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INTEGRATING 7D BIM MODELING INTO CONSTRUCTION PROJECT MANAGEMENT TO OPTIMIZE AND CONTROL SUSTAINABILITY PRINCIPLES: A CASE STUDY IN IRAQ

Hawraa Mohammedhussein Musa BAHRALELOUM

Master`s Thesis

Supervisor

Assoc. Prof. Dr. Sepanta NAİMİ

Istanbul, 2023

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The thesis titled INTEGRATING 7D BIM MODELING INTO CONSTRUCTION PROJECT MANAGEMENT TO OPTIMIZE AND CONTROL SUSTAINABILITY PRINCIPLES: A CASE STUDY IN IRAQ prepared by HAWRAA MOHAMMEDHUSSEIN MUSA BAHRALELOUM and submitted on 12/04/2023 has been **accepted unanimously** for the degree of Master of Science in Mechanical Engineering.

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I hereby declare that this thesis meets all format and submission requirements of a Master’s thesis.

Submission date of the thesis to Institute of Graduate Studies: ___/___/___

I hereby declare that all information presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Hawraa Mohammedhussein Musa BAHRALELOUM

Signature

DEDICATION

I would like to dedicate this work to my wonderful parents, who have always supported me and helped me with my homework and projects in any way they could. The civil engineering department at Altınbaş University, including my supervisor and the rest of the department's employees, is also recognized and thanked for their help, guidance, and vast knowledge. My supervisor was very helpful in pointing me in the right direction and giving me resources for my quantitative simulation using the REVIT software.

Additionally, I would like to express my gratitude to every person at Altınbaş University who assisted me with my REVIT research.

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I also want to thank the people on the test committee who helped me by giving me advice and feedback. Also, I would like to thank the civil engineering team at Altınbaş University.

ABSTRACT

INTEGRATING 7D BIM MODELING INTO CONSTRUCTION PROJECT MANAGEMENT TO OPTIMIZE AND CONTROL SUSTAINABILITY PRINCIPLES: A CASE STUDY IN IRAQ

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This master's study was directed to analyze and look into the critical roles and positive effects of using 7D BIM model technology in the construction industry to make it more sustainable and minimize carbon dioxide emissions and other things that are bad for the environment. The research was based on a case study of a building project for the Royal Baghdad. Quantity take-off of the building materials used in this project was done by hand and with the help of REVIT. Furthermore, the REVIT 7D modeling was implemented to find out what are the most critical steps that can be taken to make this project more sustainable. The results revealed that the BIM technology, including the REVIT software tool, plays a critical role in facilitating the management of large construction projects, like the commercial one considered in this case study, offering a positive rationale for better time, cost, and effort management, with accuracy rates between approximately 90.7% and 99.9%. Implementing this innovative technology could help complete the required work quickly and efficiently without various human mistakes and calculation errors. Thus, it can be said that these BIM applications, including the functional REVIT software tool, are the future of modern construction projects. Employing the REVIT software tool provided significant accuracy, performance, and reliability rates in estimating the quantity of various construction materials, offering optimum levels of reliability, performance, and cost-effectiveness required for the quantity take-off compared with the manual quantity take-off. Considering the 7D BIM technology in the Royal Baghdad project can manage some challenging issues that may cause adverse environmental impacts, including carbon emissions.

Keywords: BIM Technology, 7D Level, Building Modeling, REVIT, Sustainability.

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ABBREVIATIONS

AEC	:	Architecture, Engineering, and Construction
BIM	:	Building Information Modelling
CIM	:	City Information Modelling
CW	:	Construction Waste
CAD	:	Computer-Assisted Design
CPM	:	Critical Path Method
CBRs	:	Cost-Benefit Ratios
CWM	:	Construction Waste Management
EIA	:	Environmental Impact Assessment
EMS	:	Environmental Management System
EFA	:	Exploratory Factor Analysis
ETAB	:	Emerging Technologies Advisory Board
ICE	:	Inventory of Carbon and Energy
LEED	:	Leadership in Energy and Environmental Design
LCC	:	Life Cycle Costing
LCA	:	Life Cycle Assessment
LCSA	:	Life Cycle Sustainability Assessment
SEM	:	Structural Equation Modeling
SDG	:	Sustainable Development Goals
SLR	:	Systematic Literature Review

1. INTRODUCTION

1.1 RESEARCH BACKGROUND

Adopting a new and modern strategy in the design and construction of sustainable buildings has become necessary due to the increase in environmental problems and the new requirements that aim to reduce the environmental impact when designing sustainable buildings by adopting a budget within the permissible limits and fulfilling these requirements and standards to achieve sustainability within the required period [1].

Architects must use not only analytical tools but also use tools that combine the perfect balance between the environment and the building systems to achieve the goals of sustainable architecture [2]. The primary purpose of designing sustainable buildings is energy effectiveness. This important factor results in the minimizing of the consumption of sources by the structure and justifies consequent options in terms of substances and techniques solutions which permit minimizing as well the environmental impact during the stage construction [3].

Sustainability estimation ways can be employed as methods in support of design, proposing a different function during the many design stages. In the primary assessment stage relating to design alternatives, they can be utilized in order to determine the requirements of sustainability and the identification of the goals relating to environmental impact. These ways are identified as support instruments for designers, contributing to helping them to gain a clear understanding of how the environmental factors of the building are impacted by design selections and how scholars can optimize the cost utilization [4].

Suppose the environmental impact of the building was taken into account via the utilization of substances and energy during the project stage. In that case, we could determine their environmental performance as the actual capability of the structure to achieve optimum utilization of the natural sources available during its serviceability life to obtain sustainability objectives [5].

Building Information Modelling (BIM) is one of the most important tools for transforming the construction industry and encouraging the use of information methodologies based on collaboration [6]. The BIM technology secures communication between project participants [7].

A BIM system can also be defined as the digital representation of the physical and functional characteristics of a building project, which acts as a common knowledge source for information about the project forming a reliable basis for decisions during its life cycle from inception onwards [8]–[25].

BIM utilization can solve design issues and achieve building performance and quality. BIM should offer enhancement of design [26]–[28]., moreover the capability of BIM in project administering, cost management, and facilities management. Consequently, the BIM simulation in terms of 4D, 5D, 6D and 7D that's basic cost, period, facility administering, and sustainability concepts, will enhance the performance of the project. Sustainability concepts utilized to design and construction processes is an important issue in the twenty-first century [29]. Sustainable design can be more effective and save money by utilizing the BIM tool that enables the design group and another participant in projects to develop an organization and give a visualization of information and documentation for specific design accurately, modeling and analysing the project with cost assessing, and enhancing the environmental effect for the project via the whole life cycle. Designing sustainable buildings becomes simpler by using BIM. BIM, in the last years, has shown high performance in designing sustainable projects [30]. The integration of sustainable design procedures and BIM techniques has the probability of changing conventional design methods and making high-performance designs. The improvement of technology will boost both sustainability and BIM in setting criteria of perfection for the future.

1.2 PROBLEM STATEMENT

The world is facing many environmental problems that pose great challenges. To face these problems, reliance on sustainability has become necessary, and since its construction, the industry has had a great impact on the environment. The sustainable principles are great procedures, which require achieving their purpose a lot of time and high cost .in addition, more effort, and to achieve sustainable building uses, advanced technology should be applied to simplify and speed up the procedures and estimate their economic effect. Conventional methods utilized in designing sustainable buildings and calculating quantities are considered one of the troubles that need time, cost, effort, and the occurrence of mankind's mistakes because of arithmetic processes and transportation.

1.3 RESEARCH SIGNIFICANCE

The importance of this thesis is to utilize the REVIT Software to compute the quantities and compare the results achieved by REVIT with the conventional and traditional approaches. This software contributes to minimising the effort, cost, effort, and humankind errors in arithmetic and transporters processes.

1.4 RESEARCH MAJOR AIM AND MINOR OBJECTIVES

This research aims to calculate the quantities for a commercial building consisting of seven stories through two aspects: the first aspect, which is the structural aspect, which includes calculating quantities of each of (walls - columns - beams - slabs - foundations - cement - reinforcement ratio. In addition, the second aspect includes the interior design of the building. Moreover, the interior decorations, the architectural facades, and the partitions are computed from the plan.

Additionally, there is a number of secondary goals are performed to achieve a study that demonstrated the following:

a. To increase understanding of the essential limits and challenges conventional and manual methods to face in terms of cost, effort, period, and humankind errors.
b. To utilize the REVIT Software in computing the quantities and conducting a comparison with the manual methods.
c. To compute quantities of each of (walls - columns - beams - slabs - foundations - cement - and reinforcement ratio).
d. To compute the interior decorations, the architectural facades, and the partitions in the plan.

1.5 THESIS STATEMENT

The title of the thesis is "Integrating 7D BIM Modeling into Construction Project Management to Optimize and Control Sustainability principles: A Case Study in Iraq." This study is conducted in order to investigate the significance of REVIT Software in simulating sustainable buildings, which aims to decrease time, cost, effort, and humankind errors.

1.6 RESEARCH QUESTION

This study is a serious attempt to answer the consequent questions:

a. How can REVIT Software contribute to simulating sustainable buildings?
b. How can REVIT Software contribute to minimizing humankind errors in arithmetic processes?
c. What are the most significant parameters utilized in REVIT?
d. How can REVIT software achieve sustainability principles?

1.7 RESEARCH ORGANIZATION

The planning of this study includes five chapters, which can be described as follows:

a. Chapter One, which contains the INTRODUCTION as a title, represents the brief background, problem statement, research significance, research's major aim and minor objectives, and the research questions.
b. Chapter Two, which includes the LITERATURE REVIEW as a title, represents some recent previous studies regarded to this study.
c. Chapter Three, which has the title of RESEARCH METHODOLOGY, is a Description of the establishment in which the principles of sustainability are to be applied using the REVIT program, specifying the stages of modelling and calculating quantities, in addition to mentioning the traditional calculation methods that will be compared with the REVIT Software.
d. Chapter Four, titled RESULTS AND DISCUSSIONS, discusses the results of research using by REVIT tool and compares REVIT results with results performed by manual methods.
e. Chapter 5, which has the title CONCLUSIONS AND RECOMMENDATION, illustrates the initial study's results regarded to results from the REVIT software. Moreover, this

chapter mentions a set of recommendations and essential ideas for further work, which will aim for future advancements in scientific works.

2. LITERATURE REVIEW

2.1 CHAPTER GOAL

This chapter represents a comprehensive review through which various recent academic publications and peer-reviewed articles are reviewed and addressed to highlight the critical benefits and substantial role of the BIM technology and the REVIT software tool importance in maintaining significant levels of sustainability and environmentally friendly measures that take into consideration various environmental aspects and standards to alleviate the adverse influences and harmful waste impact on nature when the construction project is completed. Hence, different types of waste can be minimized, and an efficient execution process of the project can be achieved, keeping the environment clean and green.

2.2 CRITICAL BENEFITS OF BIM TECHNOLOGY AND 7D PRINCIPLES FOR MANAGING SUSTAINABILITY IN CONSTRUCTION

[31]conducted an analysis investigating the critical contributions and beneficial impacts of implementing active 7D principles associated with BIM technology to manage and monitor construction projects and reduce their negative effects on the environment and nature. The scholars reported that when a structure is constructed or renovated using conventional methods, a vast quantity of materials is used, many of which are nonrenewable and harmful. The digital construction approach made possible by building information modeling (BIM) has facilitated the acquisition of sustainable building models, generating all the data needed to sustain green building assessment all through the design process. Taking into account the accessibility of regionally sourced building materials, some research into the use of building information modeling (BIM) for green construction evaluation has been conducted. Building models were developed using a program (like REVIT 2019) as part of a Building Information Modeling process. The chosen materials and systems were adjusted directly within the REVIT database. A hierarchical construction model is offered here to investigate the multifaceted, industry-spanning relationship between material qualities and architectural layouts. In that study, researchers compared different types of buildings by taking into account regional building supplies. Based on the Inventory of Carbon and Energy (ICE) and the local materials database enabled the measurement of embodied carbon and energy footprint for regional construction materials. The results demonstrated substantial savings in

building energy consumption, as well as a marked decrease in embodied carbon and energy footprint, as a result of employing regionally available construction materials. Finally, a unified framework of economic, environmental, and social sustainability has been addressed to evaluate the long-term viability of the results and to foster a pleasant environment in which to live.

[32]published a manuscript inspecting the vital effects and substantial advantages of using BIM technology and the active 7D principles to manage and monitor construction projects to lessen their harmful effects on the natural world. The scientists mentioned that present-day project cost management is best served by total process control of building expenditures. However, it is challenging to implement highly effective management due to the high number of partners involved in the project, the lengthy construction schedule, and the lack of common data platforms for all stakeholders. With the advent of BIM technology, things have shifted. The use of BIM technology throughout the process, from planning and design through building and operation, allows for more efficient cost management and faster turnaround times.

[33]implemented a study analyzing the vital role and critical benefits of using BIM technology and the active 7D concepts connected with it, construction projects may be managed, monitored, and their adverse effects on nature and the environment can be mitigated. The scholars reported that the rapid development of China's largest cities had necessitated the construction of ever-more-impressive structures for residential and commercial use. However, project management and financial investment are not always practical. A 7D BIM (building information model in seven dimensions) is created to address this issue. First, a 3D building information model (BIM) is produced, detailing everything from the structure's blueprints to its mechanical components. The 3D BIM has been combined with a 1D schedule management approach and a 3D project management approach (including enterprise quota management, process management, and bidding management) to build a 7D BIM for a complicated project. Engineers and project managers can use the proposed 7D model to facilitate clash detection, equipment installation, structural design, 3D project planning, post-construction, and alteration maintenance by offering a clear 3D view in modelling the construction process. A study of a complicated Chinese project shows how well the concept works in practice. According to the results of that research,

implementing 7D BIM has resulted in significant time and money savings, in addition to an increase in project quality and productivity.

[34] directed an analysis exploring the stimulating effects and substantial advantages of utilizing BIM's active 7D principles to oversee and control construction projects and limit their harmful effects on the natural surroundings. The scholars suggested that BIM's introduction of collaborative information management and real-time solutions for usage across the project lifecycle has radically altered the infrastructure construction business. Previous studies have shown the significance of BIM for that sector. However, further work is needed to elaborate and validate techniques for implementing this system. Their paper set out to examine such approaches from the perspective of the BIM system, taking into account all relevant factors. Figure 2.1 illustrates the various dimensions of the BIM system.

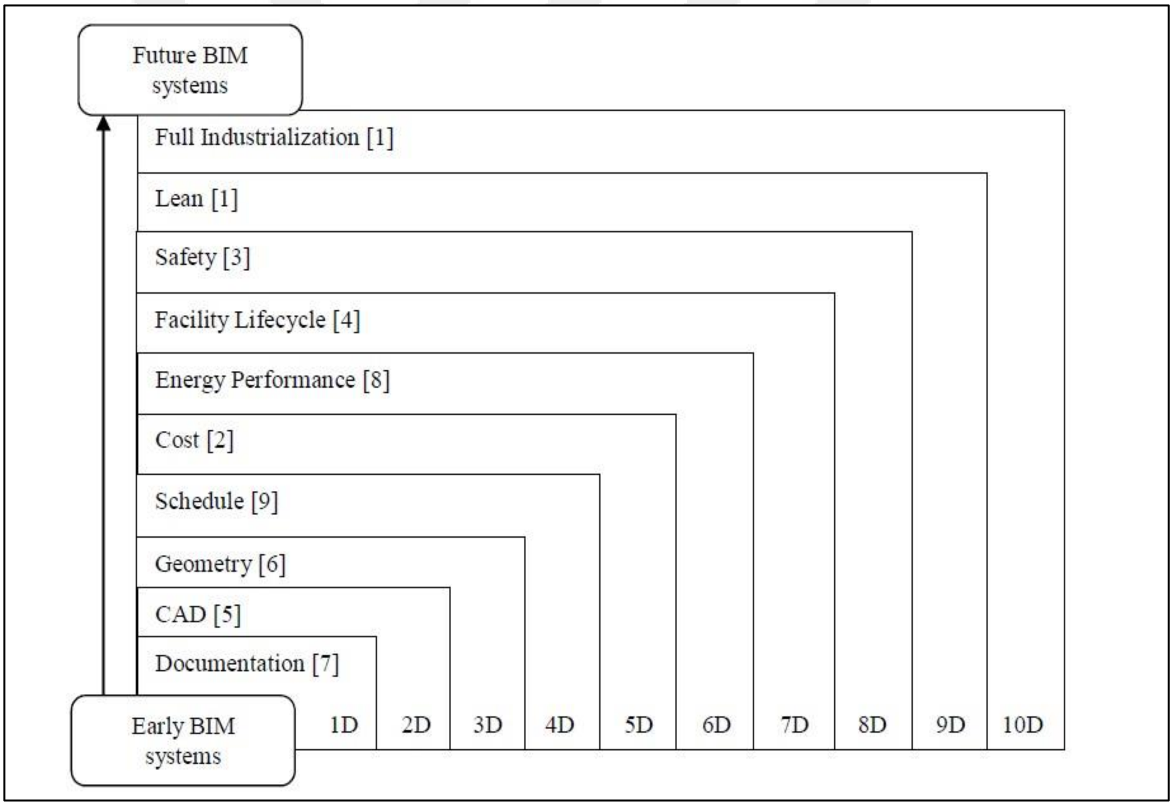

Figure 2.1: The Dimensions of the BIM System.

The results stem from a case study project conducted in New South Wales, Australia, and relied on theoretical discourse and semi-structured interviews. The findings showed that BIM incorporates several factors into infrastructure construction, such as cost, energy, safety, sustainability, time, and risk. It was determined that effective BIM implementation strategies should prioritize enhancing the BIM system's (1) automation and integrity, (2) cooperation, and (3) optimization contributions to infrastructure building. Their primary contribution was the recognition of 7 technical and management implementation techniques. The strategies outlined here give professionals an understanding of the technical and managerial steps needed to implement the BIM system.

[35] carried out a study classifying the practical advantages and considerable characteristics of integrating BIM's active 7D basic rules to the supervision and management of building projects, with the objective of reducing their damaging impacts on the earth. The researchers claimed that many obstacles exist to the implementation of Environmental Impact Assessment (EIA) studies, especially in less developed nations. Researchers looked into this issue by reading the relevant literature and administering a survey to professionals in the area. The reasons for this were mainly linked to the complexities of the EIA procedures and the isolation of the EIA process throughout the phases of the project. Consequently, the study concluded that BIM applications could be the answer to various EIA-related issues, either directly or indirectly, by improving the efficiency of the Environmental Management System (EMS). In order to construct an analysis method for a proposed BIM-based EIA framework, parameters and interrelations were defined using a keyword-based scientometric analysis. A score for how well BIM techniques were applied to an EIA process, a score for how well BIM techniques were integrated into various EIA steps, and a score for how well BIM techniques were integrated into various project phases were all offered as part of the proposed framework (Score B). A Sankey diagram illustrating the relationship between the three plans was also included. Three large building projects in Egypt, a developing country, were compared using the proposed framework to identify problem areas. Inadequate use of sophisticated BIM models to back up sustainability assessments in EIA investigations was highlighted. Moreover, the disparity in BIM use over the various stages of a project was especially mild during the maintenance and decommissioning phases. Inadequate BIM tool integration also prevented decisions from being made to help with the mitigation process. The application of a 6-dimensional BIM model will therefore facilitate the creation of countermeasures and will provide support to the optimization of the building's design both during its operational period and its decommissioning phase. This ground-breaking method provided the necessary confirmation and quality control technique for environmental engineers and decision-makers to conduct EIA studies and opened the door to additional investigations in this area.

[36] managed a study examining significant benefits and valuable uses of implementing active BIM technology principles to help manage and monitor construction projects and reduce their negative impacts on the environment and nature. The scholars reported that sustainable construction tools integrated in the BIM software are capable of providing advanced strategies and beneficial approaches of facilities' managing in terms of sustainable design, green building management, and ecological construction of intelligent structures and enviromentally friendly neighborhoods and cities. The scholars stated that BIM concept serves the most cutting-edge method that is broadly implemented worldwide in the current years. Furthermore, BIM has a significant role in facilitating the management and construction of green and smart plannings linked to structures, communities, and entire cities. The first part of authors' analysis was developed to address the BIM's foundational principles. Their second research part dives into the practical uses of BIM, known as Green BIM, which is engaged in practical sustainable tools to aid the design of environmentally friendly buildings. Lastly, the notion of City Information Modelling (CIM) was introduced as a shared platform for the design, construction, and management of the buildings, services, and infrastructures of cities and neighbourhoods that move towards sustainable and intelligent innovations.

[37] implemented a study analyzing the functional merits and active uses of applying BIM's 7D principles to facilitate the management and monitoring of construction projects, intending to minimize their destructive effects on the world ecological system. The scientists mentioned that harmful environmental and economic impacts have resulted from the construction industry's massive waste production. This means that efficient Construction Waste Management (CWM) can employ construction debris for essential activities of construction. This research aimed to clarify the conceptual relationships between CWM and BIM aspects that determine CWM's incorporation into construction management. The researchers presented a multi-dimensional framework that makes use of BIM-based automated Construction Waste (CW) estimating capabilities to advise on CWM applications, such as waste allocation, onsite reuse, CW disposal scheduling, and disposal cost estimation. Strategic alignment between traditional project goals and CWM was made possible by the framework's presentation of connections among these CWM domains and applications, including scheduling, estimate, sustainability, and site planning. Their framework was analyzed using a real-world pilot project dealing with concrete demolition

debris. The information gathered during the project and the interviews were recorded and cataloged. There was a discrepancy of 5.3% between the predicted and measured amount of concrete debris. It was anticipated in that study that recycling and reuse might save over USD 35,000 annually. According to their research, there would be multiple chances to recycle materials from the retaining wall construction process because of the need for backfill. As was discovered, containers might be set aside for particularly high-volume waste streams at any given stage of construction. The study's results would help construction professionals evaluate CWM's value in boosting their projects' efficiency, economy, and environmental friendliness. Figure 2.2 shows the structure of the seven-dimensional integrated platform between CWM and construction management.

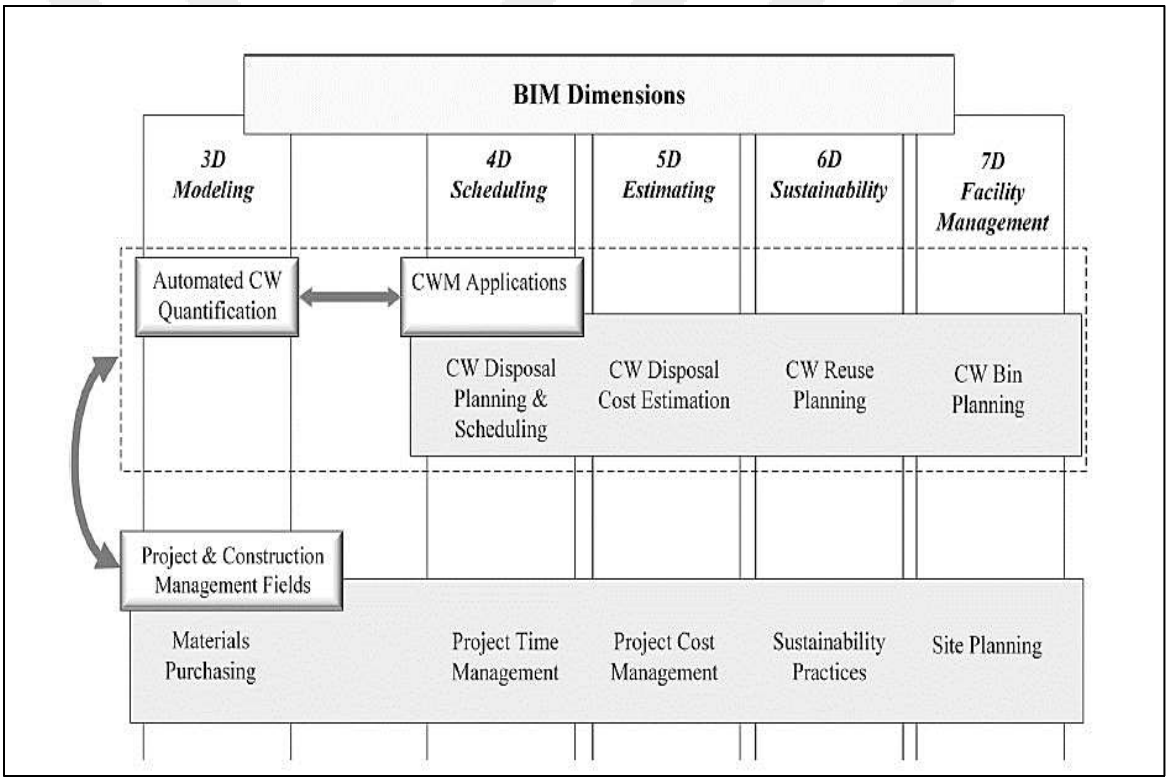

Figure 2.2: Structure of the Seven-Dimensional Integrated Platform Between CWM and Construction Management.

[38] published a manuscript inspecting the practical advantages and considerable characteristics of BIM technology in providing more precise cost estimates for construction projects than is possible using traditional methods of budget evaluation. Al-Anbar commercial complex in Al-Ramadi, Iraq, was the subject of the case study of a construction project analyzed by the scholars. Findings of the REVIT software from BIM system were compared to the human calculation approach in terms of accuracy. According to the study's

key outcomes, calculating steel, concrete, and other architectural components with BIM technology and the REVIT software was more efficient and practical than doing so manually. Cost estimates made using BIM technology and the REVIT software were shown to be more accurate compared with those made using traditional mechanisms. The removal of potential for human error during computations is the driving advantage of this software. This indicates that when using REVIT, reliable outputs can be achieved. Meantime, the results of the study showed that estimating the construction project's price manually was far more labor-intensive and costly than using BIM technology.

[39] managed a study examining the relevant impacts and positive effects of using BIM technology in directing the execution and achievement of construction projects and monitoring them actively. The scholars set out to better comprehend how design firms could benefit from the implementation of BIM technologies. Their literature acknowledged BIM as a primary motivator moving the construction industry towards intelligent management. However, the decision to engage in BIM tools was mostly a financial one for design firms. In particular, a design firm calculates the financial savings and productivity gains made possible by using BIM tools. The economic benefits of BIM technologies were examined, and several methods for calculating ROI were reviewed. Realistic ROI calculations are performed for BIM evaluation purposes. Methods and variables necessary for calculating return on investment were established. The study's findings informed an improvement to the Autodesk REVIT-based ROI calculation for the first year, enhancing its precision and straightforwardness.

[40] carried out a study classifying the significant benefits and valuable uses of utilizing BIM in directing construction enterprises. The scholars affirmed that construction project management is dynamic and unstable due to the uncertainty introduced by change iterations. Rework accounts for 30% of the total building cost, according to published research. In addition, modification orders are widely regarded as the leading contributor to garbage on construction sites. Decisions about how to adapt to new circumstances are often made by construction industry pros with only partial data to go on. The aforementioned problem is amenable to systematic treatment by means of objective methodologies using cutting-edge technology. Despite its potential, dynamic modeling based on BIM has not been studied for calculating waste generation from change orders. In their study, they used BIM to model the

field data throughout the project lifecycle and examine the knock-on impacts of various design modifications. To further understand the system's interplay, a dynamic model was constructed. The dynamic behavior of the parameters was analyzed using virtual BIM data as a result of modifications to the project's scope. Findings from their case study indicated that by committing to less waste throughout the project's preliminary planning stages and coordinating BIM design efforts, the client might cut construction waste by as much as 25%.

[41] implemented a study analyzing the functional merits and active uses of integrating BIM's active rules to the supervision and management of building projects. The researchers confirmed that while sustainability has long been an important topic in the AEC sector, Building Information Modeling (BIM) is a more recent notion. The purpose of this article is to examine the advantages of combining building information modeling (BIM) with environmentally responsible building methods. Using a quantitative methodology, a two-round Delphi survey was conducted with a total of fourteen selected experts from academia and industry. After collecting and organizing the data, rankings for each element were established, and agreement among respondents was measured using the Kendall's concordance test. The majority of the supposed advantages were rated as major and crucial. In addition, four of the 36 positive factors were rated as extremely important, including the ability to easily simulate building performance and energy usage; improved product design; more accurate geometrical depictions of structure models with embedded sustainability data; and streamlined sharing and exchange of project data. Keeping these advantages in mind and encouraging teamwork in the AEC sector is crucial to realizing the notions and ideas of a sustainably metropolitan city in practice.

[42] conducted an analysis investigating significant benefits and valuable uses of implementing active BIM principles to manage and monitor construction projects and reduce their negative impacts on the environment and nature. The authors stated that reducing energy usage, expanding industrial production, adapting to a changing climate, conserving water, minimizing waste, recycling and composting, establishing efficient transportation networks, and protecting biodiversity are all essential components of sustainable development, of which constructions is one. A sustainable structure is one that strikes a good balance between social, economic, and environmental considerations. Whole-building energy simulation tools play a significant role in the design process to help cut costs and

boost efficiency as the need for eco-friendly construction grows. When it comes to sustainability measures like location, orientation, sun-path analysis, thermal qualities of materials, heating and cooling loads, daylighting, and ventilation, however, Building Information Modeling (BIM) is used as a simulation tool. Sustainability, on the other hand, is more involved with the total building design and all environmental factors than with energy simulation. To better evaluate sustainable building designs in advance, their study introduced a streamlined method for using building information modeling (BIM)-based simulation. The proposed procedure facilitates the assessment of design alternatives according to a defined Green Building Rating system, which is essential for the success of any project. The Leadership in Energy and Environmental Design (LEED) rating system was also used as a case study to examine the implementation of BIM in accordance with LEED and to develop a user-friendly assessment template that quantifies a design's potential for meeting sustainable requirements and earning points.

2.3 THE VITAL ASPECTS OF BUILDING INFORMATION MODELING FOR SUSTAINABLE CONSTRUCTION PLANNING

[43] directed an analysis exploring some functional merits and active uses of applying BIM active principles to the management and monitoring of construction projects. The scholars reported that in order to be better productive and sustainable, and to adopt a smart and creative approach of carrying out the various operations, the built environment must overcome a number of obstacles. The purpose of their research was to uncover the significant challenges that the construction industry has when trying to implement BIM and sustainability principles. Consensus among the panel of experts was aggregated using a two-round Delphi poll based on a group of 38 variables generated from content analysis of prior research studies. The data was analyzed with descriptive and inferential tests, and the results were checked with an inter-rater agreement analysis. Industry's aversion to move from traditional working practices, a prolonged period of adaptation to innovative technology, and an absence of understanding of the processes and workflows needed for BIM and sustainability are the three primary hurdles, in descending order of significance. Conclusions were also drawn from a comparison of the various groups of experts. Their research outcomes would help move BIM and sustainable practices forward in construction projects, allowing key players to concentrate on solving the pressing problems highlighted here.

[44] executed an investigation identifying practical advantages and notable characteristics of using BIM technology and the active 7D principles to manage and monitor construction projects to lessen their harmful effects on the natural world. The scholars clarified that BIM and other recently developed digital technologies have been widely used across the project life cycle in the built environment, allowing for a wide range of new insights and decision-making capabilities. Consequently, there is a great deal of information that needs to be shared, modified, coordinated, and communicated among many parties all during the building process. The idea of a more granular built asset model has emerged in recent years due to the potential benefits it could provide in areas ranging from cost management and facility maintenance to information exchange and monitoring of the construction asset once it is installed in an environment. The growth of massive data in the architecture, engineering, and construction (AEC) industry is having a profound effect on the planning, development, and management of projects in the industry. This is due to the digitization/computerization of numerous stages and processes of built environments. One of the latest innovative and cutting-edge technological advancements in the built environment has recently been identified as the junction of digital technologies, smart systems, and data systems. However, there are still obstacles to its intelligent implementation, despite the fact that digital technology's incorporation into the AEC sector's processes has proven benefits throughout the lifecycle of the created asset and this incorporation has the potential to completely revolutionize the construction business. For instance, the substantial requirement for an understandable framework is confirmed by the difficulty of precisely and efficiently employing it to achieve the desired results. As a result, the primary purpose of this dissertation is to create a comprehensive manual for the effective deployment of digital twin technology in the built environment. To efficiently implement digitalization in the current built environment projects, a step-by-step guide framework (called a Digital Twin Execution Plan, or DTxP) is established to follow the workflows and information exchange needs. Various codes of practice were examined to ensure that the proposed framework was in line with regional and worldwide norms, and a literature review was conducted to obtain the necessary scientific data. To better understand how digitization may be applied in practice while addressing pressing issues, they also sought the input of industry practitioners. To increase productivity in a built environment project using digital twin technology, a thorough set of information on when, how, and who is responsible for what task(s) has been compiled

into a framework document. Although the document is meant to help those working with BIM implement digitalization in reinforced concrete bridge structures for purposes, such as structural performance analysis, fatigue assessment, traffic monitoring, and ground stability, the developed framework could be expanded by other professionals in the industry. In addition, when effective implementation of digital twin technology into built environment practices is required, the development document could be used as a standard or a guide.

Figure 2.3 explores a System and module framework for the BIM-based facility management system.

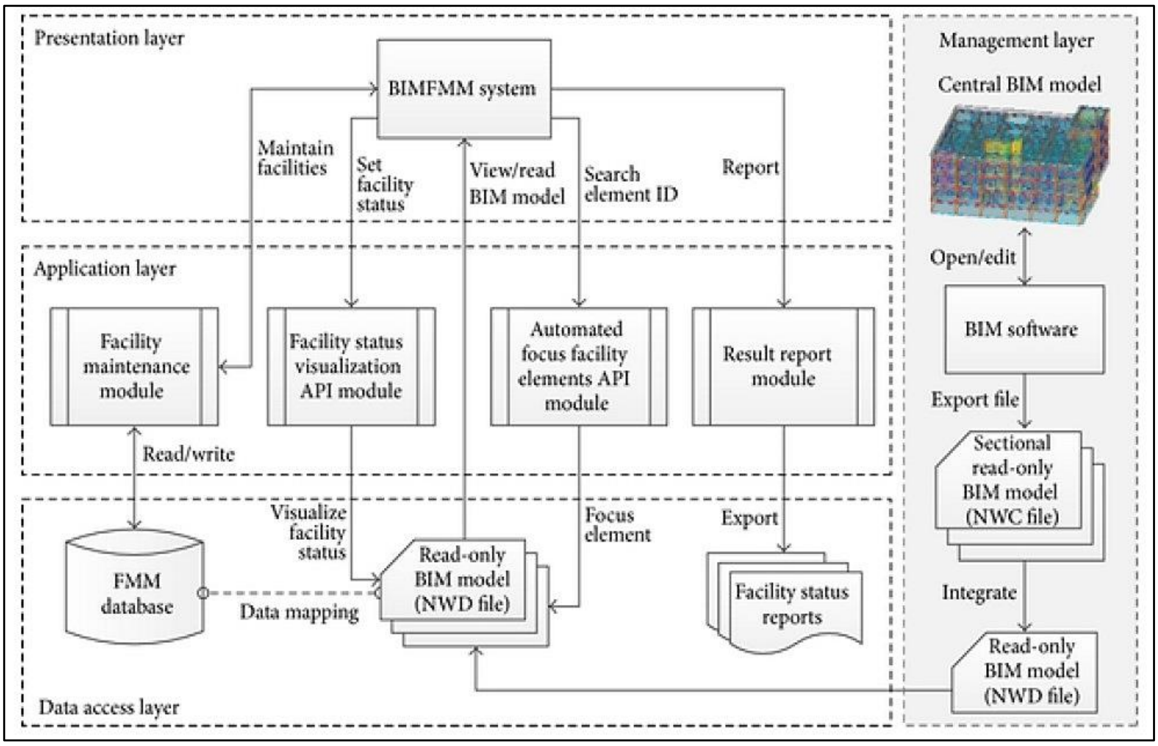

Figure 2.3: System and module framework for the BIM-based facility management system.

[45] carried out a study classifying the vital role and critical benefits of using BIM technology in managing and handling construction projects. The authors stated that the primary objective of their study was to improve upon current methods of integrating life cycle assessment (LCA) and life cycle costing (LCC) with BIM by addressing their shortcomings (such as interoperability concerns and inaccessible databases). To that end, they offered a BIM-based platform for guiding automatic LCA/LCC analysis. To better integrate BIM with LCA and LCC, the authors created a prototype tool for BIM-based environmental and economic life cycle assessment (BIMEELCA). In addition, the research's findings were verified through a pilot case study in the Netherlands, proving the method's

value in the building sector. Incorporating semantic information into the model, this research revealed the promise of BIM-based simulations for evaluating the financial and ecological effects of buildings. Predictive analyses (analyses that identify the most suitable solutions based on the data from earlier projects) can make use of the historical data contained within data-rich models, and the work presented here will hopefully lead to the development of automatic sustainability simulations, the creation of tailor-made BIM objects' libraries, and the use of such libraries.

[46] published a manuscript inspecting the critical contributions and beneficial impacts of utilizing BIM in leading cost estimation and modification to help make facilities more sustainable. The scientists explained that in contrast to the widespread prevalence of traditional architecture in Iraq, virtually no green structures can be found in the capital city of Baghdad or any of the other governorates. Many of these structures are in dire need of repairs and renovations to improve their performance in all areas (economic, environmental, and operational), and their owners are searching for ways to cut costs by adopting green building practices. Sustainable measurements of existing building grading systems like LEED or BREEAM require an optimization model, which decision-makers should be willing to back. Through minimizing upgrade costs and decreasing the building's environmental impacts, their study aimed to enhance the operational efficiency, health, and comfort of the building's occupants. The optimization procedure and the strategies and actions needed to realize the green building metrics, which have the potential to cut down on upgrading costs, were demonstrated using an existing building as a case study. The construction plans were illustrated for this kind of issue. Analytical tools (the online software ONE CLICK LCA STUDENT VERSION) could be employed to calculate the life cycle costs and environmental effect utilizing BIM/ Revit software. Their findings demonstrated that not only were discounted costs reduced by 15.4% and nominal prices reduced by 23.2 %, but that CO_2 emissions were reduced from 34,233 MT to 19,299 MT.

[47] managed a study examining the practical advantages and considerable characteristics of integrating BIM in managing construction activities. The researchers reported that the modern age of construction planning, design, and construction is here, and it's powered by BIM. Practitioners and stakeholders in the building sector in both developing and developed countries have recognized the value of this technology. There has been a pragmatic

construction shift in Iraq's construction industry, leading to increasingly complicated projects that involve a wide range of local and foreign players. Because practitioners in the Iraqi construction sector rely on antiquated methodologies such as computer aided design (CAD) approaches and the critical path method (CPM), project complexity often undermines project performance. Changes and variations in the project's length and cost are indicators of inadequacy in project performance in Iraq. The primary goals of their research were to ascertain whether or not BIM is being used to improve the efficiency and effectiveness of the Iraqi construction sector. Their research was quantitative in nature, and questionnaires are distributed to working professionals in the Iraqi construction business. Google forms were used to disseminate the questionnaire, and Smart-PLS version 3 was used to evaluate the results. Time and money efficiency in the building business were factors in the questionnaire analysis. Whereas it included the benefits of BIM in the construction industry from the perspective of practitioner in Iraq's construction sector, and investigates professionals' knowledge of BIM's features and how they use them in their work. Data from 382 Iraqi respondents working in the building industry, engineering, and architecture was collected and analyzed. The results showed that professionals in the construction business had a high degree of awareness regarding the implementation of BIM, recognizing both the advantages and disadvantages of the technology. According to the results, the study found that the construction industry's current predicament could be worsened by the relationship between BIM barriers and the construction industry. However, the benefits of BIM improved the relationship between the barriers, and the construction industry by providing the influencing factors for the BIM utilization, which would tend to improve the current project duration and cost in the Iraqi construction industry.

[48] directed an analysis exploring the advantageous influences and essential applications of implementing active 7D principles associated with BIM technology to manage and monitor construction projects and reduce their negative impacts on the environment and nature. The scholars reported that highways receive a disproportionate percentage of funding for infrastructure development at the national and regional levels. Given the scope of the road-building industry, sustainable road construction techniques can contribute to national sustainable development goals (e.g. The Federal Sustainable Development Strategy of Canada). However, the lack of knowledge, information, and tools has slowed the pursuit of sustainable road construction practices. Since the introduction of BIM, builders have had

more accessible access to information about the properties of building components. The use of building information modeling (BIM) to evaluate the long-term sustainability of different approaches to road building has been largely ignored in the existing literature. The article outlined a methodology for assessing road systems using life cycle thinking. A framework was developed to evaluate the relative merits of various strategies for constructing road pavements concerning lifecycle sustainability. To automate the suggested framework, a BIM-based visual software has been created. We compared three approaches to building a collector road to show how the software works. According to the study, geomembrane roads are the most sustainable option across all three metrics. Infrastructure managers would benefit from the suggested BIM-based tool, the Life Cycle Sustainability Assessment (LCSA) framework, and the implementation road map when making decisions about which road construction method is most conducive to achieving the Sustainable Development Goals (SDG) set forth by the United Nations.

[49] implemented a study analyzing the significant benefits and beneficial uses of applying BIM's active 7D principles to the management and monitoring of construction projects, with the goal of minimizing their destructive effects on the natural world. The authors investigated the problem that the potentials of BIM technology in accomplishing and supporting all aspects of sustainability as a human need are not being fully realized since there is no integrated methodology or model to active and apply sustainability in construction during its life. Therefore, the study's overarching goal was to develop and implement a Sustainable BIM Model that could be used in projects throughout their life cycles, thereby facilitating the management of the interplay between BIM and sustainability and yielding the highest possible interoperability performance. To model its signs and criteria, researchers looked into sustainability and the possibilities of dealing with it using cutting-edge approaches and technologies. Additionally, some techniques can be implemented to establish long-term viability. Then, sustainability indicators related to the effectiveness of project aspects were gathered and categorized to simplify connecting with BIM platforms. In addition, they explored and presented the possibilities of the overlap among sustainability and a variety of BIM platforms and their use in supporting sustainability features in a well-rounded fashion. Eventually, a strategy was derived and developed to manage the interplay between sustainability and BIM throughout a building's life cycle, resulting in a Sustainable BIM Model.

[50] carried out a study classifying the vital effects and substantial advantages of Using BIM technology and the active 7D concepts connected with it, construction projects may be managed, monitored, and their negative effects on nature and the environment can be mitigated. The scholars suggested that the construction industry generates a considerable amount of trash and greenhouse gases. A number of studies have shown that higher social and economic performance can be achieved, as well as a smaller environmental footprint if care is used throughout the design phase. Life Cycle Assessment (LCA) is a scientific approach to evaluating a building's environmental impact and developing strategies to lessen that impact, making it a key tool in the pursuit of more eco-friendly construction. However, present environmental concerns call for comprehensive solutions for integrating the three pillars of sustainability, and Life Cycle Sustainability Assessment (LCSA) is recognized as an appropriate holistic approach for this purpose. To find places where the LCSA could be useful in the architectural design process and in BIM, the authors of this research did a Systematic Literature Review (SLR) (BIM). Harmonizing the three aspects and establishing minimum data needs were significant accomplishments. The findings informed the presentation of a methodical approach to assisting with the LCSA application in BIM. The workflow and design phases of a Spanish architect were used to demonstrate the LCSA-BIM method described in their paper.

[51] executed an investigation identifying the relevant impacts and positive effects of implementing active 7D principles associated with BIM technology to manage and monitor construction projects and reduce their adverse impact on the environment and nature. The scholars reported that construction management as they know it was being revolutionized by Building Information Modeling (BIM). Rapid expansion in the construction sector coincided with a rising priority for environmentally friendly buildings that wouldn't compromise sustainability. Water conservation, energy efficiency, sustainable material procurement, manufacturing advancement, waste minimization, climate change adaptation, transportation policy, and biodiversity are all subsets of the broader field of sustainable development. Essentially, a sustainable structure strikes a good balance between social, environmental, and economic factors. A hotel's sustainability was analyzed in their study using BIM (BIM). Sun path, position, heating, cooling loads, orientation, thermal characteristics of materials, ventilation, and daylighting analyses are only some topics discussed. Tools were used, including Autodesk Green Building Studio and Autodesk Insight, and a systematic approach.

Researchers examined the effects on society, the environment, and the economy. They found that BIM makes it simple to analyze the effects of the sun, the wind, the heating and cooling loads, and the lighting and shade provided by a structure. According to the results of their research, using BIM for sustainability analysis can enhance building performance, accurately predict performance across the building's lifecycle, and cut down on resource usage. In addition, in the future, BIM technology could be used to provide Cost-Benefit Ratios (CBRs) and Investment grade audits.

[52] published a manuscript inspecting the significant benefits and beneficial uses of BIM's active 7D principles to oversee and control construction projects and limit their harmful effects on the natural surroundings. The scientists mentioned that sustainability requirements in high-rise building design should be considered at all stages of the decision-making process to reap the maximum advantages without jeopardizing project feasibility. However, there were few actual case studies of how implementing BIM in tall structures affected anything. The use of BIM to enhance the environmental friendliness of high-rise structures was a practical strategy. Therefore, that study used a combination of Structural Equation Modeling (SEM) and Exploratory Factor Analysis (EFA) to investigate the impact of using BIM in tall buildings. Critical success factors (CSFs) for BIM deployment were identified via a literature analysis, and then 205 construction industry stakeholders were surveyed via a questionnaire to gain practical information. Visualization, Coordination, Productivity, Improved safety, and sustainability are the five elements uncovered by the EFA that significantly influence the long-term building of tall structures. In addition, structural engineering modeling (SEM) was used to create the tall building specification. However, it has become clear that there is still a low degree of BIM knowledge and implementation in large structures. The scenario provided the path for further research into the domain of high-rise structures to generate more models to enhance sustainable development.

[42] Dealt with the study of sustainability to study the impact of the climate in Iraq on the heat load of the raised walls and to demonstrate the effectiveness of the insulation layers when added to the composite walls through a comprehensive statistical study.

the results reveal that depend on sustainability can lead to supporting and motivating outcomes while estimating the building substances characteristics of several projects. Also, the findings of this research illustrated that isolation substances would be greatly estimated in the construction field and future researches. The capacity to recover power from developed temperature following the substances utilized is an important factor that should be taken into account when evaluating building costs.

2.4 CRITICAL CONCLUSIONS OF THE PREVIOUS WORK

The main results and vital contributions obtained from the peer-reviewed articles and modern and recent research publications regarding the importance and implementation of 7D BIM modeling technology and modern sustainability techniques in buildings are described in Table 2.1.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter.

	Author(s)	Year	Title	Journal	Critical Findings
1	Uddin, M. N., Wei, H. H., Chi, H. L., Ni, M., & Elumalai, P.	2021	Building information modeling (BIM) incorporated green building analysis: An application of local construction materials and sustainable practice in the built environment.	Journal of building pathology and rehabilitation, 6, 1-25.	The results demonstrated substantial savings in building energy consumption, as well as a marked decrease in embodied carbon and energy footprint, as a result of employing regionally available construction materials. Finally, an unified framework of economic, environmental, and social sustainability has been addressed to evaluate the long-term viability of the results and to foster a pleasant environment in which to live.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

2	Ji, Q., & Chen, W.	2020	The application of BIM technology in the cost management of the whole process of construction projects.	In Journal of Physics: Conference Series (Vol. 1648, No. 3, p. 032016). IOP Publishing.	The findings showed that the use of BIM technology throughout the process, from planning and design through building and operation, allows for more efficient cost management and faster turnaround times.
3	Wang, Z., & Liu, J.	2020	A seven-dimensional building information model for the improvement of construction efficiency.	Advances in Civil Engineering, 2020, 1-17.	According to the results of that research, implementing 7D BIM has resulted in significant time and money savings, in addition to an increase in project quality and productivity.
4	Ershadi, M., Jefferies, M., Davis, P., & Mojtahedi, M.	2021	Implementation of Building Information Modelling in infrastructure construction projects: A study of dimensions and strategies.	International Journal of Information Systems and Project Management, 9(4), 43-59.	The findings showed that BIM incorporates several factors into infrastructure construction, such as cost, energy, safety, sustainability, time, and risk.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

5	Ismaeel, W. S., & Lotfy, R. A. E. R.	2022	An integrated building information modelling-based environmental impact assessment framework.	Clean Technologies and Environmental Policy, 1-17.	The authors examined that the disparity in BIM use over the various stages of a project was especially mild during the maintenance and decommissioning phases. Inadequate BIM tool integration also prevented decisions from being made to help with the mitigation process.
6	Dall'O', G., Zichi, A., & Torri, M.	2020	Green BIM and CIM: sustainable planning using building information modelling.	Green Planning for Cities and Communities: Novel incisive approaches to sustainability, 383-409.	The results revealed that the notion of City Information Modelling (CIM) is introduced as a shared platform for the design, construction, and management of the buildings, services, and infrastructures of cities and neighbourhoods that move towards sustainable and smart designs.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

7	Bakchan, A., Faust, K. M., & Leite, F.	2019	Seven-dimensional automated construction waste quantification and management framework: Integration with project and site planning.	Resources, Conservation and Recycling, 146, 462-474.	The study's results would help construction professionals evaluate the value of CWM in boosting the efficiency, economy, and environmental friendliness of their projects.
8	Khaleel, A., & Naimi, S.	2022	Automation of cost control process in construction project building information modeling (BIM).	Periodicals of Engineering and Natural Sciences, 10(6), 28-38.	According to the results of their study, employing BIM technology can significantly save the time, effort, and money invested in estimating the construction project's cost.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

9	Reizgevičius, M., Ustinovičius, L., Cibulskienė, D., Kutut, V., & Nazarko, L.	2018	Promoting sustainability through investment in Building Information Modeling (BIM) technologies: A design company perspective.	Sustainability, 10(3), 600.	The study's findings informed an improvement to the Autodesk REVIT-based ROI calculation for the first year, enhancing its precision and straightforward.
10	Porwal, A., Parsamehr, M., Szostopal, D., Ruparathna, R., & Hewage, K.	2020	The integration of building information modeling (BIM) and system dynamic modeling to minimize construction waste generation from change orders.	International Journal of Construction Management, 1-20.	The results of their case study indicated that by committing to less waste throughout the project's preliminary planning stages and coordinating BIM design efforts, the client may cut construction waste by as much as 25%.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter “Table Continued”.

11	Olawumi, T. O., & Chan, D. W.	2018	Beneficial factors of integrating building information modelling (BIM) and sustainability practices in construction projects.	In Hong Kong International Conference on Engineering and Applied Science (HKICEAS 2018): Conference Proceedings (141-152)	The outcomes illustrated the efficient exchange and sharing of project data, improved product design, precise geometrical representations of building modeling techniques with implanted sustainability data, and simple modeling of building performance and energy consumption. Keeping these advantages in mind and encouraging teamwork in the AEC industry can help bring sustainable urban design thoughts and ideas to life in the built form.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

12	Abdelalim, A. M., & Abo. elsaud, Y.	2019	Integrating BIM-based simulation technique for sustainable building design.	In Project Management and BIM for Sustainable Modern Cities: Proceedings of the 2nd GeoMEast International Congress and Exhibition on Sustainable Civil Infrastructures, Egypt 2018–The Official International Congress of the Soil-Structure Interaction Group in Egypt (SSIGE) (pp. 209-238). Springer International Publishing.	The findings showed that the Leadership in Energy and Environmental Design (LEED) rating system was applied to a case study to examine the configuration of using BIM in full compliance with the LEED rating system and to create an easily managed acceptable form that measures compliance with sustainable demands and measures the potential points than the structure can achieve.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

13	Olawumi, T. O., Chan, D. W., Wong, J. K., & Chan, A. P.	2018	Barriers to the integration of BIM and sustainability practices in construction projects: A Delphi survey of international experts.	Journal of Building Engineering, 20, 60-71.	The results would help move BIM and sustainable practices forward in building projects, and provide project stakeholders a better chance of tackling the significant obstacles raised in that research.
14	Afzal, M.	2021	BIM 7D: research on applications for operations & maintenance	Doctoral Dissertation	The outcomes showed that the development document may be used as a guideline or model document to implement digital twin technology effectively into existing built environment procedures.

Table 2.1: The Main Results of 7d Bim Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

15	Santos, R., Costa, A. A., Silvestre, J. D., Vandenbergh, T., & Pyl, L.	2020	BIM-based life cycle assessment and life cycle costing of an office building in Western Europe.	Building and Environment, 169, 106568.	The scholars hoped to offer work that would aid in the advancement of automatic sustainability simulations, the development of specialized libraries of BIM components, and the use of historical data included inside data-rich models to predictive assessments
16	Abdulrasool, S. A., & Mahjoob, A. M. R.	2020	Using BIM for Optimizing the Upgrading Cost to Convert the Traditional Buildings to Sustainable Buildings in Iraq.	In IOP Conference Series: Materials Science and Engineering (Vol. 901, No. 1, p. 012024). IOP Publishing.	The findings revealed that not only could the discounted and nominal expenses be reduced by up to (15.4) and (23.2) percent, but that the CO_2 emissions could be reduced from 34233 tons to just 19299 tons.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

17	Hadi, Z., Samikon, S. A., & Rahim, F. N. A.	2021	Enhancement of The Current Iraqi Construction Industry Performance (Time and Cost) By Building Information Modeling (BIM) Utilization.	Des. Eng, 4, 1330-1358.	The results showed that those working in the construction business had a good understanding of how BIM could be used, and they could name both the advantages and disadvantages of the technology.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

18	Patel, K., & Ruparathna, R.	2021	Life cycle sustainability assessment of road infrastructure: a building information modeling-(BIM) based approach.	International Journal of Construction Management, 1-10.	According to the study's findings, geomembrane roads are the most sustainable option across all three metrics. Infrastructure managers would benefit from the suggested a BIM-based tool, Life cycle Sustainability Assessment (LCSA) framework, and the implementation road map when making decisions about which road construction method is most conducive to achieving the Sustainable Development Goals set forth by the United Nations (SDG).

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

19	Mohammed, A. B.	2022	Applying BIM to achieve sustainability throughout a building life cycle towards a sustainable BIM model.	International Journal of Construction Management, 22(2), 148-165.	The results revealed the explored and presented possibilities of the overlap among sustainability and a variety of BIM platforms, and their use in supporting sustainability features in a well-rounded fashion. Eventually, a strategy was derived and developed to manage the interplay between sustainability and BIM throughout a building's life cycle, resulting in what is called a Sustainable BIM Model.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

20	Llatas, C., Soust-Verdaguer, B., & Passer, A.	2020	Implementing Life Cycle Sustainability Assessment during design stages in Building Information Modelling: From systematic literature review to a methodological approach.	Building and Environment, 182, 107164.	The findings informed the presentation of a methodical approach to assisting with the LCSA application in BIM. The workflow and design phases of a Spanish architect were used to demonstrate the use of the LCSA-BIM method described in their paper.
21	Khan, A., & Ghadg, A. N.	2019	Building Information Modelling (BIM) based Sustainability analysis for a construction project.	Proceedings of Sustainable Infrastructure Development & Management (SIDM).	According to the results of their research, using BIM for sustainability analysis has the potential to enhance building performance, accurately predict performance across the building's lifecycle, and cut down on resource usage. In addition, in the future, BIM technology could be used to provide Cost-Benefit Ratio (CBR) and Investment grade audits.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

22	Manzoor, B., Othman, I., Kang, J. M., & Geem, Z. W.	2021	Influence of building information modeling (Bim) implementation in high-rise buildings towards sustainability.	Applied Sciences, 11(16), 7626. *Periodicals of Engineering and Natural Sciences*, *10*(6), 28-38.	The scholars determined that it has become clear that there is still a low degree of BIM knowledge and implementation in large structures. The scenario provided the path for further research into the domain of high-rise structures to generate more models with the goal of enhancing sustainable development.
23	haleel, A., & Naimi, S.	2022	Automation of cost control process in construction project building information modeling (BIM)		the results illlustrated that BIM assist discover likely troubles and discrepancies after linking files for different sections of design such as mechanical ,structural and electrical designs before starting construction stage, and this technique help to minimize time and cost and enhance quality of project.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

24	Abdulwahhab, R., Naimi, S., & Abdullah, R.	2022	Managing cost and schedule evaluation of a construction project via BIM technology and experts' points of view.	-	The findings found out that using project management concepts could minimize cost , time, and effort to implement and conduct construction projects.further more , the finding reffered that deploying BIM technique and REVIT can help engineers and project directors to compute the cost and schedule of their projects more precisely , prevent mistakes.
25	Amhaimedi, S., Naimi, S., & Alsallami, S.	2023	Assessment of a decision-making model for monitoring the success of a project for smart buildings.	-	It was revealed that The RII noticed that the most efficient sides of an smart building are the number of floors in the building, the type of design of structure , and the volume of the shades cast on the face of the structure. The (MCDM) noticed important variances in designed value (PV) and real value (AC) findings. Moreover, because of this methodology , it is potential to follow budget and timelines more accurate.

Table 2.1: The Main Results of 7D BIM Modeling Technology Benefits of Publications Reviewed in this Chapter "Table Continued".

26	Maaroof, M. A. M., & Naimi, S.	2023	Developing Adaptive Project Construction Cost Control Using Multi-Nonlinear Regression Engineering Techniques	. International Journal of Intelligent Systems and Applications in Engineering, 11(4s), 579-586.	The results illustrate that utilizing a project control's real values enhances project parties ' ability to aware cost and schedule fears on time.
27	Mohammed, A. R., & Naimi, S. (2023).	2023	The Effectiveness of Thermal Insulation of the Exterior Composite Walls of Buildings in Iraq Based on Different Materials and Climate Regions using Engineering Applications.	*International Journal of Intelligent Systems and Applications in Engineering*, *11*(4s), 594-601.	the results reveal that depend on sustainability can lead to supporting and motivating outcomes while estimating the building substances characteristics of several projects. Also, the findings of this research illustrated that isolation substances would be greatly estimated in the construction field and future researches. The capacity to recover power from developed temperature following the substances utilized is an important factor that should be taken into account when evaluating building costs.

2.5 CHAPTER SUMMARY

This chapter discussed the critical benefits and vital significance associated with the implementation of 7D BIM technology, which is associated with sustainability principles and environmental impacts concept to help make the management of small and large-scale construction projects more environmentally friendly, green, and clean, and reduce their harmful and adverse has implications about damaging pollution or waste that can be generated during and after the completion of the construction project. The following chapter includes a case study representing a construction project in Iraq that considers sustainability fundamentals and green concepts to mitigate the adverse effects on the Iraqi environment with the help of BIM technology and the REVIT software package.

3. RESEARCH METHODOLOGY

3.1 CHAPTER GOAL

This chapter illustrates the necessary study procedures and analytical methods implemented in this master's thesis to examine the crucial role of 7D BIM modeling technology in enhancing the sustainability levels and positive environmentally friendly measures in the construction sector to make the buildings and facilities more sustainable, green, and clean.

3.2 THE METHODOLOGY OF THE THESIS

This research is carried out to examine the importance of 7D BIM modeling technologies in elevating sustainability standards and fostering environmentally friendly practices in the building industry to produce cleaner, greener, and more sustainable structures. To address these critical aspects, a comprehensive review is conducted, discussing the benefits of sustainability in buildings and the essential contributions and impacts of implementing modern sustainable methods and 7D schemes in providing significant levels of sustainable development in the construction sector. Then, a case study representing a building in Iraq is considered to make an analysis of 7D modeling, and BIM approaches adoption to enhance the rates of environmental responsibility, sustainability, and resilience of this Iraqi facility. Then, the results of the numerical results obtained by virtue of the BIM software (REVIT tool) will be assessed and examined with the help of a panel of BIM specialists, construction experts, and high-knowledge project managers who have rich experience in sustainability implementation in the construction sector. Finally, the main conclusions and recommendations will be proposed for this master's research.

Figure 3.1 indicates the critical research phases and a flowchart of the study approach applied in this work.

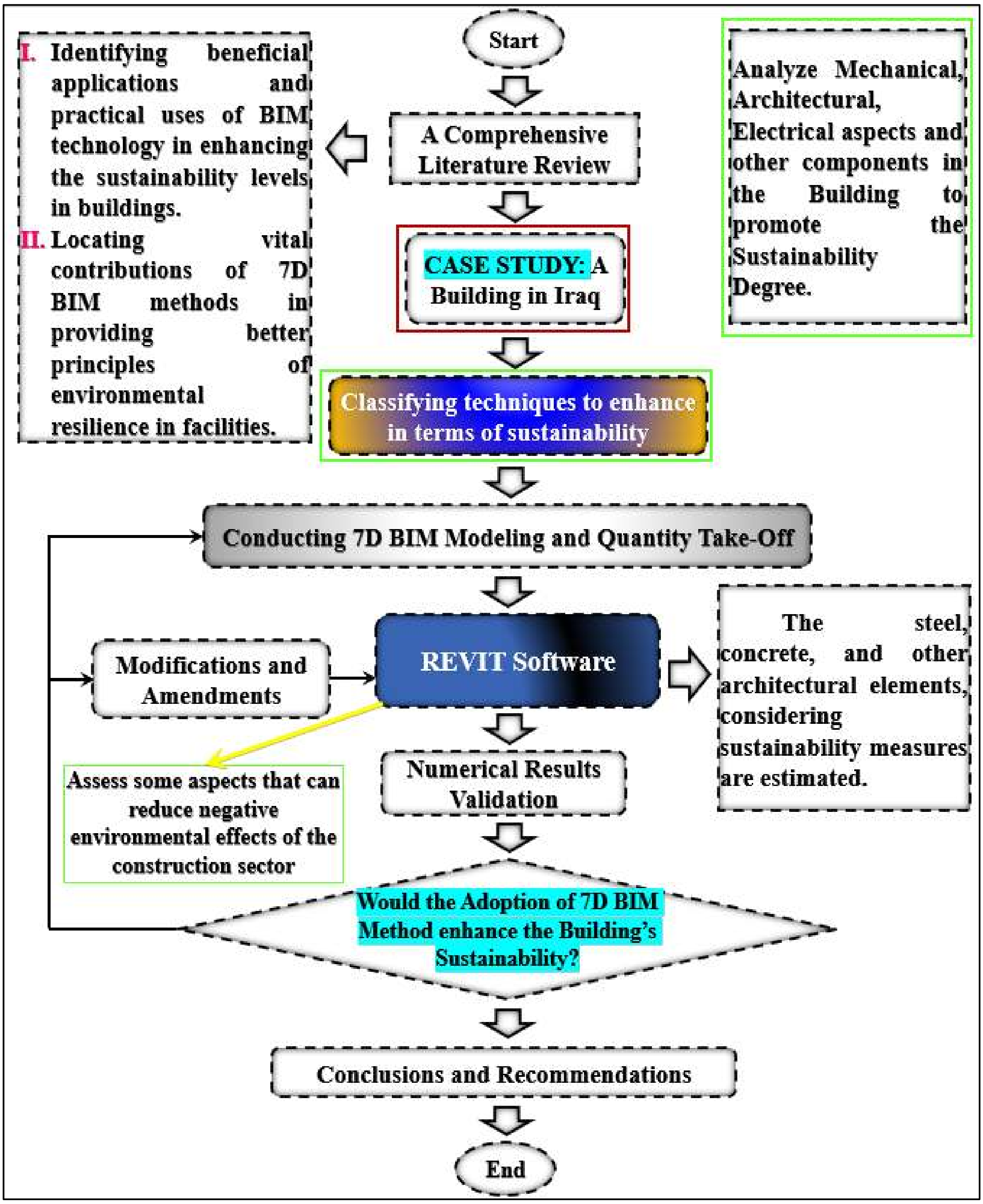

Figure 3.1: The Research Method Considered in This Work.

3.3 CASE STUDY DESCRIPTION

The case study considered in this work comprises a building in Iraq, whose overall area is 7,426.05 square meters. This building represents the “Royal Baghdad” project, located in Baghdad, Iraq. It is a multi-story commercial building. It contains different floors. For instance, the basement floor is utilized for parking purposes. At the same time, the building comprises the ground floor, a mezzanine floor, six floors and a penthouse. Figure 3.2 indicates the exterior design of the whole building.

Figure 3.2: An Outline of the Exterior Design of the Royal Baghdad Project.

A REVIT view of this building based on the Emerging Technologies Advisory Board (ETAB) technology can be illustrated in Figure 3.3.

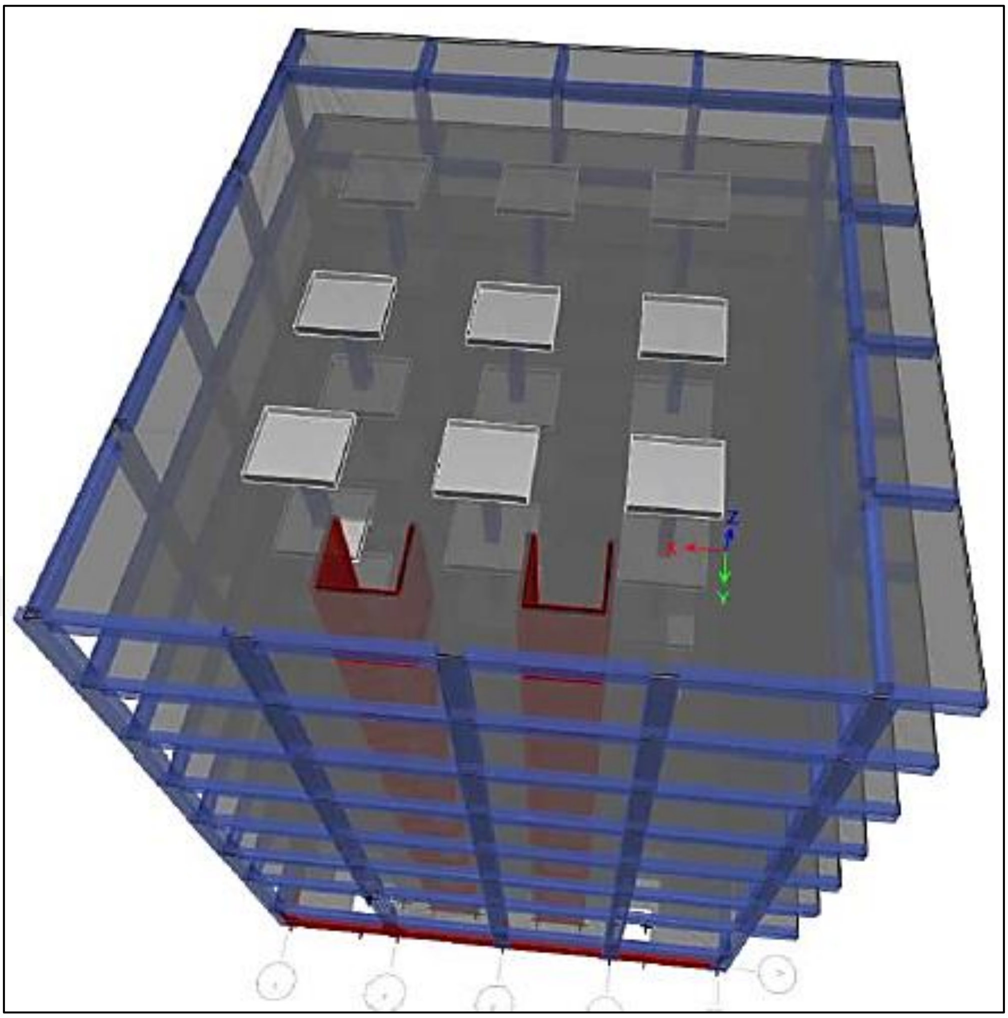

Figure 3.3: An ETAB Model of the Royal Baghdad Building Investigated in This Study.

In addition, more details regarding the architectural plans associated with this building can be described in Appendix A. The area of the Royal Baghdad Building and the critical uses of each building component can be described in Table 3.1.

Table 3.1: The Total Area of the Royal Baghdad Project and the Role of Each Floor.

Floor Symbol	Area (m^2)	The Main Role of this Floor
B_F	750	Lifts, stairs, Staff room, parking, Guard, cars entrance, store and w.c

Table 3.1: The Total Area of the Royal Baghdad Project and the Role of Each Floor. "Tables Continued."

G_F	907.50	Lifts, stairs, building entrance, electrical room, w.c and Hall.
M_F	103.55	Hall, Lifts and stairs
1st	907.50	Offices, Lifts, stairs, stores, Halls and w.c
Typical Floor (2nd, 3rd, 4th, 5th and 6th)	907.50	Offices, receptions, kitchens, Lifts, stairs, stores, Halls and w.c.
Penthouse Floor	220	Guard, kitchens, Lifts, stairs, stores and w.c.
Total area (m^2)		7,426.05

3.4 RESEARCH TOOLS AND NUMERICAL ANALYSIS

In this work, the primary research tool used to assess the sustainability principles of this project comprises the ANSYS software package. In this programming tool, the 7D BIM modelling process is implemented. The 7D modeling technology is responsible for assessing the environmental impacts of the project and carbon emissions. Furthermore, the 7D BIM modeling is associated with facility management and other critical notations, which can be expressed in Figure 3.4.

On the other hand, an intelligent, high-performance, cost-effective, and accurate quantity take-off of construction materials can be considered another vital research tool that can reduce different types of errors. Thus, project managers can give more time to consider the sustainability aspects of their projects. At the same time, cost forecasting for the facility's whole life cycle can be attained by virtue of Level 7D BIM technology [53].

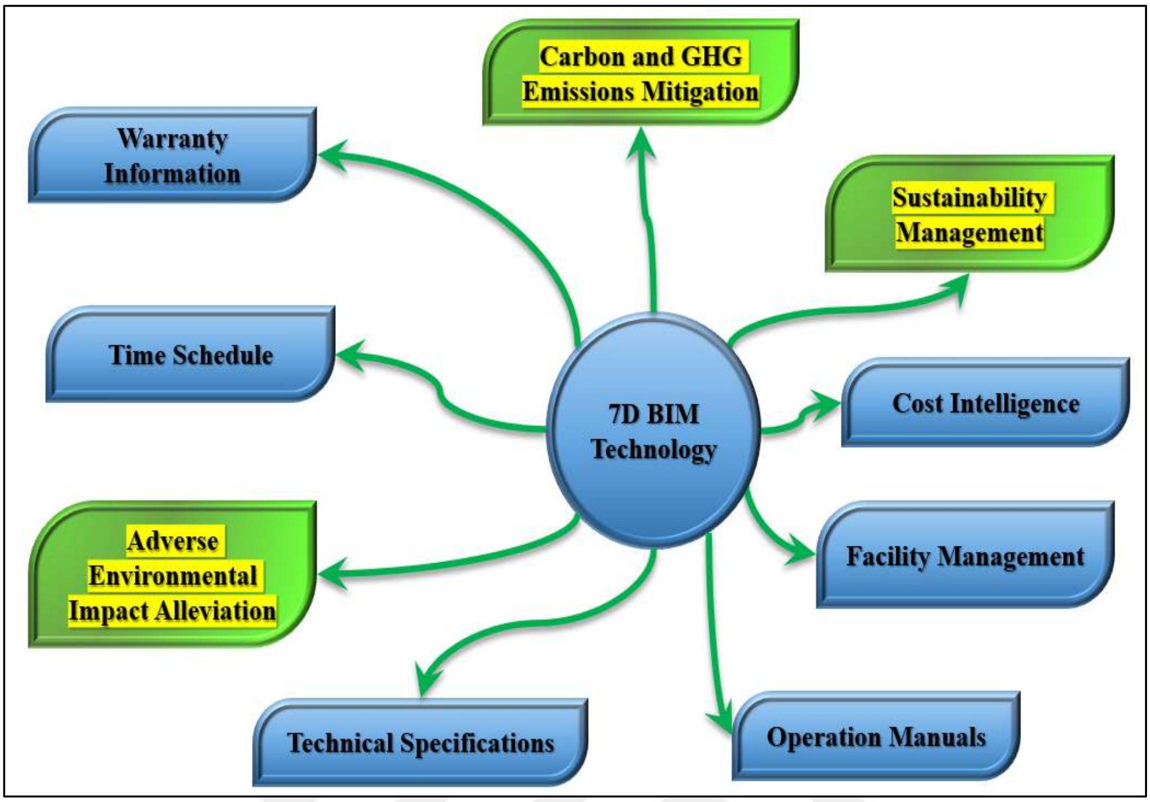

Figure 3.4: The major concepts and critical notations considered in the 7D BIM modeling technology (Author, 2023).

Moreover, the 7D BIM analysis is a technique that takes into account not only the conventional 2D drawings and plans of a building project but also the 3D models, timelines, cost intelligence, and sustainable practices of that project. Builders and project managers use 7D BIM during all stages of a project’s life cycle, beginning with the planning phase and continuing through operation and maintenance. Building information modeling (BIM) would benefit from the use of 7-dimensional computer-aided design (CAD), which would improve project management beginning with the design phase and continuing through the demolition phase [54]–[57].

The REVIT software is another major study tool used in this work to carry out two primary functions:

a. Quantity take-off, and

b. Sustainability assessment.

Thus, in this work, those two goals will be implmented on the construction project investigated in this case study.

3.5 THEORY AND MATHEMATICAL MODEL

There are some general formulas and mathematical equations implemented in this research to conduct the necessary computations and evaluations of the construction materials using the traditional quantity take-off method. One of these equations is the weight of reinforcement steel bars used in the project. This equation can be expressed using the following correlation:

$$SBW = \frac{D_{SB}^2}{162} \quad (3.1)$$

Where:

SBW : Steel bar weight (in kg/m)

D_{SB} : Diameter of the steel bar (mm)

In addition, the weight of the steel bar (in kg) can be calculated using another formula expressed in the following correlation:

$$TSBW = SBL \times SBW \times NSB \times NCI \quad (3.2)$$

Where:

$TSBW$: The total steel bar weight (kg)

SBL : The steel bar weight (in kg/m)

NSB : Number of steel bars

NCI : Number of the calculated items

The estimation of those two eqautions depends on the wieght of each steel bar corresponding to its diameter, which can be obtained from the infomration illustrated in Figure 3.4.

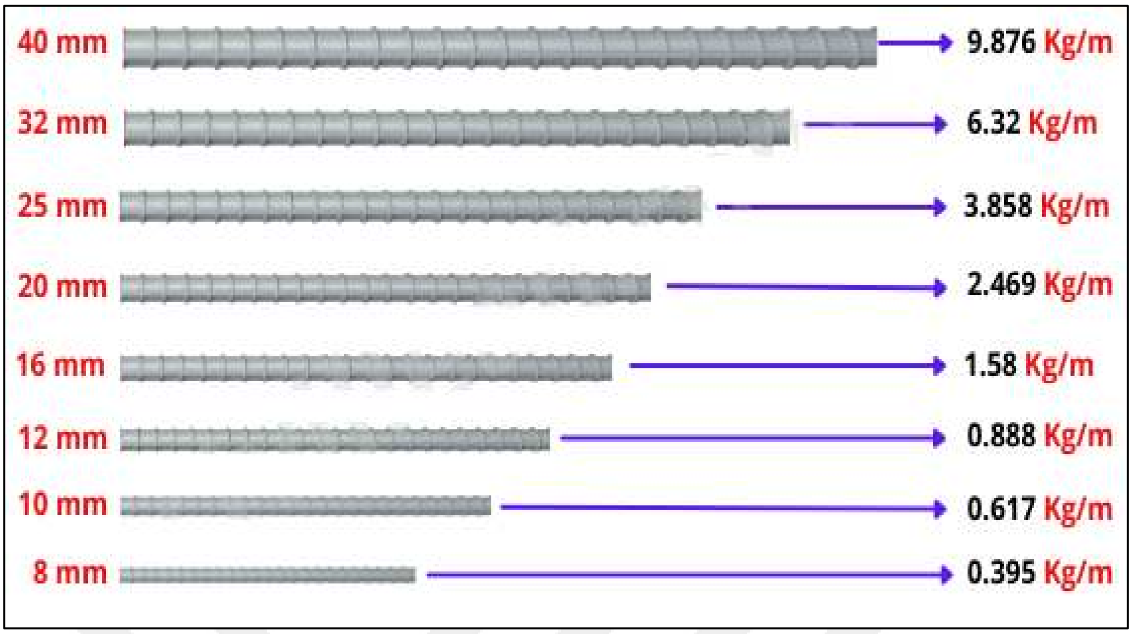

Figure 3.5: The Weight of the Steel Bar Based on its Diameter.

Furthermore, Table 3.2 illustrates the minimum lap length for the steel bar (unless it is noted or mentioned in the shop drawing).

Table 3.2: The Minimum Lap Length for the Steel Bar (Unless It Is Noted or Mentioned in the Shop Drawing).

Steel Bar Diameter (mm)	10	12	16	18	20	22	25
Lap Length in Columns (mm)	400	500	600	650	700	800	900
Lap Length in Other Places (mm)	400	600	700	800	900	1,000	1,250

Furthermore, Figure 3.5 indicates the required concrete cover (in terms of the concrete thicknes) used to make the necessary foundation in the construction project, including reinforcement concrete thicknes in slabs, beams, coulmns, walls, slab on grade, and raft foundation.

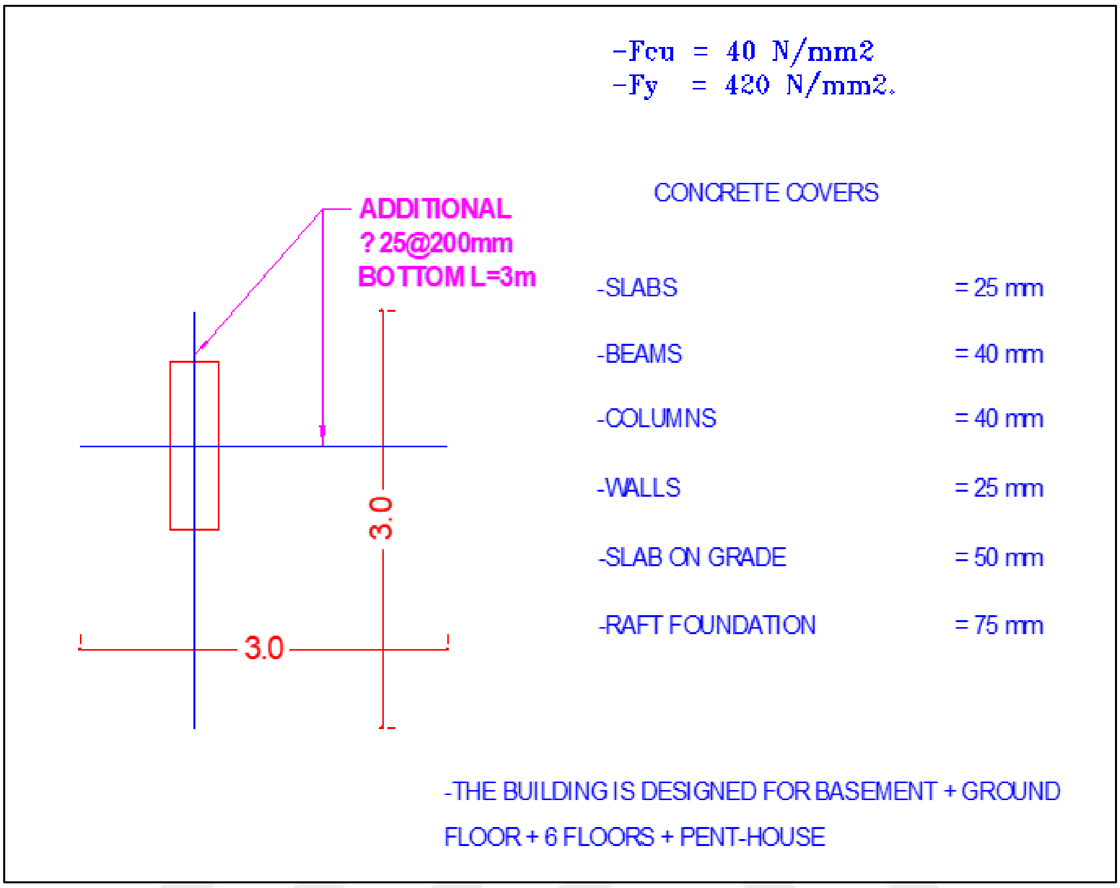

Figure 3.6: The Optimum Thickness of Concrete Covers Required in the Construction Project.

4. RESULTS AND DISCUSSIONS

4.1 CHAPTER GOAL

Based on the discussions illustrated through the previous paragraphs in chapter three, this chapter indicates the research findings associated with the construction material take-off process to calculate the materials' quantity using two aspects:

a. The traditional quantity take-off approach,
b. The REVIT software tool

In addition, the estimation of sustainability aspects based on the 7D BIM modeling technology implemented using the REVIT software tools is also addressed in this chapter.

4.2 THE QUANTITY TAKE-OFF RESULTS OF THE CASE STUDY USING THE TRADITIONAL METHOD

This section illustrates in detail the research outcomes obtained from the implementation of the manual research method to calculate the amount of construction materials amount. For instance, Table 4.1 illustrates the concrete calculation associated with the excavation process of the construction project.

Table 4.1: The Concrete Calculation Associated with the Excavation Process of the Construction Project.

Formula Used: Cut volume (m^3) = excavation area (m^2) × excavation depth (m)	
Note	**Calculations**
Ex. Level general: **-6.10 m** Ex. Level lifts: **-7.10 m**	(761.04×6.10) + (7.90×1.0) + (7.90×1.0)
Result	4658.14 (m^3)

It can be inferred from the results obtained in Table 4.1 that the amount of cut required for initiating the construction project reached approximately 4,658.14 m^3. At the same time, the conventional method used for the quantity take-off in this project revealed that concrete quantity is related to the blinding volume, which is shown in Table 4.2.

Table 4.2: The Calculation of the Blinding Volume Addressed in this Work.

Formula: Blinding volume (m^3) = Concrete Area (m^2) × blinding depth (m)	
Note	**Calculations**
depth = 0.10 m	(761.04 × 0.10)
Result	**76.10 (m^3)**

It is indicated from the study outputs illustrated in Table 4.2 that the amount of concrete volume pertaining to the blinding process amounted to approximately 76.10 m^3. At the same time, the calculations by virtue of the manual method confirmed other results of the concrete volume. For example, Table 4.3 illustrates the bolder volume calculation in the concrete.

Table 4.3: The Concrete Calculations Related to The Bolder Volume.

Formula: Bolder volume (m^3) = Bolder area (m^2) × Bolder depth (m)	
Note	**Calculations**
depth = 0.10 m	(761.04 × 0.25)
Result	**190.26 (m^3)**

It can be noted from the outputs of the manual calculation of the bolder volume for this construction project that the bolder amount calculated in this method was roughly 190.26 m^3. On the other hand, Table 4.4 provides an illustration regarding the raft foundation volume estimation, which can be expressed based on the manual method of reinforced concrete.

Table 4.4: The Raft Foundation Volume Related to the Reinforced Concrete.

Formula: R.C R. footing volume (m^3) = width (m) × length (m) × footing depth (m) – lifts opening volume				
Footing	Depth (m)	Length (m)	Width (m)	Lifts opening volume (m^3)
Raft Footing	1.10	30.00	25.00	**17.37**
Result	**807.63 (m^3)**			

It is indicated from Table 4.4 that the reinforcement concrete associated with the raft volume estimation reached a value of nearly 807.63 m^3 based on a lift opening volume of approximately 17.37 m^3. Meanwhile, the manual estimation methods provided evaluations regarding the walls and columns' volume, as shown in Table 4.5.

Table 4.5: Concrete Evaluations Regarding the Walls and Columns Volume.

Formula: Walls and Columns volume (m^3) = width (m) × length (m) × height (m) × # of Repetition					
Element	**Height (m)**	**Length (m)**	**Width (m)**	**# Of Repetition**	**Volume (m^3)**
C1- basement	4.70	0.85	0.85	9	**30.56**
C1 – GF to the penthouse floor	32.00	0.85	0.45	6	**73.44**
C1 – GF to 6th	28.50	0.85	0.45	3	**32.70**
C2- BF to the penthouse floor	36.70	0.85	0.45	4	**56.15**
C2- BF to 6th	33.20	0.85	0.45	12	**152.39**
C3	4.70	0.70	0.30	2	**1.98**
W1	38.40	10.40	0.25	2	**199.68**
W2	4.70	110.00	0.30	1	**155.10**
	6.20	17.85	0.30	1	**33.20**
Result	**735.19 (m^3)**				

It is inferred from the results obtained from the manual estimation of the concrete volume pertaining to walls, and columns reached an amount of roughly 735.19 m^3. The largest amount in this volume quantity was 199.68 m3, corresponding to the concrete in the walls located on the first floor. Furthermore, the conventional methods revealed the concrete quantity of slab volume, which is shown in Table 4.6.

Table 4.6: The Estimation Method of Concrete Slab Using the Manual Mode.

Equation:

Slabs Volume (m^3) = (volume of slab (m^3) – volume of opening (m^3)) × # of repetition element

volume of slab = Area (m^2) × thickness (m)

volume of opening = Area (m^2) × thickness (m)

Element	Slab volume (m^3)	Opening volume (m^3)	# Of Repetition	Volume (m^3)
B_F + drop panel	(750 m^2 × 0.20m) + (9.00 m^2 × 0.20m) × 8.5 **165.30 m^3**	54.25 m^2 × 0.20 m **10.85 m^3**	1	**154.45**
G_F+ drop panel	(907.50 m^2 × 0.20m) + (9.00m^2 × 0.20m) × 9 **197.70 m^3**	54.25 m^2 × 0.20 m **10.85 m^3**	1	**186.85**
M_F	(103.55 m^2 × 0.20m) **20.71 m^3**	54.25 m^2 × 0.20 m **10.85 m^3**	1	**9.86**
1st + drop panel	(907.50 m^2 × 0.20m) + (9.00m^2 × 0.20m) × 9 **197.70 m^3**	54.25 m^2 × 0.20 m **10.85 m^3**	1	**186.85**
Typical floors+ drop panel	(907.50m^2 × 0.20m) +(9.00m^2 × 0.20m) × 8.5 196.80 m^3	67.43 m^2 × 0.20 m 13.49 m^3	5	916.55
Penthouse floor + lift	(220.00 m^2 × 0.20m) + (15.80 m^2 × 0.20m) **47.16 m^3**	54.25 m^2 × 0.20 m **10.85 m^3**	1	**36.31**
Stair slab	(0.20 m × 9.57 m × 1.5 m) **2.87 m^3**	----	20	**57.42**
Stair Steps	(0.30 m × 0.17 m ×0.50 × 1.5 m) **0.0383 m^3**	----	508	**19.46**
Result	**1,567.75 (m^3)**			

It is inferred from the results attained in Table 4.6 that the manual estimation technique indicated an amount of 1,567.75 m^3. The largest concrete quantity in the slabs of this construction project was in the typical floors and the drop panel, corresponding to a value of 916.55 m^3.

In addition, the manual calculation method revealed the volume of reinforced concrete, which is employed in the drop beams. Table 4.7 illustrates those results.

Table 4.7: Volume of Reinforced Concrete Employed in the Drop Beams.

Formula: Drop beams Volume (m^3) = width (m) × length (m) × height (m) × # of Repetition

Element		Height (m)	Length (m)	Width (m)	# Of Repetition	Volume (m^3)
B_F	B2	0.50	55.00	0.30	1	**8.25**
	B3	0.65	55.00	0.85	1	**30.39**
G_F + **1st** + Typical floors	**B2**	**0.20**	**11.75**	**0.30**	**7**	4.94
	B3	0.50	15.00	0.45	7	**23.63**
	B4	0.20	14.16	0.45	7	**8.92**
	B5	0.50	12.50	0.45	7	**19.69**
	B6	0.50	55.00	0.45	7	**86.63**
	B7	0.20	55.00	0.25	7	**19.25**

Table 4.7: Volume of Reinforced Concrete Employed in the Drop Beams. "Tables Continued."

M_F	**B2**	**0.30**	**28.48**	**0.30**	**1**	2.56
	B3	0.30	12.20	0.30	1	**1.10**
Penthouse floor	B2	0.20	11.75	0.30	1	**0.71**
	B4	0.20	14.16	0.45	1	**1.27**
	B5	0.50	5.00	0.45	1	**1.13**
	B6	0.50	8.13	0.45	1	**1.83**
	B7	0.20	33.13	0.25	1	**1.66**

It is noted from the research findings associated with the manual estimation of the total reinforced volume, which is used for the drop beams design, that the overall quantity of the reinforced concrete was roughly 217.74 m^3. The final volume of the reinforced concrete used in this project can be listed and illustrated in Table 4.8.

Table 4.8: The Research Findings Related to the Total Reinforced Concrete Volume in this Project.

Foundation	**807.63 (m^3)**
Walls and Columns	**735.19 (m^3)**
Slabs	**1,567.75 (m^3)**
Drop Beams	**217.74 (m^3)**
Result	**3,328.31 (m^3)**

It is indicated from Table 4.8 that the most considerable quantity of the reinforced concrete used in this project is associated with the slabs, corresponding to a volume of roughly 1,567.75 m^3. On the other hand, the lowest amount of concrete volume is present in the drop beams. Also, Figure 4.1 indicates the overall volume of the reinforced concrete used in this project in terms of ratios.

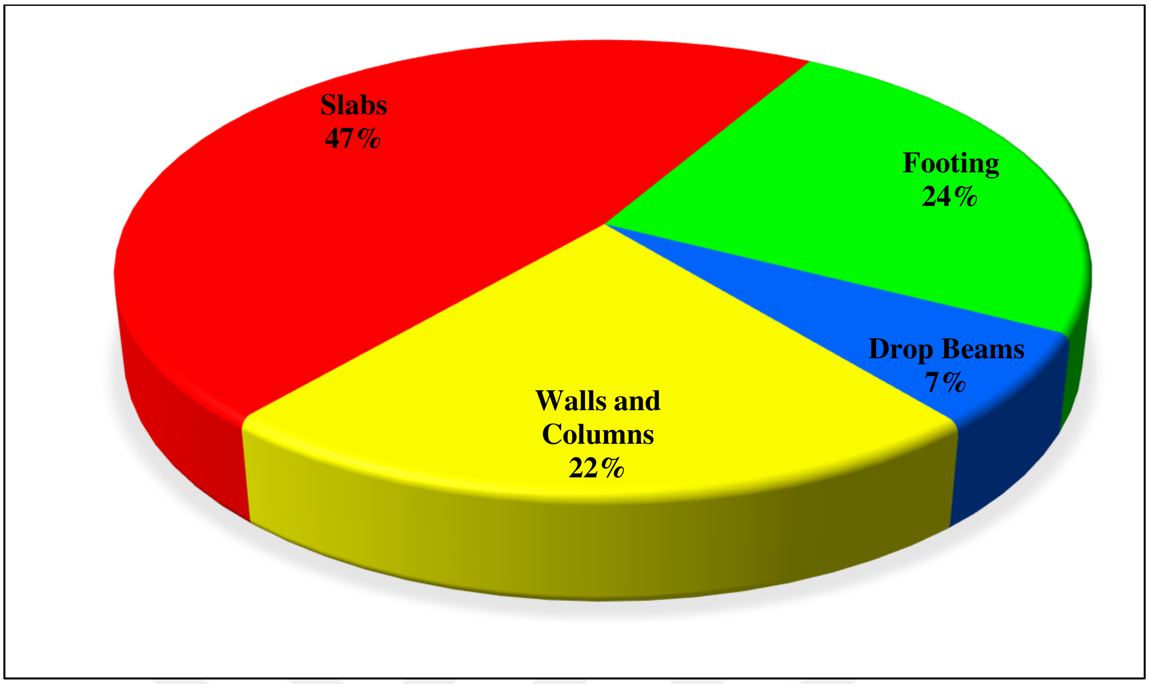

Figure 4.1: The Overall Volume of the Reinforced Concrete Used in this Project in Terms of Ratios.

It can be concluded from the results obtained in Figure 4.1 that the largest ratio of the reinforced concrete used in this construction project was 47%, corresponding to the concrete used in slabs. In contrast, the lowest ratio of concrete volume used in the building amounted to drop beams, corresponding to a concrete ratio of 7%.

4.3 MANUAL EVALUATION RESULTS OF THE STEEL BAR QUANTITY

In this section, the equations and mathematical formulas explained in the previous chapter related to the calculation of the steel bar weight in different parts of this project. For instance, Table 4.9 illustrates the raft foundation reinforcement steel bars estimation findings in terms of their weight, relying on the conventional method.

Table 4.9: The Raft Foundation Reinforcement Related to Steel Bars in Terms of Their Weight (Using the Conventional Method).

Section	Ø (mm)	Weight (kg/m)	length (m)	# Of steel bars	Number of sections	Weight of reinforcement steel bars (kg)
Long – bar top and bottom reinforcement	25	3.858	12.00	250	2	**23,148.00**
	25	3.858	9.60	125	2	**9,259.20**
Short – bar top and bottom reinforcement	25	3.858	12.00	300	2	**27,777.60**
	25	3.858	4.60	150	2	**5,324.04**
Additional steel bar bottom reinforcement	25	3.858	3.00	30	9	**3,124.98**
Results	**68,634 kg**					

It is indicated from Table 4.9 that the amount of weight related to the reinforcement steel bars used in the raft foundation reached a portion of 68,634 kg . On the other hand, the most common diameter types used in the raft foundation include only 25 mm. Furthermore, the manual methods indicate other data related to the steel bar weight linked to columns and walls. Table 4.10 indicates the column and walls reinforcement steel bars weight evaluation with the help of the traditional estimation method for this project.

Table 4.10: Column and Walls Reinforcement Steel Bars Weight (Using the Traditional Estimation Method).

Element	Ø (mm)	Weight (kg/m)	length (m)	# of steel bars	Number of elements	Weight of reinforcement steel bars (kg)
C1-basement	25	3.858	7.05	28	9	**6854.12**
	10	0.617	7.67	24	9	**1022.20**

Table 4.10: Column and Walls Reinforcement Steel Bars Weight (Using the Traditional Estimation Method) "Tables Continued".

C1 – GF to penthouse floor	**25**	**3.858**	**12.00**	**42**	**6**	11666.59
	25	3.858	5.90	14	6	**1912.02**
	10	0.617	3.93	160	6	**2327.82**
C1 – GF to 6th	25	3.858	12.00	42	3	**5833.30**
	25	3.858	1.30	14	3	**210.65**
	10	0.617	3.93	143	3	**1040.24**
C2- BF to penthouse floor	25	3.858	12.00	80	4	14814.72
	25	3.858	0.80	20	4	**246.91**
	10	0.617	3.93	184	4	**1784.66**
C2- BF to 6th	25	3.858	12.00	60	12	**33333.12**
	25	3.858	8.20	20	12	**7592.54**
	10	0.617	3.93	166	12	**4830.22**
C3 - BF	16	1.580	6.40	12	2	**242.69**
	10	0.617	3.65	24	2	**108.10**

Table 4.10: Column and Walls Reinforcement Steel Bars Weight (Using the Traditional Estimation Method) "Tables Continued".

	16	**1.580**	**12.00**	**438**	**2**	16608.96
	16	1.580	10.50	146	2	**4844.28**
Wall $_1$ - Lift	12	0.888	12.00	384	2	**8183.81**
	12	0.888	4.00	192	2	**1363.97**
	12	0.888	3.30	768	2	**4501.09**
Wall $_2$ - B$_F$	16	1.580	5.80	1100	1	10080.40
	12	0.888	12.00	432	1	**4603.39**
	12	0.888	8.30	48	1	**353.78**
	16	1.580	7.30	179	1	**2064.59**
	12	0.888	12.00	62	1	**660.67**
	12	0.888	6.45	62	1	**355.11**
Results	**147,440 kg**					

It is inferred from the results shown in Table 4.10 that the overall steel bar reinforcement weight used in this project amounted to approximately 147,440 kg. Also, it can be noted from this table that the prevalent diameters implemented in this case (which represents the steel bar reinforcement of walls and columns in this project) contain 10 mm, 12 mm, 16 mm, and 25 mm. Also, Table 4.11 indicates the beams' reinforcement steel bars' weight assessment using the conventional method.

Table 4.11: Beams Reinforcement Steel Bars Weight (Using the Conventional Method).

Element		Ø (mm)	Weight (kg/m)	Length (m)	# of Steel Bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
B_F	**B2**	25	3.858	12.00	70	1	**3240.72**
		25	3.858	5.00	14	1	**270.06**
		10	0.617	6.73	186	1	**772.35**
B_F	B3	25	3.858	12.00	20	1	925.92
		25	3.858	5.00	4	1	**77.16**
		12	0.888	12.00	16	1	**170.50**
		12	0.888	10.60	4	1	**37.65**
		10	0.617	1.88	186	1	**215.75**

Table 4.11: Beams Reinforcement Steel Bars Weight (Using the Conventional Method). "Tables Continued."

GF + 1st + Typical floors	B2	**25**	**3.858**	**11.75**	**5**	**7**	1586.60
		12	0.888	11.75	2	7	**146.08**
		10	0.617	1.28	47	7	**259.83**
	B3	25	3.858	3.00	35	7	**2835.63**
		12	0.888	3.00	20	7	**372.96**
		10	0.617	2.16	60	7	**559.74**
	B4	25	3.858	7.08	10	7	**1912.02**
		12	0.888	7.08	4	7	**176.04**
		10	0.617	1.58	58	7	**395.79**
	B5	25	3.858	2.5	30	7	**2025.45**
		12	0.888	2.5	20	7	**310.80**
		10	0.617	2.16	50	7	**466.45**

Table 4.11: Beams Reinforcement Steel Bars Weight (Using the Conventional Method). “Tables Continued.”

	B6	25	3.858	12.00	40	7	**12962.88**
		25	3.858	5.00	8	7	**1080.24**
		12	0.888	12.00	20	7	**1491.84**
		12	0.888	10.60	4	7	**263.56**
		10	0.617	2.16	186	7	**1735.20**
	B7	16	1.580	12.00	30	7	**3981.60**
		16	1.580	0.60	6	7	**39.82**
		10	0.617	1.18	186	7	**947.93**
M_F	**B2**	25	3.858	9.49	15	1	**549.19**
		12	0.888	9.49	6	1	**50.56**
		10	0.617	1.48	114	1	**104.10**
	B3	25	3.858	12.00	5	1	**231.48**
		25	3.858	1.45	5	1	**27.97**
		12	0.888	12.00	2	1	**21.31**
		12	0.888	0.80	2	1	**1.42**
		10	0.617	1.48	49	1	**44.74**

Table 4.11: Beams Reinforcement Steel Bars Weight (Using the Conventional Method). "Tables Continued."

Pent house floor	**B2**	**25**	**3.858**	**11.75**	**5**	**1**	**226.66**
		12	0.888	11.75	2	1	**20.87**
		10	0.617	1.28	47	1	**37.12**
	B4	25	3.858	7.08	10	1	**273.15**
		12	0.888	7.08	4	1	**25.15**
		10	0.617	1.58	58	1	**56.54**
	B5	25	3.858	2.5	12	1	**115.74**
		12	0.888	2.5	8	1	**17.76**
		10	0.617	2.16	20	1	**26.65**
	B6	25	3.858	8.13	8	1	**250.92**
		12	0.888	8.13	4	1	**28.88**
		10	0.617	2.16	33	1	**43.98**
	B7	16	1.580	12.00	12	1	**227.52**
		16	1.580	11.93	6	1	**113.10**
		10	0.617	1.18	144	1	**104.84**

Table 4.11: Beams Reinforcement Steel Bars Weight (Using the Conventional Method). "Tables Continued."

	Sec 2-2	**16**	**1.580**	**12.00**	**10**	**1**	**189.60**
		16	1.580	0.88	5	1	**6.95**
		12	0.888	12.00	12	1	**127.87**
		12	0.888	0.74	6	1	**3.94**
		10	0.617	2.48	97	1	**148.43**
Result		**42,338 kg**					

It is noted from the numerical data indicated in Table 4.11 that the total steel bar weight used in the building and designing of reinforcement beams of all floors of the Royal Baghdad project is around 42,338 kg . The most prevalent diameters used in the reinforcement steel bars of beams include 10 mm, 12 mm, 16 mm, and 25 mm. Appendix B (B-1) illustrates the shop drawings and critical plans associated with the design and layout of the beam in this project. Besides those results, Table 4.12 illustrates the slab reinforcement steel bars weight evaluation process by virtue of the traditional method.

Table 4.12: Slabs Reinforcement Steel Bars Weight Evaluation for the Basement (Using the Conventional Method).

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of steel bars	Number of elements	Weight of reinforcement steel bars (kg)
B_1	12	0.888	2.95	340	1	**890.66**
	12	0.888	12.00	128	1	**1363.97**

Table 4.12: Slabs Reinforcement Steel Bars Weight Evaluation (Using the Conventional Method).

"Tables Continued."

	12	0.888	7.20	64	1	**409.19**
	16	1.580	12.00	128	1	**2426.88**
	16	1.580	7.40	64	1	**748.29**
	12	0.888	1.75	27	1	**41.96**
	16	1.580	1.75	27	1	**74.66**
	12	0.888	12.00	54	1	**575.42**
	12	0.888	2.50	27	1	**59.94**
	16	1.580	12.00	54	1	**1023.84**
	16	1.580	2.70	27	1	**115.18**
	12	0.888	7.93	33	1	**232.38**
	16	1.580	7.93	33	1	**413.47**
	12	0.888	12.00	33	1	**351.65**
	12	0.888	6.87	33	1	**201.32**
	16	1.580	12.00	33	1	**625.68**
	16	1.580	7.07	33	1	**368.63**
	12	0.888	12.00	226	1	**2408.26**

Table 4.12: Slabs Reinforcement Steel Bars Weight Evaluation (Using the Conventional Method). "Tables Continued."

	12	**0.888**	**2.20**	**113**	**1**	**220.76**
	16	1.580	12.00	226	1	**4284.96**
	16	1.580	2.40	113	1	**428.50**
	12	0.888	12.00	21	1	**223.78**
	12	0.888	7.05	21	1	**131.47**
	16	1.580	12.00	21	1	**398.16**
	16	1.580	7.25	21	1	**240.56**
	12	0.888	8.45	30	1	**225.11**
	16	1.580	8.45	30	1	**400.53**
	12	0.888	3.75	15	1	**49.95**
	16	1.580	3.75	15	1	**88.88**
	12	0.888	4.10	84	1	**305.83**
	12	0.888	6.80	48	1	**289.84**

It is concluded from the numeric information represented in Table 4.12 that the overall quantity of the steel bar weight employed in basement 1 (or B1 floor), particularly for the slab of this floor, amounted to approximately 19,619.71 kg. Furthermore, it is noted that the most commonly used steel bar diameter types on this floor were 12 mm and 16 mm. On the other hand, Table 4.13 provides an illustration regarding the slabs reinforcement steel bars

weight related to the use of the conventional method.

Table 4.13: Slabs reinforcement steel bars weight for the ground and first floors (Using the conventional method).

Element	Ø (mm)	Weight (kg/m)	length (m)	# of steel bars	Number of elements	Weight of reinforcement steel bars (kg)
G_F + 1^{st}	12	0.888	2.95	360	2	**1886.11**
	12	0.888	4.00	360	2	**2557.44**
	16	1.580	7.50	138	2	**3270.60**
	20	2.469	4.50	163	2	**3622.02**
	12	0.888	12.00	80	2	**1704.96**
	12	0.888	10.20	40	2	**724.61**
	16	1.580	12.00	80	2	**3033.60**
	16	1.580	10.40	40	2	**1314.56**
	12	0.888	12.00	48	2	**1022.98**
	12	0.888	7.70	24	2	**328.20**
	16	1.580	12.00	48	2	**1820.16**
	16	1.580	7.90	24	2	**599.14**
	12	0.888	12.00	118	2	**2514.82**
	12	0.888	5.80	59	2	**607.75**

Table 4.13: Slabs Reinforcement Steel Bars Weight for the Ground and First Floors (Using the Conventional Method). "Tables Continued."

	16	**1.580**	**12.00**	**118**	**2**	**4474.56**
	16	1.580	6.00	59	2	**1118.64**
	12	0.888	12.00	280	2	**5967.36**
	12	0.888	4.70	140	2	**1168.61**
	16	1.580	12.00	280	2	**10617.60**
	16	1.580	4.90	140	2	**2167.76**
	12	0.888	6.63	22	2	**259.05**
	16	1.580	6.63	22	2	**460.92**
	12	0.888	4.25	22	2	**166.06**
	16	1.580	4.25	22	2	**295.46**

It can be concluded from the research results linked to the reinforcement steel bar weight used in the slabs of the ground and first floors that the overall quantity of the steel bars in terms of their weight accounted for around 51,702.97 kg . In addition, the typical diameters used in those floors for the steel bars implemented in the slab establishment are 12 mm, 16 mm, and 20 mm. At the same time, Table 4.14 illustrates the overall weight of the steel bar used in this project, relying on the principles of conventional calculation methods.

Table 4.14: Slab Steel Bar Assessment for the Mezzanine Floor (Using the Conventional Method).

Element	Ø (mm)	Weight (kg/m)	length (m)	# of steel bars	Number of elements	Weight of reinforcement steel bars (kg)
M_F	12	0.888	3.56	61	1	192.84
	12	0.888	12.00	15	1	**159.84**
	12	0.888	1.40	15	1	**18.65**
	12	0.888	3.56	82	1	**259.22**
	12	0.888	12.00	20	1	**213.12**
	12	0.888	1.40	20	1	**24.86**

It can be drawn from Table 4.14 that the mezzanine floor consumed a total of around 868.53 kg of reinforcement steel bars to build this floor. The only diameter considered in this project to build the mezzanine floor was 12 mm. Additionally, Table 4.15 explains the slab reinforcement steel bars' weight using the conventional estimation method.

Table 4.15: Slabs Reinforcement Steel Bars Weight for Typical Floors (Using Conventional Estimation Method).

Element	Ø	Weight (kg/m)	length (m)	# Of steel bars	Number of elements	Weight of reinforcement steel bars (kg)
Typical floors	12	0.888	2.95	340	5	**4453.32**
	12	0.888	4.00	340	5	**6038.40**
	16	1.580	7.50	138	5	**8176.50**
	20	2.469	4.50	163	5	**9055.06**

Table 4.15: Slabs Reinforcement Steel Bars Weight for Typical Floors (Using Conventional Estimation Method). "Tables Continued."

Typical floors	**12**	**0.888**	**12.00**	**80**	**5**	**4262.40**
	12	0.888	10.20	40	5	**1811.52**
	16	1.580	12.00	80	5	**7584.00**
	16	1.580	10.40	40	5	**3286.40**
	12	0.888	12.00	48	5	**2557.44**
	12	0.888	7.70	24	5	**820.51**
	16	1.580	12.00	48	5	**4550.40**
	16	1.580	7.90	24	5	**1497.84**
	12	0.888	12.00	118	5	**6287.04**
	12	0.888	5.80	59	5	**1519.37**
	16	1.580	12.00	118	5	**11186.40**
	16	1.580	6.00	59	5	**2796.60**
	12	0.888	12.00	280	5	**14918.40**
	12	0.888	4.70	140	5	**2921.52**
	16	1.580	12.00	280	5	**26544.00**
	16	1.580	4.90	140	5	**5419.40**

Table 4.15: Slabs Reinforcement Steel Bars Weight for Typical Floors (Using Conventional Estimation Method). “Tables Continued.”

Typical floors	**12**	**0.888**	**6.63**	**22**	**5**	**647.62**
	16	1.580	6.63	22	5	**1152.29**
	12	0.888	4.25	22	5	**415.14**
	16	1.580	4.25	22	5	**738.65**
Typical floors opening (-)	12	0.888	-2.00	120	5	**-1065.60**
	16	1.580	-2.00	120	5	**-1896.00**
	12	0.888	-2.25	24	5	**-239.76**
	16	1.580	-2.25	24	5	**-426.60**

It is indicated from the outputs obtained from the manual assessment technique of the slabs existing in the typical floors and typical floor opening that the overall quantity of the concrete volume used in the slabs used in various typical floors amounts to roughly 128,640.22 kg . At the same time, the amount of concrete volume used in the typical floor openings equals roughly an absolute value of 3,627.96 kg. Moreover, Table 4.16 explains the slab reinforcement steel bars’ weight evaluation using the conventional estimation method.

Table 4.16: Slabs reinforcement steel bars weight for the penthouse floor (Using conventional estimation method).

Element	Ø (mm)	Weight (kg/m)	length (m)	# Of steel bars	Number of elements	Weight of reinforcement steel bars (kg)
Penthouse floor	20	2.469	4.50	37	1	411.09
	12	0.888	6.63	22	1	**129.52**
	12	0.888	6.63	28	1	**164.85**
	12	0.888	4.25	22	1	**83.03**
	12	0.888	4.25	28	1	**105.67**
	12	0.888	12.00	30	1	**319.68**
	12	0.888	4.64	15	1	**61.80**
	12	0.888	12.00	40	1	**426.24**
	12	0.888	4.64	20	1	**82.41**
	12	0.888	8.125	39	1	**281.39**
	12	0.888	8.125	52	1	**375.18**
	12	0.888	5.63	20	1	**99.99**
	12	0.888	5.63	26	1	**129.99**
	12	0.888	3.73	64	1	**211.98**
Lift Slab	16	1.580	2.90	36	2	**329.90**
	16	1.580	2.65	40	2	**334.96**
Result		**201,033 kg**				

It is inferred from the results obtained from the results in Table 4.16 that the overall quantity of the reinforcement steel bar weight amounted to roughly 201,033 kg . Appendix B (B-2) indicates the shop drawing and some critical plans related to the slabs and slab design considering the steel bar reinforcement. At the same time, it is observed that the most employed diameter categories required to build the slabs in this project comprise 12 mm, 16 mm, and 20 mm. Furthermore, Table 4.17 illustrates the staircase reinforcement steel bars' weight using the conventional estimation method.

Table 4.17: Staircase Reinforcement Steel Bars Weight (Using Conventional Estimation Method).

Element	Ø (mm)	Weight (kg/m)	length (m)	# Of steel bars	Number of elements	Weight of reinforcement steel bars (kg)
Staircase	8	0.395	1.50	508	1	**300.99**
	8	0.395	0.77	1,524	1	**463.52**
	16	1.580	5.90	17	1	**158.47**
	16	1.580	3.24	8	1	**40.95**
	16	1.580	9.60	22	1	**333.70**
	12	0.888	1.50	15	10	**199.80**
	16	1.580	6.00	17	9	**1450.44**
	12	0.888	1.50	34	10	**452.88**
	16	1.580	12.00	20	10	**3792.00**

Table 4.17: Staircase Reinforcement Steel Bars Weight (Using Conventional Estimation Method). "Tables Continued."

Staircase	12	0.888	1.50	60	10	**799.20**
	12	0.888	1.50	128	10	**1,704.96**
Result	**9,697 kg**					

It can be inferred from the results illustrated in Table 4.17 that the total amount of steel bar weight associated with different parts built in this project accounted for approximately 9,697 kg. The most common diameters of the steel bars employed in the reinforcement steel bar of this case (the staircase) include 8 mm, 12 mm, and 16 mm. Overall, Table 4.18 illustrates the total reinforcement weight in this building with the help of the conventional estimation method.

Table 4.18: Total Reinforcement Weight in this Building (Using Conventional Estimation Method).

Part of Project	Weight (kg)
Raft Footing	**68634**
Columns & Walls	**147440**
Drop Beams	**42338**
Slabs	**201033**
Stair Case	**9697**
Result	**469142 kg**

It can be concluded from the results shown in Table 4.18 that the amount of steel bar weight consumed in this project for the whole project reached approximately 469142 kg. The largest steel bar weight consumed in this project was for the slabs, corresponding to a weight of roughly 201033 kg. At the same time, the lowest amount of steel bar weight consumed in this project was in the staircase 9697 kg. Also, Figure 4.2 illustrates a graphical representation of the overall reinforcement weight of the steel bar used in this construction project in terms of percentage.

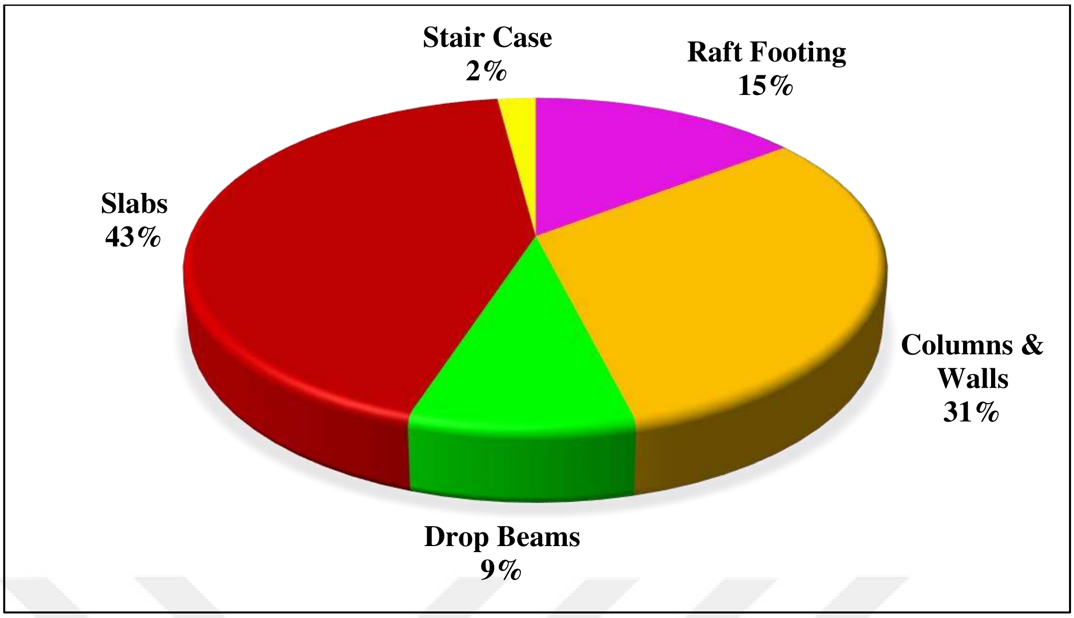

Figure 4.2: The Overall Reinforcement Weight of the Steel Bar Used in This Construction Project in Terms of Percentage.

It is inferred from the results obtained from the manual calculations of the steel bar in this project that the most part that consumes a large portion of steel bar quantity is the slab, followed by columns and walls, corresponding to 43% and 31%, respectively. In contrast, the staircase consumed the lowest weight of steel bars in this project, with a ratio of 2%.

4.3 THE QUANTITY TAKE-OFF RESULTS OF THE CASE STUDY USING THE REVIT EVALUATION METHOD

In this section, the numerical findings obtained from estimating the quantity (volume) of reinforced concrete and the weight of reinforcement steel bars used in this project are presented in the following paragraphs.

4.3.1 Numerical REVIT Estimation of Reinforcement Concrete

Before representing the results of the construction project considered in this case study (Royal Baghdad project), it is worth mentioning that the REVIT software tool provided different 3D modeling of all building components based on the definition of dimensions and elevations of the facility. Appendix C indicates these 3D configurations.

This part addressed and investigated different categories of reinforcement concrete components and activities. For instance, Table 4.19 represents the concrete volume estimation of the cut implemented in this project using the REVIT software estimations.

Table 4.19: Cut Volume (Using the REVIT Quantity Take-Off Method).

Cut	Volume
Result	the amount of concrete cut that will be achieved is approximately 4,632.83 m^3. Furthermore, the numerical findings provided some critical data related to the concrete volume associated with the blinding volume

Table 4.20: The Blinding Volume (Using the REVIT Quantity Take-Off Method).

Blinding	Volume
Result	from the results obtained from the numerical REVIT estimation technique that the concrete volume amounted to about 74.68 m^3

Also, the REVIT calculation procedures obtained some data related to the concrete volume of the bolder volume (stones). These data are shown in Table 4.21.

Table 4.21: The Bolder Volume (Using the REVIT Quantity Take-Off Method).

Bolder	Volume
Result	the REVIT analytical results that the concrete volume attained from the estimations of the stones (bolder) volume in the Royal Baghdad project amounted to roughly 187.98 m^3.

At the same time, the programming evaluation process gave an estimation of the concrete volume of other parameters in this construction project explained in this thesis. For example, Table 4.22 provides an estimation of the raft foundation volume by virtue of the REVIT quantity take-off method.

Table 4.22: Estimation of the Raft Foundation Volume (Using the REVIT Quantity Take-Off Method).

Footing	Volume
Result	the numerical process applied with the help of the REVIT software programming tool that the overall concrete volume associated with the raft foundation accounted for nearly 805.62 m^3.

Furthermore, this numerical estimation approach provided some data regarding the concrete volume evaluation employed to design and build the walls and columns in this case study. Table 4.23 shows those results.

Table 4.23: Walls and Columns Volume (Using the REVIT Quantity Take-Off Method).

Element		**Height (m)**	**Number of Repetition**	**Volume (m^3)**
C1	The Basement	7.61	9	154.52
	GF to Penthouse Floor	31.69	6	
	GF to 6^{th}	28.16	3	
C2	B_F to Penthouse Floor	35.69	4	205.39
	B_F to 6^{th}	32.85	12	
C3		4.61	2	1.94
W1		37.25	2	190.91
W2		4.61	1	150.12
		6.05	1	31.73
Results			**734.61 (m^3)**	

It is inferred from the statical data represented in Table 4.23 that the REVIT software tool used in this work estimated that the overall concrete volume used in columns and walls for this project reached a value of 734.61 m^3. C2 (or Columns 2 – category) provided the maximum portion of this amount of concrete volume. On the other hand, Table 4.24 indicates the evaluation method of the concrete volume employed to design and build the slabs with the help of the numerical REVIT quantity take-off method.

Table 4.24: Evaluating the Slab Volume (Using the REVIT Quantity Take-Off Method).

Element	Number of Repetition	Volume (m^3)
B_F + Drop Panel	1	**152.87**
G_F+ Drop Panel	1	**183.97**
M_F	1	**8.95**
1st + Drop Panel	1	**183.97**
Typical Floors+ Drop Panel	5	**905.36**
Penthouse Floor + Lift	1	**34.57**
Stair Slab	20	56.87
Stair Steps	508	**18.64**
Result	**1,545.20 m^3**	

It can be deduced from the results obtained from the calculation results of concrete volume in slabs, as shown in Table 4.24, that the value of the overall concrete volume obtained from this innovative and practical approach reached a quantity of 1,545.20 m^3. At the same instant, another result was attained for the concrete volume estimation of other parts of the building. For example, Table 4.25 indicates the drop beam volume of the reinforced concrete using the REVIT quantity take-off method.

Table 4.25: Drop Beams Volume of the Reinforced Concrete (Using the REVIT Quantity Take-Off Method).

Element		Number of Repetition	Volume (m^3)
B_F	B2	1	**7.86**
	B3	1	**28.96**
G_F + **1st** + Typical floors	B2	7	**4.69**
	B3	7	**22.65**
	B4	7	**8.48**
	B5	7	**18.57**
G_F + **1st** + Typical floors	**B6**	**7**	84.69
	B7	7	**18.57**
M_F	B2	1	**2.51**
	B3	1	**1.08**
Penthouse floor	B2	1	**0.69**
	B4	1	**1.23**
	B5	1	**1.08**
	B6	1	**1.74**
	B7	1	**1.51**
	Sec 2-2	1	**5.67**
Result		**209.98 (m^3)**	

It is shown from the numeric information described in Table 4.25 that the total amount of concrete volume required to build and design the drop beams amounted to approximately 209.98 m^3.

Overall, Table 4.26 explains the total values of reinforced concrete volume attained using the REVIT quantity take-off method.

Table 4.26: Total Reinforced Concrete Volume (Using the REVIT Quantity Take-Off Method).

Foundation	**805.62 (m^3)**
Walls and Columns	**734.61 (m^3)**
Slabs	**1,545.20 (m^3)**
Drop Beams	**209.98 (m^3)**
Results	**3,295.41 (m^3)**

It can be concluded from Table 4.26 that the largest amount of concrete volume was consumed and required to build the slabs in this project, corresponding to a concrete volume amount of 1,545.20 m^3, followed by the foundation concrete volume, which required roughly 805.62 m^3.

Moreover, Figure 4.3 explains the overall reinforced concrete volume based on the REVIT numerical quantity take-off approach.

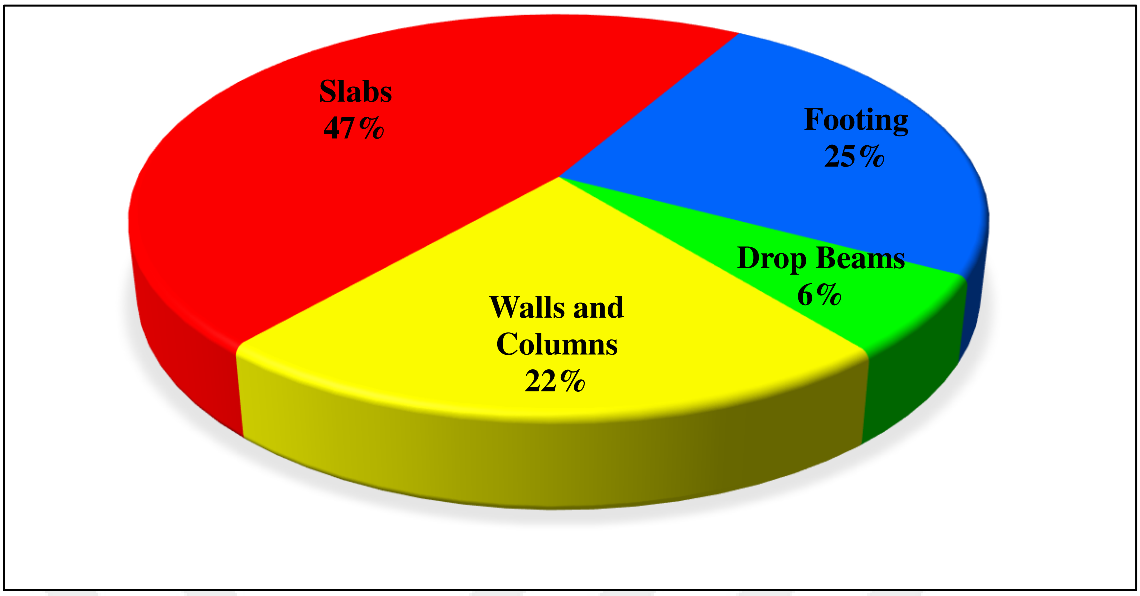

Figure 4.3: The Overall Reinforced Concrete Volume Based on the REVIT Numerical Quantity Take-Off Approach.

It can be indicated from the results presented in Figure 4.3 that the more significant ratio of the concrete volume needed in this project was for the slab, accounting for approximately 47%. In contrast, the lowest proportion of concrete volume was for the drop beams, which consumed only 6%.

4.3.2 Numerical REVIT Estimation of Steel Bar Weight

In this section, the numerical findings are associated with the REVIT software evaluation technique, which is characterized by significant rates of accuracy and performance. Firstly, the steel bar weight related to the raft foundation reinforcement steel bars is assessed. Figure 4.4 indicates the numerical 3D modeling of the raft foundation reinforcement steel bars' weight using the REVIT method.

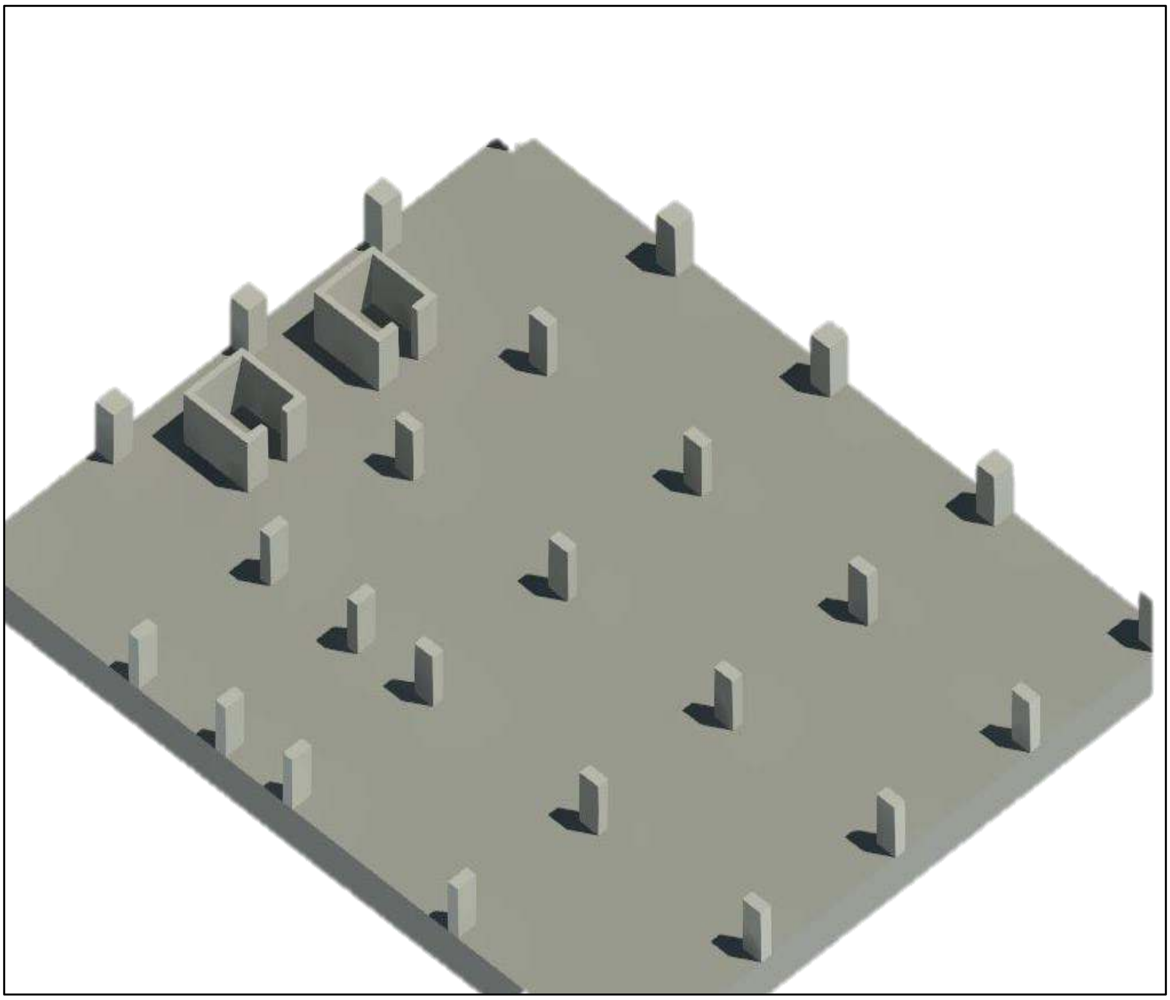

Figure 4.4: Numerical 3D modeling of the raft foundation reinforcement steel bars weight (Using the REVIT Method).

At the same time, Table 4.27 offers an explanation of the raft foundation reinforcement steel bars' weight with the support of the REVIT calculation method.

Table 4.27: Raft Foundation Reinforcement Steel Bars Weight (Using the REVIT Method).

Section	Ø (mm)	Weight (kg/m)	Length (m)	Number of Steel Bars	Number of Sections	Weight of Reinforcement Steel Bars (kg)
Long Bar (Top and Bottom Reinforcement)	25	3.858	12.00	238	2	**22,036.90**
	25	3.858	9.42	119	2	**8,649.48**
Short Bar (Top and Bottom Reinforcement	25	3.858	12.00	292	2	**27,036.86**
	25	3.858	4.33	146	2	**4,877.90**
Additional Steel Bar (Bottom Reinforcement)	25	3.858	3.00	28	9	**2,916.65**
Results	**65,518 kg**					

The nmuerical statistical results shown in Table 4.27 can explain that the overall reinforcement steel bar weight used in the design and building of the raft foundation amounted to roughly 65518kg. Also, it can be observed that the maximum steel bar weight consumed in this part (raft foundation) was for the short bars (including top and bottom reinforcement steel bars), corresponding to about 27,036.86 kg and 4,877.90 kg. Besides, Table 4.28 illustrates the weight of column and walls reinforcement steel bars obtained by virtue of the numerical REVIT estimation method.

Table 4.28: Weight of Column and Walls Reinforcement Steel Bars (Using the REVIT Method).

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of Steel Bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
C1- basement	25	3.858	6.85	28	9	**6,659.68**
	10	0.617	9.42	23	9	**1,203.11**
C1 – GF to penthouse floor	25	3.858	12.00	42	6	**11,666.59**
	25	3.858	3.65	14	6	**1,182.86**
	10	0.617	3.81	152	6	**2,143.90**
C1 – GF to 6th	25	3.858	12.00	42	3	**5,833.30**
	25	3.858	0.98	14	3	**158.80**
	10	0.617	3.81	137	3	**966.17**
C2- BF to penthouse floor	25	3.858	12.00	80	4	**14,814.72**
	25	3.858	0.74	20	4	**228.39**
	10	0.617	3.81	176	4	**1,654.94**
C2- BF to 6th	25	3.858	12.00	60	12	**33,333.12**
	25	3.858	7.77	20	12	**7,194.40**
	10	0.617	3.81	166	12	**4,682.73**

Table 4.28: Weight of Column and Walls Reinforcement Steel Bars (Using the REVIT Method). "Tables Continued."

C3 - B_F	**16**	**1.580**	**6.33**	**12**	**2**	**240.03**
	10	0.617	3.58	22	2	**97.19**
Wall $_1$ - Lift	16	1.580	12.00	423	2	**16,040.16**
	16	1.580	9.68	141	2	**4,313.02**
	12	0.888	12.00	384	2	**8,183.81**
	12	0.888	3.81	188	2	**1,272.11**
	12	0.888	3.30	756	2	**4,430.76**
Wall $_2$ - B_F	16	1.580	5.66	1082	1	**9,676.11**
	12	0.888	12.00	416	1	**4,432.90**
	12	0.888	7.85	41	1	**285.80**
	16	1.580	7.01	179	1	**1,982.57**
	12	0.888	12.00	57	1	**607.39**
	12	0.888	6.42	57	1	**324.95**
Result	**143,610 kg**					

It is concluded from the results illustrated in Table 4.28 that the numerical REVIT software tool provided an accurate assessment technique to evaluate the amount of steel bar weight related to the column and walls of the construction project considered and analyzed in this study. This value accounted for approximately 143610 kg. The most common diameter categories implemented in walls and columns were 10 mm, 12 mm, 16 mm, and 25 mm. Additionally, Table 4.29 indicates the weight of beams reinforcement steel bars computed with the help of the numerical REVIT estimation principles.

Table 4.29: Weight of Beams Reinforcement Steel Bars (Using the REVIT Method).

<table>
<tr><th colspan="2">Beam</th><th>Ø (mm)</th><th>Weight (kg/m)</th><th>Length (m)</th><th># of Steel Bars</th><th>Number of Elements</th><th>Weight of Reinforcement Steel Bars (kg)</th></tr>
<tr><td rowspan="8">B_F</td><td rowspan="3">B2</td><td>25</td><td>3.858</td><td>12.00</td><td>70</td><td>1</td><td>3240.72</td></tr>
<tr><td>25</td><td>3.858</td><td>4.16</td><td>14</td><td>1</td><td>224.69</td></tr>
<tr><td>10</td><td>0.617</td><td>6.45</td><td>177</td><td>1</td><td>704.40</td></tr>
<tr><td rowspan="5">B3</td><td>25</td><td>3.858</td><td>12.00</td><td>20</td><td>1</td><td>925.92</td></tr>
<tr><td>25</td><td>3.858</td><td>4.16</td><td>4</td><td>1</td><td>64.20</td></tr>
<tr><td>12</td><td>0.888</td><td>12.00</td><td>16</td><td>1</td><td>170.50</td></tr>
<tr><td>12</td><td>0.888</td><td>9.68</td><td>4</td><td>1</td><td>34.38</td></tr>
<tr><td>10</td><td>0.617</td><td>1.88</td><td>177</td><td>1</td><td>205.31</td></tr>
<tr><td rowspan="6">G_F + 1^{st} + Typical floors</td><td rowspan="3">B2</td><td>25</td><td>3.858</td><td>11.23</td><td>5</td><td>7</td><td>1516.39</td></tr>
<tr><td>12</td><td>0.888</td><td>11.23</td><td>2</td><td>7</td><td>139.61</td></tr>
<tr><td>10</td><td>0.617</td><td>1.11</td><td>44</td><td>7</td><td>210.94</td></tr>
<tr><td rowspan="3">B3</td><td>25</td><td>3.858</td><td>2.91</td><td>35</td><td>7</td><td>2750.56</td></tr>
<tr><td>12</td><td>0.888</td><td>2.91</td><td>20</td><td>7</td><td>361.77</td></tr>
<tr><td>10</td><td>0.617</td><td>1.98</td><td>56</td><td>7</td><td>478.89</td></tr>
</table>

Table 4.29: Weight of Beams Reinforcement Steel Bars (Using the REVIT Method).

"Tables Continued."

G_F + 1st + Typical floors	**B4**	25	3.858	6.87	10	**7**	**1855.31**
		12	0.888	6.87	4	7	**170.82**
		10	0.617	1.44	51	7	**317.19**
	B5	25	3.858	2.44	30	7	**1976.84**
		12	0.888	2.44	20	7	**303.34**
		10	0.617	1.98	45	7	**384.82**
	B6	25	3.858	12.00	40	7	**12962.88**
		25	3.858	4.16	8	7	**898.76**
		12	0.888	12.00	20	7	**1491.84**
		12	0.888	9.68	4	7	**240.68**
		10	0.617	2.16	177	7	**1651.24**
	B7	16	1.580	12.00	30	7	**3981.60**
		16	1.580	0.51	6	7	**33.84**
		10	0.617	1.06	177	7	**810.33**
M_F	**B2**	25	3.858	9.36	15	1	**541.66**
		12	0.888	9.36	6	1	**49.87**
		10	0.617	1.38	105	1	**89.40**

Table 4.29: Weight of Beams Reinforcement Steel Bars (Using the REVIT Method).

"Tables Continued."

M_F	**B3**	25	3.858	12.00	5	1	**231.48**
		25	3.858	1.28	5	1	**24.69**
		12	0.888	12.00	2	1	**21.31**
		12	0.888	0.69	2	1	**1.23**
		10	0.617	1.32	43	1	**35.02**
Pent house floor	**B2**	25	3.858	11.23	5	1	**216.63**
		12	0.888	11.23	2	1	**19.94**
		10	0.617	1.11	44	1	**30.13**
	B4	25	3.858	6.87	10	1	**265.04**
		12	0.888	6.87	4	1	**24.40**
		10	0.617	1.44	51	1	**45.31**
	B5	25	3.858	2.44	12	1	**112.96**
		12	0.888	2.44	8	1	**17.33**
		10	0.617	1.98	19	1	**23.21**
	B6	25	3.858	8.02	8	1	**247.53**
		12	0.888	8.02	4	1	**28.49**
		10	0.617	1.98	29	1	**35.43**

Table 4.29: Weight of Beams Reinforcement Steel Bars (Using the REVIT Method).

"Tables Continued."

Pent house floor	**B7**	16	1.580	12.00	12	1	**227.52**
		16	1.580	11.33	6	1	**107.41**
		10	0.617	1.03	135	1	**85.79**
	Sec 2-2	16	1.580	12.00	10	1	**189.60**
		16	1.580	0.74	5	1	**5.85**
		12	0.888	12.00	12	1	**127.87**
		12	0.888	0.63	6	1	**3.36**
		10	0.617	2.36	91	1	**132.51**
Result		**41,049 kg**					

It can be inferred from Table 4.29 that the overall quantity of the reinforcement steel bars employed in the beams of this project amounted to a total weight of 41,049 kg . On the other hand, it can be deduced from this table that not all the floors required the same quantity of steel bar weight in this project. For instance, approximately beam No. B6 has a greatly large steel bar weight compared with other beam elements of this project. Figure 4.5 provides an illustration of a 3D configuration of the quantity take-off related to the beam concrete reinforcement bars used in this case study.

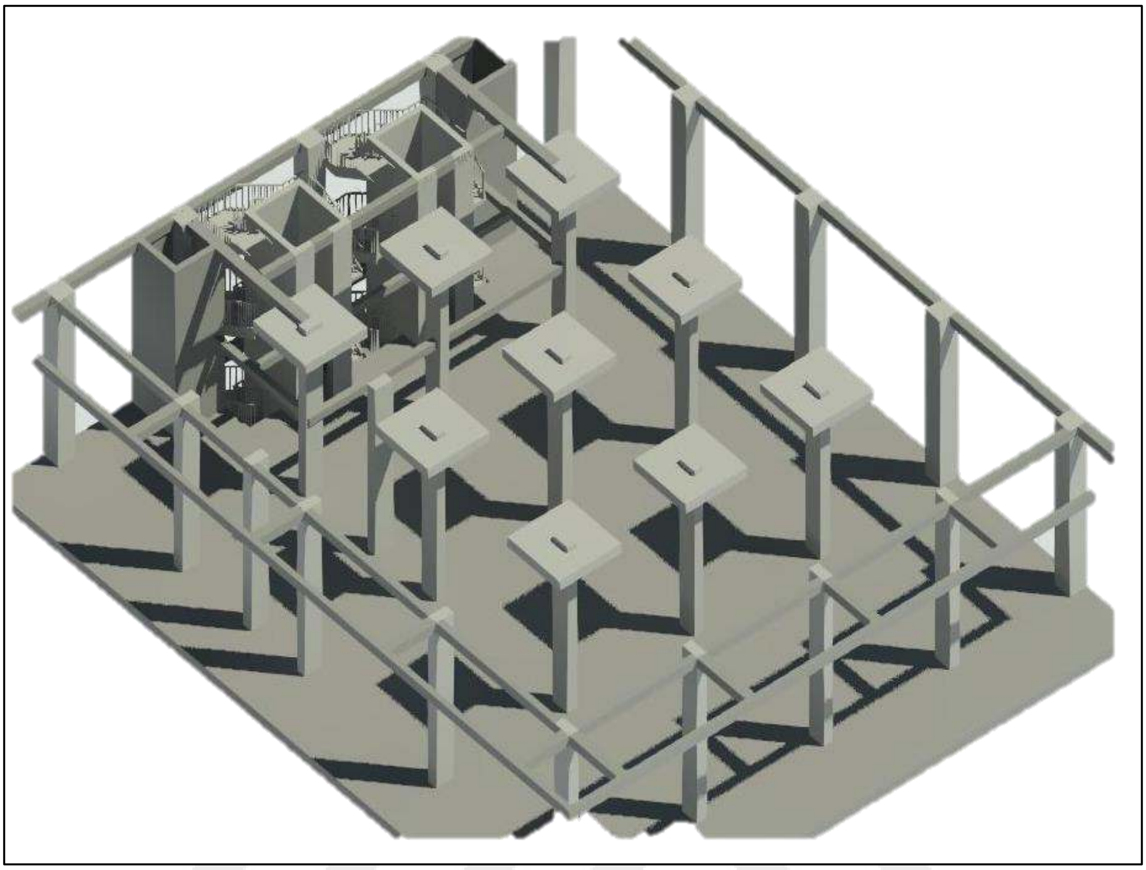

Figure 4.5: A 3D Configuration of the Quantity Take-Off Related to the Beam Concrete Reinforcement Bars.

Furthermore, Table 4.30 illustrates the weight of the reinforcement slab steel bars employing the REVIT numerical method for the basement floor.

Table 4.30: Weight of the Reinforcement Slab Steel Bars (Using the REVIT Method) for the Basement Floor.

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of Steel Bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
B_1	12	0.888	2.90	332	1	**854.97**
	12	0.888	12.00	124	1	**1,321.34**
	12	0.888	7.12	62	1	**392.00**

Table 4.30: Weight of the Reinforcement Slab Steel Bars (Using the REVIT Method) for the Basement Floor. “Tables Continued.”

B_1	16	1.580	12.00	124	1	**2,351.04**
	16	1.580	7.32	62	1	**717.07**
	12	0.888	1.68	26	1	**38.79**
	16	1.580	1.68	26	1	**69.01**
	12	0.888	12.00	52	1	**554.11**
	12	0.888	2.44	26	1	**56.33**
	16	1.580	12.00	52	1	**985.92**
	16	1.580	2.61	26	1	**107.22**
	12	0.888	7.80	31	1	**214.72**
	16	1.580	7.80	31	1	**382.04**
	12	0.888	12.00	31	1	**330.34**
	12	0.888	6.72	31	1	**184.99**
	16	1.580	12.00	31	1	**587.76**
	16	1.580	6.92	31	1	**338.94**
	12	0.888	12.00	218	1	**2,323.01**
	12	0.888	2.09	109	1	**202.30**
	16	1.580	12.00	218	1	**4,133.28**
	16	1.580	2.29	109	1	**394.38**
	12	0.888	12.00	19	1	**202.46**
	12	0.888	6.88	19	1	**116.08**
	16	1.580	12.00	19	1	**360.24**

Table 4.30: Weight of the Reinforcement Slab Steel Bars (Using the REVIT Method) for the Basement Floor. "Tables Continued."

B_1	16	1.580	7.22	19	1	**216.74**
	12	0.888	8.38	28	1	**208.36**
	16	1.580	8.38	28	1	**370.73**
	12	0.888	3.75	14	1	**46.62**
	16	1.580	3.69	14	1	**81.62**
	12	0.888	3.99	82	1	**290.54**
	12	0.888	6.72	45	1	**268.53**

It can be indicated from the numerical results represented in Table 4.30 that the overall steel bar weight, which is used in this project, particularly for the Basement '1' floor, corresponded to a quantity of 18,701.48 kilograms. Further, it is observed that the only steel bar diameters addressed and implemented on this floor were 12 mm and 16 mm. At the same time, Table 4.31 provides an illustration of the weight of the slab reinforcement steel bars with the help of the REVIT method for the ground and first floors.

Table 4.31: Weight of the Slab Reinforcement Steel Bars (Using the REVIT Method) for the Ground and First Floors.

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of Steel bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
G_{F} + 1st	12	0.888	2.90	356	2	**1,833.54**
	12	0.888	4.00	356	2	**2,529.02**
	16	1.580	7.44	135	2	**3,173.90**
	20	2.469	4.39	158	2	**3,425.10**

Table 4.31: Weight of the Slab Reinforcement Steel Bars (Using the REVIT Method) for the Ground and First Floors. "Tables Continued."

G_{F} + 1st	12	0.888	12.00	76	2	**1,619.71**
	12	0.888	9.95	38	2	**671.51**
	16	1.580	12.00	76	2	**2,881.92**
	16	1.580	10.15	38	2	**1,218.81**
	12	0.888	12.00	46	2	**980.35**
	12	0.888	7.65	23	2	**312.49**
	16	1.580	12.00	46	2	**1,744.32**
	16	1.580	7.79	23	2	**566.18**
	12	0.888	12.00	110	2	**2,344.32**
	12	0.888	5.72	55	2	**558.73**
	16	1.580	12.00	110	2	**4,171.20**
	16	1.580	5.93	55	2	**1,030.63**
	12	0.888	12.00	272	2	**5,796.86**
	12	0.888	4.62	136	2	**1,115.90**
	16	1.580	12.00	272	2	**10,314.24**
	16	1.580	4.82	136	2	**2,071.44**

Table 4.31: Weight of the Slab Reinforcement Steel Bars (Using the REVIT Method) for the Ground and First Floors. “Tables Continued.”

$G_{F} + 1^{st}$	12	0.888	6.58	21	2	**245.41**
	16	1.580	6.58	21	2	**436.65**
	12	0.888	4.21	21	2	**157.02**
	16	1.580	4.21	21	2	**279.38**

It can be indicated from the research results indicated in Table 4.31 that the overall amount of the steel bar weight considered and used for the ground and first floor is 49,478.63 kilograms. Also, it is noted that the most significant steel bar diameters that correspond to larger steel bar weight include 16 mm, followed by 12 mm, then 20 mm. Moreover, Table 4.32 illustrates the weight of the slab reinforcement steel bars using the REVIT method associated with the mezzanine floor.

Table 4.32: Weight of the Slab Reinforcement Steel Bars (Using the REVIT Method) for the Mezzanine Floor.

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of Steel Bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
M_{F}	12	0.888	3.51	59	1	**183.90**
	12	0.888	12.00	14	1	**149.18**
	12	0.888	1.33	14	1	**16.53**
	12	0.888	3.51	79	1	**246.23**
	12	0.888	12.00	19	1	**202.46**
	12	0.888	1.33	19	1	**22.44**

It is indicated from the outputs represented in Table 4.32 that the common diameter used for the steel bars in the mezzanine floor was 12 mm. The overall weight of the reinforcement steel bars used in this floor amounts to approximately 820.74 kg. In addition to those findings, Table 4.33 illustrates the numerical REVIT software findings pertaining to the slab reinforcement steel bars weight (Using the REVIT Method) for the typical floors.

Table 4.33: Slabs Reinforcement Steel Bars Weight (Using the REVIT Method) for the Typical Floors.

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of Steel Bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
Typical Floors	12	0.888	2.90	356	5	**4,583.86**
	12	0.888	4.00	356	5	**6,322.56**
	16	1.580	7.44	135	5	**7,934.76**
	20	2.469	4.39	158	5	**8,562.74**
	12	0.888	12.00	76	5	**4,049.28**
	12	0.888	9.95	38	5	**1,678.76**
	16	1.580	12.00	76	5	**7,204.80**
	16	1.580	10.15	38	5	**3,047.03**
	12	0.888	12.00	46	5	**2,450.88**
	12	0.888	7.65	23	5	**781.22**
	16	1.580	12.00	46	5	**4,360.80**

Table 4.33: Slabs Reinforcement Steel Bars Weight (Using the REVIT Method) for the Typical Floors. "Tables Continued."

Typical Floors	16	1.580	7.79	23	5	**1,415.44**
	12	0.888	12.00	110	5	**5,860.80**
	12	0.888	5.72	55	5	**1,396.82**
	16	1.580	12.00	110	5	**10,428.00**
	16	1.580	5.93	55	5	**2,576.59**
	12	0.888	12.00	272	5	**14,492.16**
	12	0.888	4.62	136	5	**2,789.74**
	16	1.580	12.00	272	5	**25,785.60**
	16	1.580	4.82	136	5	**5,178.61**
	12	0.888	6.58	21	5	**613.52**
	16	1.580	6.58	21	5	**1,091.62**
	12	0.888	4.21	21	5	**392.54**
	16	1.580	4.21	21	5	**698.44**
Typical Floors Opening	12	0.888	2.08	122	5	**1,126.69**
	16	1.580	2.08	122	5	**2,004.70**
	12	0.888	2.27	25	5	**251.97**
	16	1.580	2.27	25	5	**448.33 kg**

It can be concluded from the findings illustrated in Table 4.33 that the overall weight of steel bars related to the slabs associated with steel bars quantity used in typical floors and typical floor openings is 251970 kg. The common diameter of the steel bars used in this scenario is 12 mm, 16 mm, and 20 mm. At the same time, Table 4.34 indicates the weight calculation process of slabs reinforcement steel bars by virtue of the numerical REVIT software method for the slabs related to the penthouse floor and lift of the slab.

Table 4.34: Slabs Reinforcement Steel Bars Weight (Using the REVIT Method) for the Penthouse Floor.

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of Steel Bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
Pent House Floor	20	2.469	4.39	34	1	**368.52**
	12	0.888	6.55	21	1	**122.14**
	12	0.888	6.55	25	1	**145.41**
	12	0.888	4.21	21	1	**78.51**
	12	0.888	4.21	25	1	**93.46**
	12	0.888	12.00	28	1	**298.37**
	12	0.888	4.56	14	1	**56.69**
	12	0.888	12.00	36	1	**383.62**
	12	0.888	4.56	18	1	**72.89**
	12	0.888	8.01	35	1	**248.95**
	12	0.888	8.01	46	1	**327.19**

Table 4.34: Slabs Reinforcement Steel Bars Weight (Using the REVIT Method) for the Penthouse Floor. "Tables Continued."

Pent House Floor	12	0.888	5.52	19	1	**93.13**
	12	0.888	5.52	24	1	**117.64**
	12	0.888	3.66	61	1	**198.25**
	12	0.888	3.66	83	1	**269.76**
Lift Slab	16	1.580	2.86	35	2	**316.32**
	16	1.580	2.61	37	2	**305.16**
Result	**192,362 (kg)**					

It can be concluded from the numerical REVIT software results obtained to analyze the steel bar weight used in the slab that the overall weight of those slabs amounts to 192362 kg. The penthouse floor and lift slab consume the largest weight of these steel bars in the project. In addition, Table 4.35 provides an illustration of the steel bar weight used in the staircase of the project.

Table 4.35: The Staircase Reinforcement Steel Bars Weight (Using the REVIT Method).

Element	Ø (mm)	Weight (kg/m)	Length (m)	# of Steel Bars	Number of Elements	Weight of Reinforcement Steel Bars (kg)
Staircase	8	0.395	1.44	505	1	**287.24**
	8	0.395	0.73	1,512	1	**435.99**
	16	1.580	5.84	16	1	**147.64**
	16	1.580	3.22	8	1	**40.70**

Table 4.35: The Staircase Reinforcement Steel Bars Weight (Using the REVIT Method). “Tables Continued.”

Staircase	16	1.580	9.55	21	1	**316.87**
	12	0.888	1.44	14	10	**179.02**
	16	1.580	5.91	15	9	**1,260.60**
	12	0.888	1.44	31	10	**396.40**
	16	1.580	12.00	18	10	**3,412.80**
	12	0.888	1.41	57	10	**713.69**
	12	0.888	1.44	125	10	**1,598.40**
Result	8,790 (kg)					

It is inferred from the results described in Table 4.35 that the overall quantity required to build the staircase with the help of steel bars has a weight value of roughly 8790 kg. This value represents the least amount of steel bar weight compared with other projects’ structural components. Besides these results, Table 4.36 depicts the total reinforcement weight in this Building depending on the REVIT software tool.

Table 4.36: Total Reinforcement Weight in this Building (Using the REVIT Method).

Part of Project	**Steel Bar Weight (kg)**
Raft Footing	**65518**
Columns and Walls	**143610**
Drop Beams	**41049**
Slabs	**192362**
Staircase	**8790**
Result	**451329 kg**

It can be indicated from the results illustrated in Table 4.36 that the overall amount of steel bar weight used in this case study reached roughly 451329 kg. In addition, it can be inferred that the large steel bar weight quantity was for the slabs. The slabs consumed approximately 192362 kg, followed by the columns and walls, which required around 143610 kg. In contrast, the staircase took only 8790 kg of steel bars in this project. An overall summary based on a graphical representation of the overall steel weight ratios associated with the project parts can be illustrated in Figure 4.6.

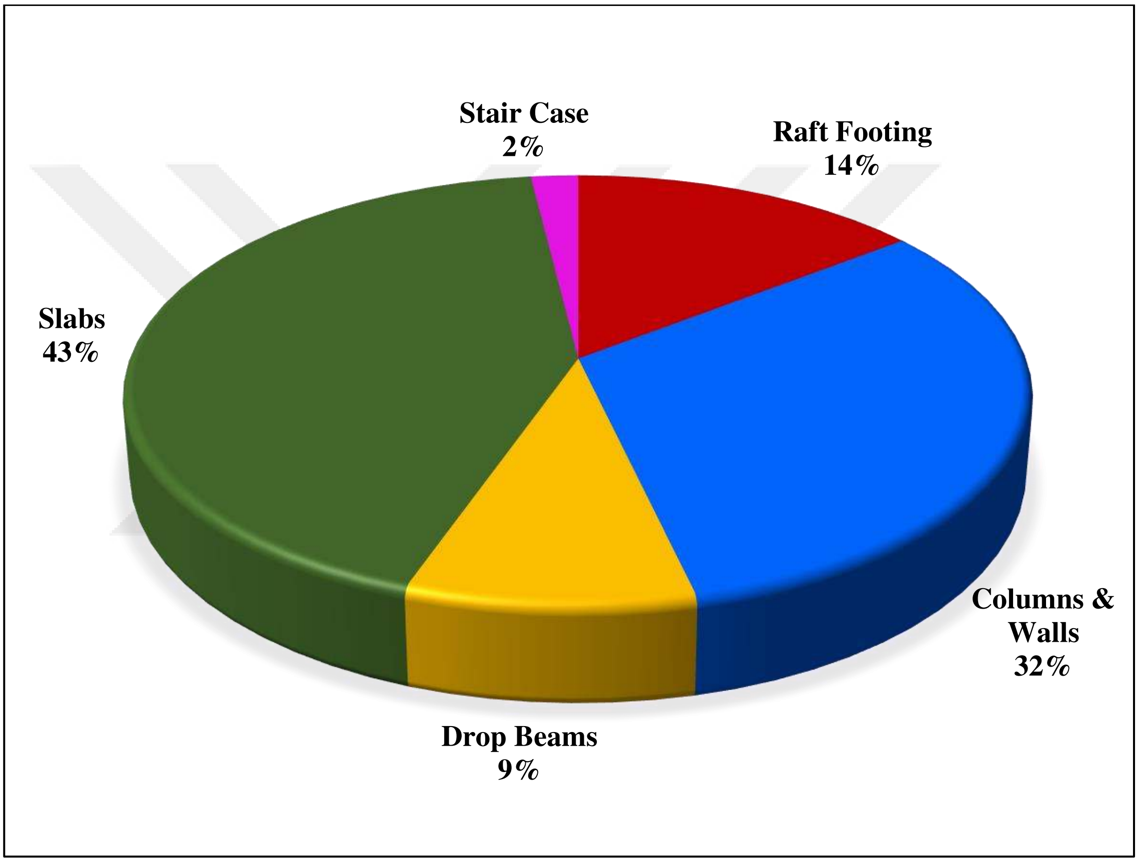

Figure 4.6: A Graphical Illustration of the Overall Reinforcement Steel Bar Weight in this Building.

It can be inferred from the graphical representation of the overall quantity of the steel bar weight considered in this project that the most significant part of the building that consumed massive amounts of steel bar weight is the slabs, corresponding to a ratio of 43%.

On the other hand, the lowest rate of steel bar weight was recorded for the staircase, which registered a percentage of 2%. Furthermore, Figure 4.7 indicates a 3D model of the construction project considered in this work using the REVIT software numerical analysis.

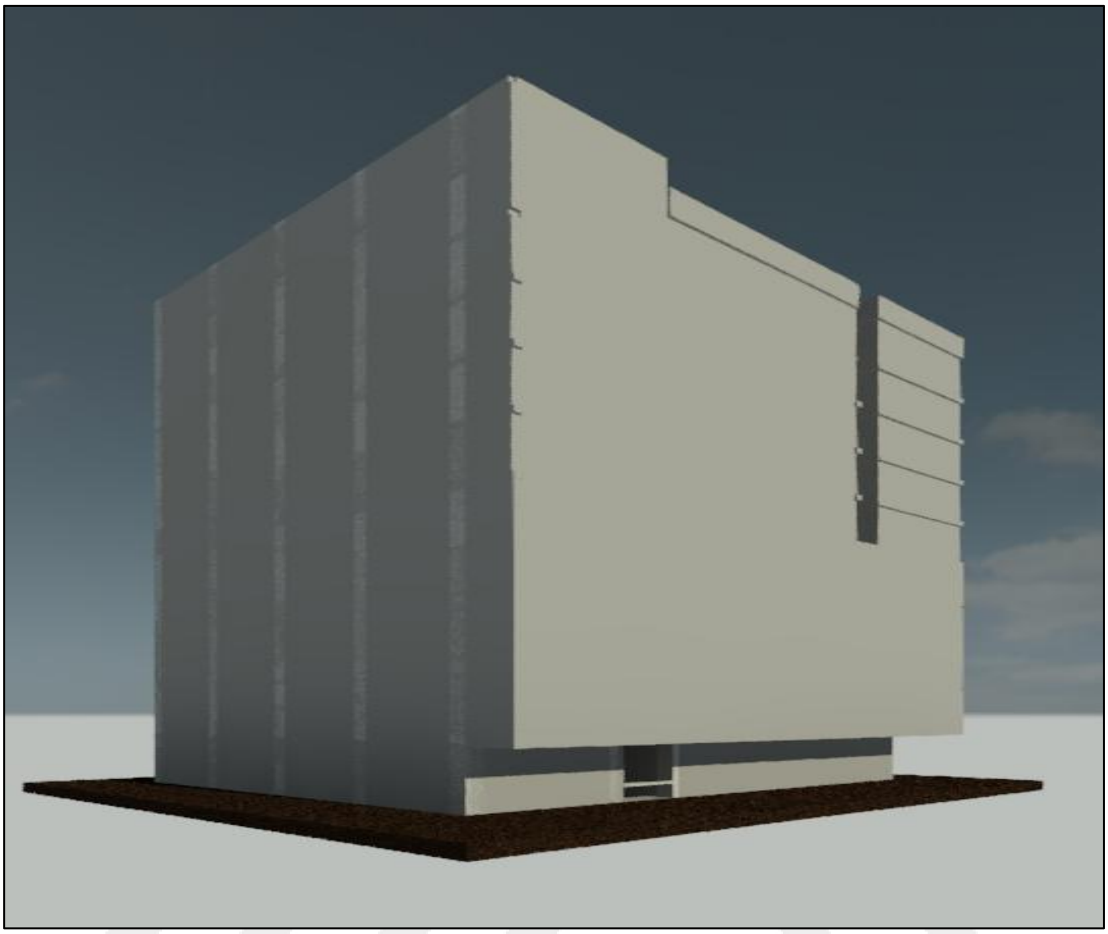

Figure 4.7: A 3D Model of the Construction Project Considered in this Work Using the REVIT Software Numerical Analysis.

4.4 QUANTITY TAKE-OFF COMPARATIVE ANALYSIS

A comparative analysis was carried out to validate the effectiveness of the BIM technology and REVIT software in conducting high-performance, reliable, and accurate quantity take-off associated with the amount of materials considered and used in the construction project, which represents here the case study of the Royal Baghdad project. The comparative analysis examines here the percentage of improvement that can be accomplished by the REVIT programming tool compared with manual calculation. Table 4.37 illustrates the results of this comparative analysis considered for the cut, blinding, and bolder.

Table 4.37: The Results of the Comparative Analysis Considered for the Cut, Blinding, And Bolder.

Category	Method of Quantity Takeoff		Rate of Accuracy (%) $(\frac{Q.Revit}{Q.Manual})\times 100$
	Manual (m^3)	REVIT (m^3)	
Cut	4,658.14	4,632.83	**99.46%**
Blinding	76.10	74.68	**98.13%**
Bolder	190.26	187.98	**98.80%**

Based on the comparative investigation between the REVIT software and the manual quantity take-off method described in Table 4.37, it can be inferred that the rate of accuracy provided by the REVIT software when the calculations of cut, blinding, and bolder were executed amounted to a significant rate of precision, which corresponds to 99.46%, 98.13%, and 98.80%, respectively. These results indicate the importance and vital contributions of the REVIT software in carrying out an accurate quantity take-off process for the construction material estimation. A graphical comparison between the bolder and blinding volumes can be represented in Figure 4.8.

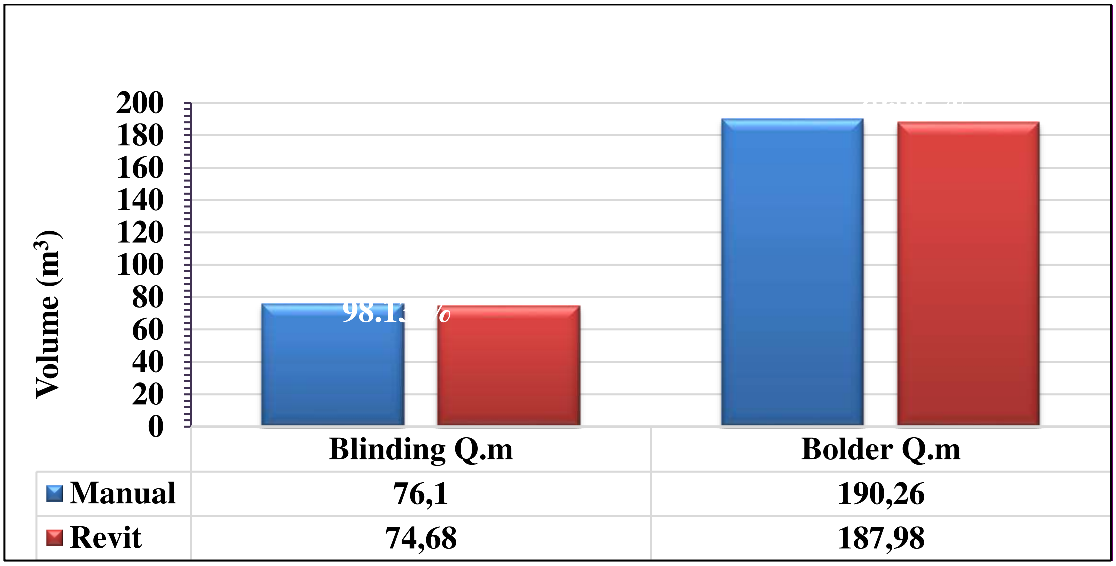

Figure 4.8: A Graphical Comparison Between the Bolder and Blinding Volumes.

It can be inferred from Figure 4.8 that the results of the REVIT software obtained from the implementation of BIM principles gave remarkably accurate findings to the hand calculation outputs with a considerable degree of efficiency. Besides this figure, another configuration is represented in Figure 4.9, explaining the comparison between the manual and REVIT quantity take-off levels related to the cut volume for the project.

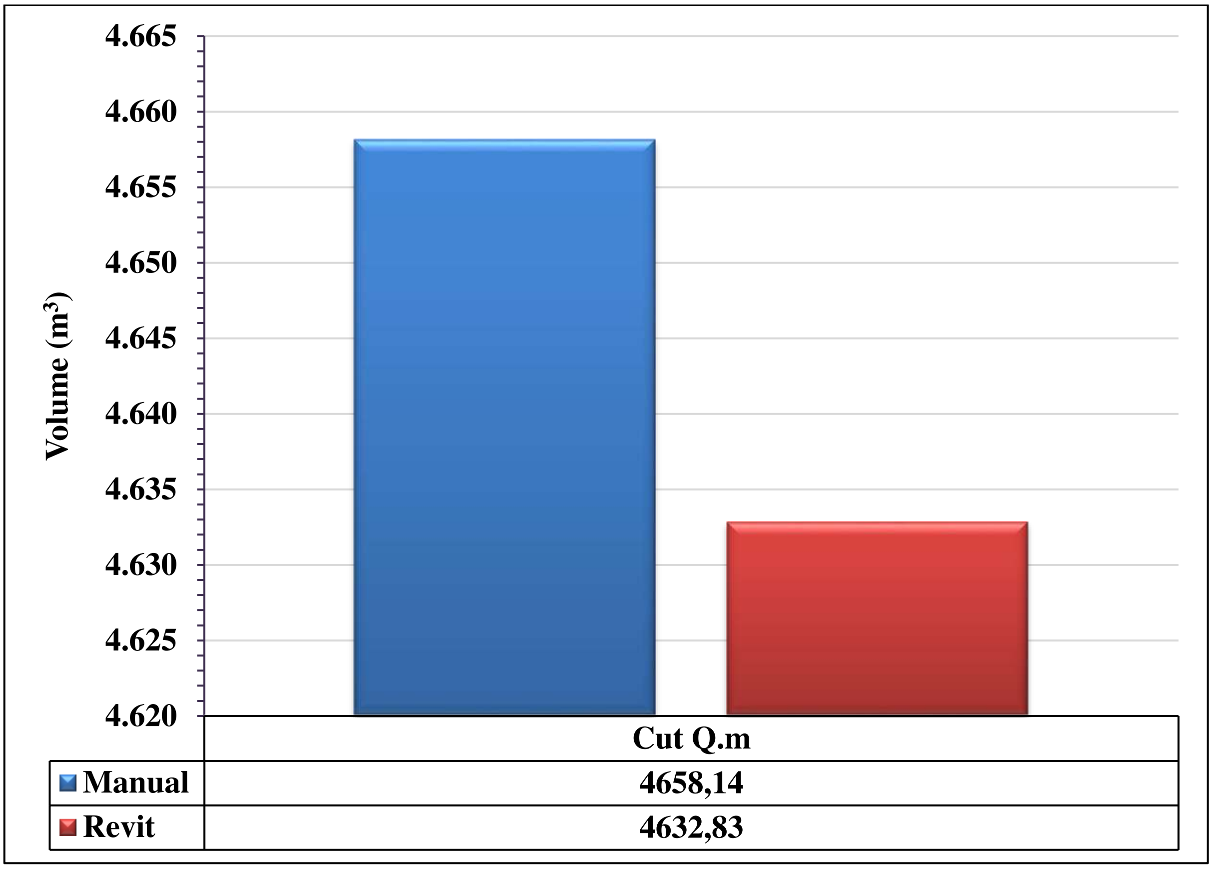

Figure 4.9: A Comparison Between Manual and REVIT Quantity Take-Off Estimation Approaches of the Cut Volume.

It can be concluded from the findings obtained from the results attained in Figure 4.9 that the amount of cut estimated by the REVIT software tool is significantly lower than that evaluated by virtue of manual calculations. However, based on the accuracy obtained from all cases, it is indicated that the quantity estimated by the REVIT software would be more accurate compared with the volume estimations followed using manual methods. Thus, the most accurate value is related to the REVIT programming tool. Hence, this result is considered.

4.5 VOLUME OF REINFORCEMENT CONCRETE ESTIMATION OF OTHER ELEMENTS IN THE PROJECT

The volume of the reinforcement concrete was also assessed for the volume of other elements implemented in the construction project (Royal Baghdad building) considered in this case study. Table 4.38 depicts the thesis outcomes associated with the manual and BIM technology methods applied to the construction material quantities related to the following items:

a. Foundation,
b. Walls and columns,
c. Slabs, and
d. Drop beams.

Table 4.38: The Comparison Findings Between Manual and REVIT Calculation Methods Related to the Estimation of Elements Volume in the Project.

Element Compare	Manual (m^3)	REVIT (m^3)	Rate of Accuracy (%) $(\frac{Q.Revit}{Q.Manual})\times 100$
Foundation	807.63	805.62	**99.75%**
Walls and Columns	735.19	734.61	**99.92%**
Slabs	1,567.75	1,545.20	**98.56%**
Drop Beams	217.74	209.98	**96.44%**

It is deduced from the outcomes illustrated in Table 4.38 that the percentage of reinforcement concrete volume estimation of foundation, walls and columns, slabs, and drop beams contributed to very low rates of errors, as the rate of accuracies achieved for estimating those elements were 99.75%, 99.92%, 98.56%, and 96.44%, respectively. In addition, a graphical layout of the results illustrated in Table 4.20 can be expressed in Figure 4.10.

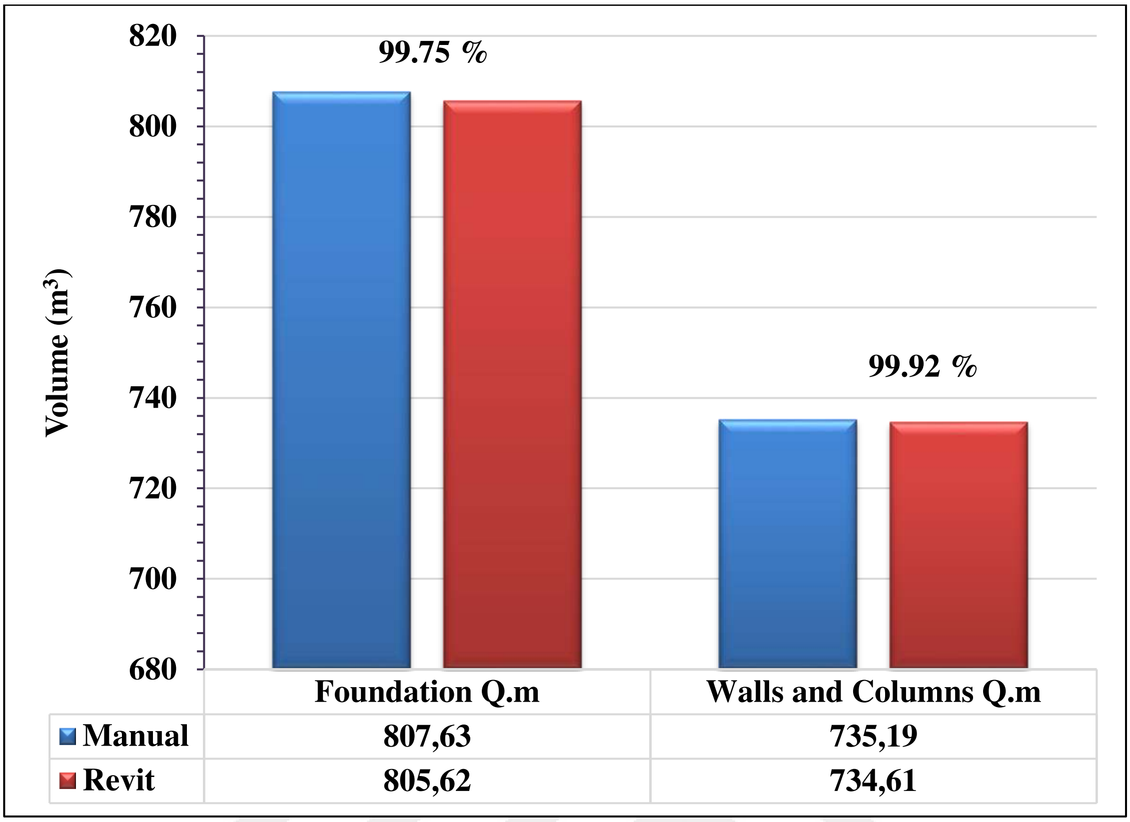

Figure 4.10: A Comparison Between the Manual and REVIT Software Quantity Estimation Methods to Evaluate the Volume of the Foundation, Walls, and Columns.

It is concluded from the results obtained in Figure 4.10 from the manual and REVIT approaches that the reinforcement concrete volume pertaining to the foundation, walls, and columns is remarkably approximate and closer to each other. At the same time, in all cases, the REVIT software gave the most accurate results in terms of concrete estimation. Thus, this result is significantly convenient. Meanwhile, Figure 4.11 indicates the research findings about the comparative analysis carried out to estimate the reinforcement concrete volume of slabs and drop beams concrete volume using manual and REVIT software methods.

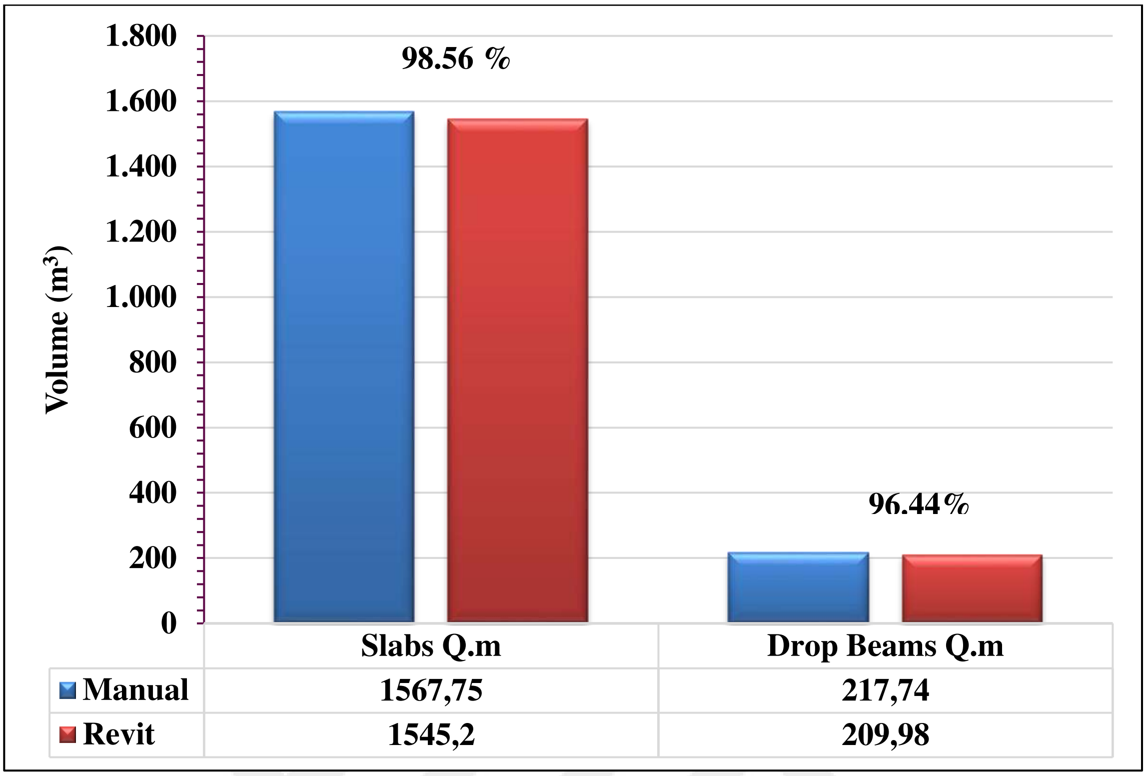

Figure 4.11: The Comparative Results of Slabs and Drop Beams Concrete Volume Using Manual and REVIT Software Methods.

Similar to previous figures represented in the last paragraphs, Figure 4.11 describes that the results obtained from the quantity take-off associated with the manual construction material amount evaluation were highly approximate and precise compared with the REVIT software. Therefore, it can be said that the REVIT software is reliable in making concrete volume estimations numerically using BIM principles.

Besides the estimation of reinforcement concrete implemented in the previous sections, this section indicates some numerical statistics and vital results regarding the evaluation of the steel bars in terms of weight (in kg). The estimation was carried out using two estimation methods:

a. Manual, and
b. REVIT software tool quantity take-off estimation.

Table 4.39 depicts the results of the steel bar weight assessment for some elements in the project of the case study.

Table 4.39: The Comparative Analysis Outputs of Manuakgl and REVIT Software Tool Estimations of Steel Required for Some Elements in the Building.

Element Compare	Manual (ton)	REVIT (ton)	Rate of Accuracy (%) $(\frac{Q.Revit}{Q.Manual})\times 100$
Raft Footing	68.634	65.518	**95.46%**
Columns and Walls	147.440	143.610	**97.40%**
Drop Beams	42.338	41.049	**96.96%**
Slabs	201.033	192.362	**95.69%**
Stair Case	9.697	8.790	**90.65%**

It is indicated from the results represented in Table 4.39 that the quantities estimated from both approaches are substantially closer to each other, recording accuracy rates of 95.46%, 97.40%, 96.96%, 95.69%, and 90.65%, corresponding to raft footing, columns and walls, drop beams, slabs, and staircase, respectively. A graphical representation of those results is illustrated in Figure 4.12.

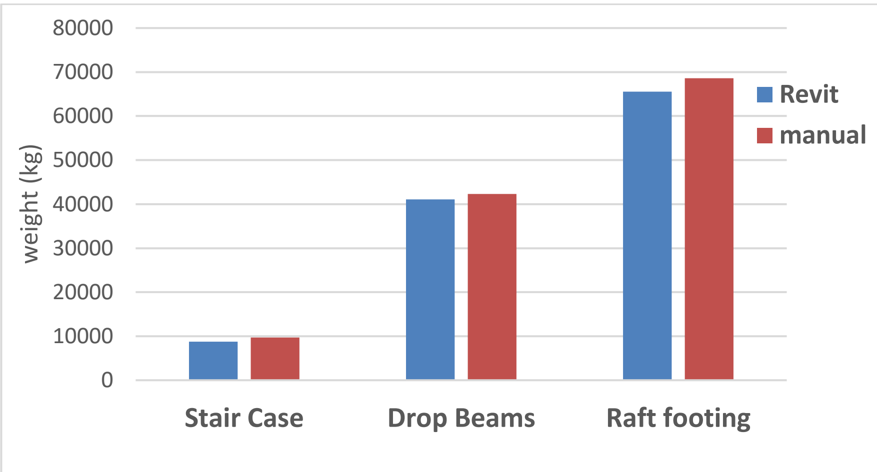

Figure 4.12: A Graphical Illustration of the Comparative Analysis Findings Related to the Steel Bar Estimation in Terms of Kg Using Two Estimation Techniques.

It is observed from the findings attained in Figure 4.12 from the manual and numerical (REVIT software and BIM technology) approaches that both approaches provided notably approximate results in estimating the amount of steel bars used in raft foundations, drop beams, and staircases in kg.

A similar graphical illustration of the steel bar quantity of kg of steel bars utilized in the Royal Baghdad project is indicated in Figure 4.30.

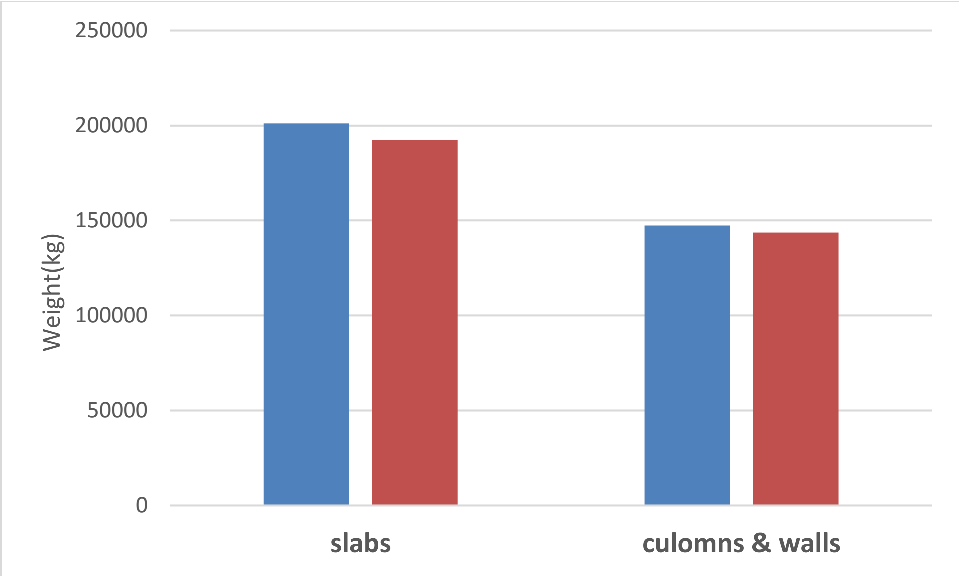

Figure 4.13: A Graphical Layout of Steel Bar Amount Evaluation (in Kg) Related to the Columns and Walls, And Slabs.

It is noted from the estimation results represented in Figure 4.30 that the amount of steel bars (in kg) determined by manual and numerical REVIT tactics were substantially closer to each other, explaining higher levels of reliability and accuracy of the REVIT and BIM technology in providing an optimum estimation of steel bar amounts assessment in the construction project with a significant degree of accuracy.

4.6 SUSTAINABILITY COMPARATIVE ASSESSMENT OF THE CONSTRUCTION PROJECT

The 7D BIM analysis is a method that considers not only the traditional 2D drawings and plans but also the 3D models, schedules, cost intelligence, and sustainability of a building project. 7D BIM is used by builders and project managers for all phases of a project's life cycle, from planning to operation and maintenance [58]. Incorporating 7-dimensional computer-aided design (CAD) into building information modeling (BIM) would improve project management from the design phase all the way to demolition. Furthermore, the 7D BIM modeling is significant to conduct some beneficial impacts for project managers in the construction project, including the following aspects [59]:

a. From the planning stages through to the deconstruction phase, 7D BIM is an invaluable tool for keeping track of how a building or other asset is being managed,

b. During the course of a building's lifecycle, it can simplify the process of replacing components and repairing the structure as a whole, and

c. It can specify the maintenance procedure that the contractor needs to follow.

Figure 4.14 illustrates some beneficial impacts of using 7D modeling principles by virtue of BIM technology in the construction sector.

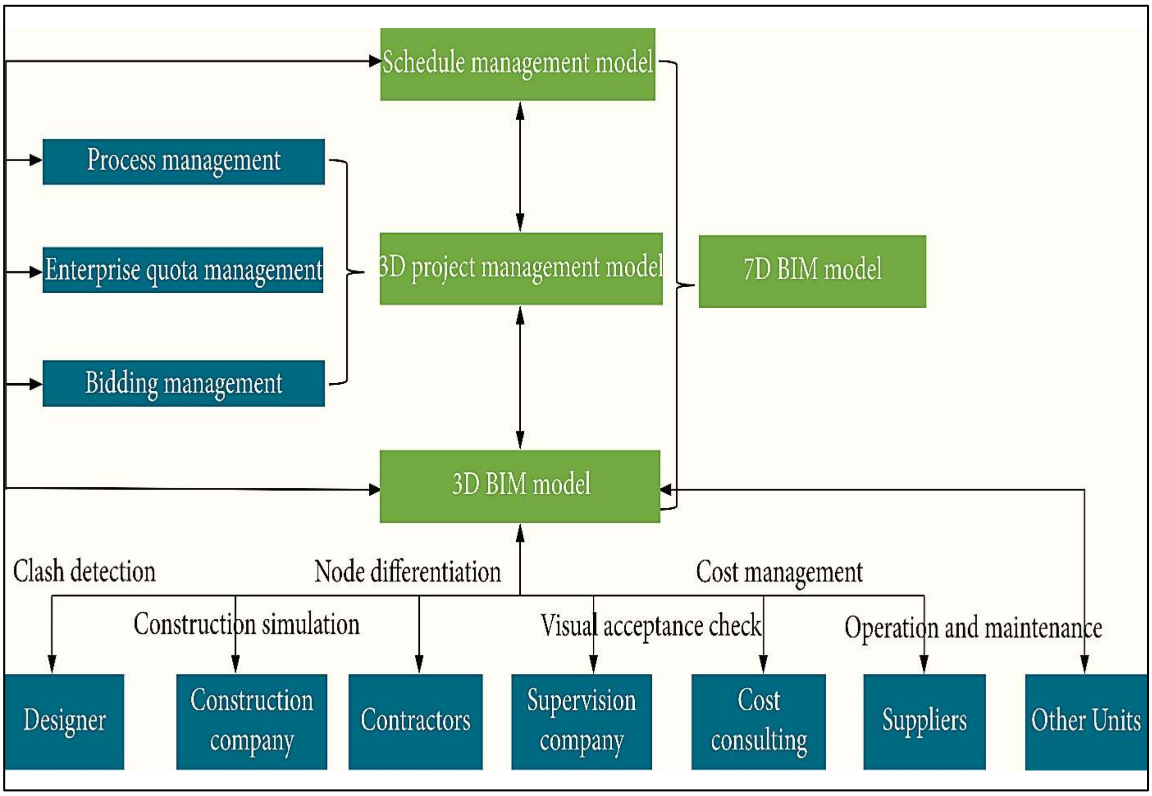

Figure 4.14: The Definition and Major Principles of 7D BIM Modeling (Facility Management) and Analysis of Sustainability Aspects in Construction Projects [60].

Furthermore, Figure 4.15 explains the results of the REVIT software tool used to assess the sustainability aspects using the 7D BIM modeling technology for the Royal Baghdad Project.

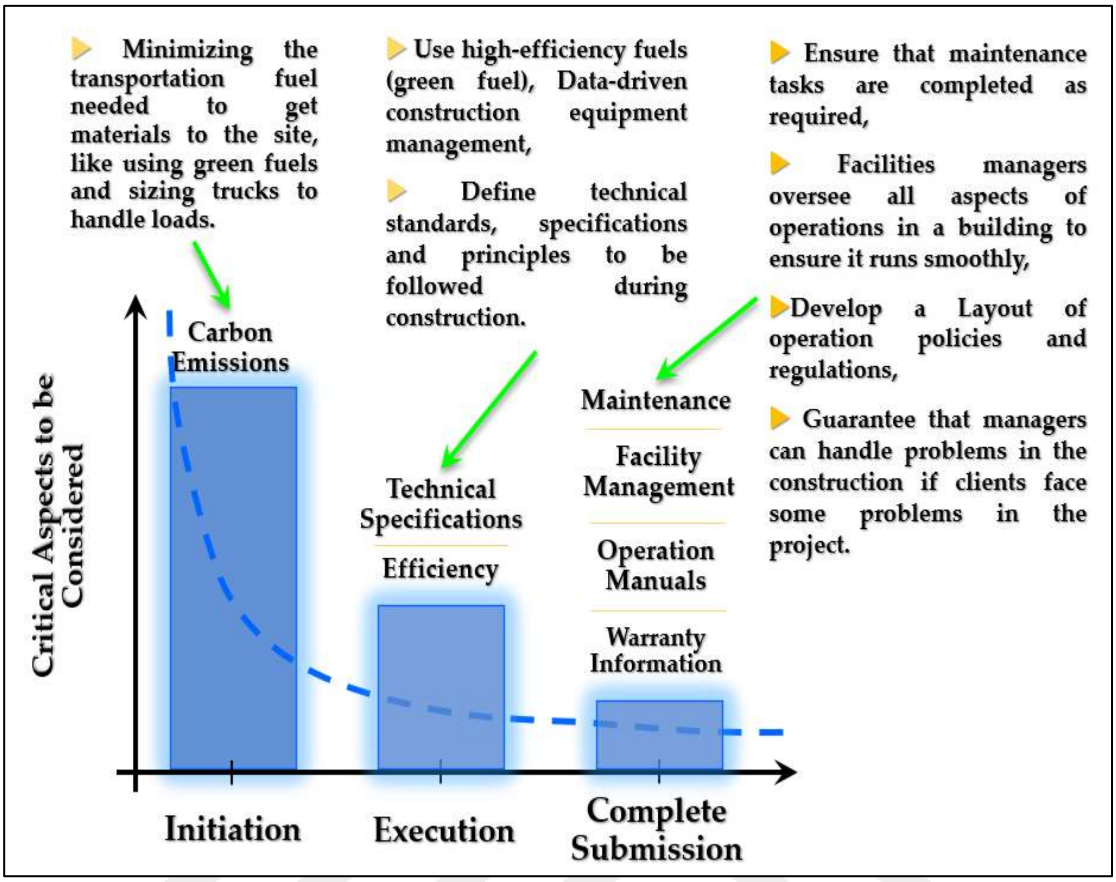

Figure 4.15: The Sustainability Aspects that are Addressed Using the 7D BIM Modeling Technology for the Royal Baghdad Project.

It can be inferred from Figure 4.15 that there are some critical considerations and vital issues that should be taken into account before, during, and after the complete execution of the construction project. For instance, carbon emissions can be managed using 7D BIM modeling principles by virtue of the utilization of green fuels and high-efficient transportation. In addition, minimizing carbon emissions can be done by implementing 7D BIM technology by considering the sizing of trucks and determining the exact weight of loads associated with the construction materials required to be transferred to the site. Other aspects linked to the sustainability management related to the Royal Baghdad project and critical 7D modeling to mitigate these issues can be indicated in Figure 4.32.

4.7 DISCUSSIONS

Through the analysis of manual quantities calculation, which is the most common approach implemented by most engineers, contractors, and high-knowledge experts, who can find it challenging to learn the principles of technical practices associated with the BIM technology, including the REVIT software tool, and through the analytical work carried out in this case study, it was determined that the BIM technology, including the REVIT software tool, plays a critical role in facilitating the management of large construction project, like the commercial one considered in this case study, offering positive rationale of a better time, cost, and effort management. In addition, it was found that the implementation of this innovative technology could help complete the required work quickly and efficiently without the occurrence of various human mistakes and calculation errors. Thus, it can be said that these BIM applications, including the functional REVIT software tool, are the future of modern construction projects. Furthermore, the results revealed that employing the REVIT software tool provided significant rates of accuracy, performance, and reliability in estimating the quantity of various construction materials, offering optimum levels of reliability, performance, and cost-effectiveness required for the quantity take-off compared with the manual quantity take-off. In addition, it was found that considering the 7D BIM technology in the Royal Baghdad project can manage some challenging issues that may cause adverse environmental impacts, including carbon emissions. Also, facility management, Maintenance and Operation (M&O), efficiency, warranty, and other vital aspects can be managed and amended with the help of 7D BIM technology to ensure that the project has significant rates of sustainability. The results of this work are consistent with the research findings of [58], [59], [61]–[74], who conducted an analysis investigating the main contributions and substantial merits and characteristics of 7D BIM technology implementation in the construction sector. The scholars find that adopting the principles of 7D BIM modeling in various small and large construction projects could play a beneficial role and offer pivotal positive advantages for project managers and clients by enhancing the sustainability levels, resilience rates, and positive environmental impacts of different buildings and facilities to make them more clean and green.

5. CONCLUSIONS AND RECOMMENDAITONS

5.1 CHAPTER GOAL

The goal of this chapter is to address the critical findings, and significant research outputs obtained from this work after the principles of 7D BIM modeling were implemented with the help of the REVIT software tool. In addition, the sustainability results obtained from this analysis are explained. Further, recommendations vital to improving this innovative technology's implementation are described.

5.2 CONCLUSIONS

This master's study was directed to analyze and examine the pivotal roles and beneficial contributions of 7D BIM model technology implementation in the construction sector to help enhance sustainability and reduce carbon emissions and other harmful environmental conditions. The research depended on a case study representing a Royal Baghdad construction project. Manual and REVIT evaluation methods were applied to make quantity take-off of the construction materials used in this project. Furthermore, the REVIT 7D modeling was conducted to determine some critical approaches that can be followed to enhance the sustainability of this project. Based on the two techniques used and sustainability assessment by 7D BIM modeling, the research outputs can be listed in the following points:

a. The BIM technology, including the REVIT software tool, plays a critical role in facilitating the management of large construction projects, like the commercial one considered in this case study, offering a positive rationale for better time, cost, and effort management, with accuracy rates between approximately 90.7% and 99.9%.
b. The total steel bar reinforcement weight used in this project reached around 469142 kg compared with 451329 kg using conventional and REVIT methods.
c. The total reinforced concrete volume amounted to 3,328.31 m^3 and 3,295.41 m^3, using the conventional and REVIT estimation methods, respectively.
d. Implementing this innovative technology could help complete the required work quickly and efficiently without various human mistakes and calculation errors. Thus, it can be said that these BIM applications, including the functional REVIT software tool, are the future of modern construction projects.

e. Employing the REVIT software tool provided significant accuracy, performance, and reliability rates in estimating the quantity of various construction materials, offering optimum levels of reliability, performance, and cost-effectiveness required for the quantity take-off compared with the manual quantity take-off.
f. Considering the 7D BIM technology in the Royal Baghdad project can manage some challenging issues that may cause adverse environmental impacts, including carbon emissions.
g. Facility management, Maintenance and Operation (M&O), efficiency, warranty, and other vital aspects can be monitored and amended with the help of 7D BIM technology to ensure that the project has significant rates of sustainability.

5.3 RECOMMENDATIONS

According to the research findings obtained from this analytical research guided to address the substantial contributions of 7D BIM modeling in boosting the sustainability rates and facility management practising in construction projects, this study proposes a set of critical recommendations that can play a practical role in enhancing the implementation of 7D BIM technology in the construction sector. These vital recommendations include the following aspects:

a. To enhance the levels of skills, experience, and knowledge of project managers and construction professionals regarding sustainability enhancement using training sessions and 7D BIM courses.
b. To enhance the awareness among junior engineers to facilitate the prevalence of sustainability principles in the construction sector with the help of 7D BIM consultants.
c. To increase the attention to sustainability considerations and 7D BIM modeling implementation in different construction sectors with the help of facilitators (like regulations and laws) to reduce carbon emissions and minimize the adverse impacts of the construction sector on the local environment.

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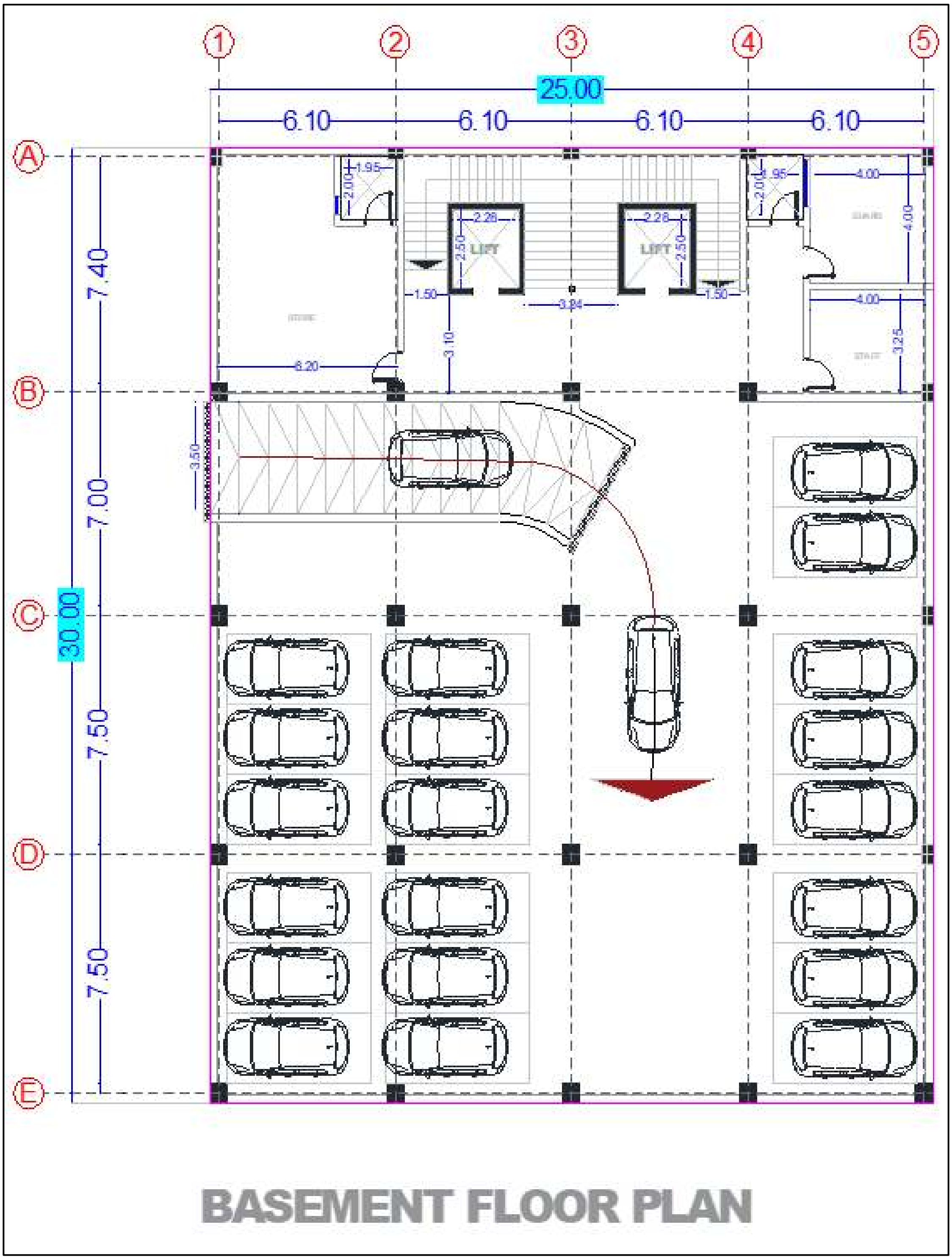
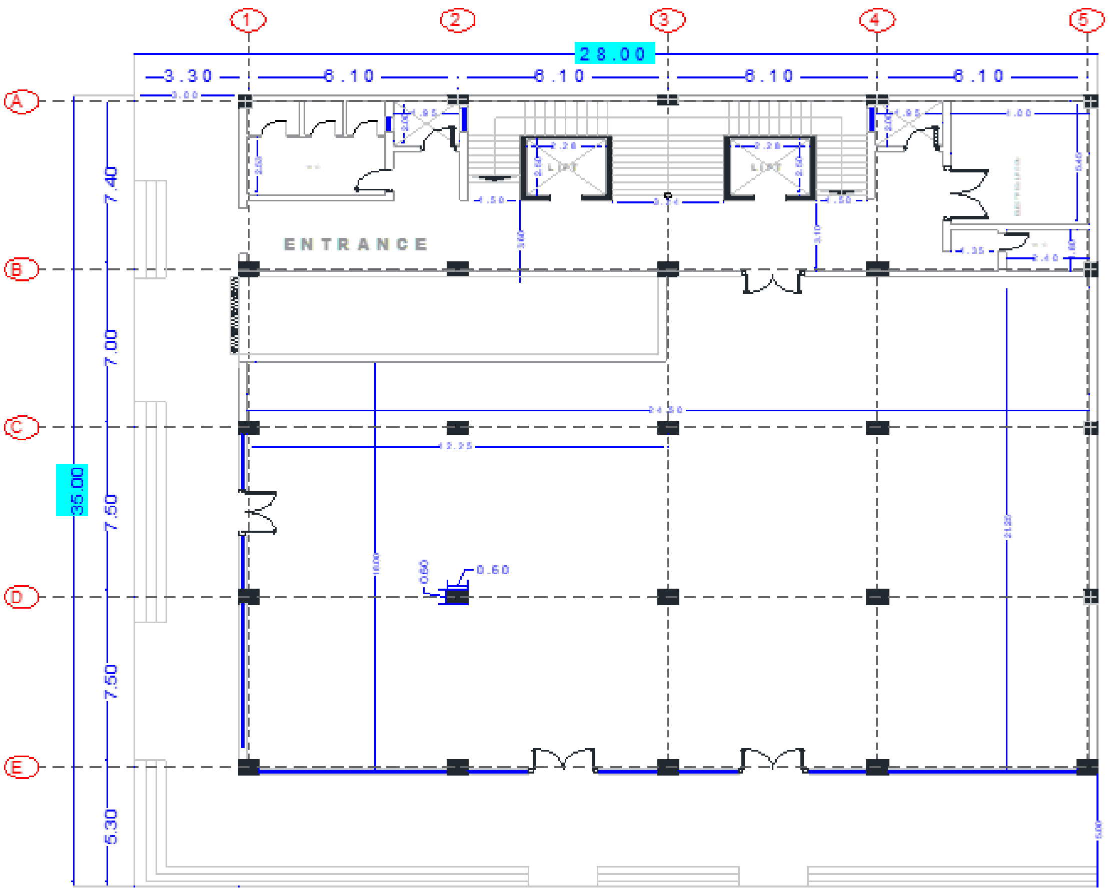
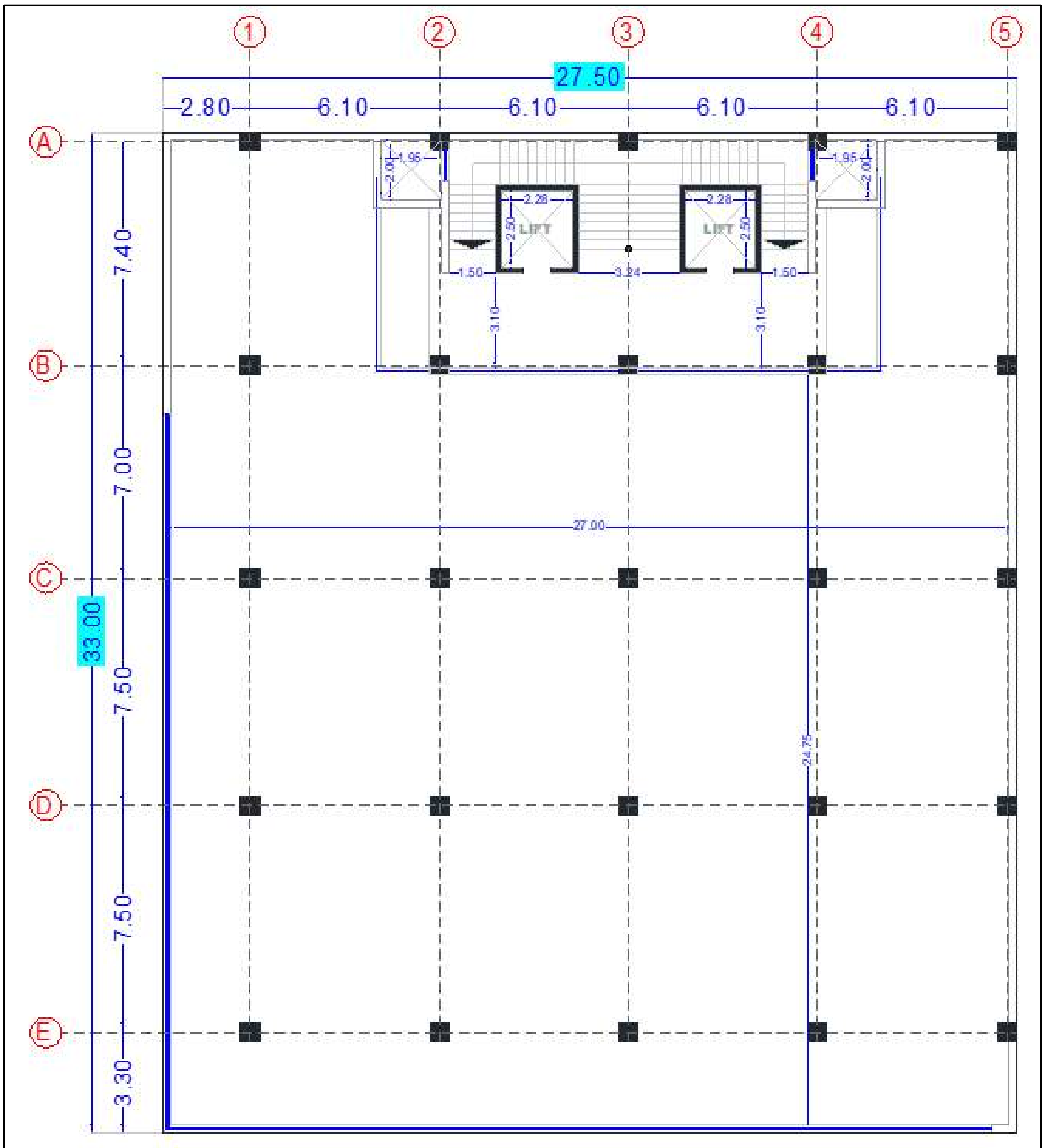
APPENDIX A

ARCHITECTURES PLANS FOR THE ROYAL BAGHDAD PROJECT

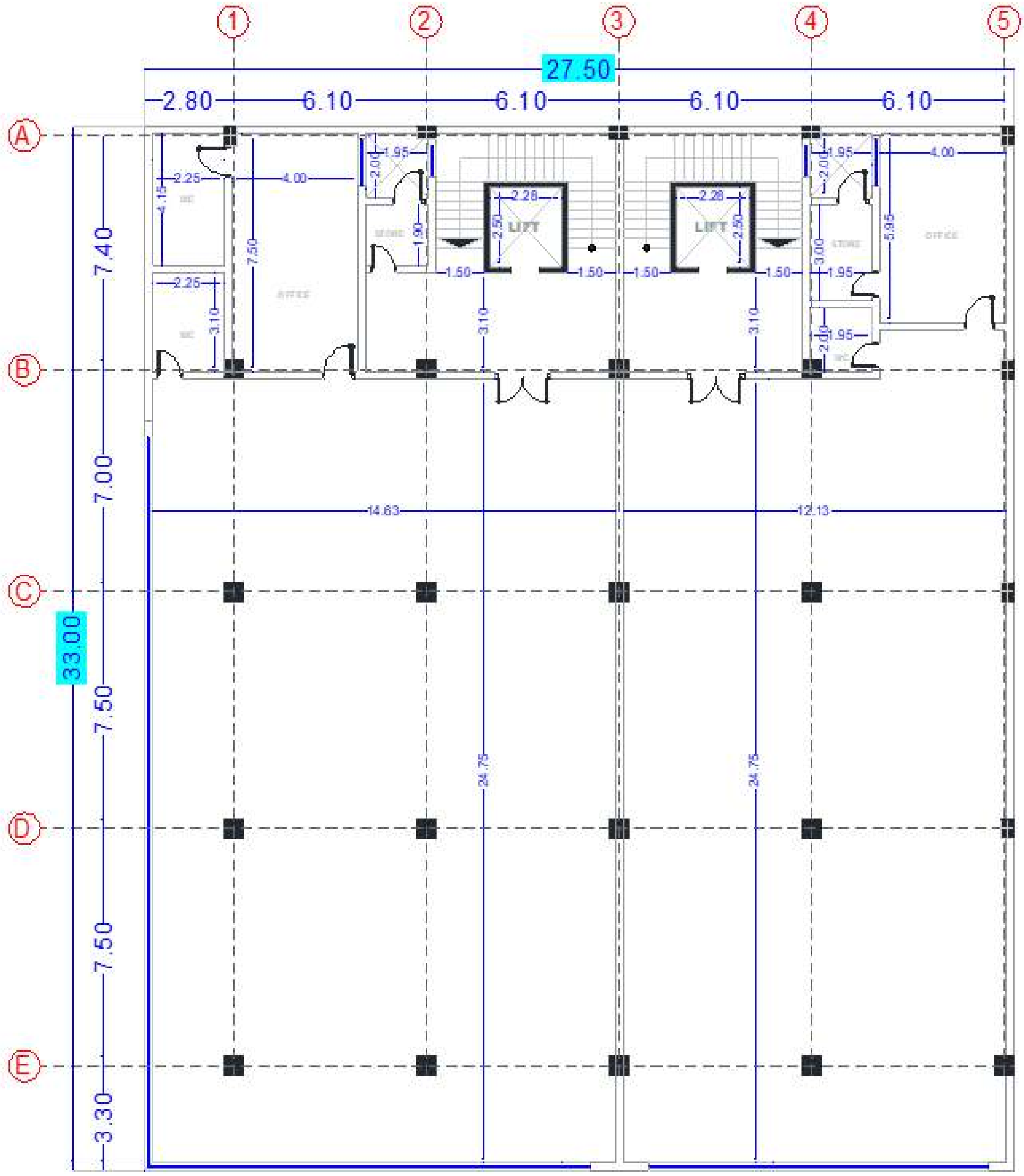




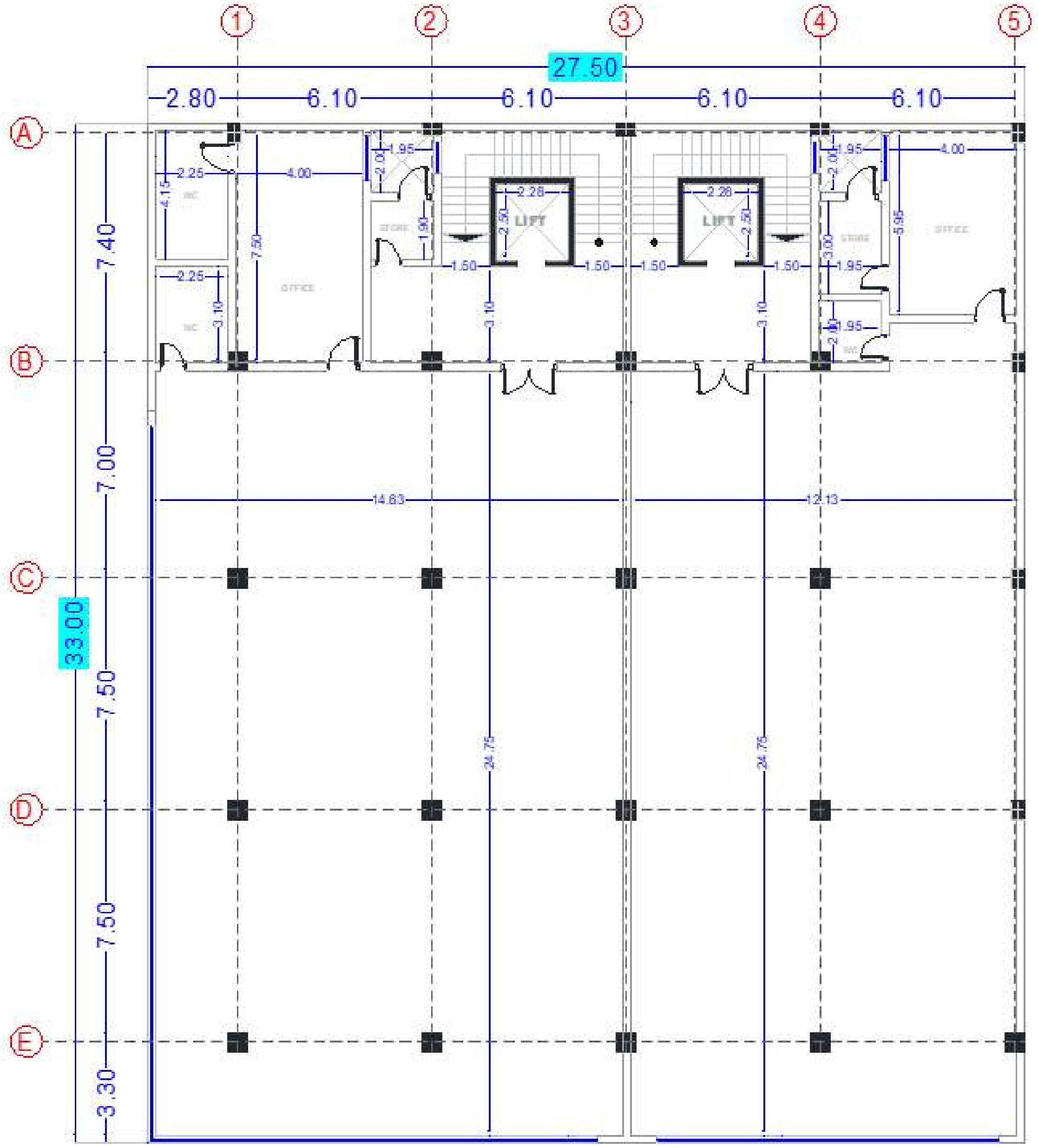
GROUND FLOOR PLAN



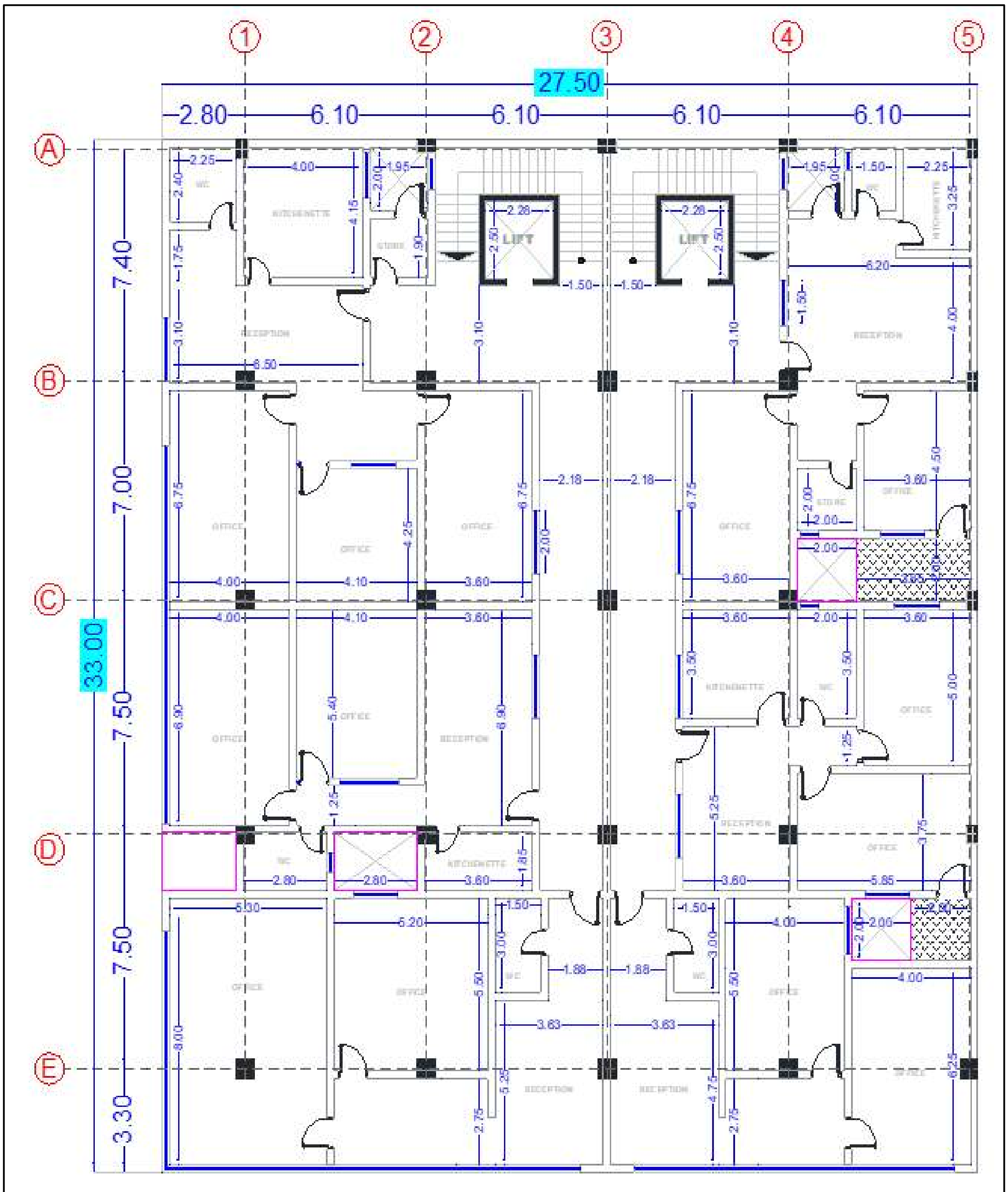
MEZZANINE FLOOR PLAN



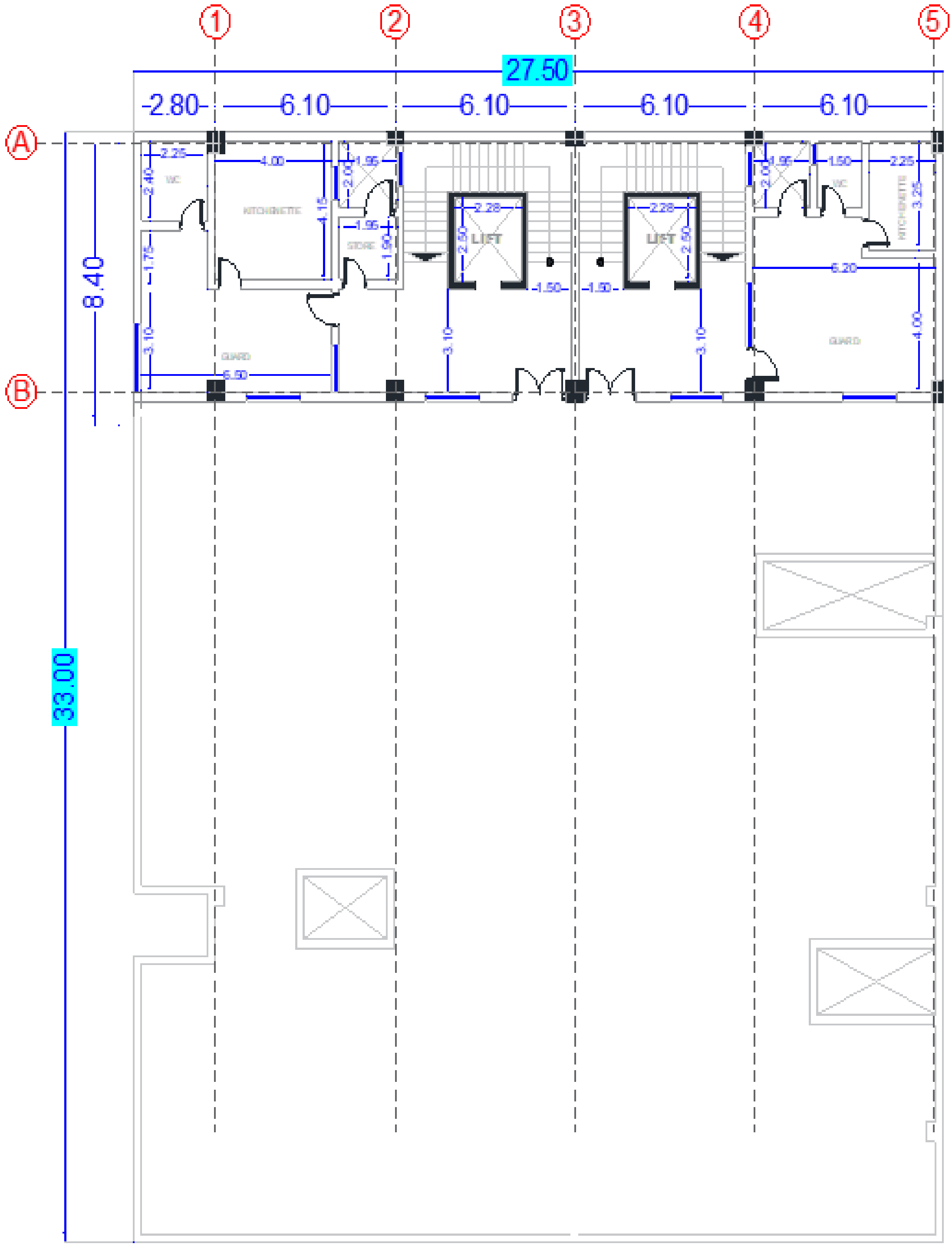
FIRST FLOOR PLAN - TWO HALL



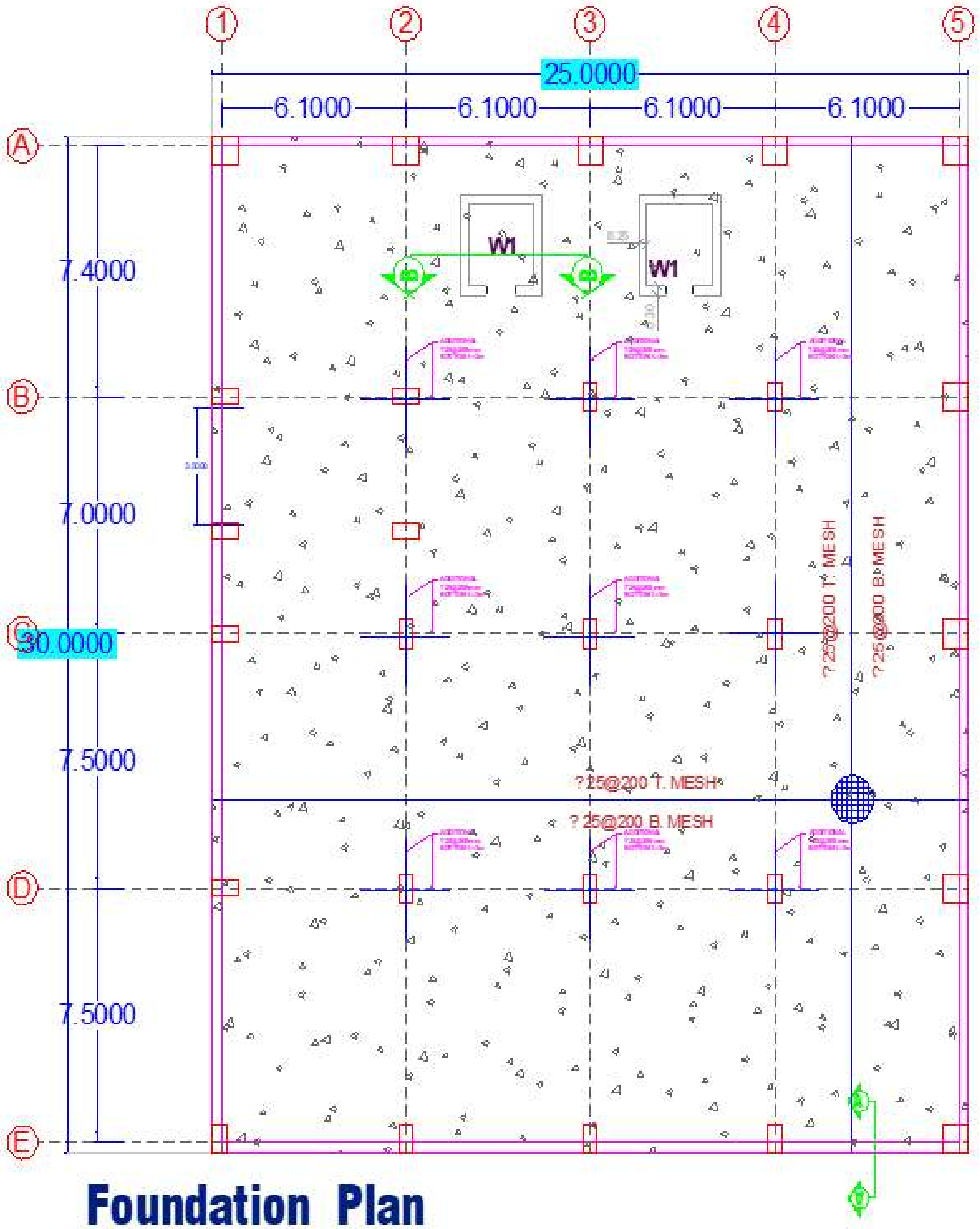
FIRST FLOOR PLAN - TWO HALL



TYPICAL FLOOR PLAN



PENTHOUSE FLOOR PLAN

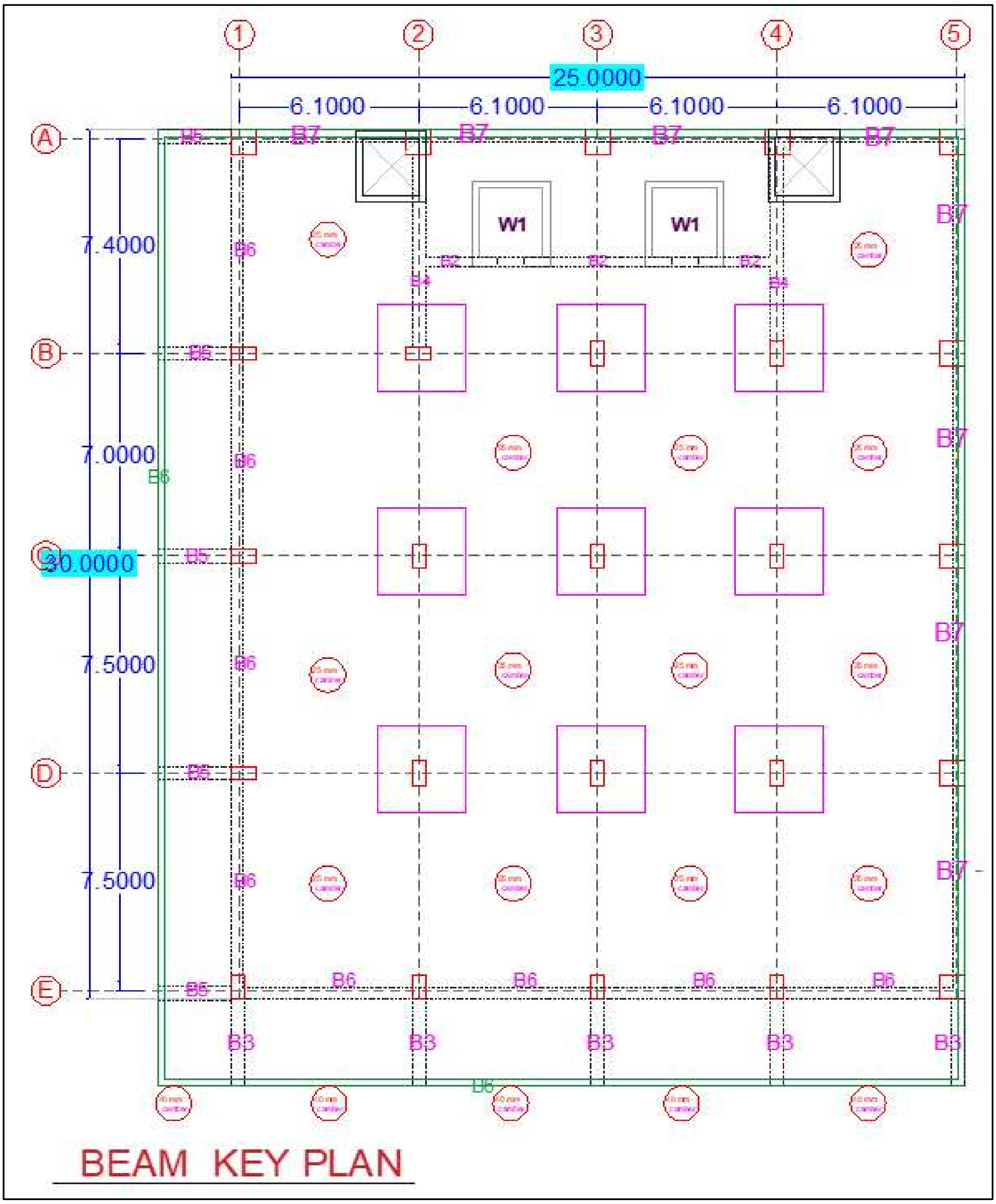


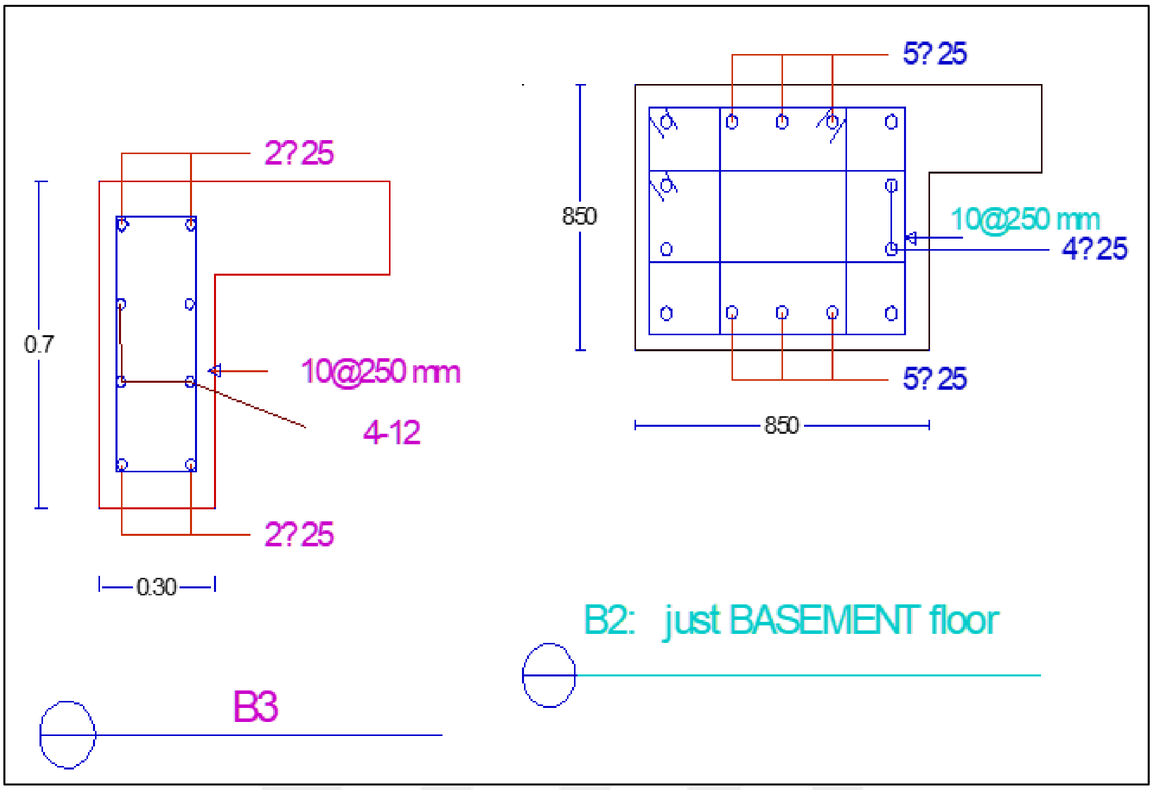
Foundation Plan

THICK. = 1100 mm

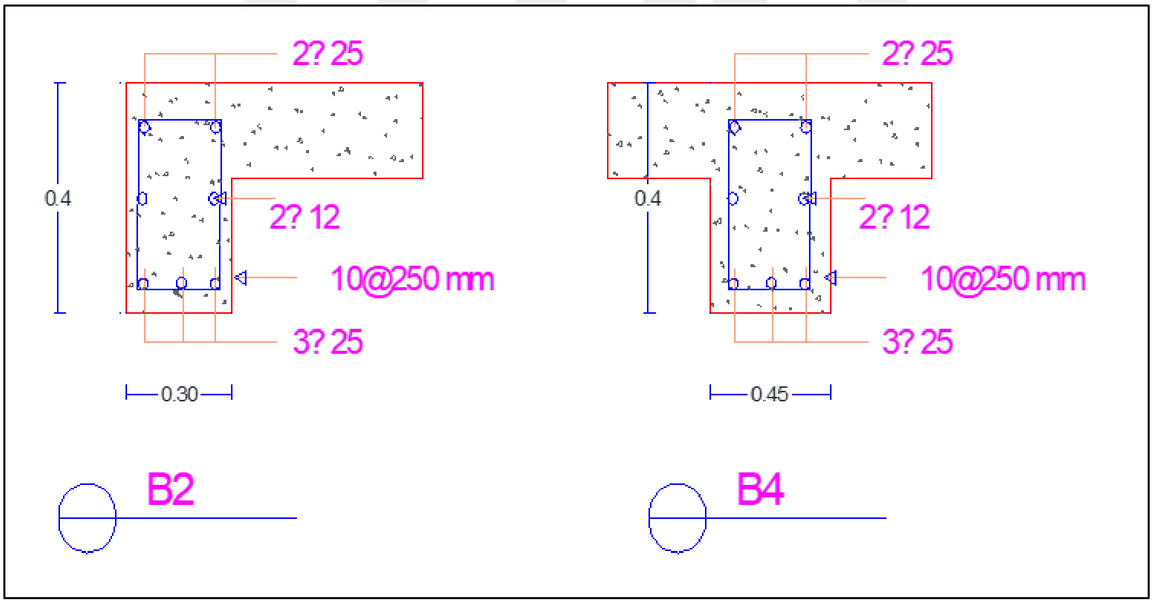
APPENDIX B

(B-1): THE PLANS OF THE 2D LAYOUT AND DESIGN OF THE BEAMS USED IN THE ROYAL BAGHDAD PROJECT

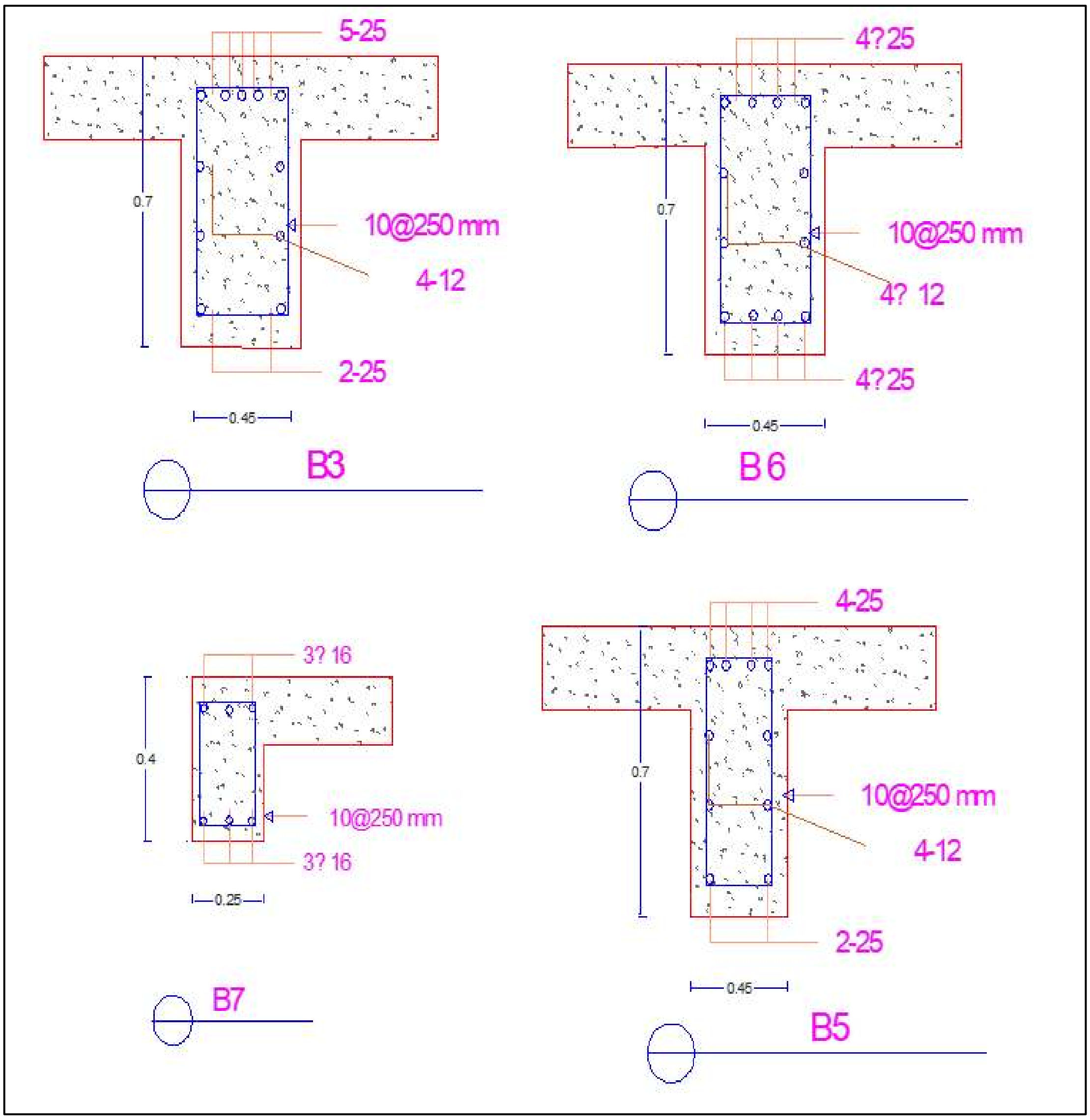


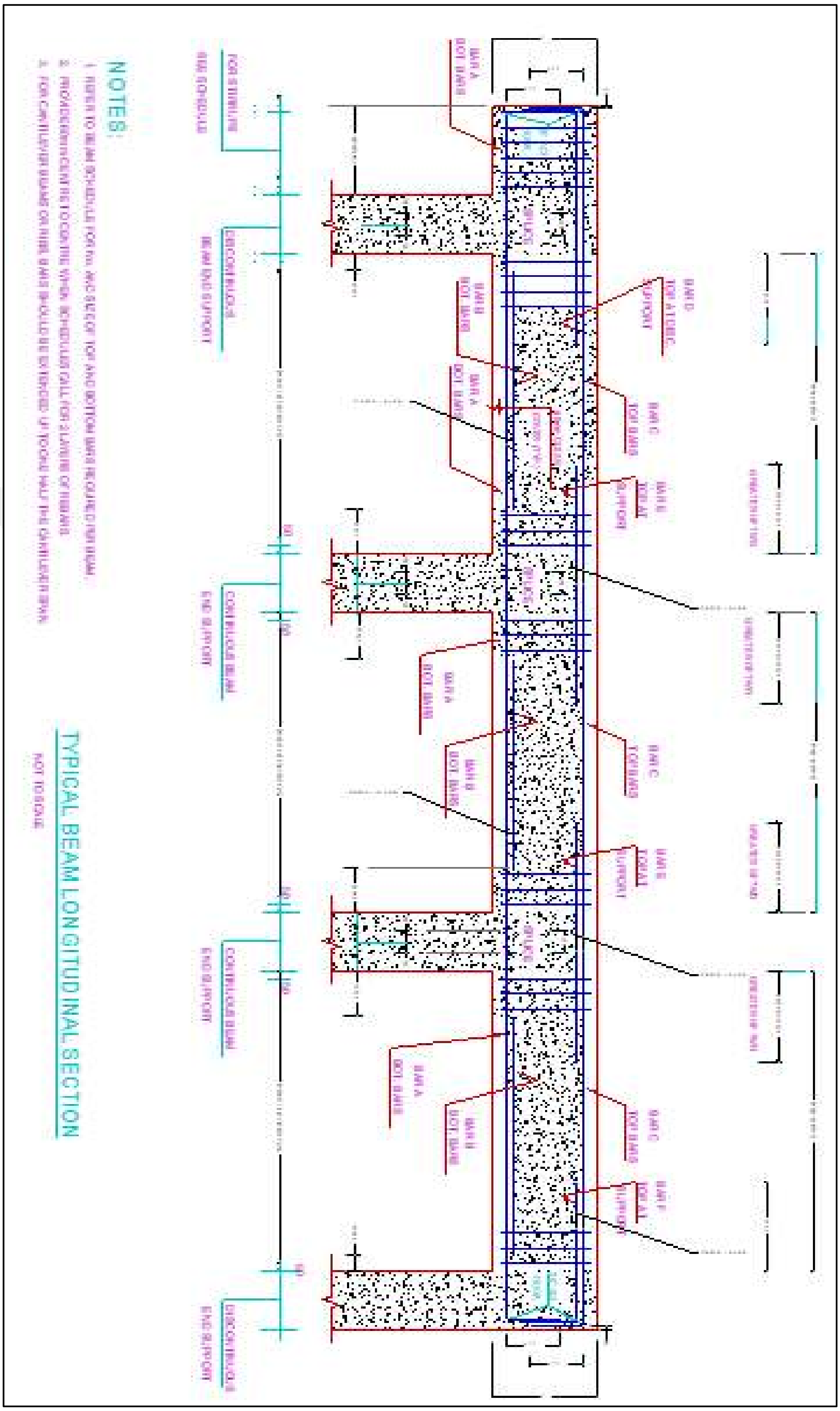


2? 25
0.7
10@250 mm
4-12
2? 25
0.30
B3
5? 25
850
10@250 mm
4? 25
5? 25
850
B2: just BASEMENT floor



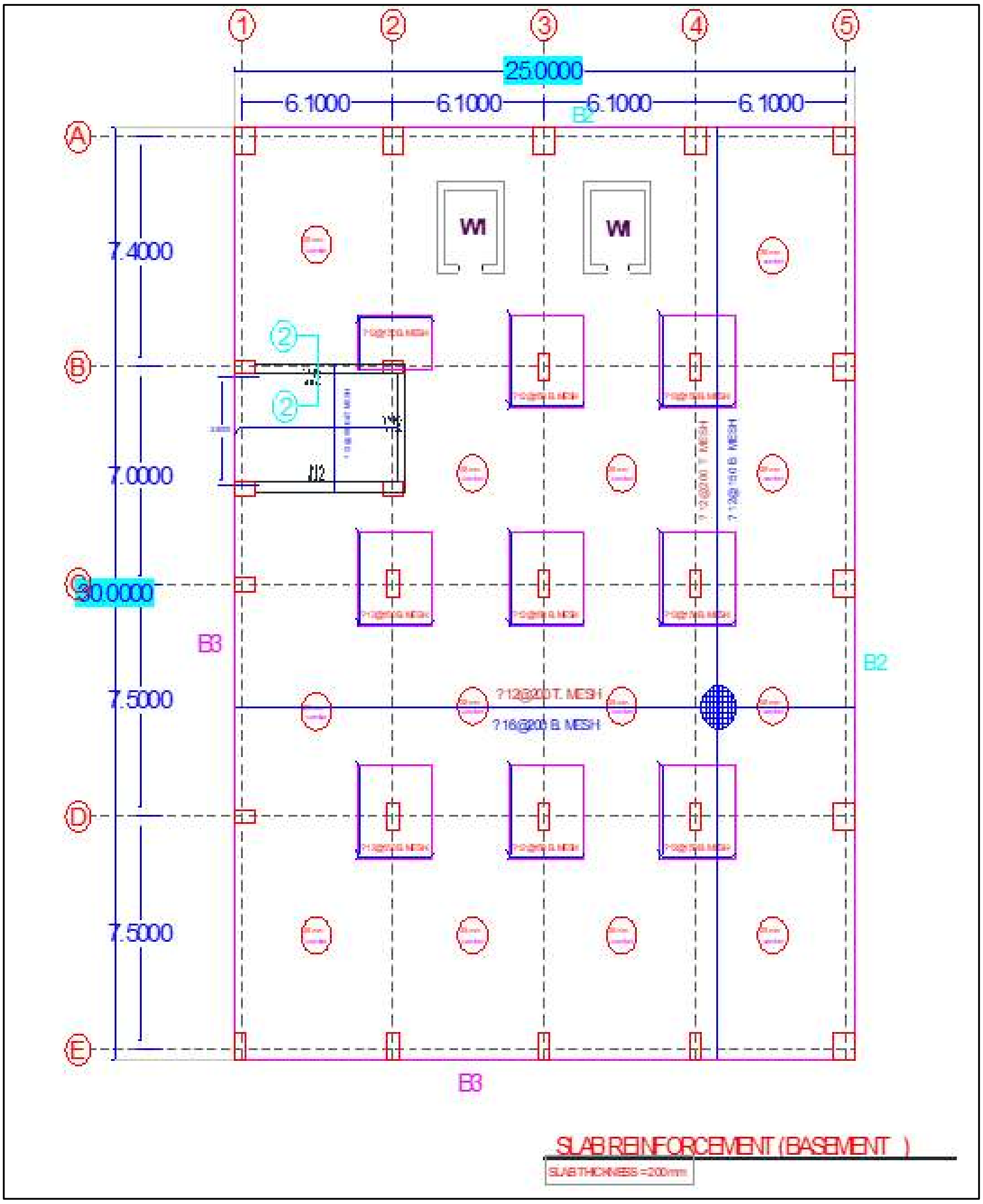
2? 25
0.4
2? 12
10@250 mm
3? 25
0.30
B2
2? 25
0.4
2? 12
10@250 mm
3? 25
0.45
B4

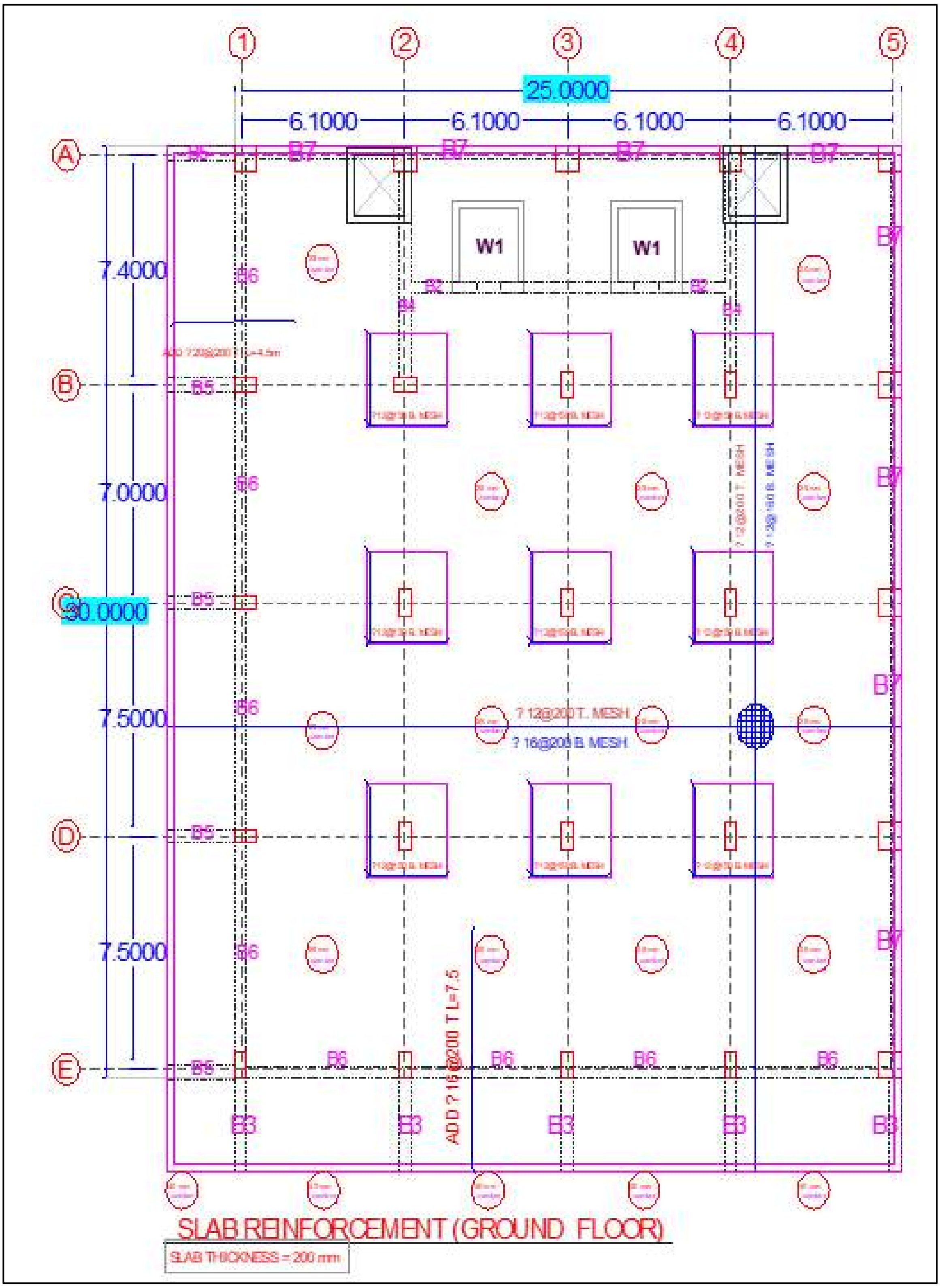

5-25
0.7
10@250 mm
4-12
2-25
0.45
B3
4?25
0.7
10@250 mm
4? 12
4?25
0.45
B 6
3? 16
0.4
10@250 mm
3? 16
0.25
B7
4-25
0.7
10@250 mm
4-12
2-25
0.45
B5



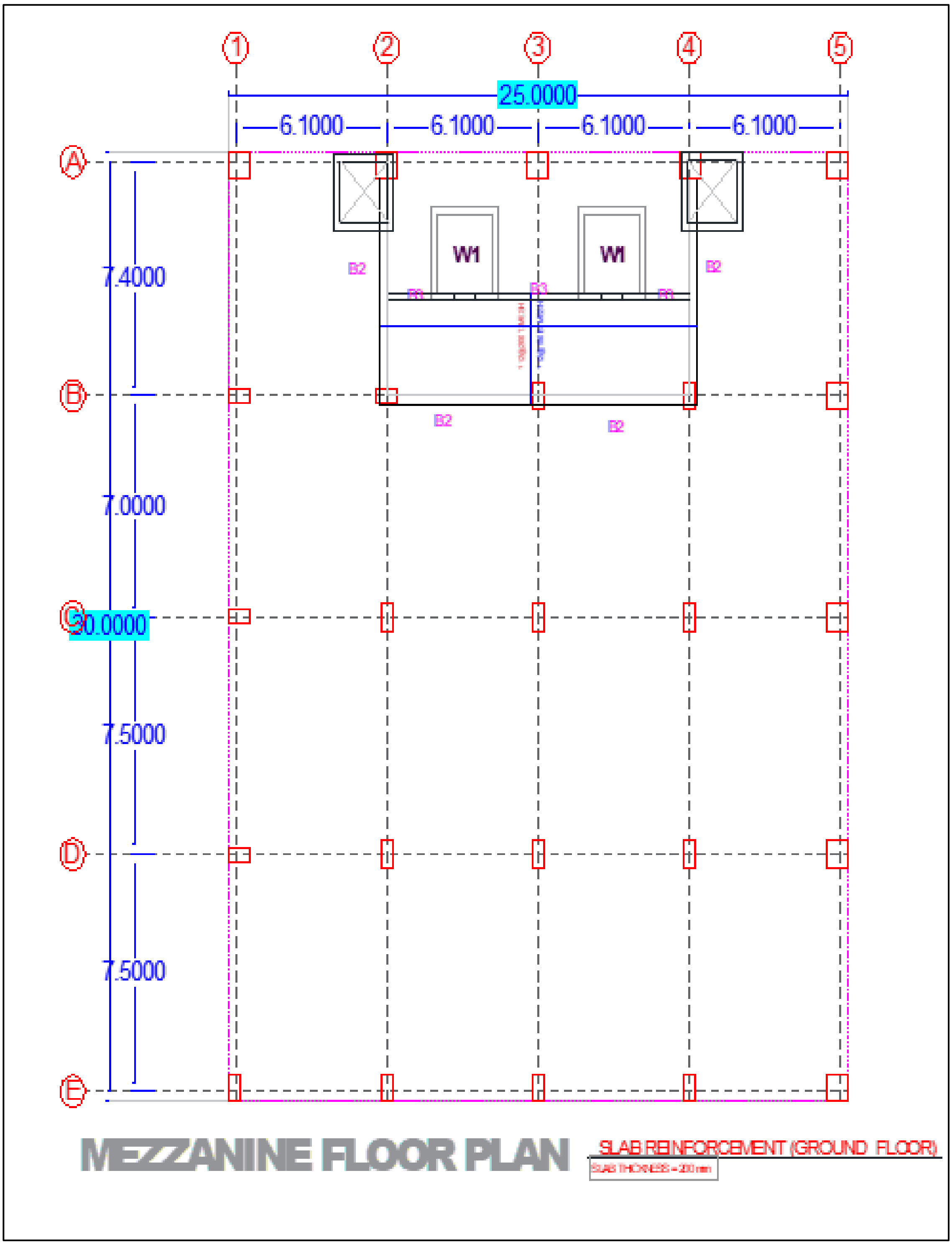
BAR D
TOP AT DISC. SUPPORT
BAR C
TOP BARS
BAR E
TOP AT SUPPORT
BAR F
TOP AT SUPPORT
BAR A
BOT. BARS
BAR B
BOT. BARS
SPLICE
FOR STIRRUPS
SEE SCHEDULE
DISCONTINUOUS
BEAM END SUPPORT
CONTINUOUS BEAM
END SUPPORT
DISCONTINUOUS
END SUPPORT
NOTES:
TYPICAL BEAM LONGITUDINAL SECTION
NOT TO SCALE

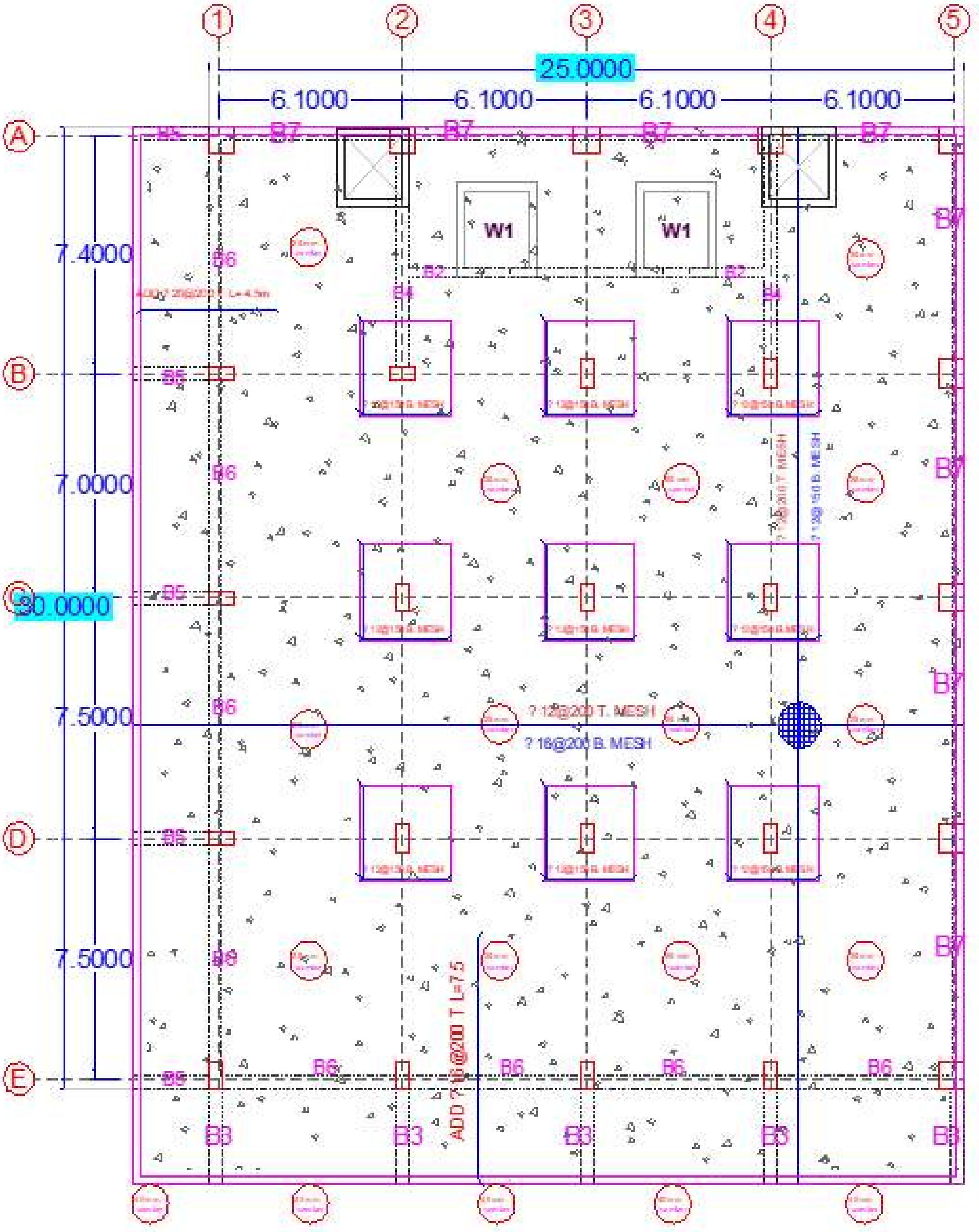
(B-2): THE PLANS OF THE 2D LAYOUT AND DESIGN OF THE SLABS USED IN THE ROYAL BAGHDAD PROJECT





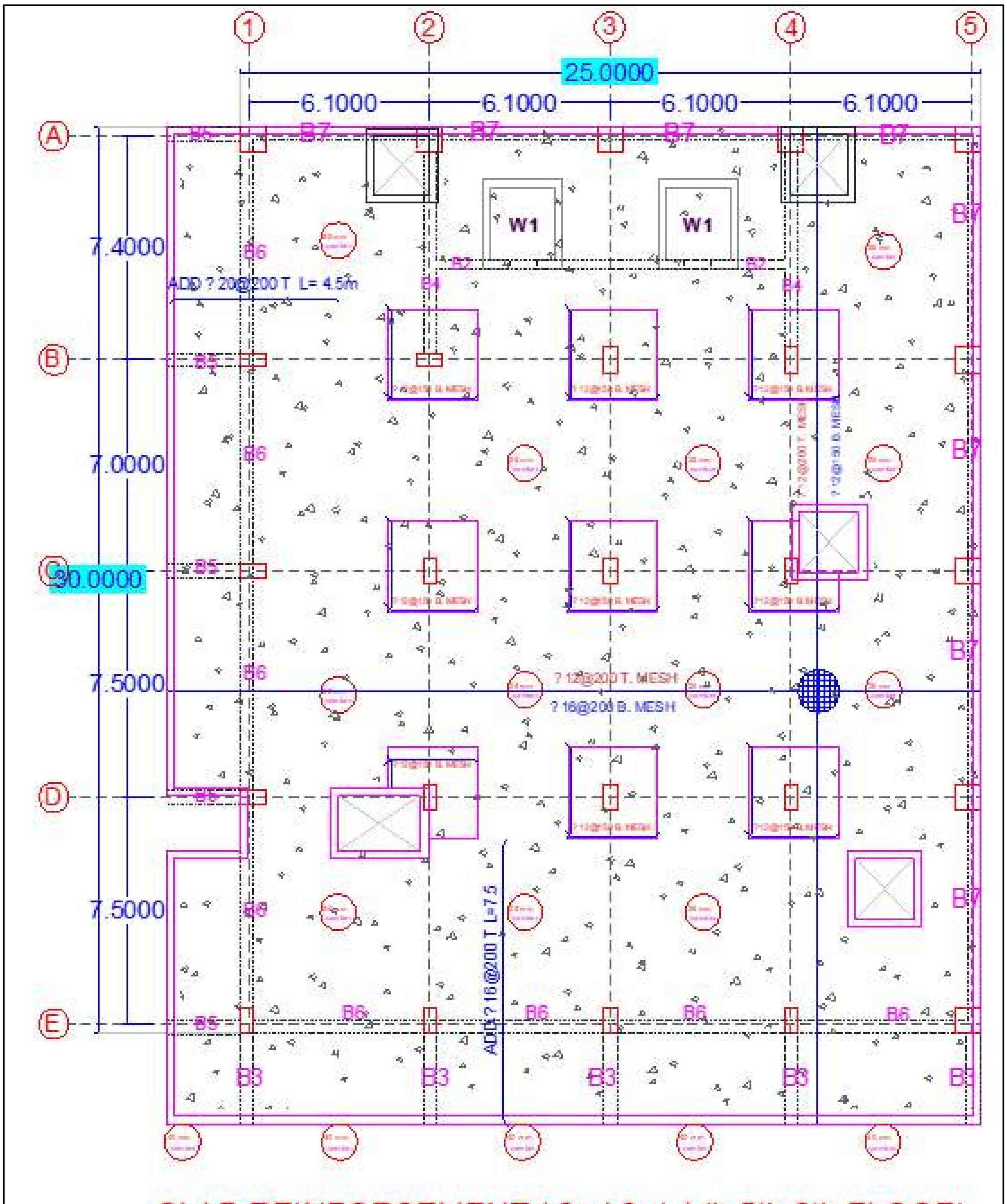
1
2
3
4
5
A
B
C
D
E
25.0000
6.1000
6.1000
6.1000
6.1000
7.4000
7.0000
30.0000
7.5000
7.5000
W1
W1
B7
B6
B5
B4
B3
B2
? 12@200 T. MESH
? 16@200 B. MESH
? 12@200 T. MESH
? 12@160 B. MESH
ADD ? 16@200 T L=7.5
SLAB REINFORCEMENT (GROUND FLOOR)
SLAB THICKNESS = 200 mm


1
2
3
4
5
25.0000
6.1000
6.1000
6.1000
6.1000
A
B
C
D
E
7.4000
7.0000
30.0000
7.5000
7.5000
W1
W1
B2
B2
B3
B2
B2
MEZZANINE FLOOR PLAN
SLAB REINFORCEMENT (GROUND FLOOR)

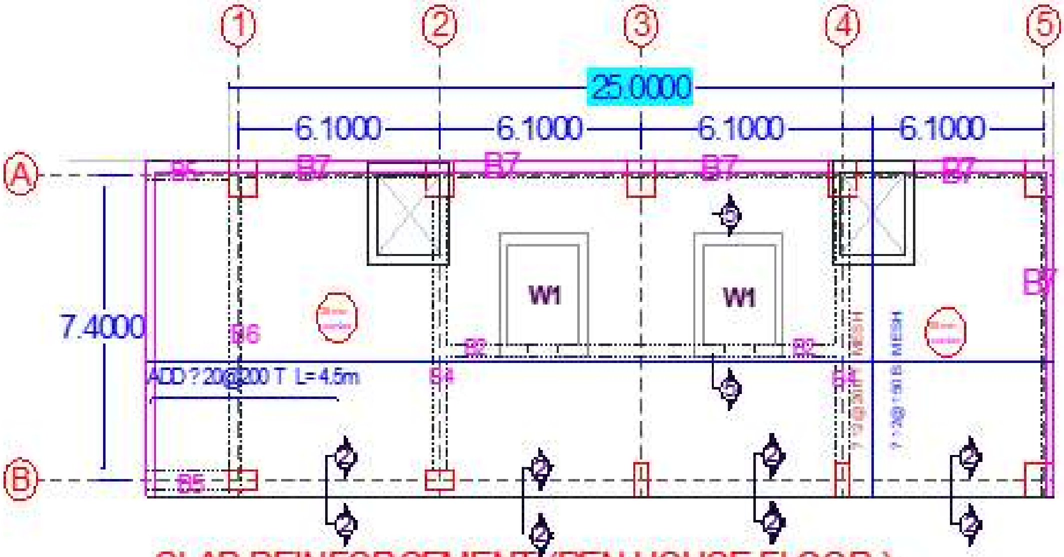


SLAB REINFORCEMENT (1st FLOOR)

SLAB THICKNESS = 200 mm

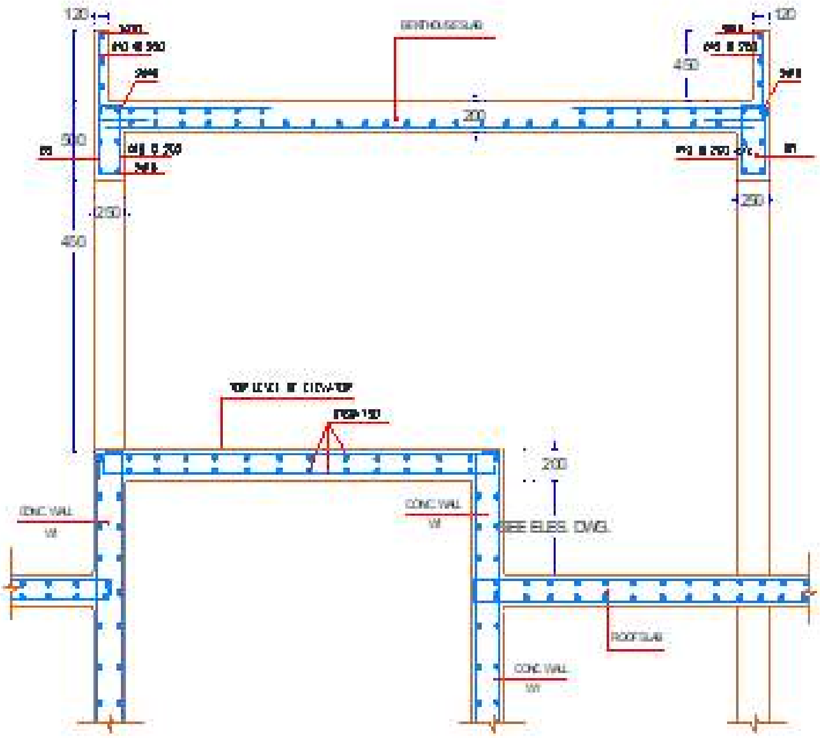


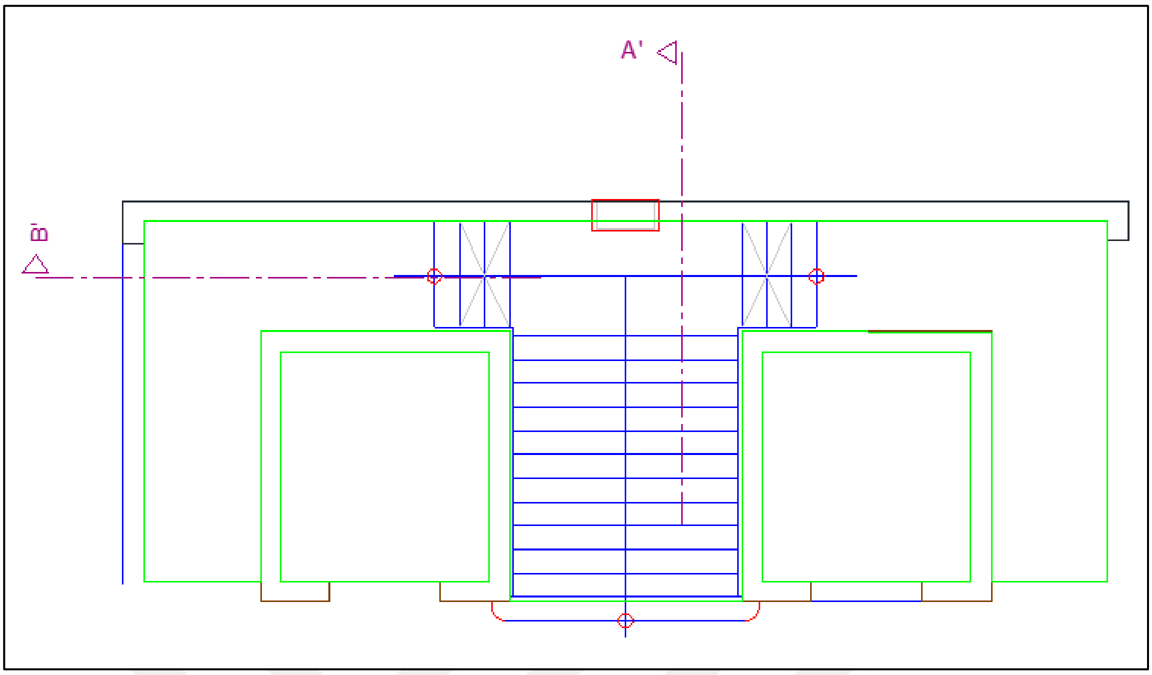
SLAB REINFORCEMENT (2nd,3rd,4rth,5th,6th FLOOR)

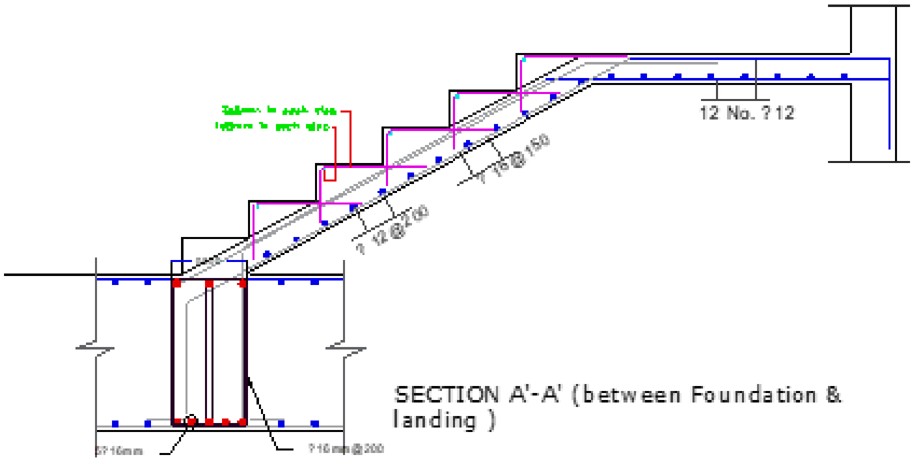


SLAB REINFORCEMENT (PEN HOUSE FLOOR)

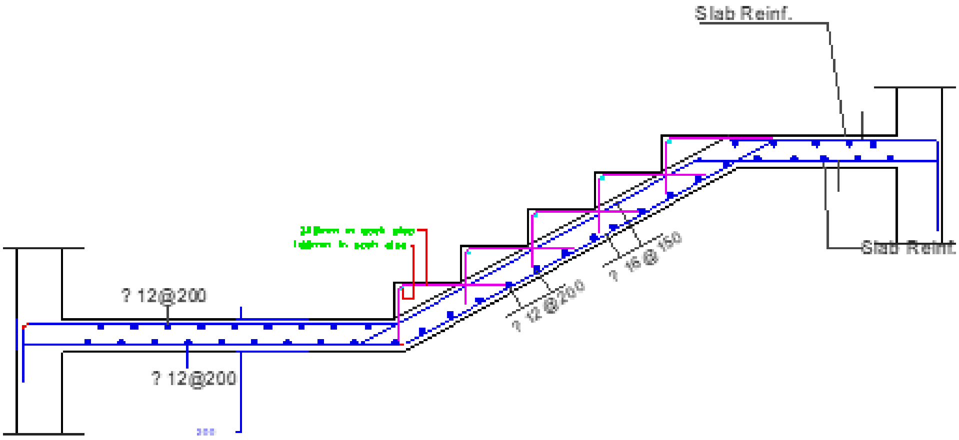
SLAB THICKNESS = 200 mm



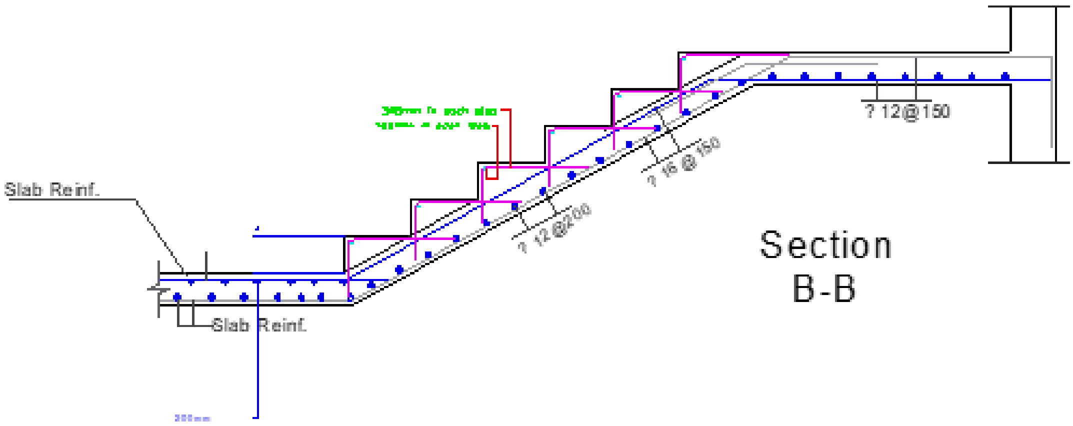

A'
B'



SECTION A'-A' (between Foundation & landing)

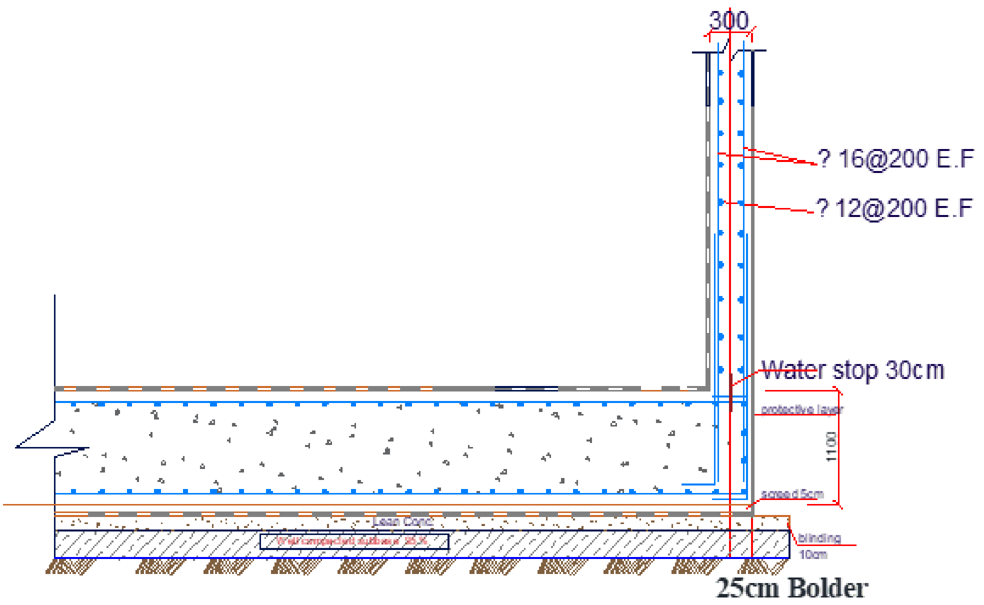


SECTION A'-A' (between slab & landing)

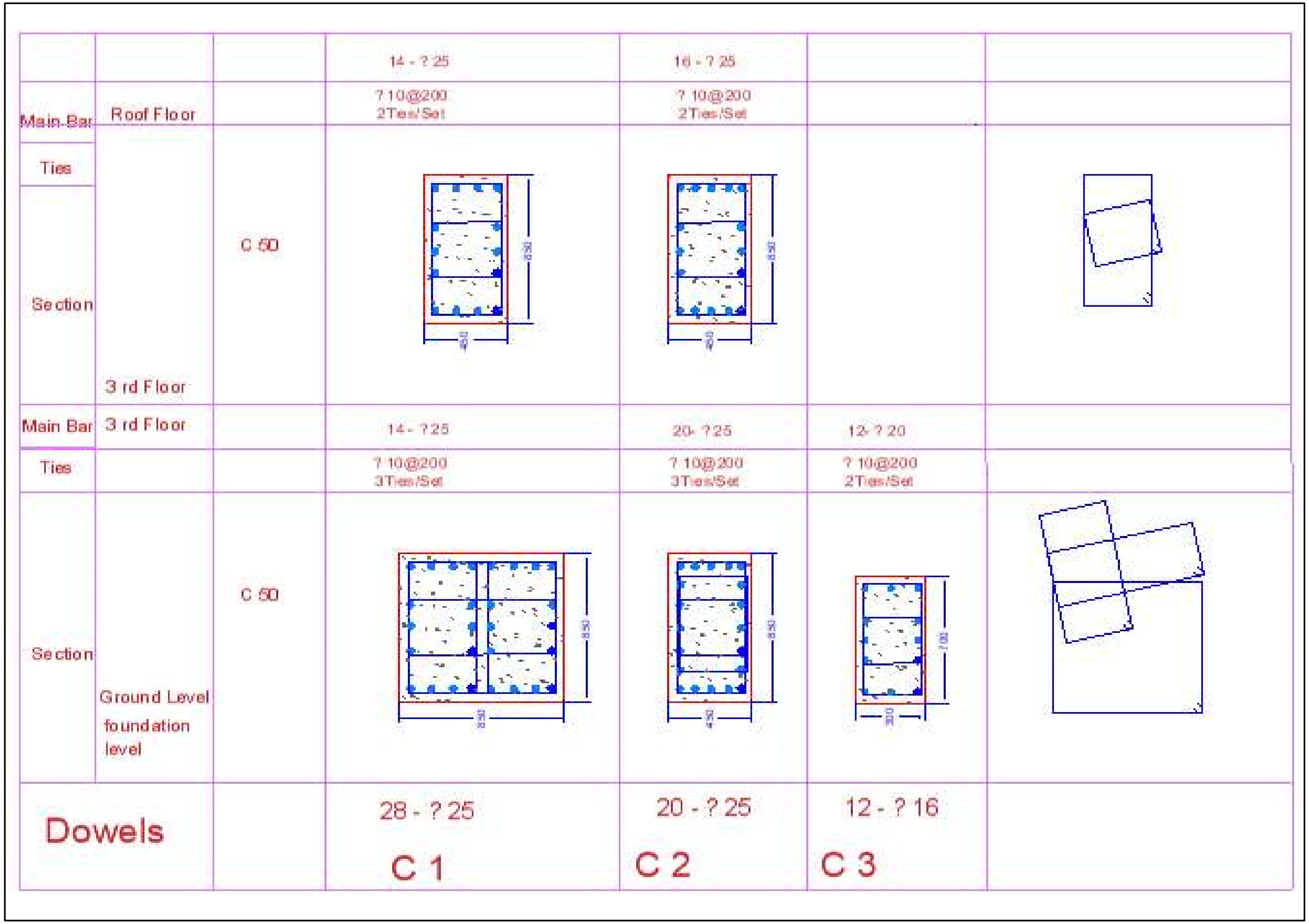


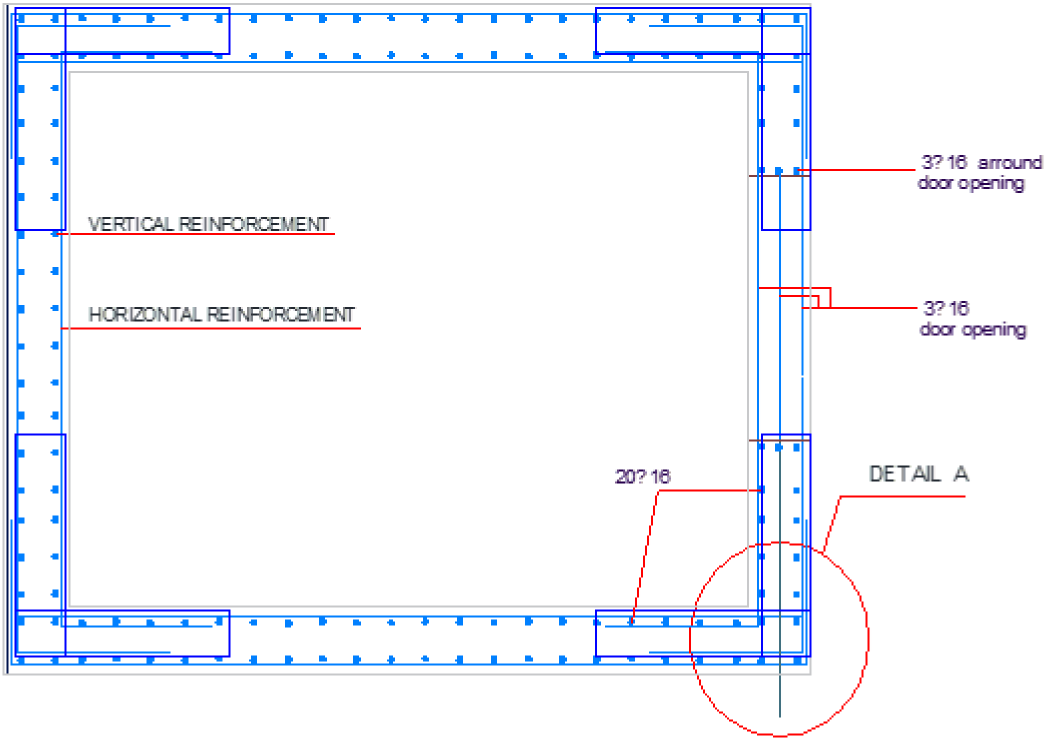
Section B-B

(B-3): THE PLANS OF THE 2D LAYOUT AND DESIGN OF THE COLUMNS AND WALLS USED IN THE ROYAL BAGHDAD PROJECT

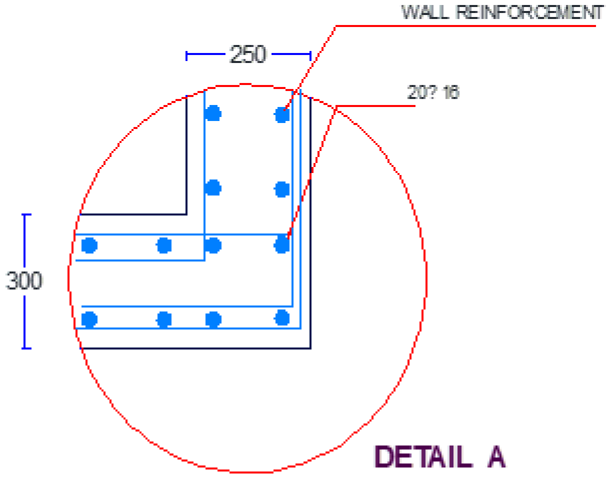


Typical Section (A-A) of raft foundation

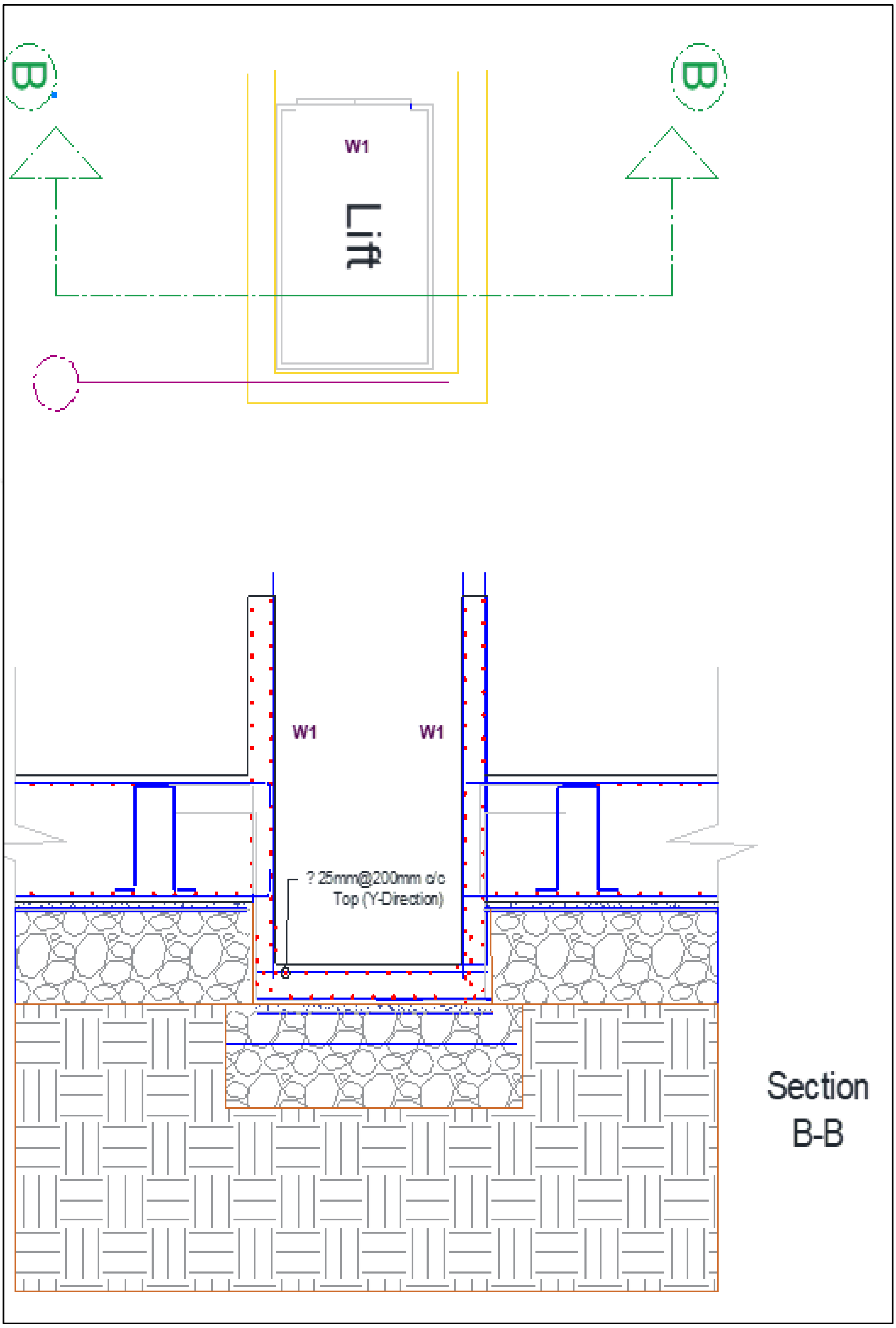

14 - ? 25
16 - ? 25
Main Bar
Roof Floor
? 10@200
2Ties/Set
? 10@200
2Ties/Set
Ties
C 50
Section
850
450
850
450
3 rd Floor
Main Bar
3 rd Floor
14 - ? 25
20- ? 25
12- ? 20
Ties
? 10@200
3Ties/Set
? 10@200
3Ties/Set
? 10@200
2Ties/Set
C 50
Section
Ground Level
foundation
level
850
850
850
450
700
300
Dowels
28 - ? 25
20 - ? 25
12 - ? 16
C 1
C 2
C 3



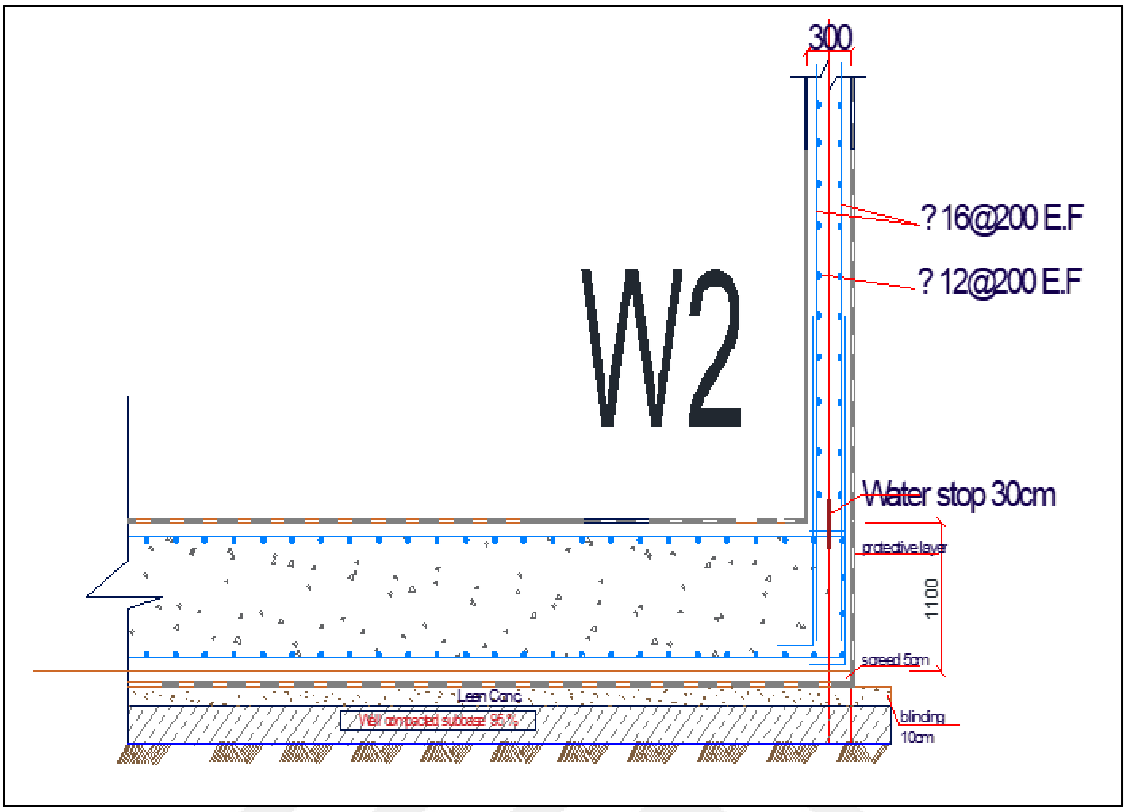
W1 Reinf.



DETAIL A



Section
B-B



300
? 16@200 E.F
? 12@200 E.F
W2
Water stop 30cm
protective layer
1100
screed 5cm
Lean Conc
Well compacted subbase 95 %
blinding
10cm

APPENDIX C

THE 3D CONFIGURATIONS OBTAINED FROM THE REVIT SOFTWARE NUMERICAL ANALYSIS OF THE CASE STUDY

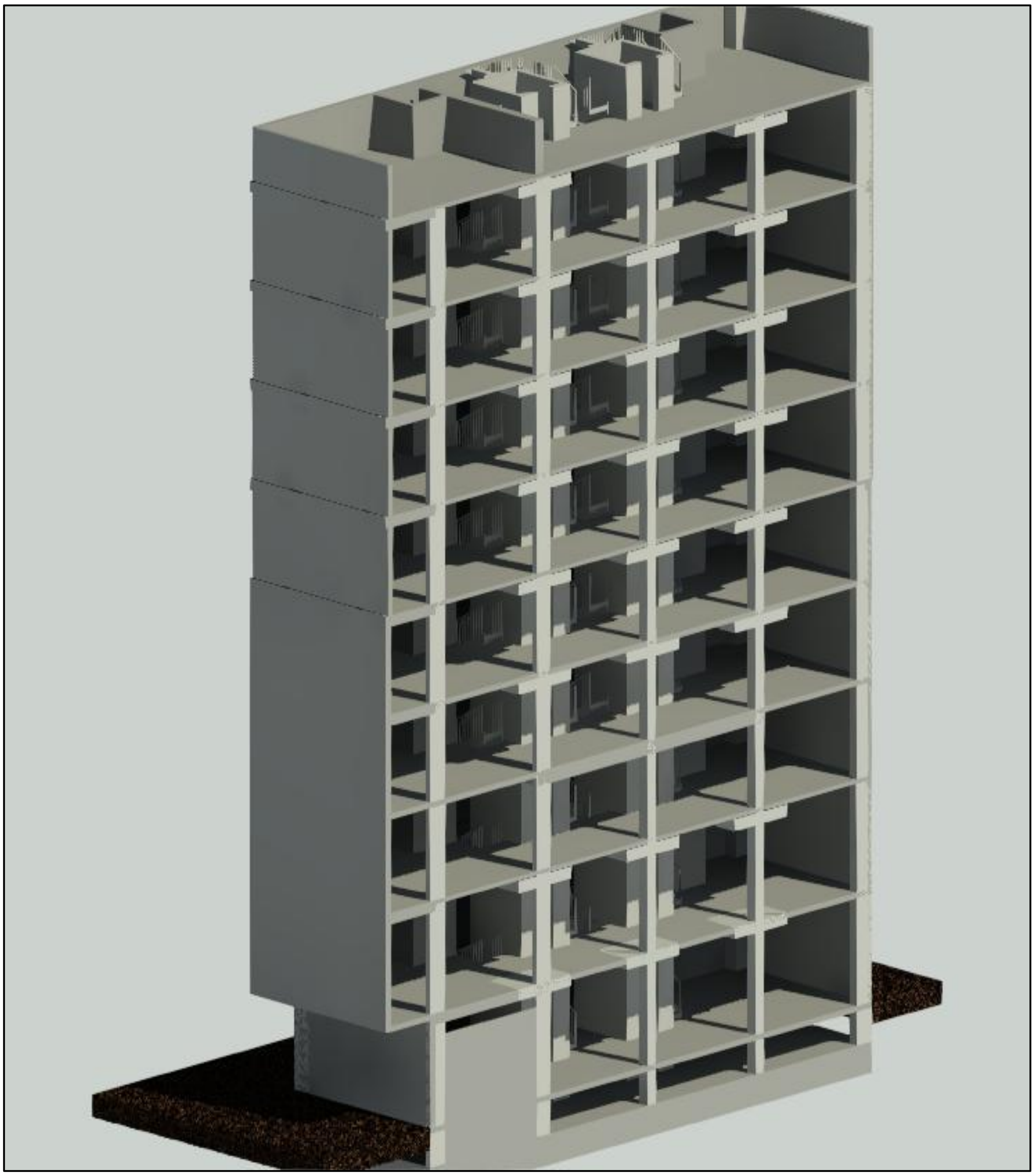


Figure 4.16: Longitudinal Section of the Building Using Revit Software.

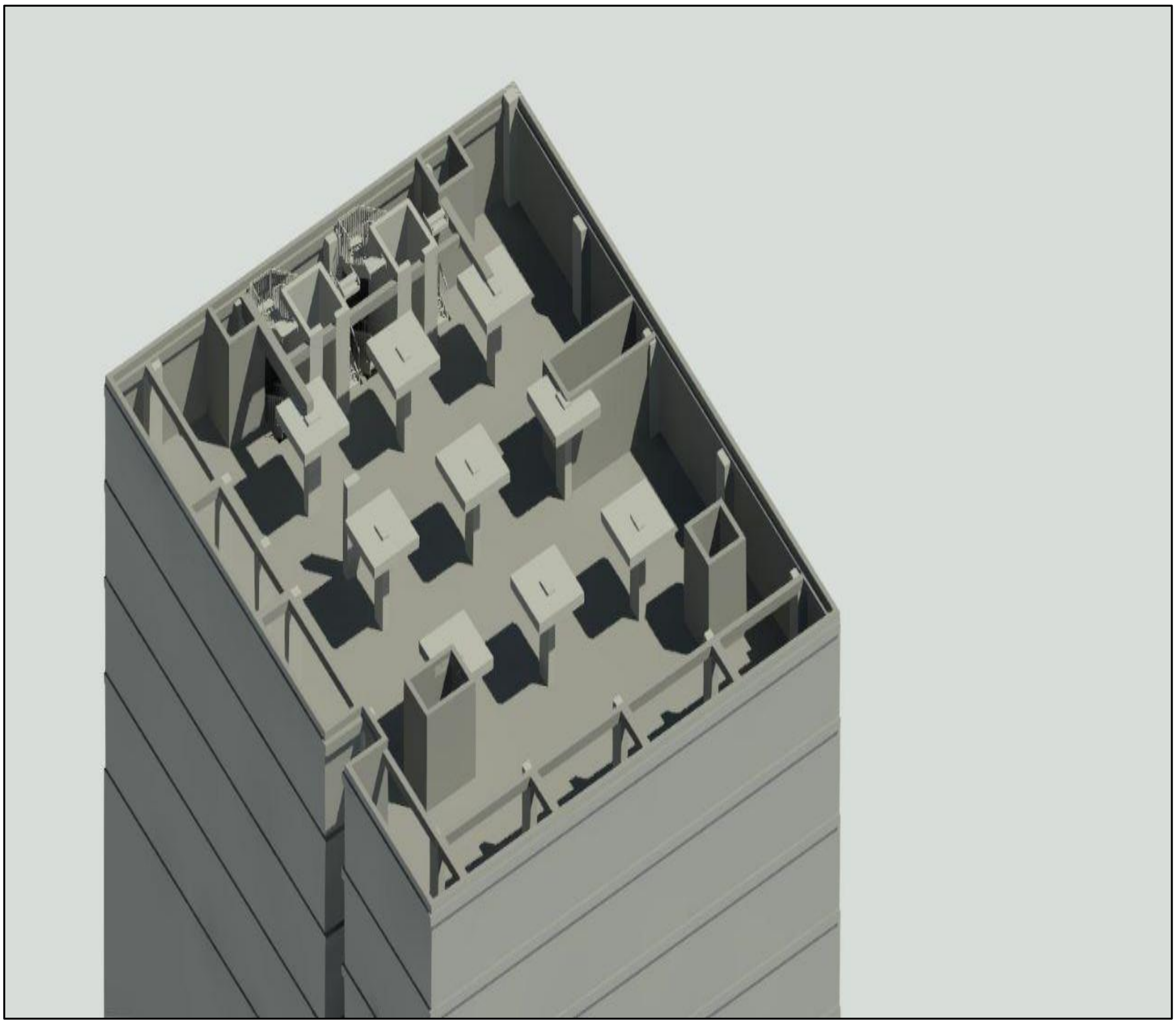


Figure 4.17: Horizontal Projection of Repeated Floors Using Revit Software.

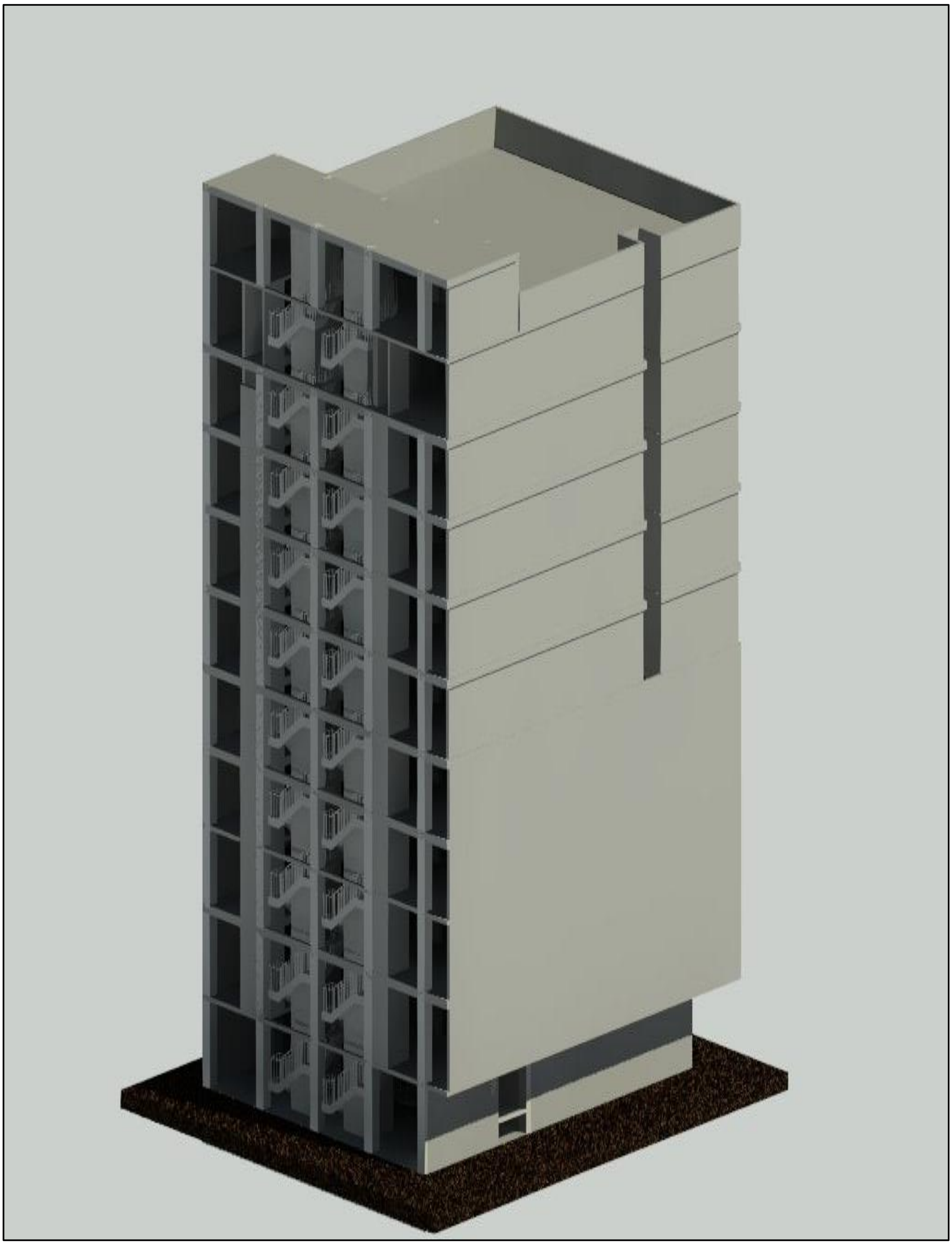


Figure 4.18: Vertical Section Showing Stairs Using Revit Software.

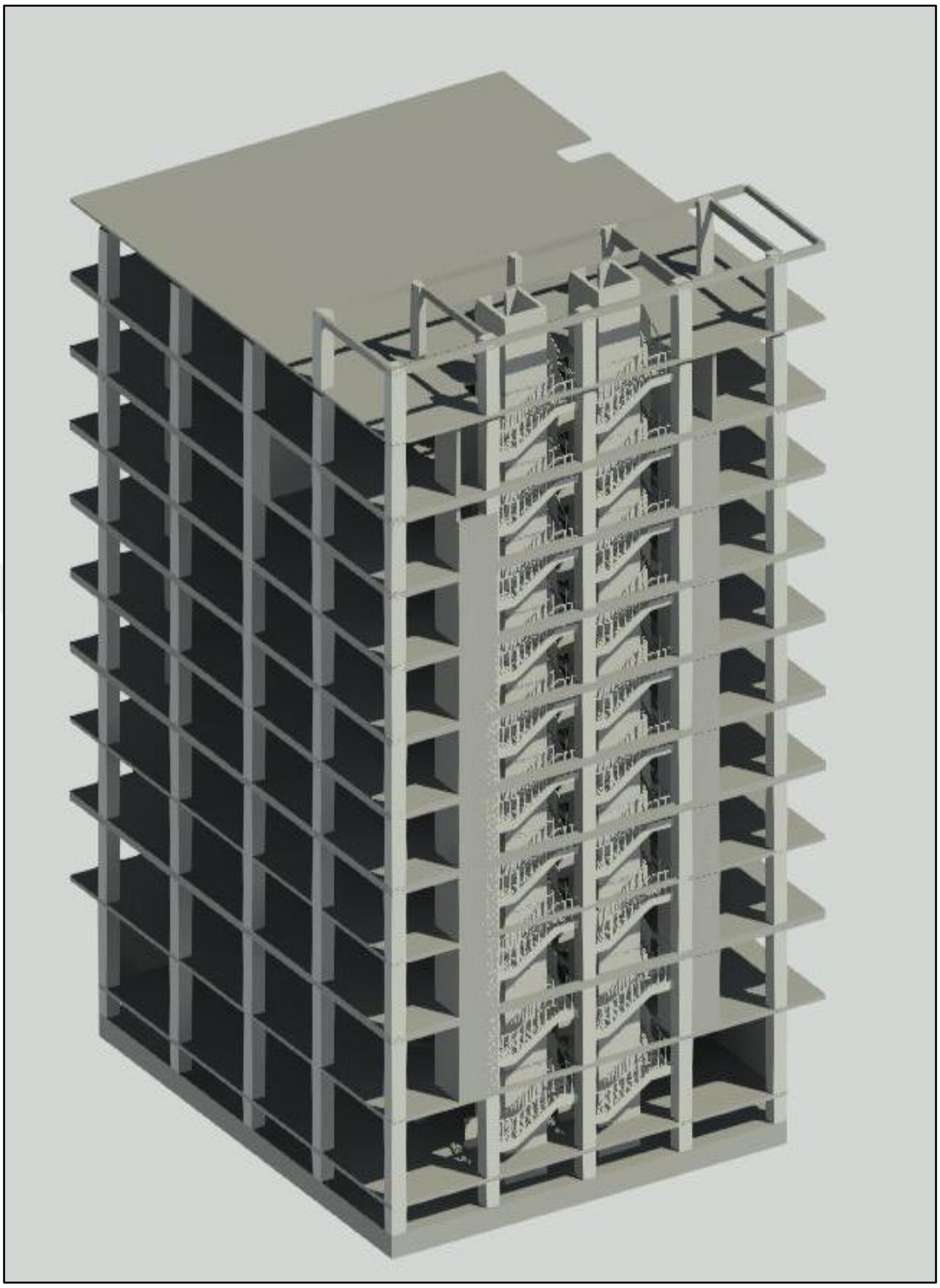


Figure 4.19: Beams, Columns, and Stairs of Building

Figure 4.20: 3D Model of the Building Using Revit Software

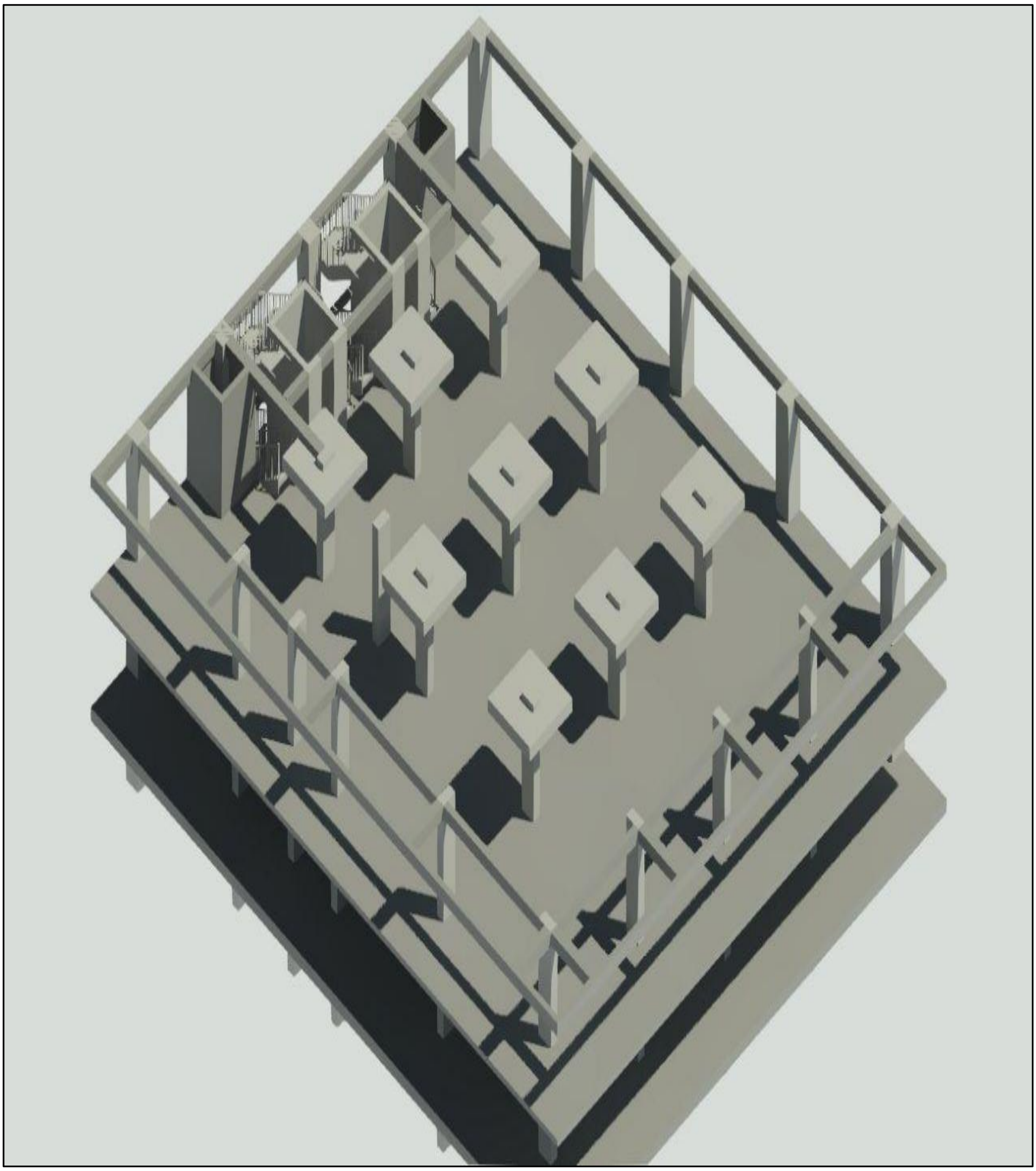


Figure 4.21: Projection of Bridges and Columns From One of the Repeated Floors.

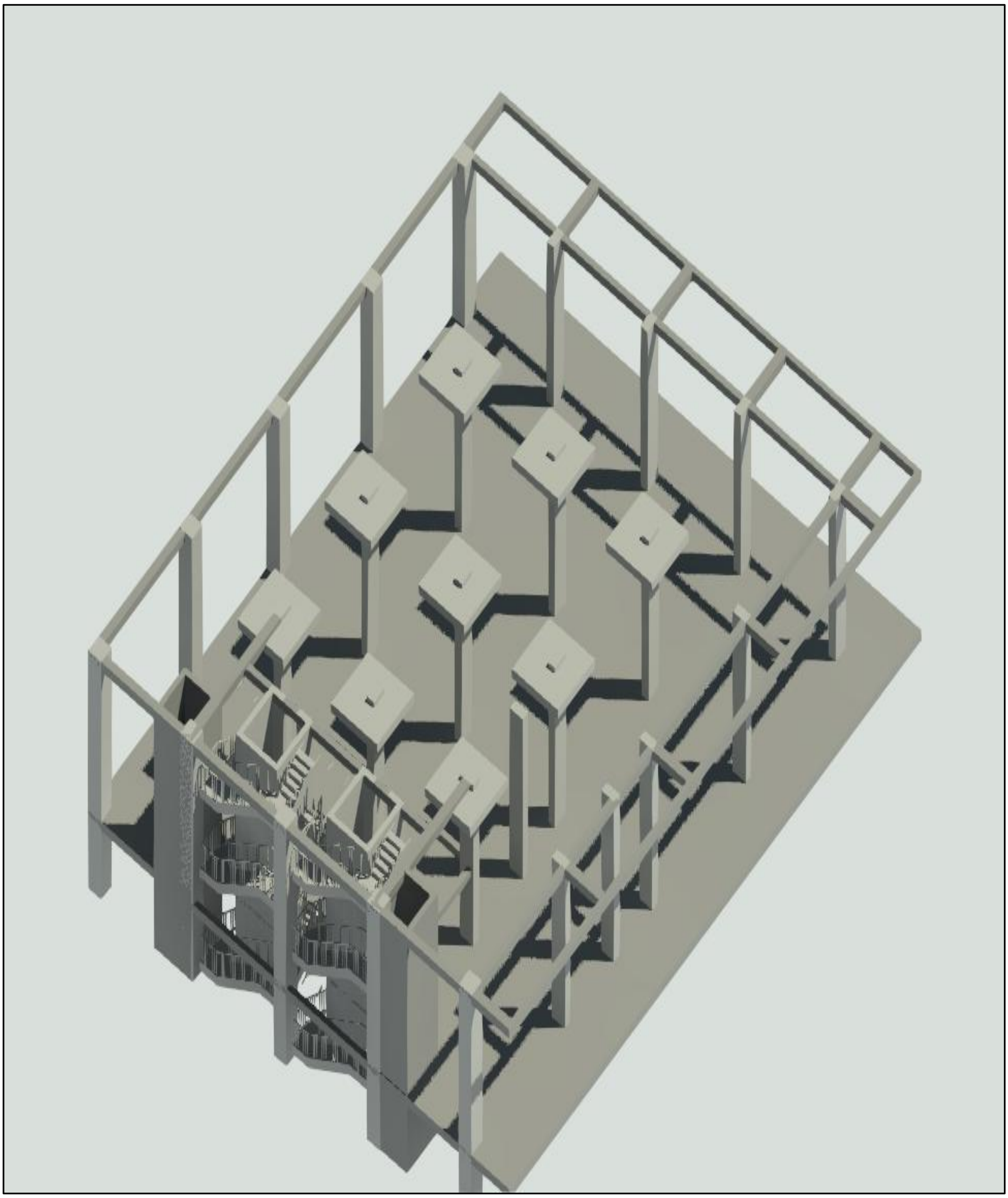


Figure 4.22: 3D Model of the First and Ground Floor.

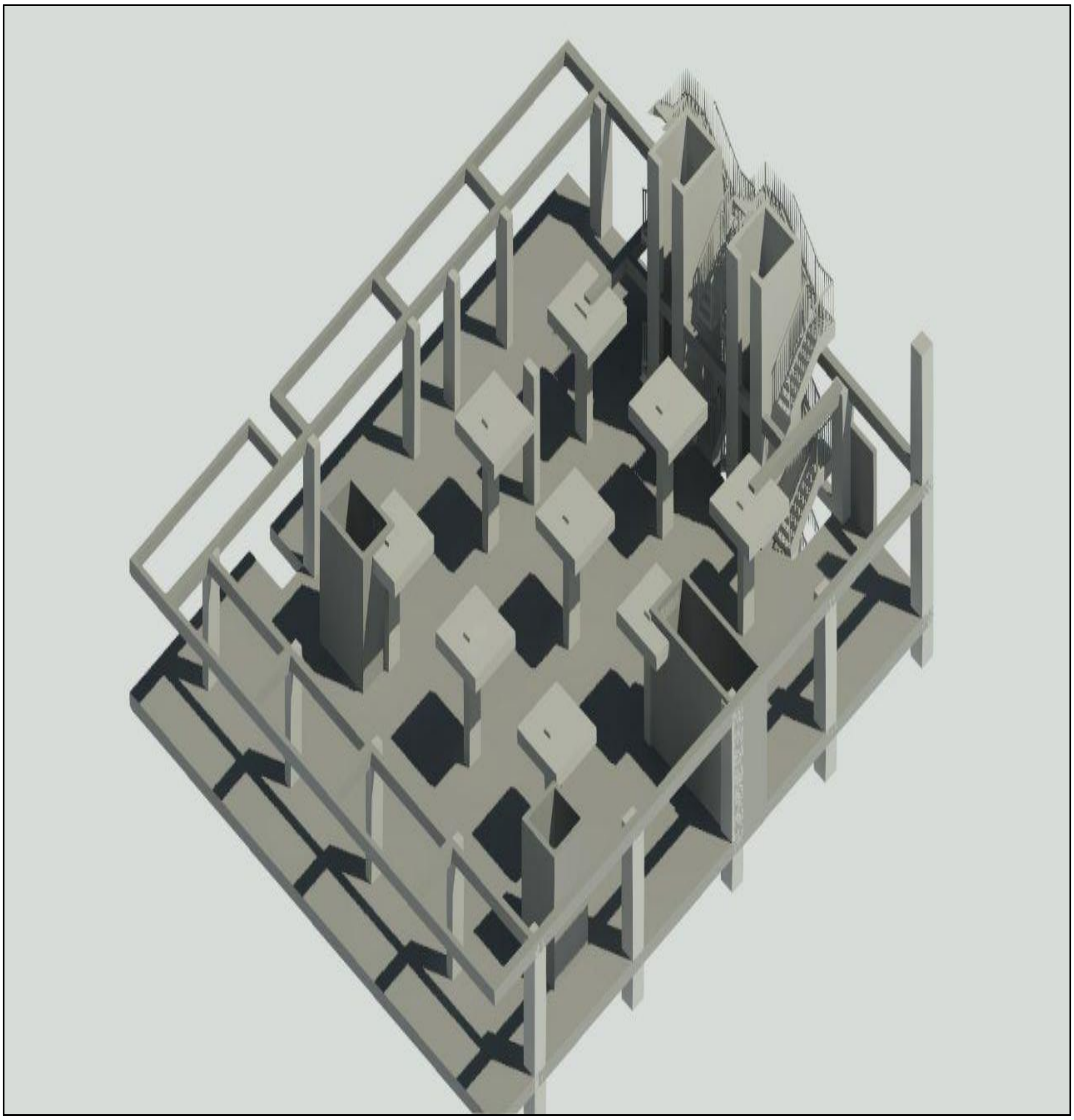


Figure 4.23: Horizontal Plan for the First Floor.

Figure 4.24: 3D Image of the Building.

Figure 4.25: Ground Floor.

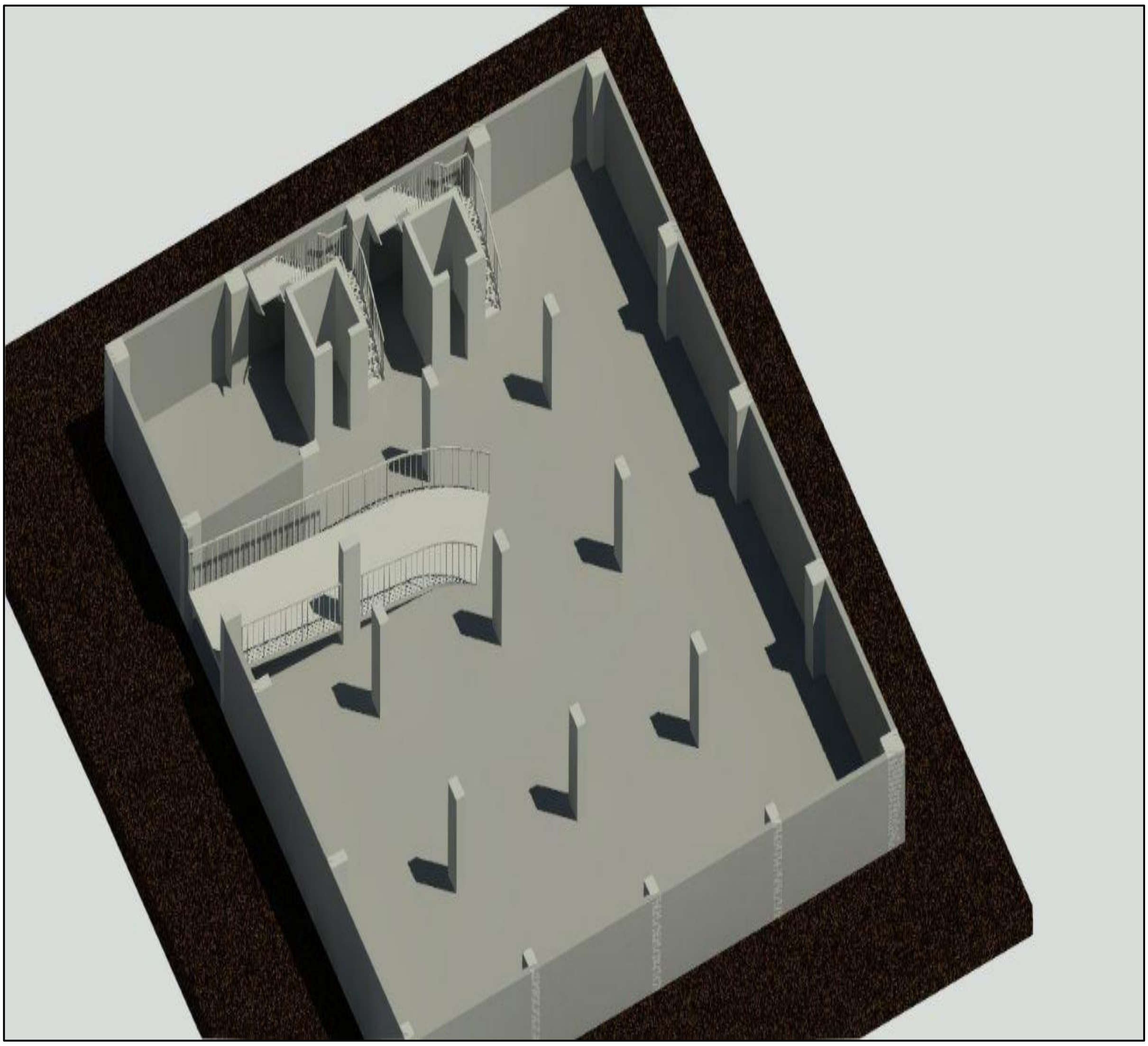


Figure 4.26: 3D Image of the Building.

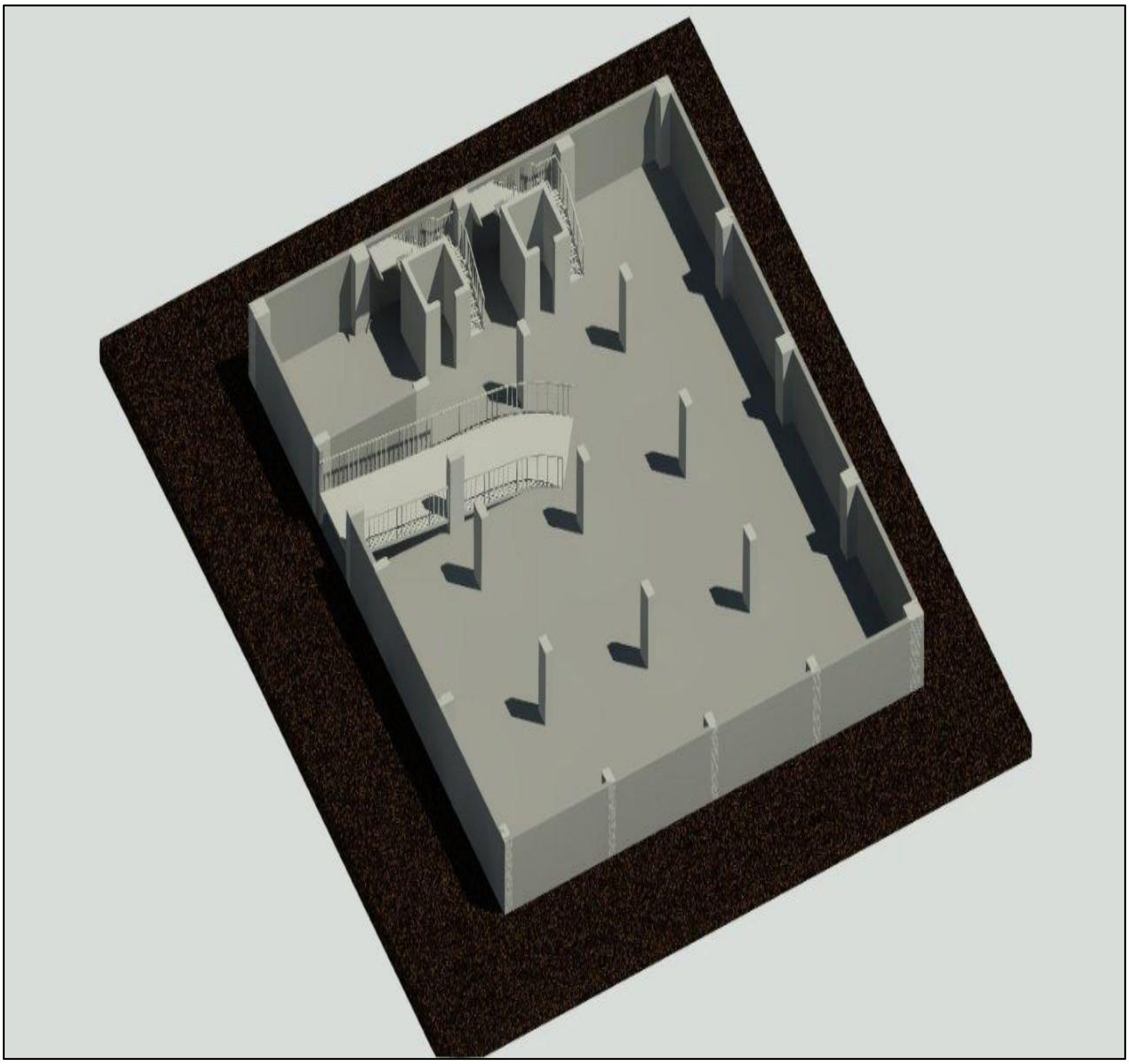


Figure 4.27: Slab of Ground Floor.

s

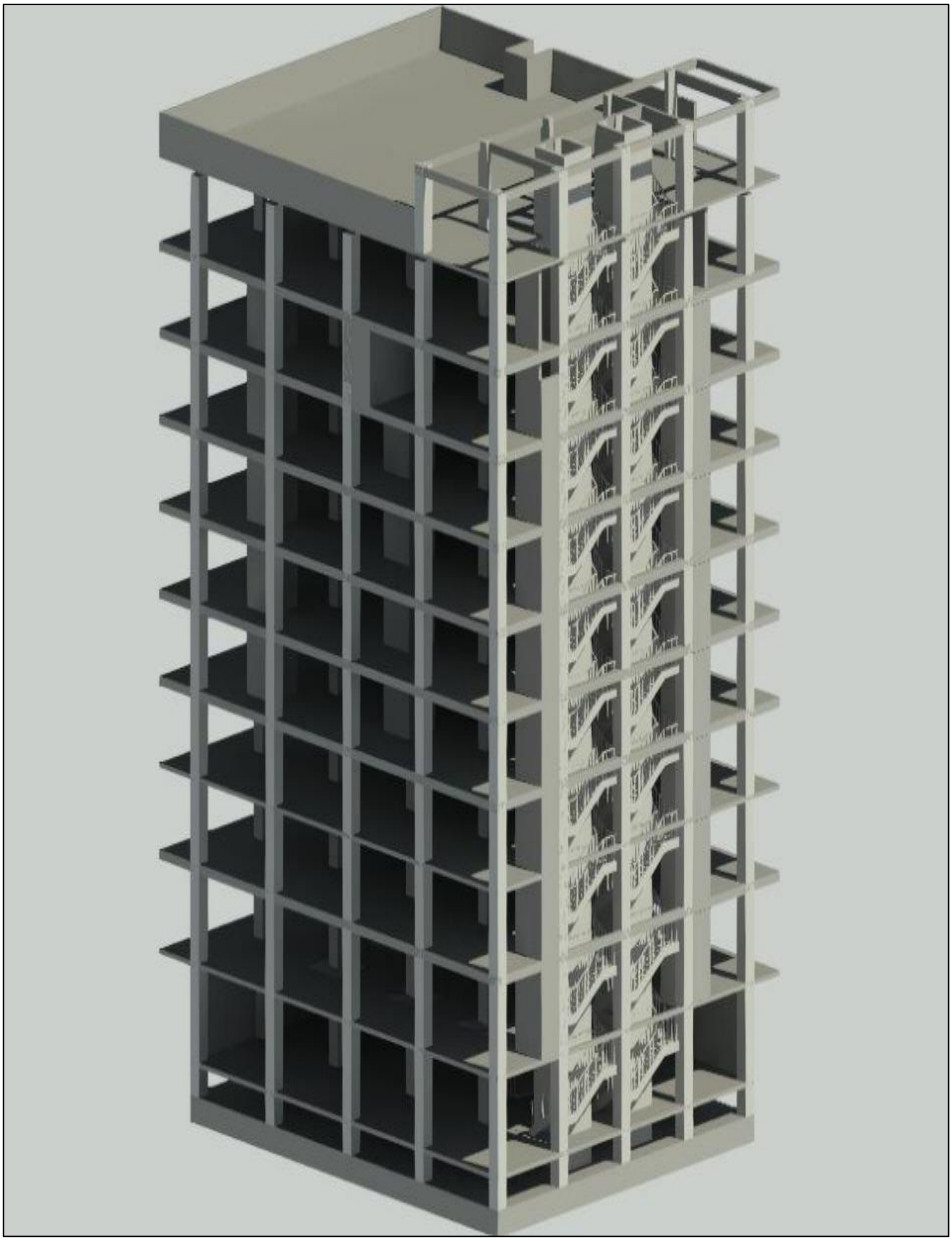


Figure 4.28: (A) 3D Model of the Structure.

Figure 4.29: (B) 3D Model of the Structure.

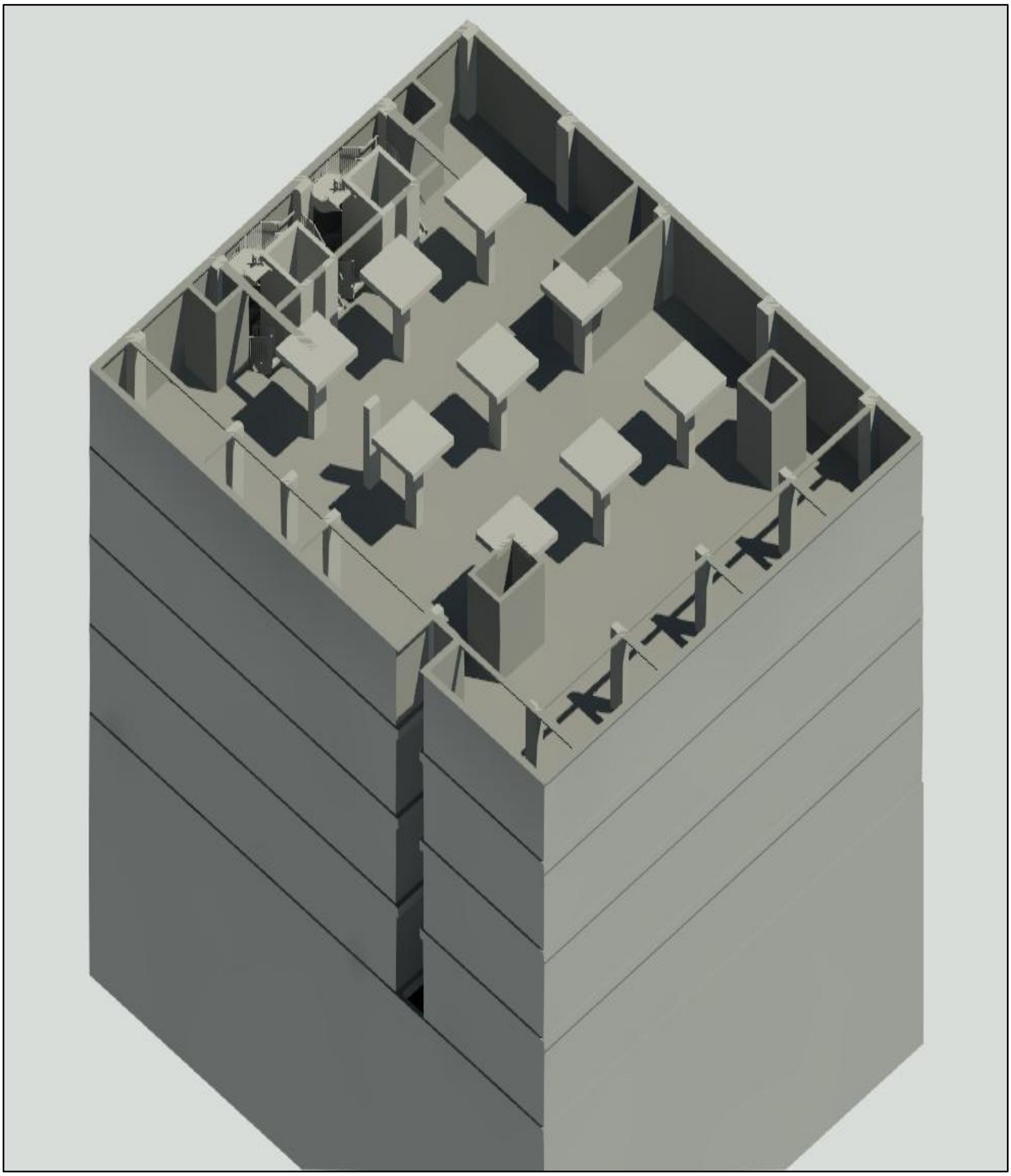


Figure 4.30: Complete Modeling of Part of the Building.

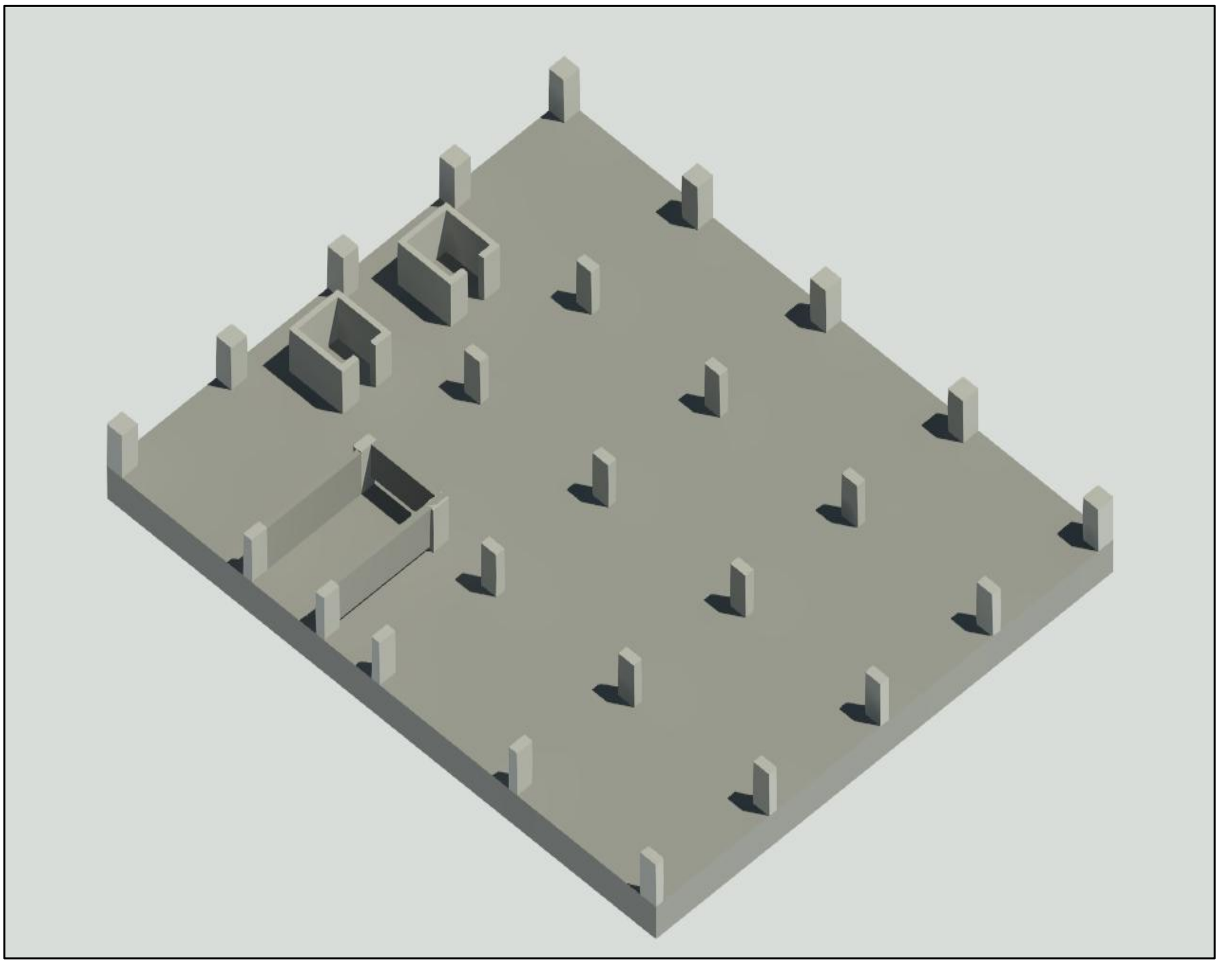


Figure 4.31: Modeling the Construction of Columns on the Ground Floor.

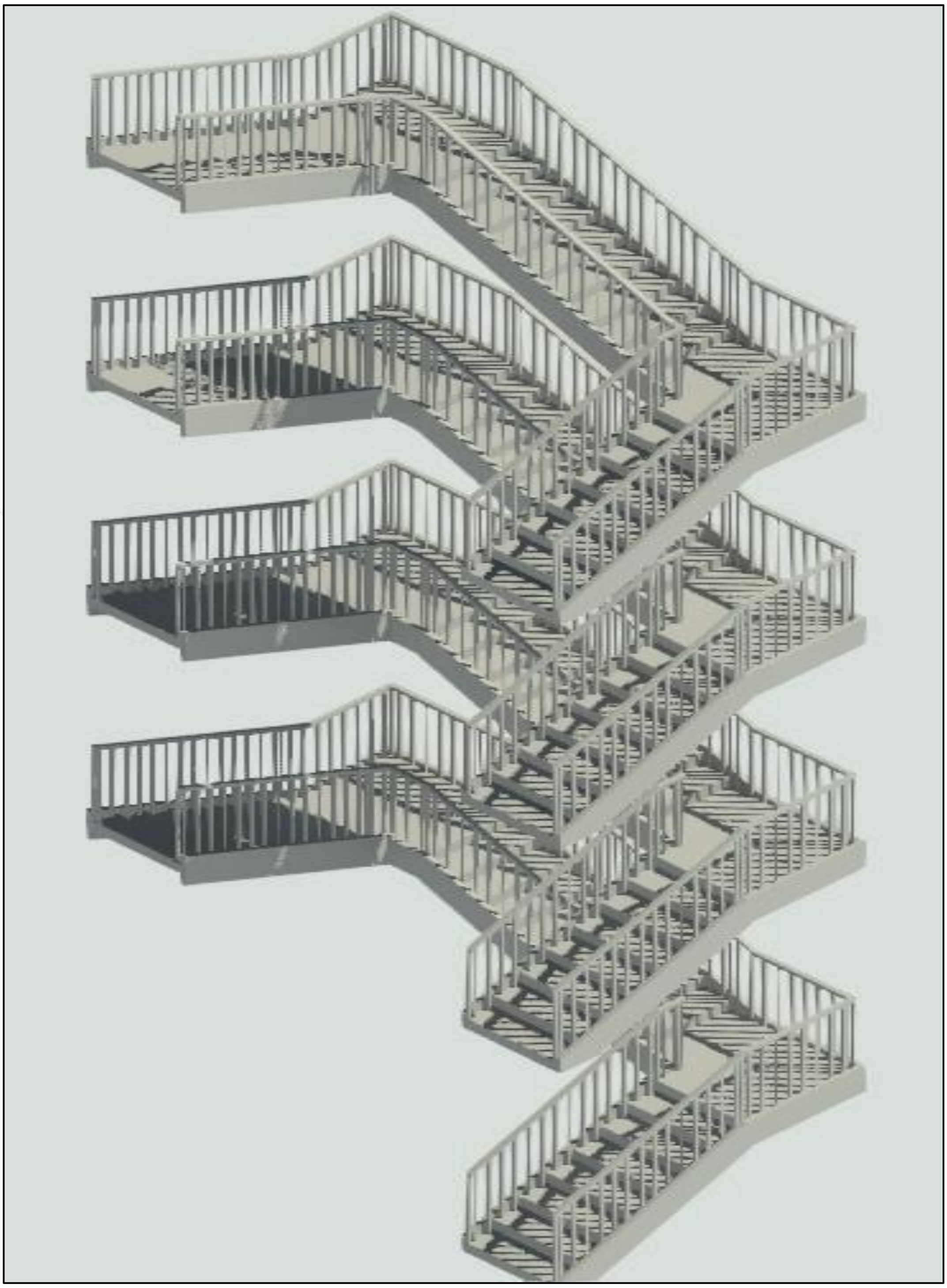


Figure 4.32: 3D Modeling of Stairs.

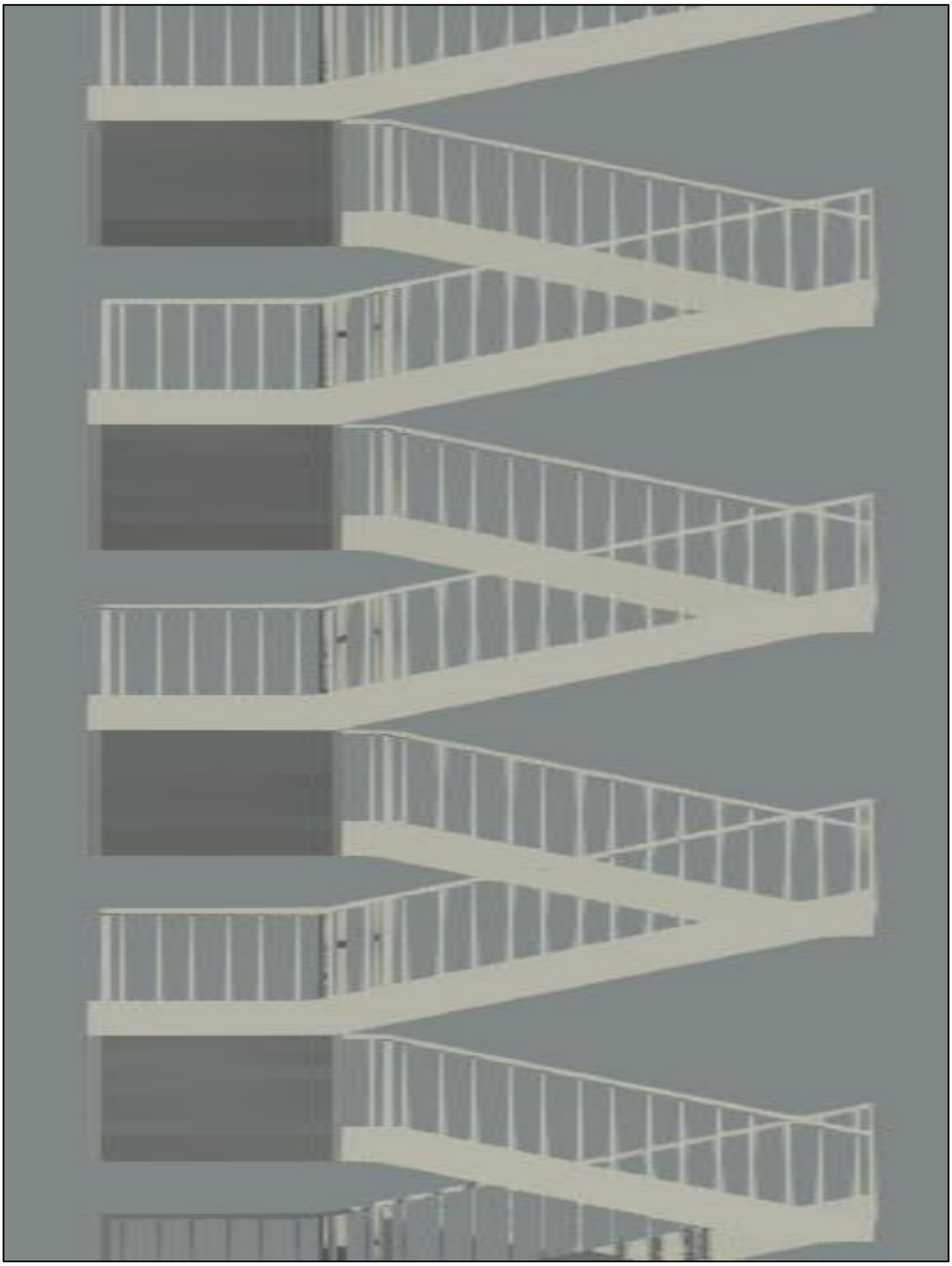


Figure 4.33: 2D Photo of Stairs.

Figure 4.34: 3D Modeling of A Staircase on A Floor.

Figure 4.35: 3D Modeling Showing the Slabs.