required. For example, acidic solutions can be used to remove the mortar that holds bricks together. However, care must be taken when using this method to avoid damaging the bricks, as the chemical can cause damage if it comes into contact with the bricks. Additionally, it is recommended to clean the bricks with a plastic or wooden scraper before using this method [16]. This requires more labor and time. Chemical solutions used locally must be cleaned with water before coming into contact with the bricks. For these reasons, chemical demolition is not preferred in the industry.

Recent studies have also suggested that digital technologies, particularly machine-learning-based classification systems, may help address some of the challenges of selective demolition. By analyzing visual and textural features of mixed demolition waste, algorithms such as Gradient Boosting (GB), Multi-Layer Perceptron (MLP), and advanced Convolutional Neural Networks (CNNs) like ResNet have been tested for material recognition and classification. These approaches promise higher accuracy and speed compared to manual separation, potentially reducing labor requirements. However, their applicability in real demolition sites remains limited due to heterogeneous waste conditions, lower classification accuracy in practice (sometimes falling below 50%)[17], and the high computational and energy costs involved[18]. Therefore, while machine learning offers a valuable complement to selective demolition, it cannot yet fully replace human expertise and controlled dismantling processes.

2.3 Recycling of Materials

Concrete debris was recycled using a three-stage mechanical process chain that included pre-crushing, Advanced Dry Recovery (ADR), Heating Air Classification System (HAS). To guarantee more efficient concrete recycling, larger parts were physically broken into smaller pieces. The ADR system then separated the cement paste leftovers and small particles from the aggregate, yielding coarse recycled aggregates RCA, RCF, and cement-based adhesive residues which is called Recycled Concrete Paste (RCP). The fundamental goal of the ADR system is to separate adhesive cement pastes on the aggregate surface via mechanical contact and friction, allowing for their recovery. Complementing this process, the HAS system uses the 1–4 mm air knife product from the ADR system and the 0–1 mm rotor product as inputs. The primary purpose of HAS is to dry these fine aggregate fractions with hot air to remove unwanted contaminants—particularly wood and plastic particles—from the environment. This results in purer, recyclable fine aggregate fractions [19].

The Electric Arc Furnace (EAF) route was adopted for the recycling of reinforcing steel and other metal components recovered after selective demolition. The EAF process is widely reported in the literature to have a lower specific carbon footprint compared to the primary Blast Furnace-Basic Oxygen Furnace (BF-BOF) route [20].

Because brick cannot be fully recycled, it was considered to be converted into Recycled Brick Powder (RBP). RBP is obtained through mechanical recycling and does not involve any chemical reactions. Research has shown that replacing up to 10% of cement with RBP ground to a fineness of 25–100 microns provides improvements, particularly in compressive strength. However, due to the porous nature of RBP, the mixture's water requirement increases, negatively impacting workability [21].

2.4 BIM

With the help of BIM, pre-demolition 3D planning and scheduling can improve waste tracking and increase recycling rates. Since waste transportation costs are a major expense during demolition [22], optimizing logistics through BIM can significantly reduce costs. Research has demonstrated that the integrating BIM with C# scripts can automatically generate outputs such as waste volumes and landfill fees, highlighting clear economic and environmental benefits [23]. BIM also supports the design of reuse, recycling, and disposal strategies through its capabilities in collaboration, project management, visualization, quantity takeoff, and waste management. Operational challenges such as cost, logistics, and occupational safety can be addressed, while sustainability analyses and optimization functions enhance reuse rates, shorten project duration, and reduce emissions [24]. One study reported that, BIM addressed 15 out of 23 identified construction and demolition waste management issues, most of which were process related [25]. BIM has also proven effective in advance decision-making. For instance, when choosing between renovation and redevelopment, BIM was used to assess the economic and environmental impacts of demolition methods and guided the final decision [26].

2.4.1 Benefits of BIM for Contractors

BIM contributes to construction in multiple ways, and helps manage potential issues that arise throughout a project. It optimizes cost and time through detailed planning and accurate quantity take-off, which improves material pricing. Multi-dimensional planning (3D geometry, time, cost, sustainability management, safety) enables more precise scheduling and risk analysis. Since construction is dynamic, with changes occurring during execution, creating a digital twin allows conflicts and design changes to be identified in advance. Collaboration is also strengthened by providing a shared digital workspace where architects, engineers, and contractors can coordinate, ensuring smoother project delivery. Together, these features support contractors by reducing costs and timelines, improving safety, and enhancing sustainability.

The integration of BIM is equally important in demolition. A pre-existing BIM model supports selective demolition and recycling by identifying material types and connections between load-bearing and non-load-bearing elements. This enables recyclable materials to be identified in advance, a waste management plan to be prepared, and demolition to contribute added value within a circular economy framework. Planning demolition on a model also allows stakeholders to coordinate time, logistics, budgeting, and sustainability considerations. In this way, BIM transforms demolition from a largely ad-hoc process into a controlled, planned, material-focused, and sustainable practice.

2.5 Gaps in The Literature and Research Significance

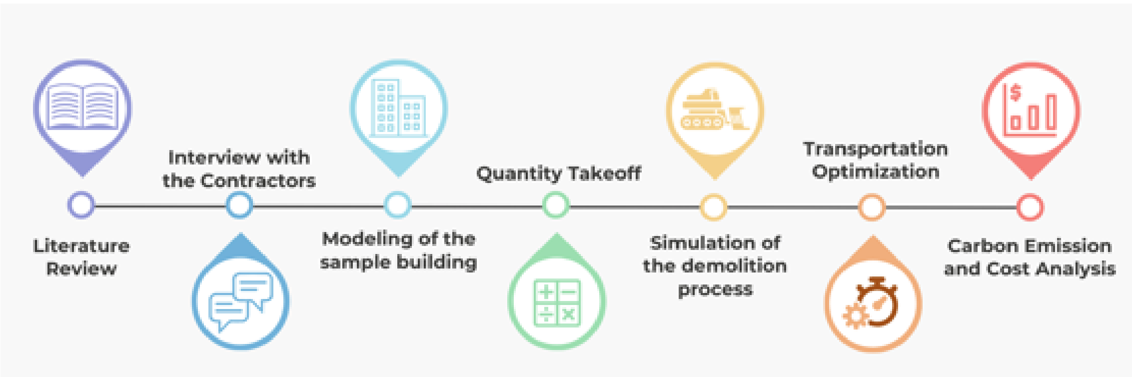
Research on selective demolition has mostly centered on financial considerations and on identifying practical difficulties in its application. While these perspectives are valuable, they leave out important environmental aspects and broader sustainability impacts. There is also very little comparative work on different demolition methods, such as hydraulic breaker excavators and mini excavators, especially with respect to how they differ both economically and environmentally. BIM is often highlighted in the literature as a useful tool for renovation, demolition, and waste management planning, yet studies rarely bring together three essential elements at once: the amount of waste generated at the building scale, the environmental benefits of reusing that waste, and the economic return of recycled materials. Considering these dimensions in combination would provide a stronger basis for policy design and practical guidance.

Another clear gap is the absence of detailed research in Türkiye that calculates demolition waste logistics on a day-to-day basis with the help of digital twin technologies, even though international studies acknowledge that logistics represent a major cost burden. Likewise, the separate evaluation of recycled concrete fractions—such as coarse aggregate, fine aggregate, and recycled concrete paste (RCP) has been overlooked in terms of their individual economic potential. Processes like Advanced Dry Recovery (ADR) and Hot Air Separation (HAS) are occasionally mentioned, but their integration into BIM workflows at the level of specific buildings has not been explored. The lack of this type of holistic approach means that current studies remain fragmented, often focusing on either environmental, economic, or material aspects in isolation. Addressing these missing links is important for advancing circular economy practices, guiding incentive policies, and offering contractors clearer decision-making tools.

3. METHODS AND IMPLEMENTATION

Following the literature review, and interviews with the contractors, a 3D model of a six-story residential building was developed as a case study using Autodesk Revit 2025 to model and simulate the selective demolition process. The 3D model was created using the building's .dwg drawings, and all structural and non-structural elements were modeled according to standard design practices. Dynamo was used to automatically extract material quantity calculations from the BIM model, while Autodesk Navisworks Manage 2025 was used for the simulation and planning of demolition phases. A schedule was created for the integration of this section into the application, and a waste transportation schedule, an excavator usage schedule, and a worker schedule were created using Excel. Additionally, carbon emission factors for the materials used in the case study building were identified from the literature to calculate the carbon emissions resulting from the use of raw materials, and these were integrated into the model for calculation. Finally, the carbon emissions generated during concrete recycling and brick reprocessing were calculated. The methodology flowchart can be seen in **Figure 3.1.**

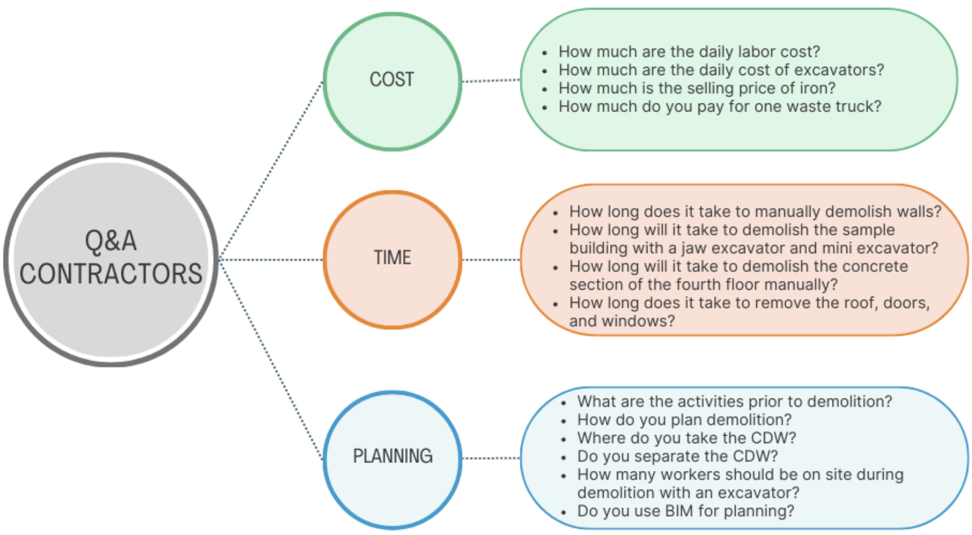
Figure 3.1: *Methodology Flowchart*



3.1 Interview with the Contractors

Before starting modeling and simulation work, interviews were conducted with experienced contractors to better understand the practical methods of demolition applications. During these interviews, questions were asked about labor and equipment costs, the duration of manual and mechanical demolition methods, waste transportation, and the use of BIM in demolition planning. The information obtained was integrated into the project and reflected in the scenarios in accordance with the contractors suggestions. The key questions asked during the interviews are summarized in the **Figure 3.2**.

Figure 3.2: *Questions Asked to Contractors*

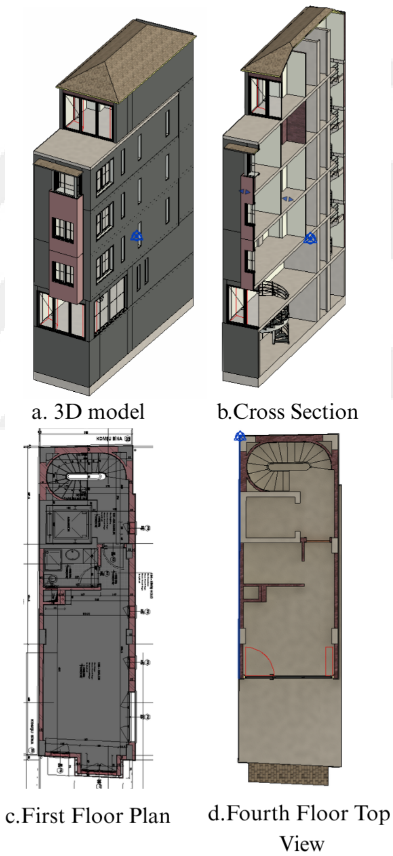


3.2 Model Generation

3.2.1 3D Modeling in Autodesk Revit

The building model includes a basement, a ground floor, three identical upper floors, and a roof floor (**Figure 3.3**). Two L-shaped columns of different sizes were modeled using the Revit Family Editor. Due to varying floor heights across different stories, two additional columns were created to accommodate those levels. Appropriate types and sizes of windows and doors were also added. All model elements were developed at Level of Detail (LOD) 300 [27]. Parameters of elements such as length, area, volume, floor levels, and attribute information like material type and material ID were defined. Finally, a custom "task ID" parameter was created in Revit to support the modeling and simulation process in Autodesk Navisworks Manage.

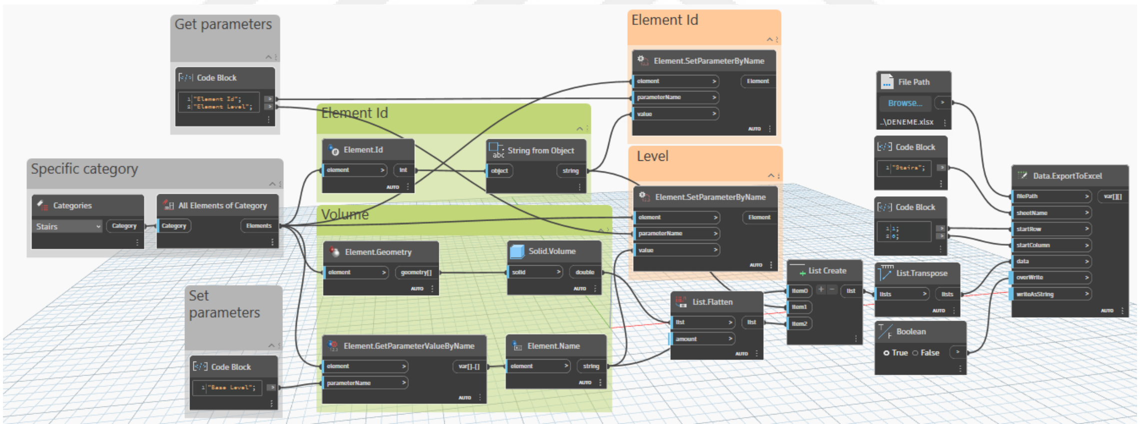
Figure 3.3: *3D model of the case study building in Revit*



3.2.2 Quantity Take-off using Dynamo

With the Dynamo visual programming tool, the quantity take-off process in Revit was automated. Custom scripts were developed to extract quantities and values such as volume, area, floor level, element ID (a custom parameter) and element name. For every element, different code blocks were created in Dynamo. Since the parameter names of floors are different for every material, different parameter names had to be used for Dynamo code blocks to extract the information from the BIM model to Excel. For example, the "Base Constraint" string is used to extract the floor level information of the walls, while the "Base Level" string is used to extract the same information for structural columns. The stairs were manually modelled in Revit which allowed the geometry of the stairs to be customized precisely according to the building's layout and dimensions. Since the geometry of the stairs is different, Revit does not allow the extraction of the volume of stairs with the "Volume" string in Dynamo. Therefore, the "Solid Volume" string was used to extract the volume of stairs as seen in **Figure 3.4**.

Figure 3.4: *Dynamo script for extracting information from Revit to Excel for Stairs*



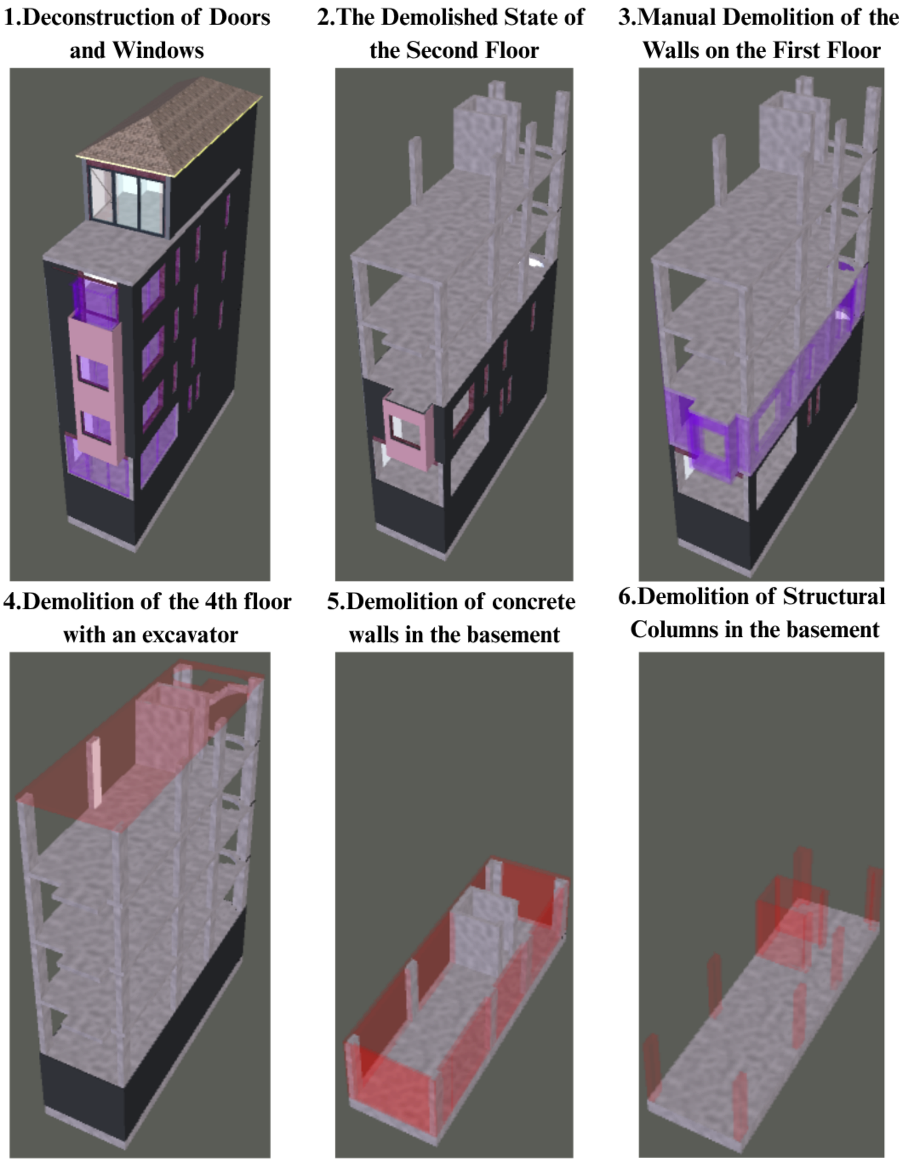
3.2.3 Simulation of the demolition process in Autodesk Navisworks Manage 2025

The completed Revit model was exported in NWC format and imported into Autodesk Navisworks Manage. Building elements were grouped as "demolition sets" according to their respective floor levels and structural types (e.g., structural walls, walls, and columns). Using Excel, a phased demolition schedule was developed and imported into Navisworks, considering the floor sequence from top to bottom, ending with the basement as seen in **Table 3.1.** Each demolition phase was linked to a timeline task to simulate the selective demolition process. This 4D simulation provided a visual insight into the sequence and duration of demolition activities. A new task type (Demolish Manual) was defined in Navisworks to represent the type to identify whether the demolition was done manually or with an excavator in the simulation. The transparent purpel color and transparent red color in **Figure 3.5** show that the demolition was carried out manually and with an excavator, respectively. The demolition schedule prepared in Excel was then exported into Navisworks as a .CSV file, enabling simulation by linking the demolition sets with the custom Task ID parameter created in Revit using "auto-attach" rules.

Table 3.1: *Demolition schedule visualized in Navisworks after importing from Excel*

Active	Name	Status	Planned Start	Planned End	Task Type	Attached
	New Data Source (Root)		3.02.2025 08:00	21.02.2025 18:00		
	Predemolition		N/A	N/A		
	Deconstruction of Doors and Windows of 4. Floor		3.02.2025 08:00	3.02.2025 10:00	Demolish Manual	Sets->Task ID->110
	Deconstruction of Doors and Windows of 3. Floor		3.02.2025 10:00	3.02.2025 12:00	Demolish Manual	Sets->Task ID->110
	Deconstruction of Doors and Windows of 2. Floor		3.02.2025 13:00	3.02.2025 15:00	Demolish Manual	Sets->Task ID->110
	Deconstruction of Doors and Windows of 1. Floor		3.02.2025 15:00	3.02.2025 17:00	Demolish Manual	Sets->Task ID->110
	Deconstruction of Doors and Windows of Ground Floor		3.02.2025 17:00	3.02.2025 18:00	Demolish Manual	Sets->Task ID->110
	Deconstruction of Roof		4.02.2025 08:00	4.02.2025 18:00	Demolish Manual	Sets->Task ID->120
	Deconstruction Wall of 4. Floor		5.02.2025 08:00	5.02.2025 18:00	Demolish Manual	Sets->Task ID->130
	Deconstruction Wall of 3. Floor		6.02.2025 08:00	6.02.2025 18:00	Demolish Manual	Sets->Task ID->140
	Deconstruction Wall of 2. Floor		7.02.2025 08:00	7.02.2025 18:00	Demolish Manual	Sets->Task ID->150
	Deconstruction Wall of 1. Floor		10.02.2025 08:00	10.02.2025 18:00	Demolish Manual	Sets->Task ID->160
	Deconstruction Wall of Ground Floor		11.02.2025 08:00	11.02.2025 18:00	Demolish Manual	Sets->Task ID->170
	Deconstruction Strucral Columns of 4. Floor		17.02.2025 08:00	17.02.2025 10:00	Demolish	Sets->Task ID->180
	Deconstruction Floor of 4. Floor		17.02.2025 10:00	17.02.2025 14:00	Demolish	Sets->Task ID->190
	Deconstruction Stairs of 3. Floor		17.02.2025 14:00	17.02.2025 15:00	Demolish	Sets->Task ID->200
	Deconstruction Strucral Columns of 3. Floor		17.02.2025 15:00	17.02.2025 17:00	Demolish	Sets->Task ID->210
	Deconstruction Floor of 3. Floor		18.02.2025 08:00	18.02.2025 11:00	Demolish	Sets->Task ID->220
	Deconstruction Stairs of 2. Floor		18.02.2025 11:00	18.02.2025 12:00	Demolish	Sets->Task ID->230
	Deconstruction Strucral Columns of 2. Floor		18.02.2025 13:00	18.02.2025 15:00	Demolish	Sets->Task ID->240
	Deconstruction Floor of 2. Floor		18.02.2025 15:00	18.02.2025 18:00	Demolish	Sets->Task ID->250
	Deconstruction Stairs of 1. Floor		19.02.2025 08:00	19.02.2025 09:00	Demolish	Sets->Task ID->260
	Deconstruction Strucral Columns of 1. Floor		19.02.2025 09:00	19.02.2025 11:00	Demolish	Sets->Task ID->270
	Deconstruction Floor of 1. Floor		19.02.2025 11:00	19.02.2025 14:00	Demolish	Sets->Task ID->280
	Deconstruction Stairs of Ground Floor		19.02.2025 14:00	19.02.2025 17:00	Demolish	Sets->Task ID->290
	Deconstruction Strucral Columns of Ground Floor		20.02.2025 08:00	20.02.2025 09:00	Demolish	Sets->Task ID->300
	Deconstruction Floor of Ground Floor		20.02.2025 09:00	20.02.2025 12:00	Demolish	Sets->Task ID->310
	Deconstruction of Stairs of Basement		20.02.2025 13:00	20.02.2025 13:00	Demolish	Sets->Task ID->320
	Deconstruction of Basement Floor Concrete Wall		20.02.2025 13:00	20.02.2025 18:00	Demolish	Sets->Task ID->330
	Deconstruction of Basement Floors Structrual Columns and Curtain Wall		21.02.2025 08:00	21.02.2025 11:00	Demolish	Sets->Task ID->340
	Deconstruction of Foundation		21.02.2025 11:00	21.02.2025 18:00	Demolish	Sets->Task ID->350

Figure 3.5: *Simulation of the Case Study Building Demolition*



3.3 Implementation

3.3.1 Waste Transportation Optimization

To optimize waste transportation, daily waste was calculated using an Excel schedule created for Naviswork. Since selective demolition is assumed, the roof is first dismantled manually, and then the brick and EPS part of the building are dismantled top to down manually. Subsequently, two different scenarios were considered for the demolition of the reinforced concrete section of the building. In the first scenario, the building would be demolished with a hydraulic breaker excavator, while in the second, a mini-excavator would be brought to the top of the building and a top-down demolition strategy would be implemented. To assess the carbon emissions of these two demolition methods, operators were contacted to obtain the hourly fuel consumption of the equipment used. The formula for the carbon emissions generated by the excavators used for demolition is shown in **Eq.(3.1).**

$$\text{Carbon Emission} = \text{Fuel Consumption}*\text{Emission Factor}[28] \tag{3.1}$$

For safety and to reduce the load on the building, all waste removed from the building was considered to be sent to landfills daily, and a waste transportation schedule was developed accordingly.

3.3.2 Carbon Emitted While Recycling

This study examined the recycling processes of three different materials and integrated them into the industry. The recycling processes for concrete and iron were examined, and the currently implemented methods were determined.

The article under review states that concrete recycling consists of three stages: crushing, advanced dry recovery, and heating air classification. The energy requirement of this system ranges from 106.49 to 179.41 MJ/t.[29]. The highest energy reference was taken as the basis for calculating the maximum carbon emissions that could be generated in this study (179.41 MJ/t). To calculate the energy consumption, the carbon emission factor of natural gas was examined[30], and the amount of natural gas needed as fuel to generate this amount of energy was calculated.

As previously shared, bricks can be substituted for cement when reduced to a certain particle size, resulting in positive effects on concrete strength. Therefore, a recycling method was developed to reduce bricks to a particle size of 25-100 microns[21]. After deciding on the machines[31, 32, 33], the catalogs of the relevant machines were examined and the electrical energy consumed to turn the brick into brick powder was calculated and used to calculate the carbon emissions. **Formula 3.2** was used to calculate the carbon emissions generated by electricity consumption. The production line used to repurpose brick wastes and the electric consumed are shown in **Figure 3.6**.

Figure 3.6: *Brick Repurposing Production Line and Electric Consumptions*

$$\text{Carbon Emission=Electric Consumption*Emission Factor[34]} \qquad (3.2)$$

Electric Arc Furnace will be used for iron recycling, and research has found that EAC's CO_2 emissions are 0.3 CO_2t/t[20].

3.3.3 Proposal Recycled Mix Design

To calculate the carbon emissions of the raw materials used in traditional concrete, it has been assumed that 1/6 cement, 2/6 sand, and 3/6 coarse aggregate are used in the concrete mix. Accordingly, the carbon emissions generated by the raw materials used in traditional concrete are calculated as follows:

- Cement: 840 kg CO_2/ton[35][36]
- Fine Aggregate: 5.51 kg CO_2/ton[37]
- Coarse Aggregate: 6.18 kg CO_2/ton[37]

Using these ratios and emission factors, the total carbon emissions generated for the production of 1 ton of concrete were calculated as follows:

$$\begin{aligned} CE_{\text{concrete}} &= \left(\frac{1}{6}\cdot 840\right) + \left(\frac{2}{6}\cdot 5.51\right) + \left(\frac{3}{6}\cdot 6.18\right) \\ &= 140 + 1.84 + 3.09 \\ &= \mathbf{144.93}\,\text{kg CO}_\mathbf{2}/\text{ton concrete} \end{aligned} \tag{3.3}$$

3.3.3.1 %15 Recycled Concrete Powder Substitute

To calculate carbon emissions in recycled concrete design, it was assumed that the RCP portion of the recycled concrete material was substituted for cement. **Formula 3.4** was used to calculate the carbon emissions generated by replacing 15% of cement with RCP. The energy consumed for recycling concrete is 0.17941 MJ/kg. It was calculated that the energy consumed for recycling 0.15 kg of RCP is 0.02691 MJ, and when multiplied by the carbon emission factor of natural gas 0.0561 kg CO_2/MJ, the carbon emissions from recycling RCP are 0.00151 kg CO_2/kg. Considering that the carbon emissions of cement are 0.84 kg CO2/kg, it is calculated that this ratio can be reduced to 0.71551 with a 15% substitution as seen in equation 3.5. The effect of replacing cement with RCP on the carbon dioxide emitted by concrete is calculated in Figure 3.6.

$$CE_{\text{sub}} = R_{\text{OPC}} \cdot CE_{\text{OPC}} + R_{\text{RCP}} \cdot E_{\text{RCP}} \cdot EF_{\text{NG}} \tag{3.4}$$

$$CE_{\text{sub}} = 0.85 \cdot 0.84 + 0.15 \cdot 0.17941 \cdot 0.0561 = 0.7155\,\text{kg CO}_2/\text{kg} \tag{3.5}$$

$$\begin{aligned} CE_{\text{Concrete, RCP}} &= \left(\frac{1}{6}\cdot (0.7155\cdot 1000)\right) + \left(\frac{2}{6}\cdot 5.51\right) + \left(\frac{3}{6}\cdot 6.18\right) \\ &= \mathbf{124.18}\,\text{kg CO}_\mathbf{2}/\text{ton concrete} \end{aligned} \tag{3.6}$$

3.3.3.2 %10 Recycled Brick Powder Substitute

After deciding on the right machines, the kWh required to process 1 ton of material was calculated, as shown in **Table 3.2**. Then, it was multiplied by the carbon emission factor and calculated to be 0.06 kg CO2/kg for brick dust production, as shown in **Equation 3.7**. Then, as shown in **Equation 3.8**, the carbon emissions resulting from the substitution of cement were calculated.

Table 3.2: *Energy Consumption and Carbon Emissions per Kilogram of Processed Material*

Equipment Model	**Power (kW)**	**Throughput (t/h)**	**Energy Consumption (kWh/ton)**	**Emission Factor (kg CO_2/kWh)**	**CO_2 Emission (kg CO_2/kg)**
Jaw Crusher (QJ241)	168	225	0.75	0.426	0.00
Ball Mill (TAURUS 1830)	45	1	45.00	0.426	0.02
Air Classifier (URAL 1250)	105	1	105.00	0.426	0.04
Total			**150.75**		**0.06**

The carbon emissions generated for the reprocessing of 1 kg of RBP are as follows:

$$\frac{0.06C0_2kg/h}{1kg/h} = 0.06\text{ kg CO}_2/\text{kg RBP} \tag{3.7}$$

$$\begin{aligned} CE_{\text{beton, RBP}} &= \left(\frac{1}{6} \cdot (0.90 \cdot 840 + 0.10 \cdot 64.22)\right) + \left(\frac{2}{6} \cdot 5.51\right) + \left(\frac{3}{6} \cdot 6.18\right) \\ &= \mathbf{132.00}\,\text{kg CO}_\mathbf{2}/\text{ton concrete} \end{aligned} \tag{3.8}$$

4. RESULTS AND DISCUSSIONS

This chapter presents the results obtained from the analyses and simulations conducted in this study. The findings are structured under six subheadings: (1) Material Quantification and Demolition Scheduling, (2) Waste Logistics and Costs, (3) Excavator and Labor Cost, (4) Cost Analysis, (5) Carbon Emission Calculation for Materials, and (6) Carbon Emitted by Excavators.

4.1 Material Quantification and Demolition Scheduling

A Dynamo script extracted detailed material volumes from the BIM model. Custom families created for L-shaped columns and sketch-based stairs ensured accurate calculations. Custom parameters (Task_ID, Element ID) enabled material categorization by floor and type, facilitating waste tracking and recycling analysis.

The BIM model was imported into Navisworks to develop a selective demolition schedule for both scenarios. Non-load-bearing brick walls and insulation were manually dismantled using demolition drills, followed by the C30 concrete elements (structural walls, columns, slabs, stairs) demolished top-down with a hydraulic breaker excavator and mini excavator. Contractor interviews indicated that three workers could demolish brick walls on one floor in one day, while one worker was needed for dust control using water spraying during excavator operations.The study estimated working hours to be 8:00 a.m. to 6:00 p.m., with a one-hour lunch break. Consequently, the demolition was planned for a nine-hour workday. The demolition schedule projected 393.87 tons of waste over 10 workdays, including 149.7 m³ of C30 concrete waste for the case study building. Daily waste quantities were tracked in Excel. Concrete volumes, extracted from the BIM model using Dynamo, were multiplied by a density factor of 2305.9 t/m³[38] to calculate tonnage. Similarly, brick waste volumes were multiplied by 788 t/m³ [39] and EPS volumes multiplied by 15 t/m³[40] for tonnage estimation.

4.2 Waste Logistics and Costs

The amount of waste produced per day was calculated using Dynamo, Naviswork schedule and Excel for both scenarios. A formula was created in Excel so vehicles with three different waste carrying capacities [41]can optimally complete the daily waste transportation at the fewest turns and at the lowest price. Assuming that the waste would be transported from Beyoglu (where the building is located) to Arnavutkoy Waste Disposal Facility, it was multiplied by the fee for 1 ton of CDW transported for 1 kilometer, given by Istanbul the Metropolitan Municipality. The distance between the building site and the Arnavutkoy Waste Disposal Facility is 28 km. Because two different demolition scenarios are implemented, the daily waste volumes vary, and therefore the waste transportation scenarios also change.

4.2.1 Scenario 1: Demolition with Hydraulic Breaker

In scenario 1, it was decided with the contractors that the demolition would be carried out using a hydraulic breaker excavator with a 20-meter BOP length and a capacity of 20 tons. The reason for this is that the building is approximately 15 meters high and an excavator with sufficient BOP length must be used so that the excavator can move comfortably. Based on the interview done with contractors, it was decided that a hydraulic breaker excavator would be able to demolish the structure more quickly and require less manpower than a mini excavator due to its greater crushing power. This higher daily waste generation means higher-capacity transport vehicles can be used, resulting in lower overall waste transportation costs. Logistic cost for Scenario 1 can be seen in **Table 4.1**.

Table 4.1: *Waste Volume and Transport Cost for Scenario 1*

Date	Volume	#Truck	Ton	Vehicle Price to Landfill (VPL)	Waste Carry Cost (WCC)	Transport and Acceptance Document (VAD)	TOTAL(TL)
5.02.2025	13.79	1	9.55	3,990.00	1,032.35	480.00	5,502.35
6.02.2025	20.33	2	14.30	6,840.00	1,545.65	960.00	9,345.65
7.02.2025	20.97	2	14.71	6,840.00	1,589.83	960.00	9,389.83
10.02.2025	19.84	2	13.69	6,840.00	1,479.28	960.00	9,279.28
11.02.2025	12.76	1	8.61	3,990.00	930.80	480.00	5,400.80
17.02.2025	24.59	2	56.70	7,980.00	6,127.90	960.00	15,067.90
18.02.2025	27.54	2	63.50	7,980.00	6,863.03	960.00	15,803.03
19.02.2025	18.96	2	43.72	5,415.00	4,724.87	960.00	11,099.87
20.02.2025	38.62	3	81.59	11,970.00	8,818.04	1440.00	22,228.04
21.02.2025	37.95	3	87.50	10,830.00	9,457.34	1440.00	21,727.34
TOTAL	**235.34**	**20**	**393.87**	**72,675.00**	**42569.08**	**9,600.00**	**124,844.08**

4.2.2 Scenario 2: Demolition with Mini Excavator

In scenario 2, the demolition was assumed to be carried out with a 5-ton mini-excavator. Because the mini-excavator has less crushing power than a hydraulic breaker excavator, the daily waste output is less than in scenario 1. Less daily waste output means the arrival of lower-capacity waste transport vehicles. Consequently, the number of vehicles arriving at the site is higher than in Scenario 1 as can be seen in **Table 4.1** and **4.2**.

Table 4.2: *Waste Volume and Transport Cost for Scenario 2*

Date	Volume	#Truck	Ton	Vehicle Price to Landfill (VPL)	Waste Carry Cost (WCC)	Transport and Acceptance Document (VAD)	TOTAL(TL)
5.02.2025	13.79	1	9.55	3,990.00	1032.35	480.00	5502.35
6.02.2025	20.33	2	14.30	6,840.00	1545.65	960.00	9345.65
7.02.2025	20.97	2	14.71	6,840.00	1589.83	960.00	9389.83
10.02.2025	19.84	2	13.69	6,840.00	1479.28	960.00	9279.28
11.02.2025	12.76	1	8.61	3,990.00	930.80	480.00	5400.80
12.02–14.02.2025	6.63	1	9.15	2,850.00	1551.77	480.00	4881.77
17.02–19.02.2025	9.36	1	21.58	2,850.00	2332.37	480.00	5662.37
24.02.2025	18.07	2	41.67	5,415.00	4503.43	960.00	10778.43
25.02.2025	18.07	2	41.67	5,415.00	4503.43	960.00	10778.43
26.02.2025	17.95	2	41.39	5,415.00	4472.82	960.00	10847.82
27.02.2025	18.04	2	41.60	5,415.00	4496.48	960.00	10871.48
28.02.2025	29.38	3	69.35	6,510.00	6514.00	1440.00	14464.00
3.03.2025	30.16	3	69.55	9,405.00	7516.87	1440.00	18361.87
TOTAL	**235.34**	**24**	**393.87**	**74,670.00**	**42569.08**	**11,520.00**	**128,759.08**

4.3 Excavator and Labor Cost

Excel spreadsheets were created to calculate the number of days the workers would work and the excavators would operate. According to interviews with contractors, the demolition of the brick walls on one floor would take one day with three workers. Also, after manual demolition, the excavator would start demolition and a worker would need to be there to water the concrete to prevent dust the day the excavator would operate.

4.3.1 Scenario 1: Demolition with Hydraulic Breaker

The demolition contractors interviewed stated that the jaw excavator can demolish approximately 1 to 1.5 floors per day. 3.000 TL per day will be paid to a worker for each working day and the daily rental cost of a jaw excavator including an operator is 50.000 TL. Given that the excavator is scheduled to be used for five days, it was determined that commencing the demolition at the beginning of the week would optimize cost efficiency and minimize additional expenses. The total costs of the hydraulic breaker excavator and labor costs are shown in **Tables 4.3** and **4.4**, respectively.

Table 4.3: *Excavator Usage with Daily Cost for Scenario 1*

Date	Excavator	Daily Cost (TRY)
4.02.2025	0	0
5.02.2025	0	0
6.02.2025	0	0
7.02.2025	0	0
10.02.2025	0	0
11.02.2025	0	0
17.02.2025	1	50,000
18.02.2025	1	50,000
19.02.2025	1	50,000
20.02.2025	1	50,000
21.02.2025	1	50,000
TOTAL	**5**	**250,000**

Table 4.4: *Daily Worker Cost Schedule for Scenario 1*

Date	Duration	#Workers	Daily Cost (TRY)
4.02.2025	1	3	9,000
5.02.2025	1	3	9,000
6.02.2025	1	3	9,000
7.02.2025	1	3	9,000
10.02.2025	1	3	9,000
11.02.2025	1	3	9,000
17.02.2025	1	1	3,000
18.02.2025	1	1	3,000
19.02.2025	1	1	3,000
20.02.2025	1	1	3,000
21.02.2025	1	1	3,000
TOTAL			**69,000**

4.3.2 Scenario 2: Demolition with Mini Excavator

[H] The demolition contractors interviewed also stated that the building could be demolished using a mini-excavator. The brick walls were to be demolished as in **Scenario 1**. Since the crane could not reach the top floor of the building, it was planned that workers would demolish the fourth floor, and after the fourth floor was completely demolished, the mini excavator would be lifted to the third floor by crane. Based on the interviews done with the contractors, it was discussed that the hourly cost of the crane was 40,000 TL and the daily cost of the mini excavator, including its operator, was 20,000 TL. The total amounts to be paid for the crane and mini-excavator can be seen in **Tables 4.5 and 4.6**. In addition, the contractors mentioned that the mini excavator could demolish one floor of the sample building in 1-2 days. Given that the mini excavator had been used for six days, it was assumed that it had arrived on site at the beginning of the week to allow comparison with the demolition excavator.

Table 4.5: *Excavator and Crane Usage with Daily Costs for Scenario 2*

Date	Excavator	Crane	Daily Cost (TL)
4.02.2025	0	0	0
5.02.2025	0	0	0
6.02.2025	0	0	0
7.02.2025	0	0	0
10.02.2025	0	0	0
11.02.2025	0	0	0
12.02.2025–14.02.2025	0	0	0
17.02.2025–19.02.2025	0	0	0
24.02.2025	1	1	60,000
25.02.2025	1	0	20,000
26.02.2025	1	0	20,000
27.02.2025	1	0	20,000
28.02.2025	1	0	20,000
3.03.2025	1	0	20,000
TOTAL			**160,000**

Table 4.6: *Daily Worker Cost Schedule for Scenario 2*

Date	Duration	#Workers	Daily Cost (TL)
4.02.2025	1	3	9,000
5.02.2025	1	3	9,000
6.02.2025	1	3	9,000
7.02.2025	1	3	9,000
10.02.2025	1	3	9,000
11.02.2025	1	3	9,000
12.02.2025–14.02.2025	3	3	27,000
17.02.2025–19.02.2025	3	3	27,000
24.02.2025	1	1	3,000
25.02.2025	1	1	3,000
26.02.2025	1	1	3,000
27.02.2025	1	1	3,000
28.02.2025	1	1	3,000
3.03.2025	1	1	3,000
TOTAL			**126,000**

4.4 Cost Analysis

To demonstrate the contribution of recycled materials to the circular economy, the revenue generated from the sale of iron was calculated by multiplying the regionally assigned iron rates[42] by the price of iron purchased from scrap dealers. The sales prices of the coarse aggregate, fine aggregate, RCP obtained from recycling determined to be half of the materials they would replace[43]. The selling price of brick powder was set at the same price as the market price. The original prices of the materials and the sales prices used in the study can be seen in **Table 4.7**.

Calculations using Revit's material takeoff feature were made to determine the revenue that could be generated from the sale of materials obtained from concrete recycling and brick repurposing. As the costs associated with the excavator, labor, and waste vehicles for the demolition process had been previously calculated, the total expenses and revenues were aggregated in this step. The total cost of the three expense items was found

Table 4.7: *Original and Selling Prices of Materials (per unit volume or mass)*

Materials	Original Cost (TL/m³ or TL/t)	Selling Price (TL/m³ or TL/t)	Reference
Fine Aggregate	343.92 TL/m³	171.96 TL/m³	[43]
Coarse Aggregate	304.92 TL/m³	152.46 TL/m³	[43]
Cement	2,095.00 TL/t	1,047.50 TL/t	[43]
Brick Powder	2,300.00 TL/t	2,300.00 TL/t	[44]
Iron	–	10.60 TL/kg	Scrap Dealer

to be **443,844 TL** in **Scenario 1** and **414,759 TL** in **Scenario 2**. The profits obtained from the sale of scrap iron, recycled concrete fragments, and repurposed bricks can be seen in **Tables 4.8**. Subsequently, a financial analysis was conducted to determine the potential profit or loss for demolition contractors, assuming selective demolition is performed. The results showed that approximately **391,762 TL** revenue could be generated from the sale of recycled iron, recycled concrete, and repurposed brick powder.

Table 4.8: *Revenue Obtained from the Sale of Recycled Materials*

Material	Material Weight (kg)	Revenue from Sold Material (TL)
Concrete C30	332,987.36	42,410.79
Iron	20,170.02	213,802.20
Brick Powder	58,934.90	135,550.27

4.5 Carbon Emission Calculation for Materials

Using Revit's Material Take-off feature, the volumes of the materials were extracted, and using appropriate filters, the volumetric quantities used were determined based on their names. The densities of the materials were determined from literature and catalogs. To find the weight of the materials, the densities were multiplied by the volumes of the materials, and the amount of each material used in kilograms was found.

After determining the material weights, the carbon emission coefficients (kg CO_2/kg material) specified in the literature were used to calculate the total carbon emissions for each type of material by multiplying their weights.

4.5.1 Carbon Emissions from Conventional Construction Materials

Among the materials used, concrete generates the most carbon emissions. Although concrete's carbon emissions factor are lower than those of other materials used in buildings, its high volume of use makes it the material that causes the most carbon emissions, as shown in **Table 4.9**.

Despite being the third most used material in a building by weight, iron has the second highest carbon emissions due to its high carbon content. Concrete and iron account for 85% of the carbon emissions from materials used in building construction.

Among the materials with the lowest carbon emissions are brick and EPS. Despite having a carbon factor of 0.24 kg CO2kg/kg[45], brick is the second most used material by weight and has emitted more carbon dioxide than EPS as can be seen in **Table 4.10**

Table 4.9: *Carbon Emissions Based on Material Quantities and Emission Factors*

Material Name	Material Weight (kg)	Carbon Emission Factor (kg CO_2/kg)	Total Carbon Emission (kg CO_2)
Concrete C30	332,987.36	0.14	48,259.86
Iron	20,170.02	2.20	44,374.04
Brick	58,934.90	0.24	14,144.38
EPS	245.56	2.78	682.65
Total	–	–	**107,460.93**

Approximately 108 tons of carbon dioxide were emitted from the materials used in building construction.

4.5.2 Carbon Emission from the Use of Recycled Materials

In the scenario where recycled materials are used, using 10% RBP resulted in higher carbon emissions than using 15% RCP. Therefore, it was decided that using RCP derived from concrete recycling was more appropriate to reduce both carbon emissions and maintain the workability of the concrete. **Table 4.10** shows the reduction in carbon dioxide emissions achieved by substituting RCP and RBP for cement.

Table 4.10: *Comparison of Carbon Emissions for Different Concrete Types*

Concrete Type	**Material Weight (kg)**	**Carbon Capture (kg)**	**Carbon Emission Factor (kgCO_2/kg)**	**CO_2 (kg)**
Traditional	33,2987.36	–	0.14	48,259.86
10% RBP	33,2987.36	–	0.13	43,954.33
15% RCP	33,2987.36	2131.12	0.12	39,219.25

Iron recycling has been shown to be the most effective way to reduce carbon emissions. This is because raw material usage can be reduced to zero, allowing it to be melted down and reused as iron. The carbon emitted by the recycling of iron can be seen in **Table 4.11.**

EPS is one of the most preferred insulation materials because it's 96% air. Although it has very high carbon emissions during production, it doesn't produce high carbon emissions overall because it's used less than other materials during building construction and has a lower density. The carbon emitted by the use of recycled EPS in buildings can be seen in **Table 4.11.**

Table 4.11: *Carbon Emissions from Iron and EPS*

Material	Material Weight (kg)	CO_2 Emission Factor ($kgCO_2/kg$)	CO_2 (kg)
Iron	20170.02	0.30	6,051.01
EPS	245.56	1.89	464.11

Since brick cannot be fully recycled, when comparing carbon emissions, it was assumed that the classical clay bricks was used in the building and carbon emissions were calculated accordingly.

Calculations indicate that substituting RCP for cement and its carbon sequestration properties prevented approximately 9 t of CO2 emissions from concrete use. Furthermore, recycling rebar from building demolition prevented approximately 38.3 t of CO2 emissions.

4.6 Carbon Emitted by Excavators

To compare the carbon emissions emitted by excavators, contractors and operators were asked about their hourly fuel consumption. The calculation was multiplied by the diesel fuel's carbon emission factor, assuming a 9-hour workday, to determine the excavator's carbon emissions during demolition. The operators and contractors reported that a 20-meter hydraulic breaker excavator consumes 35 liters of diesel fuel per hour, while a mini excavator consumes 5 liters per hour. The results showed that the hydraulic breaker excavator emits approximately five times more carbon dioxide as can be seen in **Table 4.12** and **4.13**. This is due to its higher breaking power and ability to transmit power to higher altitudes.

Table 4.12: *Carbon Emission of Mini Excavator (CO_2kg/kg)*

Date	Excavator	Crane	Carbon Emission (CO_2kg/kg)
4.02.2025	0	0	0
5.02.2025	0	0	0
6.02.2025	0	0	0
7.02.2025	0	0	0
10.02.2025	0	0	0
11.02.2025	0	0	0
12.02.2025–14.02.2025	0	0	0
17.02.2025–19.02.2025	0	0	0
24.02.2025	1	1	226.95
25.02.2025	1	0	120.15
26.02.2025	1	0	120.15
27.02.2025	1	0	120.15
28.02.2025	1	0	120.15
3.02.2025	1	0	120.15
TOTAL	–	–	**827.7**

Table 4.13: *Carbon Emission of Hydraulic Breaker Excavator*

Date	Excavator	Carbon Emission (CO_2kg/kg)
4.02.2025	0	0.00
5.02.2025	0	0.00
6.02.2025	0	0.00
7.02.2025	0	0.00
10.02.2025	0	0.00
11.02.2025	0	0.00
17.02.2025	1	841.05
18.02.2025	1	841.05
19.02.2025	1	841.05
20.02.2025	1	841.05
21.02.2025	1	841.05
TOTAL	-	**4,205.25**

4.7 Discussion

This research highlights areas where previous studies on selective demolition and BIM have remained incomplete. Much of the earlier work has concentrated on financial aspects or on the practical barriers of implementation. While those studies are important, they often overlook the wider environmental effects. By bringing together cost considerations, waste flows, and carbon outcomes in a single framework, this study takes a more integrated perspective that many earlier papers have called for but have not fully achieved.

One of the most striking points is the role of equipment choice. Earlier research has tended to compare traditional demolition with selective demolition in broad terms, but rarely has it looked at how different machines influence both economics and environmental impact at the same time. The comparison of large-scale and small-scale equipment in this study shows that decisions made at the level of machinery can change not only cost efficiency but also the overall sustainability of the process. This is an angle that has been missing in much of the discussion so far.

Waste logistics is another area where the findings expand on what has been published before. Although past studies have mentioned transportation as a cost driver, they usually treat it as a single figure or as a background assumption. By tracking it in detail and linking it with digital twin tools, this research shows how logistics can become a decisive factor in the feasibility of selective demolition. This approach is especially relevant in Türkiye, where such daily operational analyses are almost non-existent, and it provides a clearer picture for both contractors and policymakers.

The recycling chain results also push the conversation forward. Previous studies often highlight the economic value of metals, especially steel, but stop short of looking at finer fractions of demolition waste. This study shows that materials like recycled concrete paste and brick powder deserve more attention, since they also contribute to both environmental benefits and economic recovery. This broader view of recycling supports the shift towards circular economy strategies that move beyond a focus on only the highest-value materials.

Finally, the integration of advanced recovery techniques such as ADR and HAS into a BIM-based demolition plan is an area where this research breaks new ground. Most earlier work has examined these technologies separately, without embedding them into building-specific models. Showing how they can be combined with BIM not only demonstrates the value of these methods but also suggests a pathway for connecting fragmented strands of research. BIM here acts not just as a modeling tool but as a decision-making platform that links material recovery, environmental assessment, and cost evaluation.

5. CONCLUSIONS

This thesis set out to evaluate selective demolition methods using a BIM-based 4D simulation framework focusing on economic, logistical, and environmental outcomes. A demolition simulation of the case study building was performed with two different excavators, and the resulting waste transportation to storage areas was analyzed and optimized for both scenarios. According to the simulation results, the first scenario required fewer truck trips, reducing transportation costs, while the second scenario proved more economical overall despite higher labor requirements. Differences in excavator rental costs and associated carbon emissions further indicated that selective demolition with a mini-excavator was the more suitable approach. These findings demonstrate how BIM-enabled demolition simulations can provide actionable insights for contractors, supporting better-informed decisions that balance cost, efficiency, and sustainability in future demolition projects.

Furthermore, the carbon emissions from traditional materials were compared with those from recycled materials, and the results showed a significant reduction through recycling. The largest reduction was observed in iron reinforcement, since it can be fully replaced with recycled materials. Brick powder, however, was not used as a cement substitute due to its low substitution limit (10%), lack of carbon retention, and negative impact on workability. Instead, it was considered more appropriate to sell it directly at market value. RCA, RFA, and RCP from concrete recycling were assumed to be sold at half the price of the materials they substituted, which limited their economic benefit. RCP, however, provided greater environmental value. With a 15% substitution rates and carbon sequestration capacity, it reduced cement-related emissions more effectively than brick powder. The importance of integrating selective demolition with BIM becomes clear here, as it provides a structured way to link material recovery, carbon reduction, and economic evaluation within a single framework.

5.1 Limitations

- **Hypothetical Study:**This study is based entirely on a digital building model and reflects a hypothetical demolition case rather than an on-site project. Because of this, the outcomes should be viewed as illustrative. The model helps to estimate waste amounts, logistics, and possible economic or environmental effects, but field data from real demolitions would be needed to confirm and refine these results.
- **Local Carbon Footprints:** Carbon emission models are based on average values in the literature, and future location-specific calculations can be made using emission factors used in local production processes. Calculations may be uncertain as there is no market for recycled materials.
- **Absence of Recycled Material Market:** Calculations may be uncertain as there is no market for recycled materials.
- **Recycling Ratio:** A recycling rate of 100% was used, which is not actually possible in a construction site environment.
- **Rental Fees and Fuel Consumption:** Excavator rental fees and fuel expenses were obtained from industry stakeholders; the figures obtained may vary depending on the excavator model.

5.2 Future Works

In this study, two different demolition scenarios were simulated using BIM with hydraulic breakers, excavators, and mini excavators. However, improvements can be made to increase accuracy and applicability when applying this to real life.

The major problem in this study stems from the inability to accurately determine the performance of workers. In future studies, a management system could be developed to monitor the performance of workers and excavators. This would enable a more accurate schedule to be drawn up for future demolition work. It would also make the site safer in terms of health and safety.

In future studies, logistics can be made autonomous and integrated with Geographic Information System (GIS) to track waste, optimize routes, reduce fuel consumption, and thus reduce carbon dioxide emissions.

Furthermore, the integration of immersive technologies, such as Augmented Reality (AR) and Virtual Reality (VR), into BIM can assist in decision-making.

- AR can be used to detect materials that are not visible in the area, such as asbestos. This enables safer and more controlled selective demolition.
- With VR, project can navigate through the 3D construction site to identify issues and take preventive measures in advance.

Finally, the integration of machine learning with BIM can provide recycling rates, waste utilization areas, and material prices based on past demolition data.

REFERENCES

[1] D. v. Z. M. İstanbul Büyükşehir Belediyesi, "İstanbul İli Olası Deprem Kayıp Tahminleri İlçe Kitapçıkları," teknik rapor, İstanbul Büyükşehir Belediyesi, 2020. "İstanbul İli Olası Deprem Kayıp Tahminlerinin Güncellenmesi Projesi (2019)" kapsamında hazırlanmıştır. 39 ilçe için ayrı ayrı kitapçıklar mevcuttur.

[2] Deloitte, "Construction and demolition waste management in denmark," 2015.

[3] M. Zajac, J. Skocek, M. Ben Haha, and J. Deja, "Co2 mineralization methods in cement and concrete industry," *Energies*, vol. 15, no. 10, p. 3597, 2022.

[4] SKD, "Kentsel dönüşüm, deprem ve olası diğer afetler sonucunda oluşan yıkıntı atıklarının yönetim rehberi," 2024.

[5] F. de Andrade Salgado and F. de Andrade Silva, "Recycled aggregates from construction and demolition waste towards an application on structural concrete: A review," *Journal of Building Engineering*, vol. 52, p. 104452, 2022.

[6] P. Purnell and A. Dunster, "Recycling of concrete," in *Management, Recycling and Reuse of Waste Composites*, pp. 569–591, Elsevier, 2010.

[7] Public Fill Committee and Civil Engineering and Development Department, "Guidelines for selective demolition & on-site sorting," technical report, Public Fill Committee, Civil Engineering and Development Department, Hong Kong, Hong Kong, July 2004. Retrieved from CEDD website (PDF).

[8] B. Sizirici, Y. Fseha, C.-S. Cho, I. Yildiz, and Y.-J. Byon, "A review of carbon footprint reduction in construction industry, from design to operation," *Materials*, vol. 14, no. 20, p. 6094, 2021.

[9] K. E. Maçin and İ. Demir, "Kentsel donusum surecinde istanbul'da insaat ve yikinti atiklari yonetimi," *Adıyaman Üniversitesi Mühendislik Bilimleri Dergisi*, vol. 5, no. 9, pp. 202–210, 2018.

[10] Anadolu Ajansı, "İstanbul'da hafriyat depolama ücretlerine yüzde 449'a varan oranda zam yapıldı," 2024. Accessed: 2025-07-17.

[11] G. Gullu, "Istanbul'da kentsel donusum, insaat ve yikinti atiklari," *Cihannüma Teknoloji Fen ve Mühendislik Bilimleri Akademi Dergisi*, vol. 1, no. 1, pp. 39–72, 2022.

[12] A. E. Dincer, A. Demir, and Ö. Dilmen, "A cleaner demolition scheduling methodology considering dust dispersion: A case study for a post-earthquake region," *Journal of Cleaner Production*, vol. 478, p. 143906, 2024.

[13] S. Akduman, R. Aktepe, A. Aldemir, E. Ozcelikci, B. Alam, and M. Sahmaran, "Opportunities and challenges in constructing a demountable precast building using c&d waste-based geopolymer concrete: A case study in türkiye," *Journal of Cleaner Production*, vol. 434, p. 139976, 2024.

[14] Y. Egercioğlu and A. İregöl, "Evaluation of sustainable construction waste management for urban regeneration project in izmir," 2017.

[15] T. Esin and N. Cosgun, "A study conducted to reduce construction waste generation in turkey," *Building and environment*, vol. 42, no. 4, pp. 1667–1674, 2007.

[16] U.S. General Services Administration (GSA), *Removing Lime Mortar Deposits from Brick Masonry*. U.S. General Services Administration, July 2025. Last updated: July 31, 2025.

[17] V. Prasad and M. Arashpour, "Real-time instance segmentation of recyclables from highly cluttered construction and demolition waste streams," *Journal of Environmental Management*, vol. 372, p. 123365, 2024.

[18] C. G. Samal, D. R. Biswal, G. Udgata, and S. K. Pradhan, "Estimation, classification, and prediction of construction and demolition waste using machine learning for sustainable waste management: A critical review," *Construction Materials*, vol. 5, no. 1, p. 10, 2025.

[19] A. T. Gebremariam, F. Di Maio, A. Vahidi, and P. Rem, "Innovative technologies for recycling end-of-life concrete waste in the built environment," *Resources, Conservation and Recycling*, vol. 163, p. 104911, 2020.

[20] J. Suer, M. Traverso, and N. Jäger, "Review of life cycle assessments for steel and environmental analysis of future steel production scenarios," *Sustainability*, vol. 14, no. 21, p. 14131, 2022.

[21] Ö. Sallı Bideci, A. Bideci, and A. Ashour, "Utilization of recycled brick powder as supplementary cementitious materials—a comprehensive review," *Materials*, vol. 17, no. 3, p. 637, 2024.

[22] X. J. Ge, P. Livesey, J. Wang, S. Huang, X. He, and C. Zhang, "Deconstruction waste management through 3d reconstruction and bim: a case study," *Visualization in engineering*, vol. 5, no. 1, p. 13, 2017.

[23] J. C. Cheng and L. Y. Ma, "A bim-based system for demolition and renovation waste estimation and planning," *Waste management*, vol. 33, no. 6, pp. 1539–1551, 2013.

[24] V. Rebekka, "Building information modeling for existing buildings–deconstruction planning and management," *Building Information Modeling: Shared Modeling, Mutual Data, the New Art of Building*, p. 147, 2023.

[25] J. Won and J. C. Cheng, "Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization," *Automation in Construction*, vol. 79, pp. 3–18, 2017.

[26] B. Wu and R. Maalek, "Renovation or redevelopment: The case of smart decision-support in aging buildings," *Smart Cities*, vol. 6, no. 4, pp. 1922–1936, 2023.

[27] J. Shin and J. Song, "Dismantling quantity estimation for nuclear power plant: scan-to-bim versus conventional method," *KSCE Journal of Civil Engineering*, vol. 28, no. 5, pp. 1607–1621, 2024.

[28] Department for Energy Security and Net Zero, "Greenhouse gas reporting: Conversion factors 2025," June 2025. Published 10 June 2025.

[29] C. Zhang, M. Hu, M. van der Meide, F. Di Maio, X. Yang, X. Gao, K. Li, H. Zhao, and C. Li, "Life cycle assessment of material footprint in recycling: A case of concrete recycling," *Waste Management*, vol. 155, pp. 311–319, 2023.

[30] Intergovernmental Panel on Climate Change (IPCC), Working Group III, *Annex II: Metrics & Methodology*. Geneva, Switzerland, Apr. 2014. Part of the AR5 WGIII report "Climate Change 2014: Mitigation of Climate Change".

[31] Sandvik Rock Processing Solutions, "QJ241 Mobile Jaw Crusher – Technical Specification Sheet." `https://www.rockprocessing.sandvik/en/products/mobile-crushers-and-screens/mobile-jaw-crushers/qj241-mobile-jaw-crusher/`, 2023. Includes specification sheet (PDF) with crusher dimensions, engine power, capacity and key features.

[32] NETZSCH Trockenmahltechnik GmbH, *NETZSCH Ball Mill Taurus: Ball Mill for Fine and Ultrafine Products*. Hanau, Germany, September 2024. Technical data sheet and product description for Taurus ball mill series, including operational principles and configurations.

[33] NETZSCH Trockenmahltechnik GmbH, *NETZSCH Air Classifier Mill Ural: Air Classifier for Special Products*. Hanau, Germany, September 2024. Technical document from the Business Unit Grinding & Dispersing.

[34] Climate Transparency, "Climate transparency report 2022: Turkey," 2022. Comparing G20 Climate Action: Country Profile – Turkey.

[35] M. Á. Sanjuán, C. Andrade, P. Mora, and A. Zaragoza, "Carbon dioxide uptake by cement-based materials: A spanish case study," *Applied Sciences*, vol. 10, no. 1, p. 339, 2020.

[36] S. Prakasan, S. Palaniappan, and R. Gettu, “Study of energy use and co2 emissions in the manufacturing of clinker and cement,” *Journal of The Institution of Engineers (India): Series A*, vol. 101, no. 1, pp. 221–232, 2020.

[37] National Stone, Sand & Gravel Association (NSSGA), “Aggregates Industry Greenhouse Gas Emissions, Low Emissions, High Resiliency,” tech. report, National Stone, Sand & Gravel Association, April 26 2021. Greenhouse gas emissions per production ton: 6.18kg COe/ton crushed stone, 5.51kg COe/ton construction sand (pp.7–9).

[38] Sphera Solutions GmbH / BBSR (ÖKOBAUDAT), *Ready-mix concrete C30/37*, 2023. Process data set for production of 1m³ ready-mix concrete (reference flow); density 2305.9kg/m³; reference year 2022, valid until 2024.

[39] Modular Clay Products, “Clay bricks vs hollow clay bricks – which is best?,” 2023. Accessed on July 29, 2025.

[40] BEWI ASA, Insulation and Construction, “Environmental product declaration: Greenline re80 denmark.” Environmental Product Declaration in accordance with ISO 14025 and EN 15804+A2, June 2024. Declaration number: NEPD-6787-6103-EN.

[41] İstanbul Büyükşehir Belediyesi Çevre Koruma Şube Müdürlüğü, “2025 yılı Ücret tarifesi.” *Resmi Rapor*, 2025. Erişim Tarihi: September 2, 2025.

[42] S. C. Ugochukwu, E. A. Nwobu, E. I. Udechukwu-Ukohah, O. G. Odenigbo, and E. C. Ekweozor, “Regression models for predicting quantities and estimates of steel reinforcements in concrete beams of frame buildings,” *Journal of Scientific Research and Reports*, vol. 26, no. 7, pp. 60–74, 2020. Article no.JSRR.60484.

[43] T.C. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı, “2025 yılı birim fiyatları,” 2025. Yüksek Fen Kurulu Başkanlığı tarafından yayımlanmıştır.

[44] T.C. Kültür ve Turizm Bakanlığı, “Tuğla tozu fiyat analizi,” 2025. Yapı İşleri Genel Müdürlüğü analiz poz numarası: 04.013/3.

[45] J. A. Olsson, H. Hafez, S. A. Miller, and K. L. Scrivener, “Greenhouse gas emissions and decarbonization potential of global fired clay brick production,” *Environmental Science & Technology*, vol. 59, no. 4, pp. 1909–1920, 2025.

APPENDICES

APPENDIX A. IMPLEMENTATION DETAILS

Table A.1: *CSV File created for use in Autodesk Navisworks Manage*

TaskID	Type	Title	Duration	Resources	Expected Start	Expected End	Pred 1	Pred 2	Pred 3	Pred 4	Pred 5
1		Predemolition					1				
110	Demolish	Deconstruction of Doors and Windows of 4. Floor			3.02.2025 08:00	3.02.2025 10:00	110				
110	Demolish	Deconstruction of Doors and Windows of 3. Floor			3.02.2025 10:00	3.02.2025 12:00	110				
110	Demolish	Deconstruction of Doors and Windows of 2. Floor			3.02.2025 13:00	3.02.2025 15:00	110				
110	Demolish	Deconstruction of Doors and Windows of 1. Floor			3.02.2025 15:00	3.02.2025 17:00	110				
110	Demolish	Deconstruction of Doors and Windows of Ground Floor			3.02.2025 17:00	3.02.2025 18:00	110				
120	Demolish	Deconstruction of Roof			4.02.2025 08:00	4.02.2025 18:00	120				
130	Demolish	Deconstruction Wall of 4. Floor			5.02.2025 08:00	5.02.2025 18:00	130	13.79	2	2.061111	11.73
140	Demolish	Deconstruction Wall of 3. Floor			6.02.2025 08:00	6.02.2025 18:00	140	20.33	3	2.688413	17.64
150	Demolish	Deconstruction Wall of 2. Floor			7.02.2025 08:00	7.02.2025 18:00	150	20.97	3	2.843009	18.13
160	Demolish	Deconstruction Wall of 1. Floor			10.02.2025 08:00	10.02.2025 18:00	160	19.84	2	3.056247	16.79
170	Demolish	Deconstruction Wall of Ground Floor			11.02.2025 08:00	11.02.2025 18:00	170	12.76	2	2.255332	10.50
180	Demolish	Deconstruction Strucral Columns of 4. Floor			12.02.2025 08:00	14.02.2025 18:00	180	6.63	1		6.63
190	Demolish	Deconstruction Floor of 4. Floor			17.02.2025 08:00	19.02.2025 18:00	190	9.36	1		9.36
200	Demolish	Deconstruction Stairs of 3. Floor			24.02.2025 08:00	24.02.2025 09:00	200	1.01	1		1.01
210	Demolish	Deconstruction Strucral Columns of 3. Floor			24.02.2025 09:00	24.02.2025 12:00	210	7.59	1		7.59
220	Demolish	Deconstruction Floor of 3. Floor			24.02.2025 13:00	24.02.2025 18:00	220	9.47	1		9.47
230	Demolish	Deconstruction Stairs of 2. Floor			25.02.2025 08:00	25.02.2025 09:00	230	1.01	1		1.01
240	Demolish	Deconstruction Strucral Columns of 2. Floor			25.02.2025 09:00	25.02.2025 12:00	240	7.59	1		7.59
250	Demolish	Deconstruction Floor of 2. Floor			25.02.2025 13:00	25.02.2025 18:00	250	9.47	1		9.47
260	Demolish	Deconstruction Stairs of 1. Floor			26.02.2025 08:00	26.02.2025 09:00	260	1.01	1		1.01
270	Demolish	Deconstruction Strucral Columns of 1. Floor			26.02.2025 09:00	26.02.2025 12:00	270	7.47	1		7.47
280	Demolish	Deconstruction Floor of 1. Floor			26.02.2025 13:00	26.02.2025 18:00	280	9.47	1		9.47
290	Demolish	Deconstruction Stairs of Ground Floor			27.02.2025 08:00	27.02.2025 09:00	290	1.01	1		1.01
300	Demolish	Deconstruction Strucral Columns of Ground Floor			27.02.2025 09:00	27.02.2025 12:00	300	7.47	1		7.47
310	Demolish	Deconstruction Floor of Ground Floor			27.02.2025 13:00	27.02.2025 18:00	310	9.56	1		9.56
320	Demolish	Deconstruction of Stairs of Basement			28.02.2025 08:00	28.02.2025 09:00	320		0		0.00
330	Demolish	Deconstruction of Basement Floor Wall			28.02.2025 09:00	28.02.2025 12:00	330	21.59	3	3.46651	18.13
340	Demolish	Deconstruction of Basement Floors Structrual Columns and Curtain Wall			28.02.2025 13:00	28.02.2025 15:00	340	7.79	1		7.79
350	Demolish	Deconstruction of Foundation			28.02.2025 15:00	3.03.2025 18:00	350	30.16	4		30.16

Table A.2: *Transportation Estimation in Excel*

Date	Volume	#Truck	Ton	Vehicle Price to Landfill(VPL)	Waste Carry Cost(WCC)	Transport and Accaptance Document(VAD)	Number of Truck(MOD AND COST)
5.02.2025	13.79	1	9.27	3990	1002.279041	480	=INT(P9/14)*3990 + IF(MOD(P9;14)=0;
6.02.2025	20.33	2	13.94	6840	1506.424116	960	IF(MOD(P9;14)<=5;1425;
7.02.2025	20.97	2	14.33	6840	1548.34755	960	IF(MOD(P9;14)<=10;2850;
10.02.2025	19.84	2	13.27	6840	1434.686128	960	3990)))+Y9
11.02.2025	12.76	1	8.31	3990	897.8949114	480	IF(logical_te
12.02.2025-14.02.2025	6.63	1	15.28	2850	1651.766553	480	[illegible]
17.02.2025-19.02.2025	9.36	1	21.58	2850	2332.370283	480	5662
24.02.2025	18.07	2	41.67	5415	4503.364217	960	10878
25.02.2025	18.07	2	41.67	5415	4503.427229	960	10878
26.02.2025	17.95	2	41.38	5415	4472.829161	960	10848
27.02.2025	18.04	2	41.60	5415	4496.481841	960	10871
28.02.2025	29.38	3	59.80	9405	6463.480603	1440	17308
3.03.2025	30.16	3	69.55	9405	7516.868891	1440	18362
TOTAL	**235.34**	**24**	**391.66**	**74670**	**42330.22052**	**11520**	**128520**

Figure A.1: *Data Source and Created Sets in Navisworks*

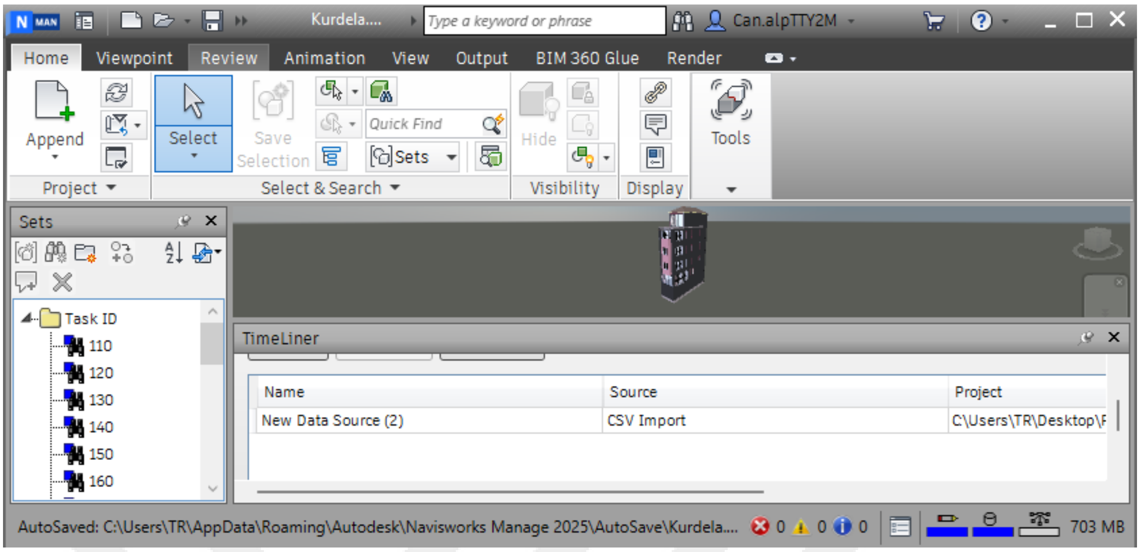


Figure A.2: *Dynamo Script for Structural Foundation*

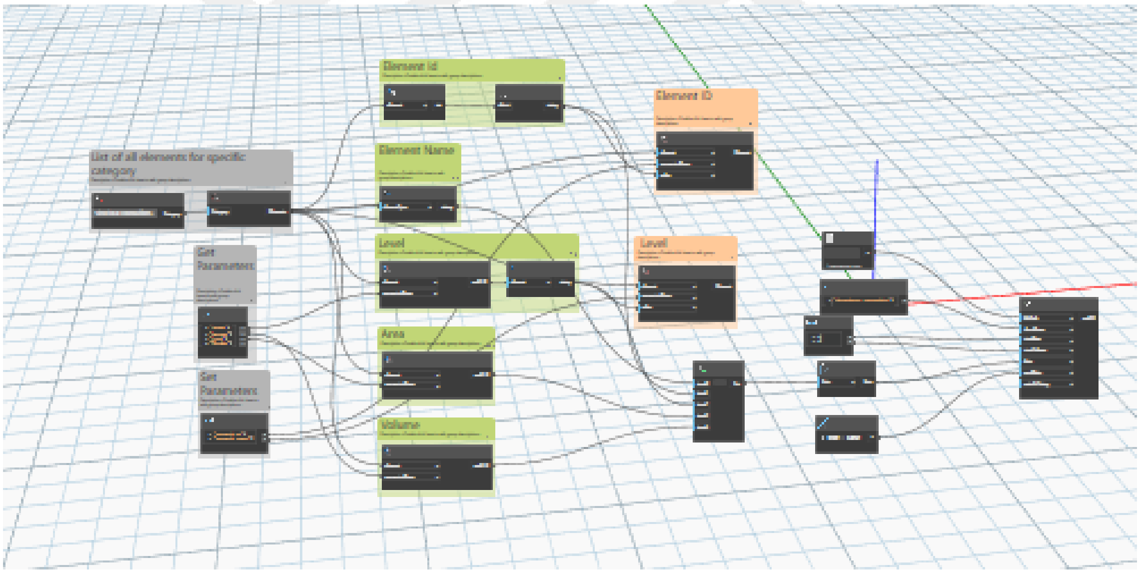


Table A.3: *Dynamo Output in Excel*

	A	B	C	D	E	F	G	H	I	J	K
1											
2	10 cm Brick	347195	0.Ground Floor	34.27206	1.001613	0.071355					
3	15 cm Brick	341389	0.Ground Floor	794.4726	20.56522	3.084783					
4	15 cm Brick	345889	0.Ground Floor	1175.832	18.17509	2.726341					
5	20 cm Brick	338279	0.Ground Floor	150.3153	3.718829	0.687887		10.49982			
6	25 cm Brick	338276	0.Ground Floor	354.2451	1.351107	0.251163					
7	25 cm Brick	338277	0.Ground Floor	262.06	7.337681	1.744874				Brick	74.79048
8	25 cm Brick	338278	0.Ground Floor	167.5832	4.413598	1.102849				EPS	16.37062
9	8 cm Brick	338281	0.Ground Floor	144.9494	3.896305	0.268511					
10	8 cm Brick	338282	0.Ground Floor	159.8791	4.151817	0.237881					
11	8 cm Brick	348550	0.Ground Floor	160.8977	4.355456	0.324175	Curtain Wall	4.034596		Curtain Wall	24.38387
12	Curtain Wall	338270	0.Ground Floor	35.01829	1.259679	0.251936					
13	Curtain Wall	338271	0.Ground Floor	213.0945	6.037628	1.207329				Concrete	140.3615
14	Curtain Wall	338272	0.Ground Floor	34.99751	1.25993	0.251986					
15	Curtain Wall	338273	0.Ground Floor	212.464	6.020066	1.203494					
16	Curtain Wall-25 cm	338274	0.Ground Floor	179.9788	4.479404	1.119851					255.9064
17	EPS	412535	0.Ground Floor	385.0053	10.86432	0.325925		2.255332			
18	EPS	412536	0.Ground Floor	1168	22.93892	0.688146					
19	EPS	412538	0.Ground Floor	1275.18	35.70776	1.071152					
20	EPS	551875	0.Ground Floor	26.18257	0.596016	0.017826					
21	EPS	916881	0.Ground Floor	26.07071	0.602434	0.018014					
22	EPS	919061	0.Ground Floor	341.1253		0					
23	EPS	919534	0.Ground Floor	338.7468	1.01624	0.030487					
24	EPS 5 cm	412584	0.Ground Floor	132.0791	2.07896	0.103783		16.78738			
25	10 cm Brick	382450	1.First Floor	177.6125	3.059375	0.305937					
26	10 cm Brick	383121	1.First Floor	239.4694	6.355671	0.635514					
27	10 cm Brick	383879	1.First Floor	60.00025	1.680007	0.168001					
28	10 cm Brick	384108	1.First Floor	72.61113	1.683638	0.168311					
29	15 cm Brick	348950	1.First Floor	804.517	20.56726	3.084969					
30	15 cm Brick	374240	1.First Floor	69.38763	1.942854	0.291428					
31	15 cm Brick	376952	1.First Floor	167.2604	4.852228	0.629837					
32	15 cm Brick	377407	1.First Floor	66.7889	1.870553	0.280516					
33	15 cm Brick	377822	1.First Floor	66.803	2.290939	0.343021					
34	15 cm Brick	378076	1.First Floor	54.4922	0.96516	0.103466					
35	15 cm Brick	378870	1.First Floor	132.8057	1.485951	0.222893					
36	15 cm Brick	391431	1.First Floor	164.1895	2.099893	0.314248					
37	20 cm Brick	384257	1.First Floor	65.00025	1.680007	0.336001					