REPUBLIC OF TÜRKİYE

ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Civil Engineering

EVALUATION OF CONSTRUCTION PROJECT'S CIVIL COST VIA BIM TECHNOLOGY

Ruwaida Saleh Jabbar AL-MUSAWI

Master`s Thesis

Supervisor

Assoc. Prof. Dr. Sepanta NAİMİ

Istanbul, 2022

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2022

The thesis titled EVALUATION OF CONSTRUCTION PROJECT'S CIVIL COST VIA BIM TECHNOLOGY prepared by RUWAIDA SALEH JABBAR AL-MUSAWI and submitted on 22/12/2022 has been **accepted unanimously** for the degree of Master of Science in Civil Engineering.

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Assoc. Prof. Dr. Sepanta NAİMİ

the Supervisor

Thesis Defense Jury Members:

Assoc. Prof. Dr. Sepanta NAİMİ	Department of Civil Engineering, Altınbaş University	__________________
Asst. Prof. Dr. Mohsen SEYEDİ	Department of Civil Engineering, Altınbaş University	__________________
Asst. Prof. Dr. Kaveh DEHGHANIAN	Department of Civil Engineering, İstanbul Aydın University	__________________

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

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I hereby declare that all information 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.

Ruwaida Saleh Jabbar AL-MUSAWI

Signature

DEDICATION

I dedicate this research to both my great father and my beloved mother for their continuous love, support, endless aid, and energy to conduct my study. Additionally, I dedicate my work to my supervisor, all civil engineering doctors, and employees working at Altınbaş University for their advice, help, and worth of information needed to complete this work. Besides, my supervisor provided me with significant knowledge and large support to help me conduct my numerical work.

Also, I would like to dedicate this work to all the people who helped me at Altınbaş University for the time offered to me to analyze and carry out my work.

ACKNOWLEDGEMENTS

I am pleased to extend my heartfelt thanks and appreciation to those who taught me, or contributed to my teaching, and all the respected professors to whom the credit is due after Glory be to God Almighty for teaching and helping me.

I also extend my heartfelt thanks and appreciation to Associate, Professor, Dr. Sepanta NAİMİ Head of civil engineering department, the people of luminous thought and beautiful giving. I ask God to extend his life and give him health and wellness for what he has done to help me complete this modest study.

The owner of high morals, good style, good handling, giving advice and guidance on what is best for me in completing this modest study.

And thanks to the management of Altinbas university, for their good facilitation and provision of services for students' study and assistance in matters that would give them a comfortable space to seek knowledge in order and safety.

To whom I carry his name with pride. on whom I derive my strength, on whom I derive my strength, and from whom I derive my knowledge, for my teacher and an ideal in life, my father, the consultant engineer: (Saleh Jabbar al-Mousawi), may God protect him.

To the one who stayed up the nights and showered me with her kindness, to the flower that does not wither, to the one who spent her life. to whom her prayer was the secret of success, to the one whom words cannot describe, to the one who sees me with her heart before her eyes are the source of tenderness and the smile of life, my dear mother.

To those who showed what is more beautiful than life and life without them is nothing, and without you, I am nothing, to those who are closer than my soul. To my condolences, my pride, and my support in this life, my brother, and sisters.

To all the martyrs of my beloved Iraq. To all the sincere hearts that pray for me, and to everyone who looks at this effort, a student, or a reader, to all of you I dedicate this humble work.

ABSTRACT

EVALUATION OF CONSTRUCTION PROJECT'S CIVIL COST VIA BIM TECHNOLOGY

Al-musawi, Ruwaida

M.Sc. Civil Engineering, Altınbaş University

Supervisor: Assoc. Prof. Dr. Sepanta NAİMİ

Date: 12 / 2022

Pages: 132

This research is conducted to shed light on the critical role of the BIM technology and the REVIT software package in evaluating the construction projects' cost with significant levels of effectiveness and accuracy. A case study is taken into account, representing a construction project of a hospital building. The budget of this building is calculated and analyzed using two techniques. Also, a comparative analysis between these two approaches is guided in terms of accuracy, performance, human effort, the time required, and the budget needed to make a cost estimation. These two approaches include manual quantity surveying and numerical project take-off, which depends on the REVIT software package that employs BIM principles. The quantity take-off of steel, concrete, and other vital architectural elements and structural building components was considered. The results revealed that there are excellent agreements between the conventional cost-estimation method and the ANSYS numerical calculation associated with all construction elements and components, indicating that BIM technology can offer a reliable solution to determine the construction project cost with higher complexity and diverse project elements. Also, the employment of the REVIT software could cut a significant number of human errors that occurred during the estimation process and quantity take-off for the project cost. The REVIT software has saved much time and human effort needed for engineers to estimate the budget related to this challenging case study that represents a hospital building with various structural components. The numerical method of cost estimation was more economically feasible and provided a cost-effective approach for evaluating construction projects' budgets compared with conventional methods.

Keywords: BIM Technology, The REVIT Software Package, Cost Evaluation, Construction Projects' Cost, Accuracy, Performance.

TABLE OF CONTENTS

LIST OF TABLES

Pages

LIST OF FIGURES

Pages

ABBREVIATIONS

3D	:	Three-Dimensional
BIM	:	Building Information Modelling
LEAN	:	Leadership. Eliminate Waste. Act Now. Never Ending
ML	:	Machine Learning
R&D	:	Research and Development
REVIT	:	Revise-Instantly

1. INTRODUCTION

1.1 RESEARCH BACKGROUND

The whole globe witnessed significant growth in the construction industry for both developed and developing nations due to the remarkable evolution in urbanization and the substantial expansion of the worldwide population [1]. Figure (1.1) presents the annual increase of the global population between 1950 and 2100.

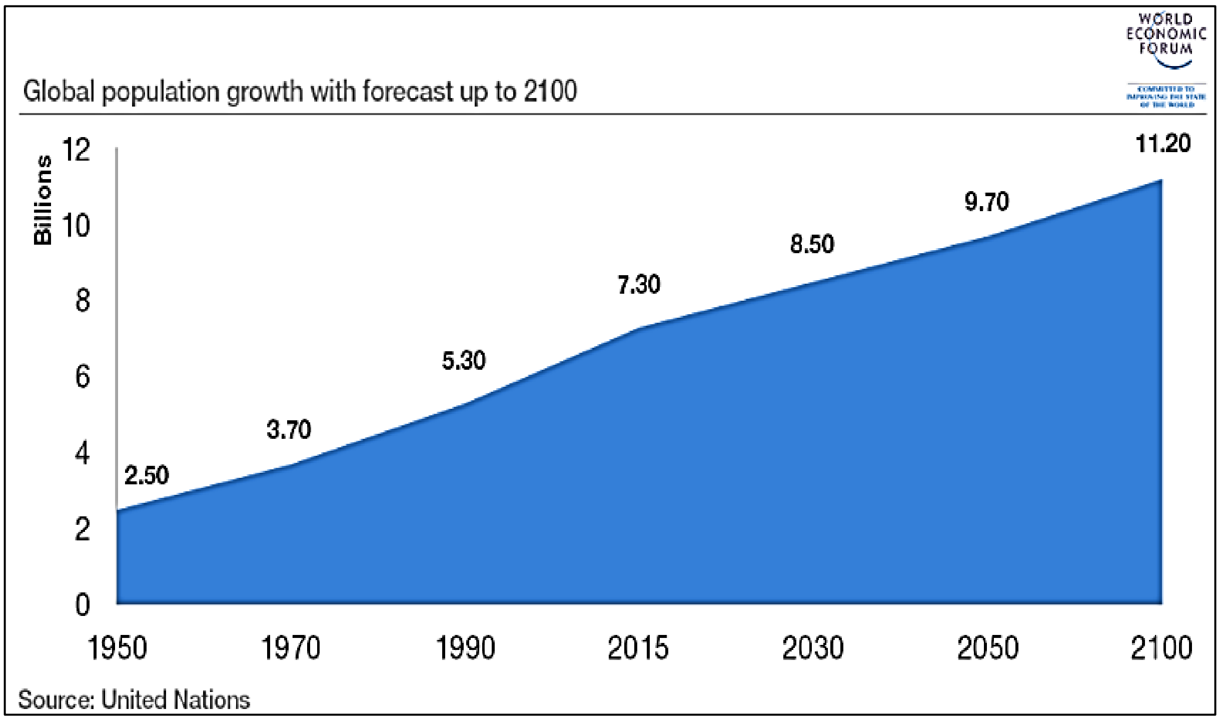


Figure 1.1: The global population growth between 1950 and 2100. [2].

Over the last decades, diverse research and development (R&D) efforts have been carried out, leading to a considerable evolution of smart approaches and strategic methods that help engineers estimate the budget, resources, schedule, and human resources for small-, medium, and large-scale construction projects. One of these innovative methods is building information modelling (BIM) technology [3]–[5]. The emergence of the BIM technique came from developing the information technology infrastructure and increasing the use of digital tools. Consequently, it is vital to define the BIM concept to help understand the principles of this thesis. BIM technology can be illustrated as “A state-of-the-art method that depends on defining construction project information, including the budget, resources, and human resources. It is important to predict optimized values of this information and estimate the required construction project boundaries without human calculations, which corresponds to inaccuracy and mathematical errors. BIM is vital to help architectures, civil engineers, project managers, and designers collaborate to provide better outputs of the constriction project’s planning, design, and execution [6].” As can be inferred from the description of the BIM concept, this digital approach enables engineers and designers to evaluate different construction project parameters, such as cost, schedule, resources, and human resources, with less time, effort, and cost. Furthermore, BIM technology provides an efficient calculation method for construction projects with a very low number of errors and a higher precision rate. Figure (1.2) shows the major principles of BIM technology. BIM technique is associated with 3D, 4D, 5D, 6D, 7D, and 8D analysis. The following paragraphs illustrate these types with their aim [7]:

a. 3D modelling – in which BIM software tools can visualize the building and provide a graphical and geometrical representation of the construction project through its lifecycle,
b. 4D modelling – in which the BIM program offers an analysis of the construction project based on the project’s activities time and scheduling. It divides the construction project into a set of phases to execute over a specified period.
c. 5D modelling – by which the BIM software conducts cost estimation and manages the project’s budget and makes financial analysis of activities.
d. 6D modelling – through which environmental concerns of the construction project are analyzed, including energy consumption, energy efficiency, sustainability, and the project’s impact on the environment.
e. 7D modelling – by which the operation and maintenance aspects and costs are analyzed through the construction project lifecycle.
f. 8D modelling – through which BIM software analyzes predicted site accidents to prevent them during the construction phases and project execution.

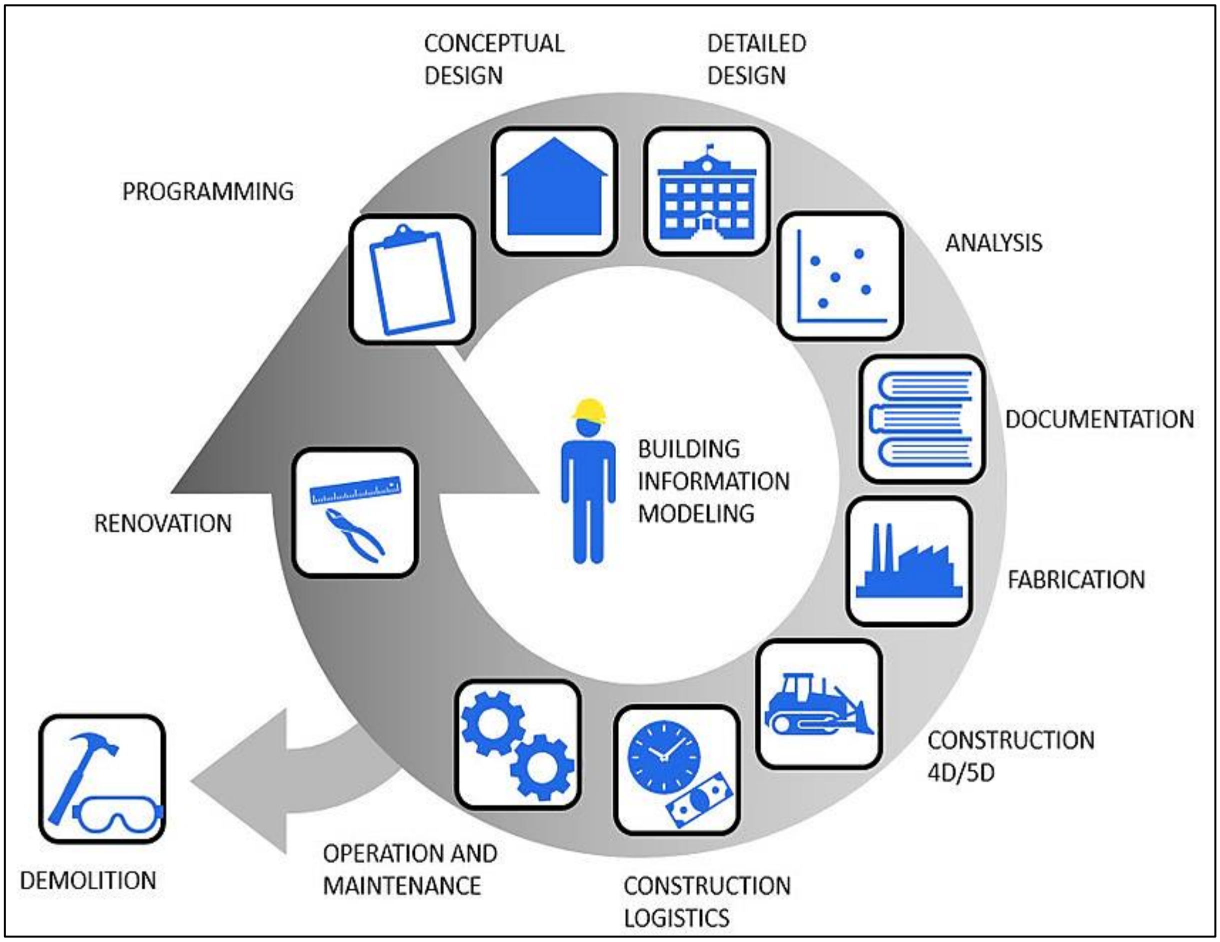


Figure 1.2: Major principles of BIM technology. [8].

1.2 PROBLEM STATEMENT

Because of the increasing number of small-, medium-, and large-scale construction projects in each company, and due to the growing rate of project complexity, the calculation process of the construction project budget has become more complex, time-consuming, and needs more effort [9]. This aspect is since activities related to the same construction project and the parameters of each project have been increasing in the last decades, which requires a software tool capable of estimating these parameters and the project's cost with less time and effort. In addition, if the calculation process depends on human effort, the cost evaluation will include several errors, less accuracy, and it will consume much time. Consequently, BIM technology and BIM software tools provide a state-of-the-art approach by which these problems can be easily resolved.

Moreover, engineers and scientists developed BIM programs to evaluate the budget of complex and large-scale construction projects associated with a large number of activities. In this project, the BIM technology is implemented to calculate the budget of a construction project based on REVIT software, one of the innovative software tools that implement BIM principles in their calculation process.

1.3 RESEARCH SIGNIFICANCE

This thesis contains a set of significant relevance. One of this work's relevance is the execution of a comprehensive literature review. The broad literature review will highlight major phases of BIM technology development and evolution over time from the time it was invented until the current years. Also, the literature review will cover major modelling types of BIM technology and its main principles in evaluating the costs of construction projects. Through the second relevance, this thesis will classify the leading advantages and critical benefits of the BIM technology in estimating the project's costs and activities budget with less time needed and a higher accuracy rate than the human calculation process. It will compare human efforts, the time required, and accuracy, resulting in estimating the constriction project cost. Also, BIM technology software tools' contribution will be compared to the human calculation process and trials in providing better precision and optimized time to evaluate the construction project budget with fewer errors. In addition, this work has another relevance in which a case study of a construction project will be analyzed and investigated. REVIT software tool will be used to evaluate the construction project's budget with less time and improved accuracy for this case study. Depending on the results obtained in this work, this thesis will suggest key aspects and important future work that can help designers and architectures optimize the calculated budget. These recommendations are important to benefit from the REVIT software tool to calculate the cost of activities and the whole project's budget more flexibly.

1.4 RESEARCH MAJOR AIM AND MINOR OBJECTIVES

The major goal of this work is to carry out cost estimation of a construction project with higher accuracy and less time needed compared to the human calculation process. Depending on this major goal, the thesis's minor objectives can be classified through the following articles:

a. To conduct a comprehensive literature review and highlight major phases of BIM technology development and evolution over time from the time it was invented until the current years.
b. To review critical modelling types of BIM technology and its main principles in evaluating the costs of construction projects.
c. To classify the leading advantages and critical benefits of the BIM technology in estimating the project's costs and activities budget with less time needed and a higher rate of accuracy than the human calculation process.
d. To investigate a case study in which a construction project will be selected, analyzed, and investigated to estimate its budget.
e. To use the REVIT software tools that implement the BIM technology principles to provide an accurate calculation process of the construction project with less time and errors.
f. To make results validation and estimation to the REVIT software calculation process depending on experts' points of view.

1.5 RESEARCH QUESTIONS

This work depends on the BIM technology principles to estimate the cost of a construction project selected in the thesis case study. The work tries to answer the thesis's questions which are illustrated through the following points:

i. What are the critical modelling types of BIM technology and its main principles in evaluating the costs of the construction projects
ii. What are the major BIM technology contributions and leading benefits for calculating the construction project cost compared to human trial?

iii. Is the accuracy of the REVIT software tool that implements BIM technology principles competitive with human precision?
iv. Can the REVIT software provide sufficient time and less effort in estimating the construction project budget than the human calculation process?
v. Are there any limitations to the BIM technology in calculating the construction project budget with higher accuracy, fewer errors, and optimized time?

1.6 RESEARCH HYPOTHESES

This study is carried out to provide the validity and invalidity of some hypotheses. The proof of the validity related to these hypotheses is conducted based on the results of the REVIT software and BIM technology principles. The following paragraphs present the research hypotheses:

a. Null Hypothesis, H_o: "The use of BIM technology and the REVIT software would not offer effective solutions and key improvements in terms of the calculation time of construction project budget, accuracy, and time needed for the calculation compared to the conventional human computing process."
b. First Hypothesis, H_1: "The use of BIM technology and the REVIT software provides effective solutions and key improvements in terms of the calculation time of construction project budget, accuracy, and time needed for the calculation compared to the conventional human computing process."
c. Second Hypothesis, H_2: "The implementation of BIM technology and the REVIT software is not helpful for engineers, designers, and architectures like human efforts in the budget calculation process."
d. Third Hypothesis, H_3: "The implementation of BIM technology and the REVIT software is more helpful for engineers, designers, and architectures than human efforts in the budget calculation process."
e. Fourth Hypothesis, H_4: "Utilizing the REVIT software and BIM technology could not save significant duration needed for project cost estimation and reduce common human errors when engineers calculate the construction budget using manual methods."

f. Fifth Hypothesis, H_5: “Utilizing the REVIT software and BIM technology can save significant duration needed for project cost estimation and reduce common human errors when engineers calculate the construction budget using manual methods.”

1.7 THESIS STATEMENT

The title of this research is “Evaluation of Construction Project’s Civil Cost via BIM Technology.” A case study is investigated via selecting a construction project in this research. This construction project will be analyzed in terms of budget calculation. It is predicted that using the BIM technology via the REVIT software will achieve significant benefits and contributions in estimating the project cost with less time, fewer errors, and higher accuracy.

1.8 THESIS LAYOUT

The layout of this work includes five chapters. These chapters cover several aspects associated with the implementation of the BIM technology and the REVIT software to evaluate the construction project budget, which will be chosen and analyzed in this research. The layout of this thesis can be described in the following table:

a. Chapter One: It describes the research background, research significance, problem statement, research questions, study hypothesis, thesis’s major goal and minor objectives, and thesis title.
b. Chapter Two: It presents the literature review. The comprehensive literature review provides data on major phases of BIM technology development and evolution over time from when it was invented until the current years. It reviews critical modeling types of BIM technology and its main principles in evaluating the costs of construction projects. It classifies the leading advantages and critical benefits of BIM technology in estimating the project’s costs and activities budget with less time needed and a higher rate of accuracy than the human calculation process.
c. Chapter Three: It shows the research methodology and the conceptual approach pursued to carry out the analysis and investigation of the case study. It describes the REVIT software tool’s major principles and features that depend on the BIM technology to calculate the project’s cost with higher accuracy.

d. Chapter Four: It describes the major results obtained from the REVIT software analysis. These findings are associated with the calculation process of the construction project using the BIM technology principles.
e. Chapter Five: It presents the major conclusions of the findings obtained in this work. Furthermore, this chapter illustrates key recommendations and future work suggestions to help designers and engineers conduct further improvements and investigations on the BIM technology and promote its role in effectively and accurately estimating the cost of construction projects.

2. LITERATURE REVIEW

2.1 AIM AND INTRODUCTION

The previous chapter presented data on the research background, research significance, problem statement, research questions, study hypothesis, thesis's major goal and minor objectives, and thesis title. Chapter two illustrates the major phases of BIM technology development and evolution over time from when it was invented until the current years. It reviews critical modelling types of BIM technology and its main principles in evaluating the costs of construction projects. It classifies the leading advantages and critical benefits of the BIM technology in estimating the project's costs and activities budget with less time needed and a higher accuracy rate than the human calculation process.

2.2 MAJOR DEVELOPMENT STEPS AND EVOLUTION PHASES OF BIM TECHNOLOGY

[10] executed a study identifying major characteristics and key development of BIM technology in several Chinese projects. [10] implemented quantitative and macroscopic data analysis through which 4,591 patents associated with BIM technology were analyzed and investigated. In addition, their research focused on exploring influential factors and critical parameters that affect the success of projects that implement BIM technology. They also implemented Barrat, Barthelemy, Vespignani model to predict the development trend of BIM technology in China. Their quantitative and macroscopic study covered a period between 2011 and 2020. Their analytical work confirmed that the Chinese construction sector faces some challenges and difficulties that limit effective BIM technology implementation in the construction sector. However, there is a significant trend and several opportunities for BIM technology expansion and development in the Chinese construction industry. Furthermore, their quantitative and macroscopic data analysis revealed that BIM technology played a significant role in facilitating construction projects' execution for several civil, structural, and architectural engineers, attracting much attention in the construction industry. Also, they reported that their breakthrough study results are significant for the Chinese government to enact effective laws and active policies which can encourage the adoption and implementation of BIM technology

in the Chinese construction sector. [11] conducted an analysis to highlight major contributions and critical benefits of BIM technology in the specific construction industry, namely ecosystems. [11] depended on a qualitative research approach through which a comprehensive literature review was carried out to examine the major role of BIM principles in improving the ecosystem and sustainability. The comprehensive literature review analysis revealed that BIM technology is greatly beneficial and critical for the ecosystem. It implements a set of sustainable policies, ecosystem standards, environmental protocols, and environmentally friendly processes that ensure the development and organization of the ecosystem in the construction industry. [12] published a manuscript investigating the beneficial impact of BIM model implementation in the construction industry. [12] relied on a systematic literature review by which substantial relevance and contributions of BIM models were addressed and identified. The papers and recent publications reviewed by [12] were between 2012 and 2022. Their systematic literature analysis revealed that BIM technology and BIM models play a significant role in facilitating construction activities. BIM paradigms can also make automatization, sustainability, and interoperability. Further, BIM technology can save ten percent of the cost and seven percent of the time required to estimate the construction project budget. Also, BIM models contribute to significant cost evaluation flexibility, higher accuracy level, and minimization of human errors when the construction project's budget is calculated.

2.3 CRITICAL MODELLING TYPES OF BIM TECHNOLOGY

[13] executed research exploring major modelling types implemented in BIM technology and highlighting their key characteristics. [13] implemented a systematic literature review through which BIM models, trends, and challenges were classified. Their systematic literature review analysis revealed that BIM technology is greatly beneficial and effective in the construction industry, as several BIM models are implemented, including 3D (three geographical dimensions are analyzed for the construction project), 4D (project's three dimensions and submission schedule), 5G (three dimensions, time, and cost of execution), 6D (three dimensions, time, cost, and site management), 7D (three dimensions, time, cost, site management, and sustainability evaluation), and 8D (three dimensions, time, cost, site management, sustainability evaluation, and safety management). However, [13] reported some critical obstacles despite several

beneficial impacts of BIM technology. These include the requirements for a sufficient budget to offer information technology and digitalization to implement BIM paradigms effectively.

[14] conducted an analysis of the BIM technology implementation in the construction industry. They investigated a case study in which BIM modelling was applied. Their case study analysis revealed that BIM modelling could be classified into six major approaches, including 3D modelling (in which a three-dimensional virtual model is formulated for the construction project), 4D (in which time is added), 5D (through which cost and time are added to the 3D configuration), 6D (that makes project's facilities management), 7D and 8D which add the sustainability aspects and health and safety concerns to the 3D modelling of the construction project.

[15] performed a study examining key BIM modelling impacts and beneficial contributions to the construction industry. In addition, [15] classified a group of BIM technology modelling approaches and discussed their characteristics. [15] implemented a cross-sectional quantitative descriptive approach through which data were collected based on 380 construction engineering experts' knowledge and BIM technology professionals' points of view. The cross-sectional quantitative descriptive method results revealed that BIM technology has several positive impacts and considerable contributions to construction projects. In addition, BIM technology utilizes a panel of modelling techniques, including 3D (for x, y, and z virtual project configuration), 4D (that adds scheduling to 3D), 5D (that integrates budget estimation to the 4D), 6D (which considers facility management), 7D (that takes project sustainability into account), and 8D (a recent modelling technique that assesses health and safety issues in the construction project). [16] carried out research exploring the use of BIM technology in several small- and large-scale construction projects and identified major BIM features and key benefits. [16] implemented an extensive literature review through which BIM paradigms and their characteristics were addressed and discussed. The literature analysis affirmed that BIM technology could play a critical role in improving construction projects' efficiency and facilitating a circular economy. Furthermore, [16] found that BIM modelling implemented 3D in the past. However, several research and modifications have been conducted to generate and develop new BIM models. In this context, 4D, 5D, 6D, 7D, and 8D modelling processes were

recently produced, relating to the time, cost, facility management, sustainability, and health and safety aspects, respectively.

2.4 LEADING ADVANTAGES AND CRITICAL BENEFITS OF THE BIM TECHNOLOGY IN ESTIMATING THE PROJECTS COSTS

[17] executed research examining the beneficial impacts and critical role of BIM technology implementation on the construction industry in Egypt. [17] applied quantitative, analytical, and descriptive methods to achieve the study goal. [17] reported that the Egyptian construction industry faces some challenges mirrored by losses in construction materials, budget, and execution time. The quantitative, analytical, and descriptive analysis (which covered 106 Egyptian experts in BIM technology) revealed that applying BIM technology is greatly beneficial for the Egyptian construction sector and can significantly improve the project management procedure throughout the project's lifetime. [18] carried out research exploring the major advantages and key characteristics of BIM technology in the construction industry. [18] selected a case study (presenting a veterinary clinic) using the REVIT/ Auto-Desk software package. They implemented 5D BIM modelling through which a three-dimensional configuration of the veterinary clinic was executed, besides cost and time estimation. Their BIM analysis of their case study revealed that applying BIM principles with 5D contributed to significant accuracy in evaluating the budget and schedule of the veterinary clinic. Also, it was found that using BIM technology can replace manual calculation approaches for construction projects' time and cost, saving much effort and reducing human errors. In addition, results indicated that the design process could be effectively automated, making BIM modelling greatly beneficial for construction project performance. [19] conducted an analysis examining the critical role of BIM technology modelling in facilitating construction projects' execution and improving performance. [19] integrated machine learning (ML) principles into the BIM system. They also developed a prototype to train the ML algorithms in estimating the construction project's cost with fewer errors. The software that operated these ML algorithms with 5D-BIM modelling was the MATLAB software. Their numerical analysis revealed that using 5D modelling of BIM technology and integrating ML algorithms into the estimation process contributed to significant improvements in evaluating the construction project's budget. Also,

numerical results confirmed that BIM technology implementation with ML algorithms provided higher accuracy and eliminated human errors. [20] carried out research investigating the critical role of BIM technology in evaluating the construction project's cost. [20] applied critical content and systematic reviews through which BIM technology's contribution and substantial role in estimating construction projects cost were identified. Their critical literature analysis revealed that implementing BIM technology, particularly 5D modelling, has several significant advantages to the construction project. Results indicated that 5D modelling helps engineers and surveyors estimate the construction project budget with a higher accuracy degree and minimizes human errors as manual calculation methods can be avoided. [21] guided a study identifying major BIM technology roles and critical contributions to the construction project in estimating safety index and productivity. [21] depended on a case study analysis of Singapore's safety system and intelligent productivity framework. Also, [21] followed a comprehensive literature review. Several recent articles and academic publications addressed the importance of critical BIM technology significance in accomplishing higher safety standards and productivity of construction projects. The comprehensive literature analysis revealed that BIM technology plays a beneficial role and positively impacts the construction industry in achieving considerable safety standards. Also, BIM technology can improve construction projects' productivity rate and manage their resources. [22] executed an analysis examining the important role of BIM principles in managing and designing a seismic building associated with Malaysian governmental construction projects. [22] depended on a semi-structured qualitative approach through which interviews were conducted with construction industry experts and stakeholders from the Malaysian government to address the critical role of BIM technology in seismic building design. Their qualitative research approach revealed that BIM technology plays a significant role in managing, designing, and monitoring buildings with earthquakes and seismic impacts. Also, BIM modelling can help control project activities and improve construction projects' performance. [23] performed research investigating the significance of BIM technology adoption and implementation in improving the performance of several construction projects. [23] applied a cross-sectional descriptive quantitative study through which questionnaire surveys were applied, covering 159 experts in the BIM technology used in the construction sector. Their cross-sectional research findings indicated that implementing BIM technology in the construction industry provides advantageous impacts and positive effects for facility managers, contractors, owners, structural and architectural engineers, and other construction stakeholders. Also, the results revealed that BIM technology contributed to several significant improvements in the design drawings' quality. In addition, the use of BIM technology offered a remarkable reduction in the changes/ conflicts/ claims throughout the project execution. Moreover, BIM implementation helped offer flexible planning and resource management, and mobilization. Also, utilizing BIM principles contributed to a considerable reduction in human errors and time savings in estimating the construction project's cost and time. [24] conducted research examining the critical role of BIM technology in accomplishing flexible and effective quantity surveying of construction projects. In addition, [24] aimed to identify major strategies, key drivers, and main limitations of BIM and LEAN principles in the construction industry. [24] applied a cross-sectional quantitative descriptive study through which the study goals are implemented and achieved. Their cross-sectional quantitative research analysis revealed that implementing BIM technology and LEAN principles is beneficial and advantageous to construction engineers. BIM and LEAN principles could reduce significant construction projects' complexities, uncertainties, and difficulties associated with quantity surveying. Nevertheless, the results reported a shortage in the BIM and LEAN principles implementation, experience, and knowledge, making construction engineers, designers, and quantity surveyors hesitant to implement BIM and LEAN approaches. Thus, they utilized conventional complicated quantity surveying methods that consume much time, effort, and cost. Additionally, their analytical work affirmed that there is a shortage in the financial aspects, including the need for training costs, software, and hardware expenses. Also, findings confirmed the shortage of BIM technology professionals and LEAN principles experts in the construction industry. [25] carried out research examining the critical BIM technology contributions and major benefits in facilitating quantity surveying of construction projects in Spain. [25] depended on analyzing a case study that presented a Spanish construction project. They implemented BIM 5D modelling and made quantity surveying using the numerical approach of BIM technology. Their numerical modelling and quantity surveying via BIM software revealed that BIM principles and BIM 5D modelling played a critical role in facilitating the quantity surveying of the case study (Spanish construction project). In addition, 5D BIM modelling significantly reduced human errors and provided better accuracy and performance in the quantity surveying of the construction project. [26] executed research exploring major BIM technology in quantity surveying of the construction project. In addition, they classified the critical contributions of modelling in improving the accuracy and performance of the construction project. [26] applied 3D modelling through which a three-dimensional configuration was developed to make quantity surveying. The numerical BIM 3D modelling and quantity surveying analysis revealed that implementing BIM 3D modelling contributed to significant accuracy and flexibility in calculating the cost of the construction project. Furthermore, it was found that using BIM 3D modelling enabled engineers to compute the construction project's cost with less effort and time.

[27] published a manuscript exploring BIM technology's critical contribution and beneficial role in estimating the construction project cost. [27] applied BIM modelling using a software tool through which numerical analysis of a selected construction project was implemented to calculate the project's budget. The numerical analysis revealed that implementing BIM technology has a great positive impact on evaluating the construction project cost. Findings confirmed that using BIM technology enables flexible cost estimation with higher accuracy avoiding human errors and saving much time and effort in assessing the construction project budget. [28] performed a study investigating the major relevances and contributions of BIM technology implementation in the Indian construction industry in evaluating the construction projects' cost. [28] followed a cross-sectional qualitative study through which interviews were conducted with Indian construction professionals and BIM technology experts. Their interviews revealed that applying BIM technology is greatly beneficial for the Indian construction sector. It allows Indian structural engineers and designers to calculate the costs of construction projects with less effort and time. Additionally, using BIM modelling to evaluate the Indian construction project contributed to significant accuracy, as traditional cost evaluation methods associated with many human errors can be avoided. [29] conducted a study examining critical BIM technology's effect and major benefits on the Vietnamese construction industry. [29] investigated a case study in which a construction project in Vietnam was selected (which presented high-rise construction projects). BIM technology was used to evaluate the construction project's cost. [29] applied quantity surveying (quantity take-off) numerically to

determine the major contribution of BIM principles in estimating the cost of high-rise construction projects in Vietnam. Their numerical calculation approach revealed that using BIM technology is remarkably effective and practical in evaluating the quantity of high-rise construction projects. BIM principles could greatly cut down the effort and time needed to make quantity take-off of such large construction projects. Besides, BIM technology is greatly beneficial in evaluating high-rise projects' costs with higher accuracy, resolving the problem of cost calculation complexity. Furthermore, [30]–[59] led several studies and research analyses to predict the effectiveness and critical contributions of BIM technology, 3D, 4D, and 5D modeling, and the REVIT software package in estimating the costs of different construction projects. They found that implementing BIM principles and the REVIT cost-estimation numerical method could save significant levels of time and effort and result in considerable accuracy degree.

2.5 CHAPTER SUMMARY

It can be inferred from reviewing several research articles and recent academic publications that BIM technology plays a critical role in facilitating construction projects' cost estimation and quantity surveying, cutting down much effort and time required by structural engineers and designers to make quantity take-off. In addition, it was found that implementing BIM technology is remarkably beneficial in enabling engineers to calculate the constriction project with higher accuracy than traditional calculation methods in which a large number of human errors can occur. Also, the literature review analysis indicated that utilizing BIM technology is greatly effective in handling complex cost calculation processes such as the cost estimation of high-rise buildings.

3. RESEARCH METHODOLOGY

3.1 CHAPTER GOAL

This chapter describes the main research methodology, and the critical conceptual approach pursued to carry out the analysis and investigation of the case study. It describes the REVIT software tool's important principles and features that depend on the BIM technology to calculate the project's cost with higher accuracy.

3.2 THE RESEARCH METHOD

The research method of this work contains some steps and study procedures adopted and implemented to help carry out the analysis of the study. Firstly, a comprehensive review was executed through the literature review in chapter two to address and highlight major contributions and vital relevance's of the REVIT software package and BIM technology in calculating different construction projects' costs flexibly. Furthermore, the literature review is considerable and essential to identify some substantial benefits and critical advantages of BIM technology implementation associated with the levels of accuracy, reducing human errors, and minimizing the amount of time, budget, and effort required to conduct cost estimation of construction projects. After carrying out this step, a case study (described in the following sections) is taken into account representing a hospital building. Then, BIM principles, with the help of the REVIT software package, are considered to facilitate the project's budget estimation with a higher rate of accuracy and performance. Figure 3.1 represents the research methodology flowchart adopted in this thesis.

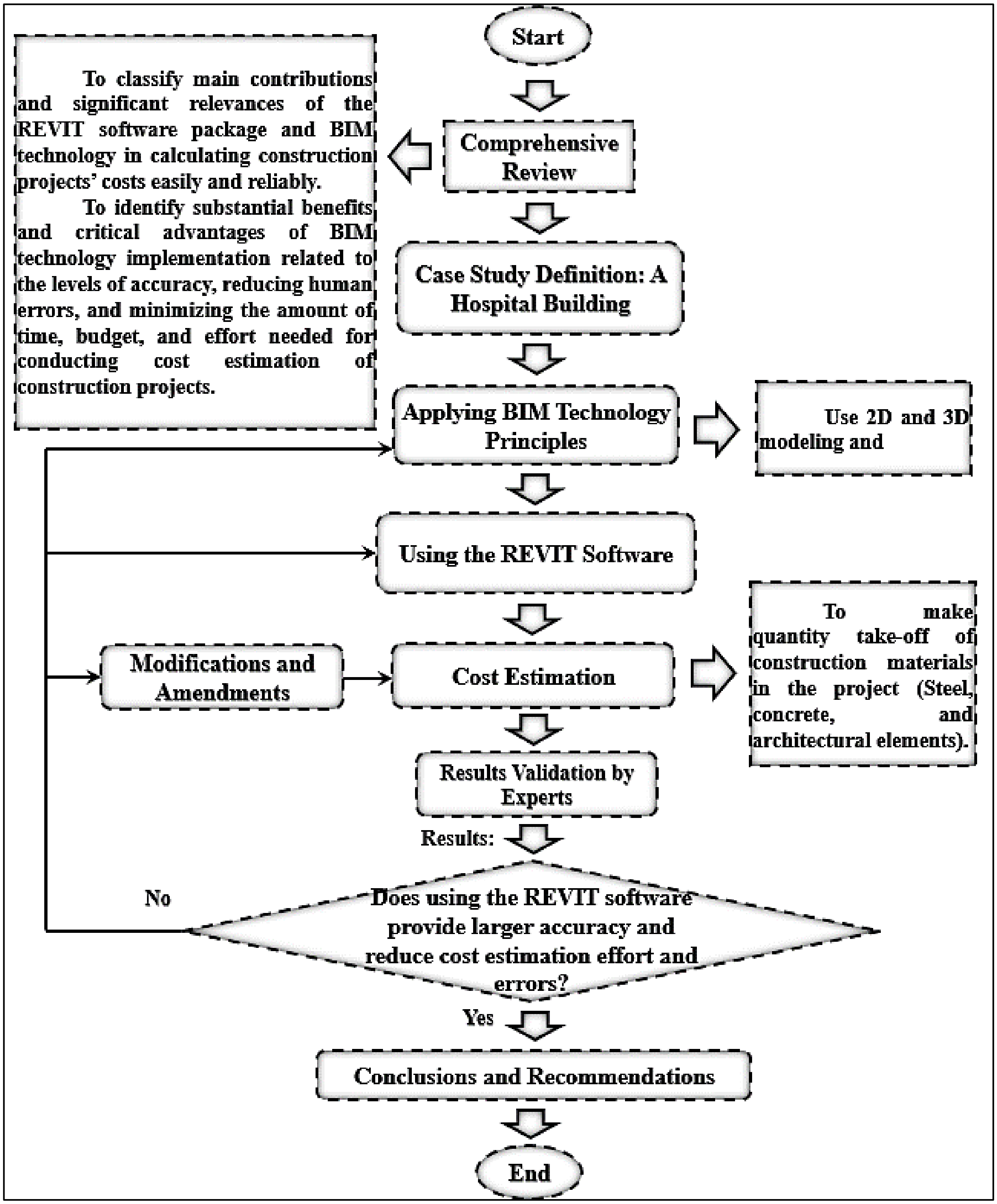


Figure 3.1: The thesis's methodology flowchart.

3.3 THE CASE STUDY DESCRIPTION

The case study consists of a hospital building comprising four floors (ground floor, first floor, second floor, and roof). The significant hospital building's zones and rooms include the main entrance, optical, pharmacy, secondary entrance, lobby, health gas system, electrical board room, main reception, waiting, special waiting, doctor room, general examination, special examination, cafeteria, prayer, garden, special corridor, nursing, patient room, locker, change clothes, doctors break, patient sterilization room, medical sterilization room, sterile corridor, operations hall, Lasik operation, kitchenette, UBS room, and an elevator room. Figure 3.2 represents a concrete-based model of the hospital building.

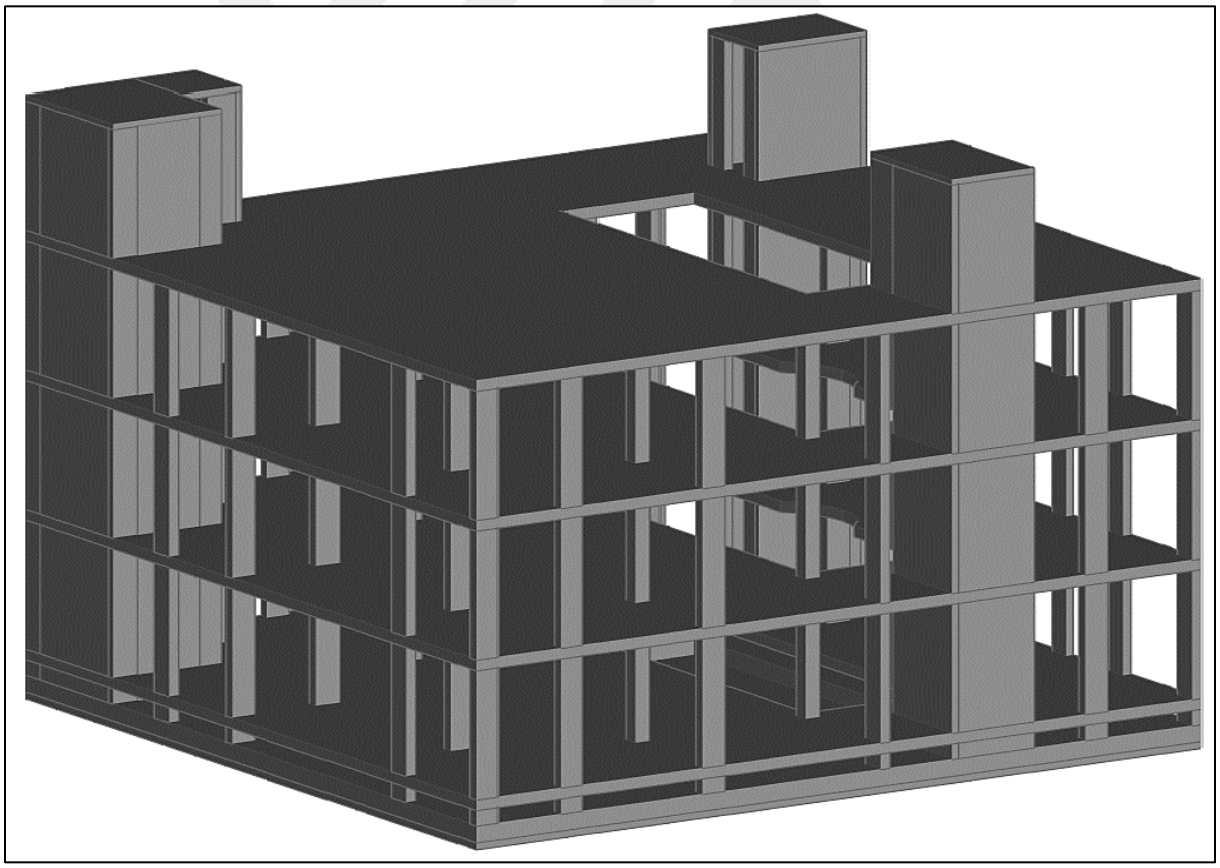


Figure 3.2: The case study investigated in this research: hospital building.

In addition, Table 3.1 illustrates the remarkable details of the floor area and floor components.

Table 3.1: The main details of the floor area and floor components of the case study building.

#	Floor	Area (m^2)	Parts of the floor, Use
1	Ground floor	600	The main entrance, Optical, Pharmacy, Secondary entrance, Lobby, Healthy gas system, Electrical Room, Main Reception, Waiting, Special Waiting, Doctor room, General Examination, Special Examination, Cafeteria, Prayer, Laboratory, Garden, Special corridor, Nursing, Inpatient room.
2	First floor	600	Locker, Change Clothes, Doctors Break, Patient sterilization room, medical sterilization room, Sterile corridor, Operations hall, Lasik Operation, Kitchenette, UBS Room.
3	Second floor	600	Locker, Change Clothes, Doctors Break, Patient sterilization room, medical sterilization room, Sterile corridor, Operations hall, Lasik Operation, Kitchenette, UBS Room.
4	Roof floor	41.65	Elevator rooms.

3.4 MANUAL PROCEDURE FOLLOWED TO MAKE QUANTITY TAKE-OFF

In this section, the quantities and amounts of materials used in the construction process, including civil and architectural elements, such as reinforcement steel, reinforcement concrete, and other architectural materials.

3.4.1 Reinforcement Concrete Quantity Manual Estimation

Table 3.2 presents the method of calculating the cut.

Table 3.2: Calculating the cut manually.

Cut (m^3) = Excavation area × Excavation depth	Value
Cut = 24.2 × 25.2 × 2.00	1,219.73 m^3

In Table 3.2 we have calculated the volume of project land soil to be removed to start the project construction process.

Table 3.3 presents the process of calculating the blinding volume.

Table 3.3: Calculating the blinding volume manually.

Blinding (m^3) (100 mm depth)	Value
Volume = (L1×L2×H) – opening volume	54.40 m^3
Volume = (24.2×25.2×0.1) – (4.8×13.7×0.1)	

In Table 3.3 we have calculated the volume of concrete for blinding layer that isolates the foundations from the soil to start implementing the foundations.

Table 3.4 presents the process of calculating the boulder volume.

Table 3.4: Calculating the boulder volume manually.

Boulder Volume (m^3) (200 mm depth)	Value
Volume = (L1×L2×H) – opening volume	108.82 m^3
Volume = (24.2×25.2×0.2) – (4.8×13.7×0.2)	

In Table 3.4 we have calculated the volume of Boulder layer that will be added to strengthen the foundation of the project.

Table 3.5 represents the process of calculating the boulder volume.

Table 3.5: Calculating the sub-base volume manually.

Sub-base Volume (m^3) (400 mm depth)	**Value**
Volume = (L1×L2×H) – opening volume	217.64 m^3
Volume = (24.2×25.2×0.4) – (4.8×13.7×0.4)	

In Table 3.5 we have calculated the volume of Sub-base layer that will be added in the pre-foundation phase.

Table 3.6 describes the process of calculating the lean concrete volume.

Table 3.6: Calculating the lean concrete volume manually.

Lean concrete Volume (m^3) (100 mm depth)	**Value**
Volume = (L1×L2×H) – opening volume	54.40 m^3
Volume = (24.2×25.2×0.1) – (4.8×13.7×0.1)	

In Table 3.6 we have calculated the volume of lean concrete layer that will be added in the pre-foundation phase.

Table 3.7 illustrates the process of calculating the bitumen volume.

Table 3.7: Calculating the bitumen volume manually.

Bitumen Volume (m^3) (8 mm depth)	**Value**
Volume = (L1×L2×H) – opening volume	4.35 m^3
Volume = (24.2×25.2*0.008) - (4.8×13.7×0.008)	

In Table 3.7 we have calculated the volume of the bitumen layer that was used for waterproofing.

Table 3.8 illustrates the calculation procedure for the reinforced concrete volume for the raft foundation.

Table 3.8: Calculating the reinforced concrete volume for the raft foundation.

Reinforced Concrete (m^3) = (length × width × depth of foundation is 0.65 m) – opining volume					
Item	**Length (m)**	**Width (m)**	**Depth (m)**	**Opening volume (m^3)**	347.26 m^3
Raft Foundation	24.00	25.00	0.65	(4.8×13.7×0.65) = 42.74	

In Table 3.8, we calculated the volume of reinforced concrete that we used in the foundations of the project, and it was Raft Foundation.

Table 3.9 illustrates the calculation for the reinforced concrete columns' volume.

Table 3.9: Calculating the reinforced concrete columns' volume.

Concrete Columns Volume = Length × Width × Height					
Total height from raft footing to second floor = (5 + 4 + 4 + 0.65) m, = 13.65 m **Total height from raft footing to second floor = (5 + 4 + 4 +4+ 0.65) m, = 17.65 m, without Slabs height**					
item	**length**	**width**	**height**	**number**	**total**
C1	0.75	0.30	13.65	10	30.72
C1	0.75	0.30	17.65	1	3.97
C2	0.75	0.30	17.65	1	3.97

Table 3.9: Calculating the reinforced concrete columns' volume. "Tables continued."

C2	0.75	0.30	13.65	10	30.72
C3	0.75	0.30	17.65	1	3.97
C3	0.75	0.30	13.65	3	9.21
C4	0.75	0.35	13.65	1	3.58
C5	0.45	0.45	13.65	4	11.06
C6	0.70	0.25	13.65	4	9.56
Total columns reinforced concrete					**106.76 m^3**

In Table 3.9, we calculated the volume of reinforced concrete that we used in the columns of the project, and it was six types (C1, C2, C3, C4, C5, C6).

Table 3.10 describes the estimation of the volume of the reinforced concrete walls.

Table 3.10: Calculating the reinforced concrete walls' volume.

Total height from raft footing to second floor = (5 + 4 + 4 +4+ 0.65) m, = 17.65 m, without Slabs height				
Reinforced concrete walls = Length × Width × Height				
item	**Length (m)**	**Width (m)**	**Height (m)**	**Total (m^3)**
SW1 & SW2	8.10	0.30	17.65	42.89
Elevator 1 & 2	18.8	0.25	17.65	82.96
Total Walls reinforced Concrete Volume				**125.85 m^3**

In Table 3.10, we calculated the volume of reinforced concrete that we used in the walls of the project, and it was two types (shear walls 1, 2 and elevator walls).

Table 3.11 describes the estimation of the volume of the reinforced concrete beams.

Table 3.11: Calculating the reinforced concrete beams' volume.

Beams Concrete = Height × Width × Length					
item	**Length (m)**	**Width (m)**	**Height (m)**	**number**	**Total (m^3)**
B1	98.00	0.35	0.70	3	72.03
B2	51.68	0.70	0.32	3	34.73
B3	42.80	0.8	0.32	3	32.87
B4	16.3	0.5	0.32	3	7.82
B6	17.43	0.35	0.7	3	12.81
B7	26.56	0.35	0.8	3	22.31
Total of Beams Reinforced Concrete					**182.57 m^3**

In Table 3.11, we calculated the volume of reinforced concrete that we used in the beams of the project, and it was seven types (B1, B2, B3, B4, B5, B6, B7).

Table 3.12 describes the estimation of the volume of the hollow/waffle blocks.

Table 3.12: Calculating the volume of the hollow/waffle blocks.

Hollow/Waffle Blocks Volume = Number of blocks × Volume of one block × Number of floors	**Value**
volume= #Blocks×0.0192	140.04 m^3
Volume = 2431 × 0.0192 × 3	

In Table 3.12, we calculated the volume of hollow blocks that we used in this project, was their number 2431 block.

Table 3.13 describes the estimation of the reinforced concrete slabs' volume.

Table 3.13: Calculating reinforced concrete slabs' volume.

Slabs reinforced Concrete Volume = (Total Volume of one slab – (Hollow Blocks Volume + Beams reinforced Concrete Volume + opening volume)) × Number of floors						
Item	**Floor total volume one floor (m^3)**	**Floor opening one floor (m^3)**	**Beams concrete one floor (m^3)**	**Hollow Blocks Volume One floor (m^3)**	**No**	**Total (m^3)**
Slab on grade 1	34.38 m^2 × 0.18 m = 6.19	---	-----	----	1	6.19
Slab on grade 2	492.77 m^2 × 0.36 m = 177.40	----	----	----	1	177.40
GF, 1st, 2nd floor	600 m^2 × 0.32 m = 192	96.37 m^2 × 0.32 m = 30.84	182.57 / 3 = 60.86	140.04 /3 = 46.68	3	160.86
Top of roof Solid slab	41.65 m^2 × 0.15 m = 6.25	----	----	----	1	6.25
steps	66 steps × 0.5 × 0.3 m × 0.165 m × 1 m = 1.63	----	----	0.36	1	1.63
stair ladders	34 m × 1 m × 0.3 m = 10.2	----	----	15.84	1	10.2
Total of Reinforced Concrete Slabs						**362.53**

In Table 3.13, we calculated the volume of reinforced concrete that we used in the slabs of the project, it is calculated by subtracting the total volume minus the volume of the opining and the volume of the blocks.

Table 3.14 describes the estimation of the total reinforced concrete volume.

Table 3.14: Calculating total reinforced concrete volume.

Raft foundation	Columns	Walls	Beams	Slabs
347.26 m^3	106.76 m^3	125.85 m^3	182.57 m^3	362.53 m^3
Total = 1,124.97 m^3				

In Table 3.14, we calculated the total volume of reinforced concrete that we used in this project. Figure 3.3 represents a pie chart describing the percentage of concrete required for main construction elements.

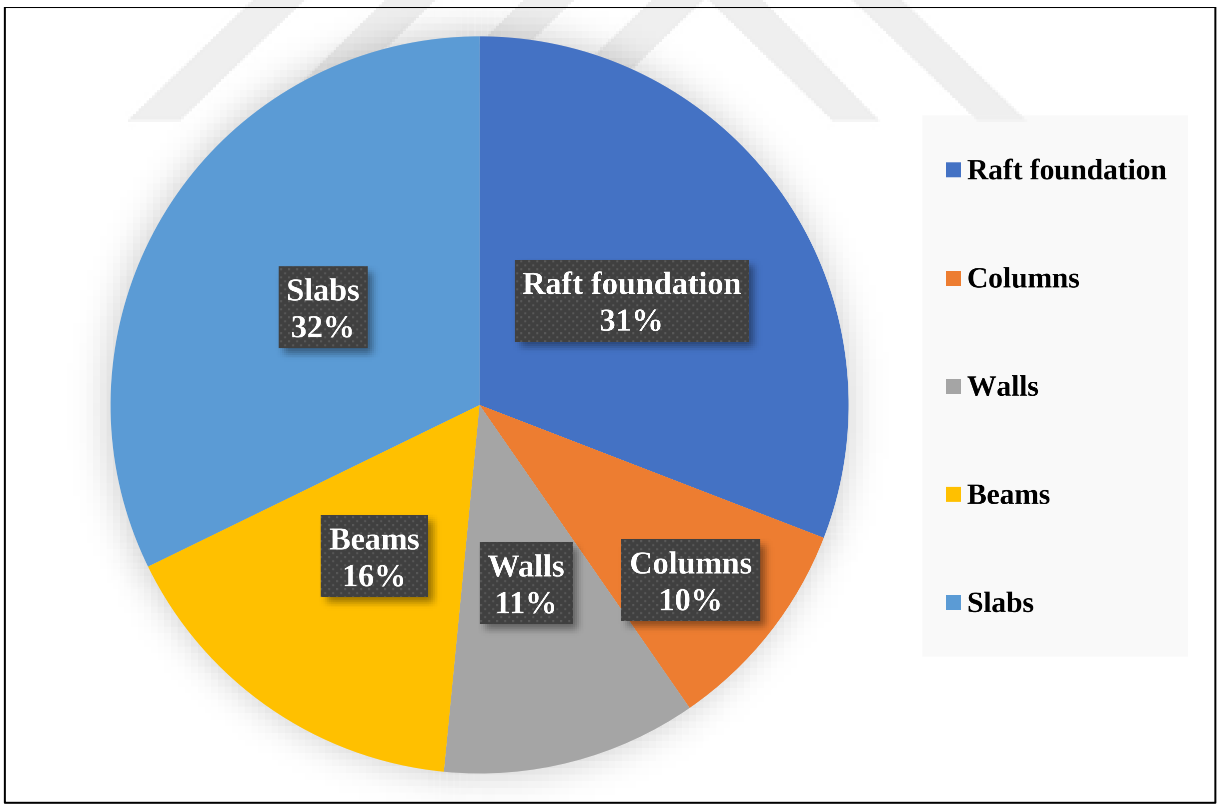


Figure 3.3: The percentage of concrete required for main construction elements.

It can be inferred from Figure 3.3 that the most significant quantities of concrete are consumed by two major elements, which are slabs and raft foundation, corresponding to percentages of 32% and 31%, requiring approximately 363 m^3 and 347 m^3 of concrete, respectively, as described in Table 3.14.

3.4.2 Reinforcement Steel Quantity Manual Estimation

The reinforcement steel is computed using the formula:

$$Reinforcement\ Steel\ (kg) = Bar\ weight\ (kg/m)\ \times Length\ (m)\ \times\ No.of\ bars\ , \qquad (3.1)$$

Where bar weight can be estimated by the expression:

$$Bar\ Weight\ (kg/m) = Diameter^2\ (mm^2)\ /\ 162, \qquad (3.2)$$

The classification of steel diameters and weights used in this project are explained in Table 3.15.

Table 3.15: The classification of steel diameters and weight used in this project.

Dia. Used in this project	Weight /m = Dia. (mm^2)/162	Total weight (kg/m)
25 mm	$(25)^2/162$	3.8
20 mm	$(20)^2/162$	2.47
18 mm	$(18)^2/162$	2.00
16 mm	$(16)^2/162$	1.580
14 mm	$(14)^2/162$	1.21
12 mm	$(12)^2/162$	0.89
10 mm	$(10)^2/162$	0.62

In Table 3.15, calculated the weight of one meter of steel bars diameters.

Table 3.16 represents the reinforcement steel estimation using the manual calculation required for the raft foundation.

Table 3.16: The reinforcement steel estimation using the manual calculation required for the raft foundation.

Steel location	Comments	Dia.	weight	L	No.	total weight
Top-transverse **With steel bars overlap**		20	2.47	12	81	2400.84
		20	2.47	12	81	2400.84
		20	2.47	2.05	81	506.35
		20	2.47	5.2	19	244.04
		20	2.47	7.1	19	333.20
Bottom-transverse **With steel bars overlap**		20	2.47	12	81	2400.84
		20	2.47	12	81	2400.84
		20	2.47	2.05	81	506.35
		20	2.47	5.2	19	244.04
		20	2.47	7.1	19	333.20
Top-longitudinal **With steel bars overlap**		20	2.47	12	41	1215.24
		20	2.47	12	41	1215.24
		20	2.47	3.05	41	3.08.87
		20	2.47	6.88	55	934.65
		20	2.47	12	55	1630.2
		20	2.47	4.53	55	615.40

Table 3.16: The reinforcement steel estimation using the manual calculation required for the raft foundation. "Tables continued."

Bottom-longitudinal With steel bars overlap		20	2.47	12	41	1215.24
		20	2.47	12	41	1215.24
		20	2.47	3.05	41	3.08.87
		20	2.47	6.88	55	934.65
		20	2.47	12	55	1630.2
		20	2.47	4.53	55	615.40
Middle bars-transverse With steel bars overlap		12	0.89	12	11	117.48
		12	0.89	12	11	117.48
		12	0.89	1.33	11	13.02
		12	0.89	7.1	3	18.96
Middle bars-longitudinal With steel bars overlap		12	0.89	12	5	53.4
		12	0.89	12	5	53.4
		12	0.89	2.33	5	10.37
		12	0.89	6.88	5	30.62
		12	0.89	12	5	53.4
		12	0.89	3.81	5	16.95
Continuous footing stirrups	-----------------	10	0.62	4.2	670	1744.68
		10	0.62	3	392	729.12
Total Raft Footing Reinforcement Steel (Kg)						**25,950.88**
25.951 tons						

In Table 3.16, calculated the weight of steel reinforcement of raft foundation in (X and Y)-direction in top and bottom of footing.

Also, Table 3.17 represents the steel reinforcement quantity calculated using hand computations to estimate the steel reinforcement required for columns.

Table 3.17: The steel reinforcement quantity calculated using hand computations to estimate the steel reinforcement required for columns.

Dia.	Weight (Kg)	L (m)	No.	Total weight (Kg)	Comments
20	2.47	4.38	16	173.10	**C1 from Footing to Roof With overlap and stirrups**
10	0.62	5.29	6	19.68	
20	2.47	6.32	16	249.77	
10	0.62	5.29	27	88.55	
20	2.47	5.32	48	630.74	
10	0.62	5.29	65	213.19	
20	2.47	4.38	160	1730.98	**C1 from Footing to 2nd With overlap and stirrups**
10	0.62	5.29	60	196.79	
20	2.47	6.32	160	2497.67	
10	0.62	5.29	270	885.55	
20	2.47	5.32	320	4204.93	
10	0.62	5.29	440	1440.31	

Table 3.17: The steel reinforcement quantity calculated using hand computations to estimate the steel reinforcement required for columns. “tables continued.”

20	2.47	4.38	18	194.73	**C2 from Footing to Roof With overlap and stirrups**
10	0.62	5.29	6	19.68	
20	2.47	6.32	18	280.99	
10	0.62	5.29	27	88.55	
20	2.47	5.32	54	709.58	
10	0.62	5.29	65	213.19	
20	2.47	4.38	180	1947.35	**C2 from Footing to 2nd With overlap and stirrups**
10	0.62	5.29	60	196.79	
20	2.47	6.32	180	2809.87	
10	0.62	5.29	270	885.55	
20	2.47	5.32	360	4730.54	
10	0.62	5.29	440	1440.31	
20	2.47	4.38	14	151.46	**C3 from Footing to Roof With overlap and stirrups**
10	0.62	4.18	6	15.55	
20	2.47	6.32	14	218.55	
10	0.62	4.18	27	69.97	
20	2.47	5.32	42	551.90	
10	0.62	4.18	65	168.45	

Table 3.17: The steel reinforcement quantity calculated using hand computations to estimate the steel reinforcement required for columns. "tables continued."

20	2.47	4.38	42	454.38	**C3 from Footing to 2nd With overlap and stirrups**
10	0.62	4.18	18	46.65	
20	2.47	6.32	42	655.64	
10	0.62	4.18	81	209.92	
20	2.47	5.32	84	1103.79	
10	0.62	4.18	132	342.09	
20	2.47	4.38	20	216.37	**C4 from Footing to Roof With overlap and stirrups**
10	0.62	4.82	6	17.93	
20	2.47	6.32	20	312.21	
10	0.62	4.82	27	80.69	**C4 from Footing to 2nd With overlap and stirrups**
20	2.47	5.32	40	525.62	
10	0.62	4.82	44	131.49	
20	2.47	4.38	80	865.49	**C5 from Footing to 2nd With overlap and stirrups**
10	0.62	3.32	24	49.40	
20	2.47	6.32	40	624.42	
10	0.62	3.32	108	222.31	
20	2.47	5.32	160	2102.46	
10	0.62	3.32	176	362.28	

Table 3.17: The steel reinforcement quantity calculated using hand computations to estimate the steel reinforcement required for columns. "tables continued."

20	2.47	4.38	80	865.49	**C6 from Footing to 2nd With overlap and stirrups**
10	0.62	3.98	24	59.22	
20	2.47	6.32	40	624.42	
10	0.62	3.98	108	266.50	
20	2.47	5.32	160	2102.46	
10	0.62	3.98	176	434.30	
Total of Columns reinforcement Steel (kg)				**39,699.8**	

In Table 3.17, calculated the weight of steel reinforcement of columns in (X and Y)-direction in top and bottom of footing, it was six types (C1, C2, C3, C4, C5, C6).

In addition, Table 3.18 illustrates the manual quantity take-off method using hand calculations to estimate the reinforcement steel required for the walls of this construction project.

Table 3.18: The manual quantity take-off method using hand calculations to estimate the reinforcement steel required for the walls of this construction project.

Dia.	Weight (Kg)	L (m)	No.	Total weight (Kg)	Comments
16	1.58	4.38	32	221.45	SW1 from Footing to Roof With overlap and stirrups
20	2.47	4.38	12	129.82	
10	0.62	5.84	6	21.72	
10	0.62	1.64	6	6.10	
10	0.62	2.94	6	10.94	
16	1.58	6.32	32	319.54	
20	2.47	6.32	12	187.32	
10	0.62	5.84	27	97.76	
10	0.62	1.64	27	27.45	
10	0.62	2.94	27	49.22	
16	1.58	5.32	96	806.94	
20	2.47	5.32	36	473.05	
10	0.62	5.84	65	235.35	
10	0.62	1.64	65	66.09	
10	0.62	2.94	65	118.48	

Table 3.18: The manual quantity take-off method using hand calculations to estimate the reinforcement steel required for the walls of this construction project. "tables continued."

16	1.58	4.38	60	415.22	**SW2 from Footing to Roof With overlap and stirrups**
20	2.47	4.38	12	129.82	
10	0.62	5.64	6	20.98	
10	0.62	1.84	6	6.84	
10	0.62	5.88	6	21.87	
12	0.89	6.08	6	32.47	
16	1.58	6.32	60	599.14	
20	2.47	6.32	12	187.32	
10	0.62	5.64	27	94.41	
10	0.62	1.84	27	30.80	
10	0.62	5.88	27	98.43	
12	0.89	6.08	27	146.10	
16	1.58	5.32	180	1513.01	
20	2.47	5.32	36	473.05	
10	0.62	5.64	65	227.29	
10	0.62	1.84	65	74.15	
10	0.62	5.88	65	236.96	
12	0.89	6.08	65	351.73	

Table 3.18: The manual quantity take-off method using hand calculations to estimate the reinforcement steel required for the walls of this construction project. "tables continued."

16	1.58	4.38	154	1065.74	**Elevator 1 from Footing to Roof** **With overlap and stirrups**
10	0.62	10.36	6	38.54	
12	0.89	2.08	6	11.11	
12	0.89	2.08	6	11.11	
12	0.89	7.98	6	42.61	
12	0.89	7.98	6	42.61	
12	0.89	5.78	6	30.87	
16	1.58	6.32	154	1537.78	
10	0.62	10.36	27	173.43	
12	0.89	2.08	27	49.98	
12	0.89	2.08	27	49.98	
12	0.89	7.98	27	191.76	
12	0.89	7.98	27	191.76	
12	0.89	5.78	27	138.89	**Elevator 1 from Footing to Roof**
16	1.58	5.32	462	3883.39	
10	0.62	10.36	65	417.51	
12	0.89	2.08	65	120.33	
12	0.89	2.08	65	120.33	

Table 3.18: The manual quantity take-off method using hand calculations to estimate the reinforcement steel required for the walls of this construction project. "tables continued."

12	0.89	7.98	65	461.64	
12	0.89	7.98	65	461.64	
12	0.89	5.78	65	334.37	
16	1.58	4.38	108	747.40	**Elevator 2 from Footing to Roof** **With overlap and stirrups**
10	0.62	8.14	6	30.28	
12	0.89	7.52	6	40.16	
12	0.89	5.38	6	28.73	
12	0.89	5.38	6	28.73	
12	0.89	4.98	6	26.59	
12	0.89	7.52	6	40.16	
16	1.58	6.32	108	1078.44	
10	0.62	8.14	27	136.26	
12	0.89	7.52	27	180.71	
12	0.89	5.38	27	129.28	
12	0.89	5.38	27	129.28	
12	0.89	4.98	27	119.67	
12	0.89	7.52	27	180.71	

Table 3.18: The manual quantity take-off method using hand calculations to estimate the reinforcement steel required for the walls of this construction project. "tables continued."

16	1.58	5.32	324	2723.41	
10	0.62	8.14	65	328.04	
12	0.89	7.52	65	435.03	
12	0.89	5.38	65	311.23	
12	0.89	5.38	65	311.23	
12	0.89	4.98	65	288.09	
12	0.89	7.52	65	435.03	
Total of Walls Reinforcement Steel (kg)				**24,534.7**	
24.534.7 tons					

In Table 3.18, we calculated the weight of steel reinforcement that we used in the walls of the project, and it was two types (shear walls 1, 2 and elevator walls).

Furthermore, Table 3.19 displays in detail the manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel required for the slabs of this construction project.

Table 3.19: The manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel for the slabs.

Dia.	Weight (kg)	L (m)	No.	Total weight (kg)	Comments
10	0.62	12	81	602.64	Slab on grade - Steel Reinforcement Top-transverse With steel bars overlap
10	0.62	12	81	602.64	
10	0.62	2.05	81	102.95	
10	0.62	5.2	19	61.26	
10	0.62	7.1	19	83.64	
10	0.62	12	81	602.64	Slab on grade - Steel Reinforcement Bottom-transverse With steel bars overlap
10	0.62	12	81	602.64	
10	0.62	2.05	81	102.95	
10	0.62	5.2	19	61.26	
10	0.62	7.1	19	83.64	
10	0.62	12	41	305.04	Slab on grade- Steel Reinforcement Top-longitudinal with steel bars overlap
10	0.62	12	41	305.04	
10	0.62	3.05	41	77.53	
10	0.62	6.88	55	234.61	
10	0.62	12	55	409.20	

Table 3.19: The manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel for the slabs. “tables continued.”

10	0.62	12	41	305.04	**Slab on grade - Steel Reinforcement** **Bottom -longitudinal** **With steel bars overlap**
10	0.62	12	41	305.04	
10	0.62	3.05	41	77.53	
10	0.62	6.88	55	234.61	
10	0.62	12	55	409.20	
2	0.89	6.32	48	269.99	**Solid Slab - Steel Reinforcement GR/1st/2nd/Roof** **With steel overlap**
12	0.89	3.7	110	362.23	
12	0.89	6.25	96	534.00	
12	0.89	2.49	72	159.56	
12	0.89	3.67	65	212.31	
12	0.89	3.22	77	220.67	
12	0.89	4.55	25	101.24	
12	0.89	2.85	`42	106.53	**Solid Slab - Steel Reinforcement GR/1st/2nd/Roof** **With steel overlap**
16	1.580	3.2	19	96.06	
16	1.580	2.4	27	102.38	
16	1.580	3.7	22	128.61	
16	1.580	2.6	33	135.56	

Table 3.19: The manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel for the slabs. “tables continued.”

12	0.89	3.67	65	212.31	
12	0.89	3.22	77	220.67	
12	0.89	5.53	198	974.50	**Hollow Slab - Steel Reinforcement GR/1st/2nd With steel overlap and stirrups**
10	0.62	6.36	60	236.59	
10	0.62	5.53	30	102.86	
10	0.62	0.90	738	411.80	
12	0.89	6.18	198	1089.04	
10	0.62	6.18	33	126.44	
10	0.62	6.67	64	264.67	
10	0.62	0.90	837	467.05	
12	0.89	5.94	198	1046.75	**Staircase Slab - Steel Reinforcement GR/1st/2nd/Roof**
10	0.62	5.94	33	121.53	
10	0.62	6.68	31	128.39	
10	0.62	5.15	33	105.37	
10	0.62	0.90	699	390.04	
12	0.89	4.15	414	1529.11	
10	0.62	4.15	69	177.54	

Table 3.19: The manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel for the slabs. “tables continued.”

10	0.62	12.00	46	342.24	
10	0.62	3.00	46	85.56	**Staircase Slab - Steel Reinforcement GR/1st/2nd/Roof**
10	0.62	0.90	1053	587.57	
12	0.89	4.27	468	1778.54	
10	0.62	4.27	78	206.50	
10	0.62	12.00	44	327.36	
10	0.62	5.32	44	145.13	
10	0.62	0.90	1396	778.97	
12	0.89	4.27	162	615.65	
10	0.62	4.27	27	71.48	
10	0.62	6.00	50	186.00	**Staircase Slab - Steel Reinforcement GR/1st/2nd/Roof**
10	0.62	0.90	456	254.45	
12	0.89	6.08	432	2337.64	
10	0.62	6.08	60	226.18	
10	0.62	12.00	62	461.28	
10	0.62	2.74	62	105.33	
10	0.62	0.9	1494	833.65	

Table 3.19: The manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel for the slabs. "tables continued."

10	0.62	3.57	66	146.08	**Staircase Slab - Steel Reinforcement GR/1st/2nd/Roof**
12	0.89	3.00	33	88.11	
12	0.89	1.00	310	275.90	
12	0.89	2.00	140	249.20	
12	0.89	2.00	84	149.52	
12	0.89	1.00	168	149.52	
12	0.89	12.00	288	3075.84	**Waffle Slab - Steel Reinforcement GR/1st/2nd** **With steel overlap and stirrups**
12	0.89	3.00	288	768.96	
10	0.62	12.00	96	714.24	
10	0.62	3.00	96	178.56	
10	0.62	12.00	150	1116.00	
10	0.62	3.00	150	279.00	
10	0.62	0.94	3080	1795.02	
12	0.89	9.45	432	3633.34	
10	0.62	9.45	144	843.70	
10	0.62	9.45	215	1259.69	

Table 3.19: The manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel for the slabs. "tables continued."

10	0.62	0.94	3150	1835.82	**Waffle Slab - Steel Reinforcement GR/1st/2nd** **With steel overlap and stirrups**
Total Slabs Reinforcement Steel (kg)				**41,504.9**	
41.504.9 tons					

In Table 3.19, we calculated the weight of steel reinforcement that we used in the slabs of the project, and it was three types (hollow, waffle and solid slabs).

Additionally, Table 3.20 displays in detail the manual quantity take-off procedure followed using hand calculations to estimate the reinforcement steel required for the beams related to the case study of the hospital construction project.

Table 3.20: The manual quantity take-off procedure in detail followed using hand calculations to estimate the reinforcement steel required for the beams related to the case study.

Dia.	Weight (Kg)	L (m)	No.	Total weight (Kg)	Comments
12	0.89	12.00	98	1046.64	**Beam 1 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
25	3.8	12.00	221	10077.60	
12	0.89	12.00	196	2093.28	
10	0.62	1.98	1470	1804.57	**Beam 1 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
10	0.62	1.72	1470	1567.61	
16	1.58	12.00	117	2218.32	**Beam 2 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
12	0.89	12.00	65	694.20	
10	0.62	12.00	26	193.44	
10	0.62	3.44	775	1652.92	
16	1.58	12.00	107	2028.72	**Beam 3 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
12	0.89	12.00	65	694.20	
10	0.62	12.00	22	163.68	
10	0.62	3.84	642	1528.47	

Table 3.20: The manual quantity take-off procedure in detail followed using hand calculations to estimate the reinforcement steel required for the beams related to the case study. "tables continued."

16	1.58	12.00	25	474.00	**Beam 4 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
12	0.89	12.00	25	267.00	
10	0.62	12.00	13	96.72	
10	0.62	2.64	245	401.02	
20	2.47	12.00	27	800.28	**Beam 5 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
16	1.58	12.00	14	265.44	
12	0.89	12.00	18	192.24	
10	0.62	2.80	262	454.83	
20	2.47	12.00	40	1185.60	**Beam 6 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
16	1.58	12.00	20	379.20	
12	0.89	12.00	27	288.36	
10	0.62	3.10	399	766.88	
Total Beams Reinforcement Steel (kg)				**31,335.20**	
31.3352 tons					

In Table 3.20, we calculated the weight of steel reinforcement that we used in the beams of the project, and it was seven types (B1, B2, B3, B4, B5, B6, B7).

Figure 3.4 represents the percentage distribution of the overall steel quantity utilized by different construction components.

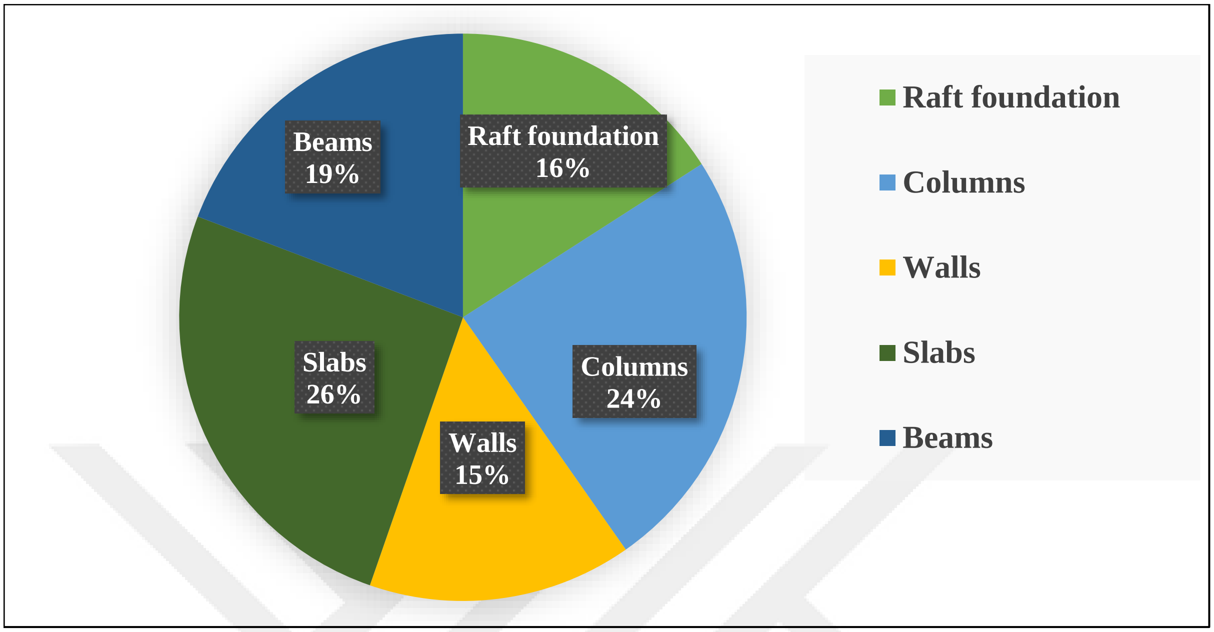


Figure 3.4: The percentage distribution of total steel amount utilized by different construction components.

The overall steel calculation is explained in Table 3.21.

Table 3.21: The overall steel calculation manually that is used in this construction project.

Part	Weight (kg)
Raft foundation steel reinforcement	25.950.88
Columns steel reinforcement	39.699.8
Walls steel reinforcement	24.534.7
Slabs steel reinforcement	41.504.9
Beams steel reinforcement	31.335.20
Total steel reinforcement in this project (kg)	163,025.5
Total = 163.0255 tons	

In Table 3.21, we calculated the total weight of steel reinforcement that we used in this project.

3.4.3 Architectural Elements Quantity Manual Estimation

The quantity calculation of external blocks is explained in Table 3.22.

Table 3.22: The quantity calculation of external blocks manually.

Blocks Number = ((L*H) – (opening area))×(1.00)/ (Area of Blocks)					
Floor	**Length (m)**	**Height (m)**	**Opening area (m^2)**	**Area of Block (m^2)**	**Total No.**
GR	74.86	5.00	79.25	0.08	3688
1st	74.86	4.00	----	0.08	3743
2nd	74.86	4.00	----	0.08	3743
Roof	74.86	1.00	----	0.08	936
Total Number of Blocks					12,110
968.8 m^2					

In Table 3.22, we calculated the area of blocks that we used in this project.

The quantity calculation of the external glass wall is illustrated in Table 3.23.

Table 3.23: The quantity calculation of the external glass wall manually.

Floor	Length (m)	Height (m)	Total area (m^2)
GR	15.01	5.00	75.05
1st	-----	----	-----
2nd	-----	----	-----
Roof	-----	----	-----
Total Area (m^2)			**75.05 m^2**

In Table 3.23, we calculated the area of external glass that we used in this project.

The quantity calculation of external plaster is illustrated in Table 3.24.

Table 3.24: The quantity calculation of external plaster manually.

Plaster Area = ((L*H) – (Opening area))				
Floor	**Length (m)**	**Height (m)**	**Opening area (m^2)**	**Total area (m^2)**
GR/ 1st / 2nd and Roof	98.00	15.79	79.25	1468.17
Plaster Area (m^2)				**1468.17 m^2**

In Table 3.24, we calculated the area of external plaster that we used in this project.

The quantity calculation of external stone is illustrated in Table 3.25.

Table 3.25: The quantity calculation of external stone manually.

Stones Area = ((L*H) – (Opening area))				
Floor	**Length (m)**	**Height (m)**	**Opening area (m^2)**	**Total area (m^2)**
GR/ 1st / 2nd and Roof	98.00	15.79	79.25	1468.17
Stones Area m^2				**1468.17 m^2**

In Table 3.25, we calculated the area of stones that we used in this project.

The quantity calculation of internal blocks is illustrated in Table 3.26.

Table 3.26: The quantity calculation of internal blocks manually.

Blocks Number = ((L*H) – (opening area))×(1.0)/Area of Blocks					
Floor	**Length (m)**	**Height (m)**	**Opening area (m^2)**	**Area of Block (m^2)**	**Total No.**
GR	114.25	5.00	46.50	0.08	6560
1st	162.56	4.00	68.5	0.08	7272
2nd	162.56	4.00	68.5	0.08	7272
Roof	----	----	----	----	----
Total Blocks					21104
1688.32 m^2					

In Table 3.26, we calculated the area of internal blocks that we used in this project.

The quantity calculation of the internal glass wall is depicted in Table 3.27.

Table 3.27: The quantity calculation of the internal glass wall manually.

Floor	Length (m)	Height (m)	Total area (m^2)
GR	44.35	5.00	221.75
1st	27.32	4.00	109.28
2nd	27.32	4.00	109.28
Roof	----	----	----
Total Area (m^2)			**440.31 m^2**

In Table 3.27, we calculated the area of internal glass that we used in this project.

The quantity calculation of the internal plaster and paint is depicted in Table 3.28.

Table 3.28: The quantity calculation of the internal plaster and paint manually.

Internal plaster and paint = ((L*H) – (opening area))				
Floor	**Length (m)**	**Height (m)**	**Opening area (m^2)**	**Total area (m^2)**
GR	324.72	5.00	168.58	1455.02
1st	433.12	4.00	154.49	1577.99
2nd	162.56	4.00	154.49	1577.99
Roof	----	----	----	----
Total Area				**4611 m^2**

In Table 3.28, we calculated the area of internal plaster that we used in this project.

The quantity calculation of the internal tiles is depicted in Table 3.29.

Table 3.29: The quantity calculation of the internal tiles manually.

Floor	Area
GR	407.04
1st	462.13
2nd	462.13
Roof	492.47
Total area of tiles	**1823.77 m^2**

In Table 3.29, we calculated the area of internal tiles that we used in this project.

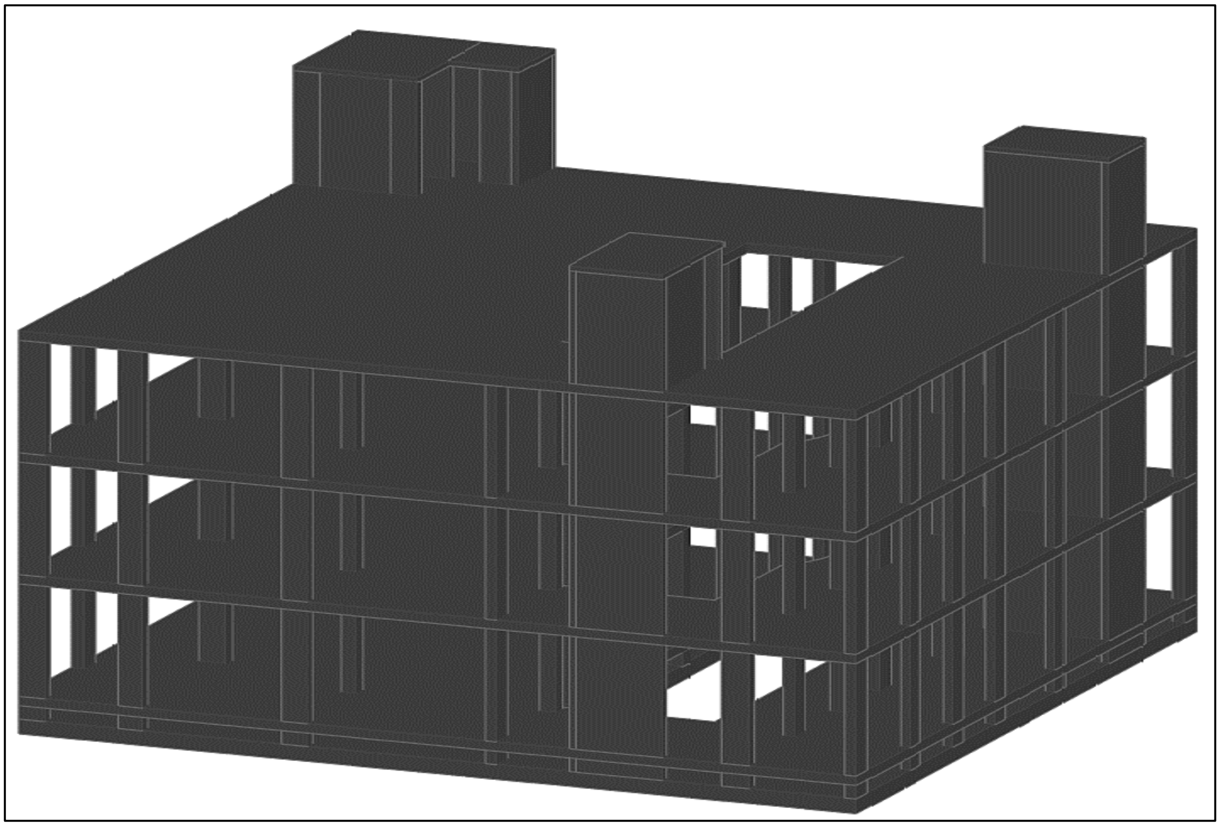


Figure 3.5: The 3D modeling of the hospital building whose cost is calculated.

The total concrete quantity calculated using the manual calculations is presented in Table 3.30.

Table 3.30: The total concrete quantity calculated using the manual calculations.

Raft foundation	**Columns**	**Walls**	**Beams**	**Slabs**
349.59 m^3	106.37 m^3	126.48 m^3	183.79 m^3	364.01 m^3
Total = 1130.24 m^3				

In Table 3.30, we calculated the total volume of reinforced concrete that we used in this project by using manual.

The total steel reinforcement estimated using the manual calculations is presented in Table 3.31.

Table 3.31: The total steel reinforcement estimated using the manual calculations.

Part	Weight (kg)
Raft foundation steel reinforcement	26566.05
Columns steel reinforcement	40123.40
Walls steel reinforcement	24936.53
Slabs steel reinforcement	40523.30
Beams steel reinforcement	30671.84
Total steel reinforcement in this project (kg)	162821.12
162.82112 Ton	

In Table 3.31, we calculated the total weight of steel reinforcement that we used in this project by using manual calculations.

4. RESULTS AND DISCUSSIONS

4.1 CHAPTER GOAL

This chapter describes the critical research findings obtained from the REVIT software analysis that is employed to calculate the cost of a hospital construction project that represents the case study of this thesis. Also, comparative analysis results are illustrated to compare the accuracy of hand calculations with the BIM technology principles' estimation using the REVIT software package. Further, the discussions of the thesis' findings are shown in chapter four.

4.2 NUMERICAL PROCEDURE FOLLOWED TO MAKE QUANTITY TAKE-OFF

REVIT software is employed to conduct a quantity take-off of the same construction materials used in the cast study that represents a hospital construction project.
Before the calculation process was initiated, the hospital building was plotted and designed in AutoCAD software. Then, it was modeled using the REVIT software. Figure 3.5 represents the 3D modeling configuration of the hospital building investigated in the thesis's case study.

4.3 THE REVIT SOFTWARE COST EVALUATION RESULTS

The REVIT software depended on the BIM technology principles to calculate the cost of the construction project of this work related to the hospital building. The quantity take-off of the construction materials was carried out with a higher degree of accuracy and performance. Table 4.1 represents the REVIT calculation results according to BIM analysis.

Table 4.1: The quantity take-off using the REVIT software of main elements used in the hospital project.

Category/ Construction Element	Quantity
Total Amount of Concrete in the Project	1,185.4 m^3
Total Amount of Steel in the Project	162,821.1 kg
Total Amount of Cut	1,222.6 m^3

Internal Glass	494.7 m^2
External Glass	72.9 m^2

In Table 4.1, we calculated the total results that we used in this project by using REVIT program.

4.2.1 Numerical Concrete Volume Estimation

Figure 4.1 represents the 3D modeling of the cut achieved for the hospital construction project.

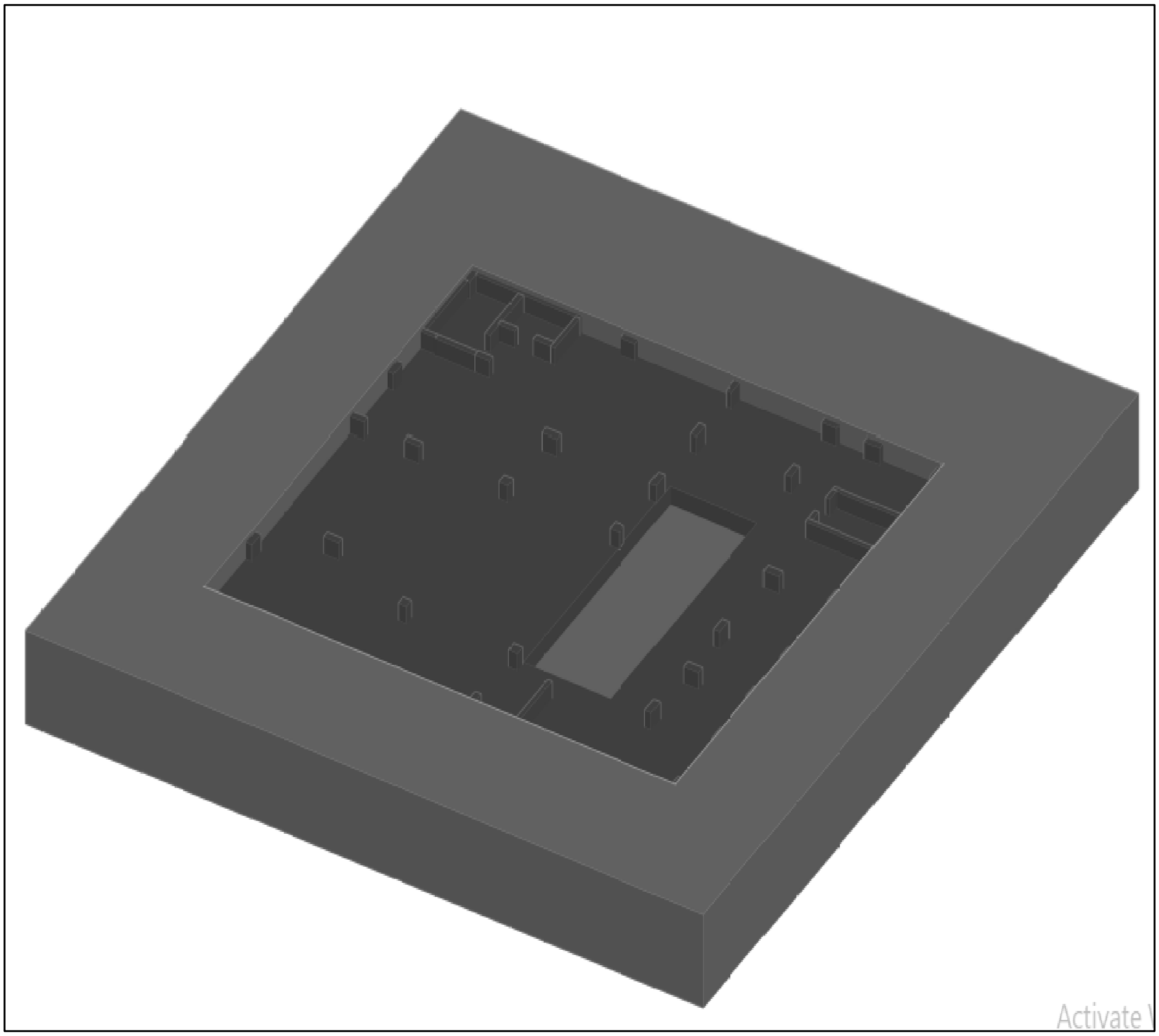


Figure 4.1: The 3D modeling of the cut implemented for the hospital project.

Furthermore, Figure 4.2 displays the 3D modeling of the columns whose quantity was examined and calculated using the REVIT software.

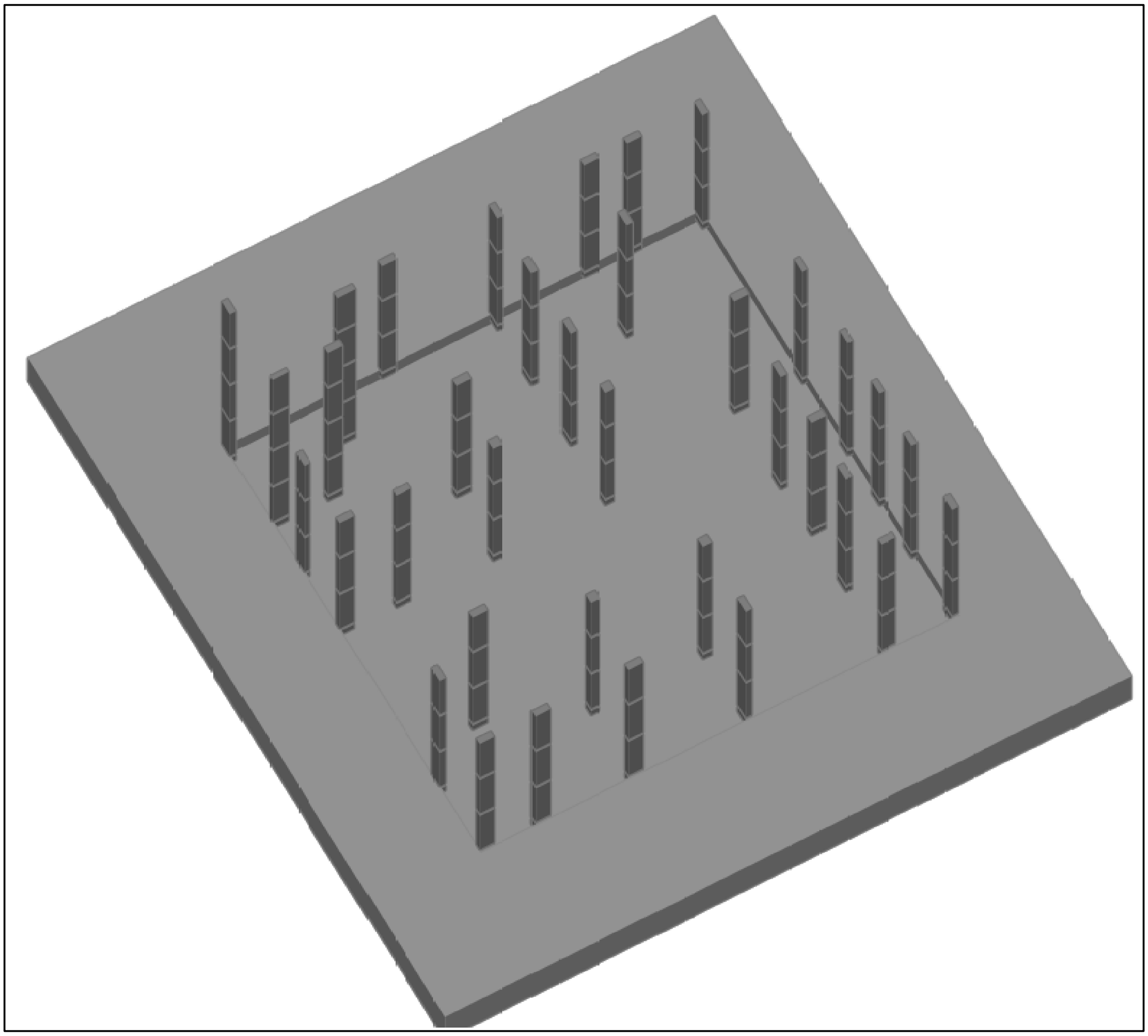


Figure 4.2: The 3D modeling of the columns whose quantity was examined and calculated using the REVIT software.

In addition, Table 4.2 describes other significant results related to the REVIT software package numerical estimation procedure of the hospital investigated in the case study.

Table 4.2: Some significant results related to the REVIT estimation of the hospital's elements' quantity.

Category	Quantity
Blinding Concrete	55.12 m^3
Boulder Volume	110.37 m^3
Sub-Base Volume	218.98 m^3
Lean Concrete Volume	55.14 m^3
Bitumen Volume	4.35 m^3
Reinforced Concrete for Raft Foundation	349.59 m^3

In Table 4.2, we calculated the total volume of many elements that we used in this project by using REVIT program.

Besides, Table 4.3 represents the total amount of concrete used to make columns reinforcement depending on the 3D model developed for the columns illustrated in Figure 4.2.

Table 4.3: Total columns reinforced concrete used in the REVIT project.

Item	Length	Width	Height	Number	Total
C1	0.75	0.30	13.60	10	30.72
C1	0.75	0.30	17.60	1	3.97
C2	0.75	0.30	17.60	1	3.97
C2	0.75	0.30	13.60	10	30.72
C3	0.75	0.30	17.60	1	3.97

Table 4.3: Total columns reinforced concrete used in the REVIT project. "tables continued."

C3	0.75	0.30	13.60	3	9.21
C4	0.75	0.35	13.60	1	3.58
C5	0.45	0.45	13.60	4	11.06
C6	0.70	0.25	13.60	4	9.56
Total Columns Reinforced Concrete					**106.37 m^3**

In Table 4.3, we calculated the total volume of reinforced concrete of columns that we used in this project by using REVIT program.

Also, Table 4.4 represents the overall volume of concrete used for making walls reinforcement based on the numerical estimation conducted via the REVIT software.

Table 4.4: The overall volume of concrete used for making walls reinforcement based on the numerical estimation conducted via the REVIT software.

Item	Length (m)	Width (m)	Height (m)	Total (m^3)
SW1 & SW2	43.19	0.30	17.60	42.89
Elevator 1 & 2	83.29	0.25	17.60	82.96
Total Walls reinforced Concrete Volume				**125.85 m^3**

In Table 4.4, we calculated the total volume of reinforced concrete of shear walls that we used in this project by using REVIT program.

Further, Table 4.5 displays the volume of reinforcement concrete utilized to make reinforcements for the beams in the construction project investigated in this thesis.

Table 4.5: The volume of reinforcement concrete utilized to make reinforcements for the beams.

Item	Length (m)	Width (m)	Height (m)	number	Total (m^3)
B1	97.30	0.35	0.70	3	71.52
B2	52.95	0.70	0.32	3	35.58
B3	43.21	0.80	0.32	3	33.19
B4	15.88	0.50	0.32	3	7.62
B6	16.97	0.35	0.70	3	12.47
B7	27.87	0.35	0.80	3	23.41
Total of Beams Reinforced Concrete					**183.79 m^3**

In Table 4.5, we calculated the total volume of reinforced concrete of beams that we used in this project by using REVIT program.

In addition, it was found that the overall volume of the hollow/ waffle blocks that will be used in this project is 136.57 m^3. The results of the numerical REVIT cost-estimation process also revealed the volume of reinforcement concrete that is employed for the slabs, as illustrated in Figure 4.2 and Table 4.6.

Table 4.6: The volume of reinforcement concrete that is employed for the slabs.

Item	Total (m^3)
Slab on grade 1	6.46
Slab on grade 2	176.51
Ground, first and second floor	163.43
Roof Solid slab	5.94
Steps	1.74
Stair ladders	9.93
Total of Reinforced Concrete Slabs	**364.01 m^3**

In Table 4.6, we calculated the total volume of reinforced concrete of slabs that we used in this project by using REVIT program.

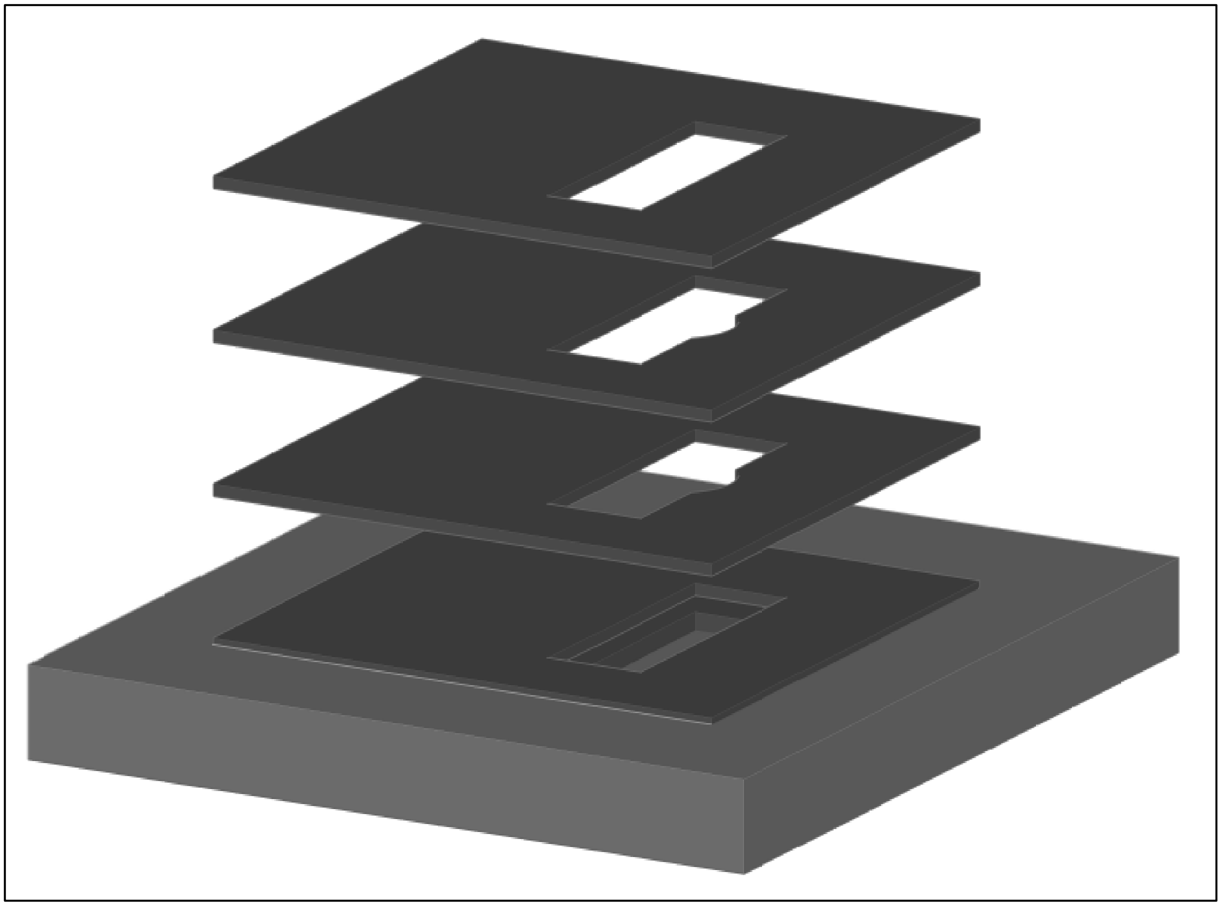


Figure 4.3: The 3D modeling and configuration of the slabs used in the project investigated in this work.

All in all, Table 4.7 illustrates the total volume of the reinforcement concrete used in this project and calculated by the REVIT software.

Table 4.7: The total volume of the reinforcement concrete used REVIT software in this project.

Raft foundation	Columns	Walls	Beams	Slabs
349.59 m^3	106.37 m^3	126.48 m^3	183.79 m^3	364.01 m^3
1130.24 m^3				

In Table 4.7, we calculated the total volume of reinforced concrete that we used in this project by using the REVIT program.

Figure 4.4 illustrates a pie chart of all concrete quantities utilized by different building components, which is calculated using the REVIT software.

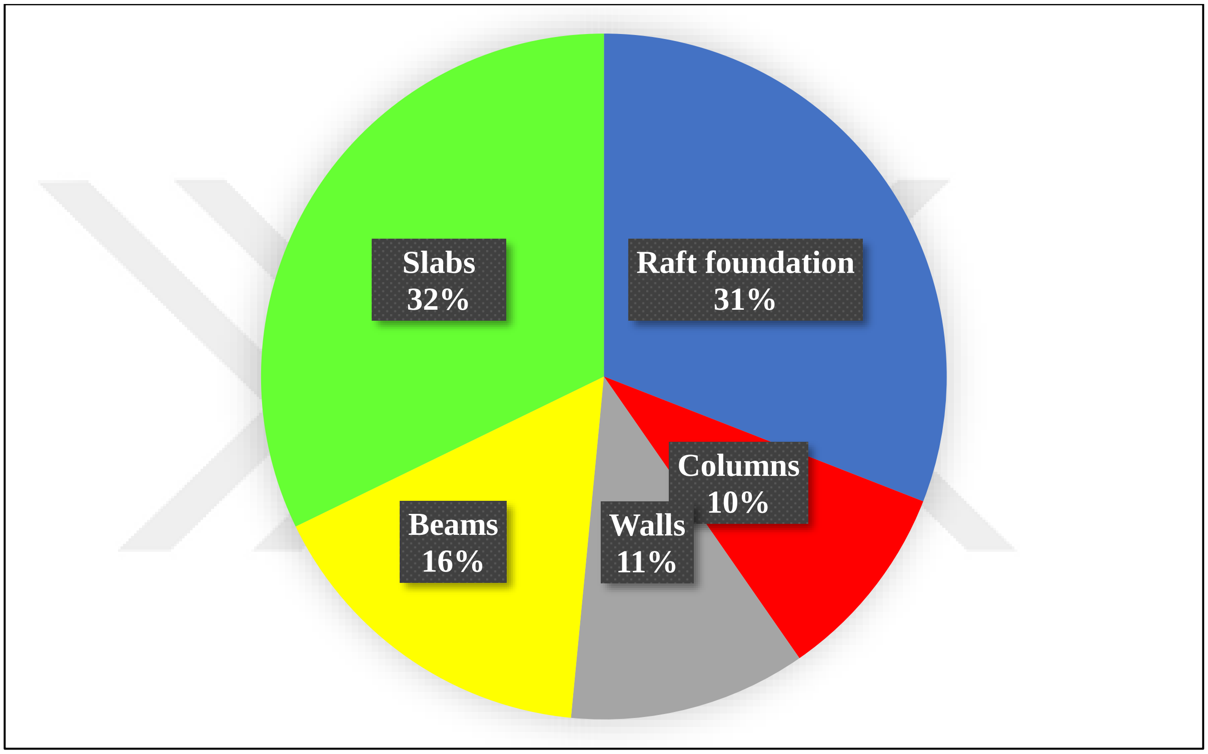


Figure 4.4: A pie chart of all concrete quantities utilized by different building components using REVIT.

4.2.2 Numerical Steel Amount Estimation

Table 4.8 describes the quantity of steel reinforcement required for the raft foundation.

Table 4.8: The quantity of steel reinforcement required for the raft foundation.

Steel location	Comments	Dia.	weight	L	No.	Total weight
Top-transverse	**With steel bars overlap**	20	2.47	12.00	82	2430.48
		20	2.47	12.00	82	2430.48
		20	2.47	2.15	82	435.46
		20	2.47	5.20	18	231.19
		20	2.47	7.20	18	320.11
Bottom-transverse	**With steel bars overlap**	20	2.47	12.00	82	2430.48
		20	2.47	12.00	82	2430.48
		20	2.47	2.15	82	435.46
		20	2.47	5.20	18	231.19
		20	2.47	7.20	18	320.11
Top-longitudinal	**With steel bars overlap**	20	2.47	12.00	42	1244.88
		20	2.47	12.00	42	1244.88
	With steel bars overlap	20	2.47	3.15	42	326.78
		20	2.47	6.88	54	917.65

Table 4.8: The quantity of steel reinforcement required for the raft foundation. “tables continued.”

		20	2.47	12.00	54	1600.56
		20	2.47	4.53	54	604.21
		20	2.47	12.00	42	1244.88
		20	2.47	12.00	42	1244.88
Bottom-longitudinal		20	2.47	3.15	42	326.78
With steel bars overlap		20	2.47	6.88	54	917.65
		20	2.47	12.00	54	1600.56
		20	2.47	4.53	54	604.21
		12	0.89	12.00	13	138.84
		12	0.89	12.00	13	138.84
Middle bars-transverse	**With steel bars overlap**	12	0.89	1.43	13	16.55
		12	0.89	7.23	4	25.74
		12	0.89	12.00	6	64.08
Middle bars-longitudinal	With steel bars overlap	12	0.89	12.00	6	64.08
		12	0.89	2.33	6	12.44
		12	0.89	6.88	6	36.74

Table 4.8: The quantity of steel reinforcement required for the raft foundation. "tables continued."

		12	0.89	12.00	6	64.08
		12	0.89	3.81	6	20.35
Continuous footing stirrups	-----------------	10	0.62	4.2	653	1700.41
		10	0.62	3	382	710.52
Total of raft footing reinforcement Steel (kg)						**26,566.05**
26.566 tons						

In Table 3.8, calculated the weight of steel reinforcement of raft foundation in (X and Y)-direction in top and bottom of footing, by using REVIT program.

Table 4.9 represents the quantity of steel reinforcement required for the foundation of the columns used in this project.

Table 4.9: The quantity of steel reinforcement required for the foundation of the column.

Dia.	Weight (kg)	L (m)	No.	Total weight (kg)	Comments
20	2.47	4.42	16	174.68	**C1 from Footing to Roof With overlap and stirrups**
10	0.62	5.48	6	20.39	
20	2.47	6.23	16	246.21	
10	0.62	5.48	27	91.74	
20	2.47	5.48	48	649.71	
10	0.62	5.42	60	201.62	
20	2.47	4.42	160	1746.78	**C1 from Footing to 2nd With overlap and stirrups**
10	0.62	5.48	60	203.86	
20	2.47	6.23	160	2462.10	
10	0.62	5.48	270	917.35	
20	2.47	5.48	320	4331.39	
10	0.62	5.42	420	1411.37	
20	2.47	4.42	18	196.51	**C2 from Footing to Roof With overlap and stirrups**
10	0.62	5.48	6	20.39	
20	2.47	6.23	18	276.99	
10	0.62	5.48	27	91.74	

Table 4.9: The quantity of steel reinforcement required for the foundation of the column. "tables continued."

20	2.47	5.48	54	730.92	
10	0.62	5.42	60	201.62	
20	2.47	4.42	180	1965.13	**C2 from Footing to 2nd With overlap and stirrups**
10	0.62	5.48	60	203.86	
20	2.47	6.23	180	2769.86	
10	0.62	5.48	270	917.35	
20	2.47	5.48	360	4872.82	
10	0.62	5.42	420	1411.37	
20	2.47	4.42	14	152.84	**C3 from Footing to Roof With overlap and stirrups**
10	0.62	5.48	6	20.39	
20	2.47	6.23	14	215.43	
10	0.62	5.48	27	91.74	
20	2.47	5.48	42	568.50	
10	0.62	4.42	60	164.42	
20	2.47	4.42	42	458.53	**C3 from Footing to 2nd With overlap and stirrups**
10	0.62	4.18	18	46.65	
20	2.47	6.32	42	655.64	
10	0.62	4.18	81	209.92	

Table 4.9: The quantity of steel reinforcement required for the foundation of the column. “tables continued.”

20	2.47	5.32	84	1103.79	
10	0.62	4.18	118	305.81	
20	2.47	4.42	20	218.35	**C4 from Footing to 2nd With overlap and stirrups**
10	0.62	5.48	6	20.39	
20	2.47	6.23	20	307.76	
10	0.62	4.48	27	75.00	
20	2.47	5.48	40	541.42	
10	0.62	4.62	42	120.30	
20	2.47	4.42	80	873.39	**C5 from Footing to 2nd With overlap and stirrups**
10	0.62	4.12	24	61.31	
20	2.47	6.52	40	644.18	
10	0.62	3.62	108	242.40	
20	2.47	5.32	160	2102.46	
10	0.62	3.62	166	372.57	
20	2.47	4.42	80	873.39	**C6 from Footing to 2nd With overlap and stirrups**
10	0.62	4.12	24	61.31	
20	2.47	6.32	40	624.42	
10	0.62	4.12	108	275.88	

Table 4.9: The quantity of steel reinforcement required for the foundation of the column. "tables continued."

20	2.47	5.44	160	2149.89	
10	0.62	4.12	176	449.57	
Total of Columns reinforcement Steel (kg)				**40,123.4**	
40.1234 tons					

In Table 4.9, calculated the weight of steel reinforcement of columns in (X and Y)-direction in top and bottom of footing, it was six types (C1, C2, C3, C4, C5, C6), by using REVIT program.

Table 4.10 displays in detail the weights and diameters of steel required for the walls' steel reinforcement.

Table 4.10: The weights and diameters of steel required for the walls' steel reinforcement using the REVIT software.

Dia.	**Weight (kg)**	**L (m)**	**No.**	**Total weight (kg)**	**Comments**
16	1.58	4.42	32	223.48	**SW1 from Footing to Roof With overlap and stirrups**
20	2.47	4.42	12	131.01	
10	0.62	5.87	6	21.84	
10	0.62	1.72	6	6.40	
10	0.62	2.97	6	11.05	

Table 4.10: The weights and diameters of steel required for the walls' steel reinforcement using the REVIT software. "Tables continued."

16	1.58	6.35	32	321.06	
20	2.47	6.35	12	188.21	
10	0.62	5.87	27	98.26	
10	0.62	1.72	27	28.79	
10	0.62	2.97	27	49.72	
16	1.58	5.35	96	811.49	
20	2.47	5.35	36	475.72	
10	0.62	5.87	65	236.56	
10	0.62	1.72	65	69.32	
10	0.62	2.97	65	119.69	
16	1.58	4.42	60	419.02	
20	2.47	4.42	12	131.01	
10	0.62	5.69	6	21.17	**SW2 from Footing to Roof**
10	0.62	1.87	6	6.96	**With overlap**
10	0.62	5.90	6	21.95	**and stirrups**
12	0.89	6.17	6	32.95	
16	1.58	6.35	60	601.98	

Table 4.10: The weights and diameters of steel required for the walls' steel reinforcement using the REVIT software. "tables continued."

20	2.47	6.35	12	188.21	**SW2 from Footing to Roof With overlap and stirrups**
10	0.62	5.69	27	95.25	
10	0.62	1.87	27	31.30	
10	0.62	5.90	27	98.77	
12	0.89	6.17	27	148.27	
16	1.58	5.38	180	1530.07	
20	2.47	5.38	36	478.39	
10	0.62	5.69	65	229.31	
10	0.62	1.87	65	75.36	
10	0.62	5.90	65	237.77	
12	0.89	6.17	65	356.93	
16	1.58	4.42	160	1117.38	**Elevator 1 from Footing to Roof With overlap and stirrups**
10	0.62	10.05	6	37.39	
12	0.89	1.91	6	10.20	
12	0.89	1.91	6	10.20	
12	0.89	7.92	6	42.29	
12	0.89	7.92	6	42.29	

Table 4.10: The weights and diameters of steel required for the walls' steel reinforcement using the REVIT software. "tables continued."

12	0.89	5.66	6	30.22	
16	1.58	6.38	160	1612.86	
10	0.62	10.05	27	168.24	
12	0.89	1.91	27	45.90	
12	0.89	1.91	27	45.90	
12	0.89	7.92	27	190.32	**Elevator 1 from Footing to Roof** **With overlap and stirrups**
12	0.89	7.92	27	190.32	
12	0.89	5.66	27	136.01	
16	1.58	5.38	480	4080.19	
10	0.62	10.05	65	405.02	
12	0.89	1.91	65	110.49	
12	0.89	1.91	65	110.49	
12	0.89	7.92	65	458.17	
12	0.89	7.92	65	458.17	
12	0.89	5.66	65	327.43	

Table 4.10: The weights and diameters of steel required for the walls' steel reinforcement using the REVIT software. "tables continued."

16	1.58	4.42	112	782.16	**Elevator 2 from Footing to Roof** **With overlap and stirrups**
10	0.62	8.02	6	29.83	
12	0.89	7.40	6	39.52	
12	0.89	5.32	6	28.41	
12	0.89	5.15	6	27.50	
12	0.89	4.88	6	26.06	
12	0.89	7.41	6	39.57	
16	1.58	6.38	112	1129.00	
10	0.62	8.02	27	134.25	
12	0.89	7.40	27	177.82	
12	0.89	5.32	27	127.84	
12	0.89	5.15	27	123.75	
12	0.89	4.55	27	109.34	
12	0.89	7.41	27	178.06	
16	1.58	5.38	328	2788.13	
10	0.62	8.02	65	323.21	
12	0.89	7.40	65	428.09	
12	0.89	5.32	65	307.76	
12	0.89	5.15	65	297.93	

Table 4.10: The weights and diameters of steel required for the walls' steel reinforcement using the REVIT software. "tables continued."

12	0.89	4.88	65	282.31	
12	0.89	7.42	65	429.25	
Total of Walls Reinforcement Steel (kg)				**24,936.53**	
1.9365 Tons					

In Table 4.10, we calculated the weight of steel reinforcement that we used in the walls of the project, and it was two types (shear walls 1, 2 and elevator walls), by using REVIT program.

Table 4.11 illustrates in detail the numerical results associated with the cost-estimation process using the REVIT software of slab steel reinforcement.

Table 4.11: The numerical results associated with the cost-estimation process using the REVIT software of slab steel reinforcement.

Dia.	**Weight (kg)**	**L (m)**	**No.**	**Total weight (kg)**	**Comments**
10	0.62	12	82	610.08	**Slab on grade - Steel Reinforcement Top-transverse With steel bars overlap**
10	0.62	12	82	610.08	
10	0.62	2.05	82	104.22	
10	0.62	5.2	20	64.48	
10	0.62	7.1	20	88.04	

Table 4.11: The numerical results associated with the cost-estimation process using the REVIT software of slab steel reinforcement. "Tables continued."

10	0.62	12	82	610.08	**Slab on grade - Steel Reinforcement Bottom-transverse With steel bars overlap**
10	0.62	12	82	610.08	
10	0.62	2.05	82	104.22	
10	0.62	5.2	20	64.48	
10	0.62	7.1	20	88.04	
10	0.62	12	42	312.48	**Slab on grade- Steel Reinforcement Top-longitudinal With steel bars overlap**
10	0.62	12	42	312.48	
10	0.62	3.05	42	79.42	
10	0.62	6.88	52	221.81	
10	0.62	12	52	386.88	
10	0.62	12	42	312.48	Slab on grade - Steel Reinforcement Bottom -longitudinal With steel bars overlap
10	0.62	12	42	312.48	
10	0.62	3.05	42	79.42	
10	0.62	6.88	52	221.81	
10	0.62	12	52	386.88	
12	0.89	6.32	51	286.8648	**Solid Slab - Steel Reinforcement GR/1st/2nd/Roof With steel overlap**
12	0.89	3.7	102	335.886	
12	0.89	6.25	91	506.1875	

Table 4.11: The numerical results associated with the cost-estimation process using the REVIT software of slab steel reinforcement. "Tables continued."

12	0.89	2.49	64	141.8304	
12	0.89	3.67	58	189.4454	
12	0.89	3.22	71	203.4718	
12	0.89	4.55	27	109.3365	
12	0.89	2.85	45	114.1425	
16	1.580	3.2	17	85.952	
16	1.580	2.4	25	94.8	
16	1.580	3.7	21	122.766	
16	1.580	2.6	30	123.24	
12	0.89	3.67	58	189.4454	
12	0.89	3.22	71	203.4718	
12	0.89	5.53	188	925.2796	**Hollow Slab - Steel Reinforcement GR/1st/2nd** **With steel overlap and stirrups**
10	0.62	6.36	50	197.16	
10	0.62	5.53	32	109.7152	
10	0.62	0.90	720	401.76	
12	0.89	6.18	188	1034.0376	
10	0.62	6.18	38	145.6008	

Table 4.11: The numerical results associated with the cost-estimation process using the REVIT software of slab steel reinforcement. "Tables continued."

10	0.62	6.67	85	351.509	**Hollow Slab - Steel Reinforcement GR/1st/2nd** **With steel overlap and stirrups**
10	0.62	0.90	812	453.096	
12	0.89	5.94	188	993.8808	
10	0.62	5.94	38	139.9464	
10	0.62	6.68	30	124.248	
10	0.62	5.15	38	121.334	
10	0.62	0.90	715	398.97	
12	0.89	4.15	410	1514.335	
10	0.62	4.15	65	167.245	
10	0.62	12.00	42	312.48	
10	0.62	3.00	42	78.12	
10	0.62	0.90	1022	570.276	
12	0.89	4.27	453	1721.5359	
10	0.62	4.27	76	201.2024	
10	0.62	12.00	42	312.48	
10	0.62	5.32	42	138.5328	
10	0.62	0.90	1338	746.604	

Table 4.11: The numerical results associated with the cost-estimation process using the REVIT software of slab steel reinforcement. "tables continued."

12	0.89	4.27	155	589.0465	
10	0.62	4.27	25	66.185	
10	0.62	6.00	53	197.16	
10	0.62	0.90	449	250.542	
12	0.89	6.08	423	2288.9376	
10	0.62	6.08	50	188.48	
10	0.62	12.00	56	416.64	
10	0.62	2.74	56	95.1328	
10	0.62	0.9	1380	770.04	
10	0.62	3.57	65	143.871	**Staircase Slab - Steel Reinforcement GR/1st/2nd/Roof**
12	0.89	3.00	31	82.77	
12	0.89	1.00	316	281.24	
12	0.89	2.00	148	263.44	
12	0.89	2.00	78	138.84	
12	0.89	1.00	162	144.18	

Table 4.11: The numerical results associated with the cost-estimation process using the REVIT software of slab steel reinforcement. "tables continued."

12	0.89	12.00	276	2947.68	**Waffle Slab - Steel Reinforcement GR/1st/2nd** **With steel overlap and stirrups**
12	0.89	3.00	276	736.92	
10	0.62	12.00	95	706.8	
10	0.62	3.00	95	176.7	
10	0.62	12.00	146	1086.24	
10	0.62	3.00	146	271.56	
10	0.62	0.94	2940	1713.432	
12	0.89	9.45	426	3582.873	
10	0.62	9.45	148	867.132	
10	0.62	9.45	223	1306.557	
10	0.62	0.94	3028	1764.7184	
Total of Slabs Reinforcement Steel (kg)				**40,523.3**	
40.5233 tons					

In Table 4.11, we calculated the weight of steel reinforcement that we used in the slabs of the project, by using REVIT program.

Table 4.12 represents the beams' steel reinforcement cost-estimation approach using the numerical REVIT software package.

Table 4.12: The beams' steel reinforcement cost estimation using the REVIT software.

Dia.	Weight (kg)	L (m)	No.	Total weight (kg)	Comments
12	0.89	12.00	102	1089.36	Beam 1 - Steel Reinforcement GR/1st/2nd With overlap and stirrups
25	3.8	12.00	218	9940.80	
12	0.89	12.00	188	2007.84	
10	0.62	1.98	1426	1750.56	
10	0.62	1.72	1426	1520.69	
16	1.58	12.00	119	2256.24	Beam 2 - Steel Reinforcement GR/1st/2nd With overlap and stirrups
12	0.89	12.00	63	672.84	
10	0.62	12.00	23	171.12	
10	0.62	3.44	760	1620.93	
16	1.58	12.00	102	1933.92	Beam 3 - Steel Reinforcement GR/1st/2nd With overlap and stirrups
12	0.89	12.00	62	662.16	
10	0.62	12.00	26	193.44	
10	0.62	3.84	633	1507.05	

Table 4.12: The beams' steel reinforcement cost estimation using the REVIT software. "tables continued."

16	1.58	12.00	24	455.04	**Beam 4 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
12	0.89	12.00	22	234.96	
10	0.62	12.00	15	111.60	
10	0.62	2.64	235	384.65	
20	2.47	12.00	24	711.36	**Beam 6 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
16	1.58	12.00	16	303.36	
12	0.89	12.00	20	213.6	
10	0.62	2.80	253	439.21	
20	2.47	12.00	36	1067.04	**Beam 7 - Steel Reinforcement GR/1st/2nd With overlap and stirrups**
16	1.58	12.00	22	417.12	
12	0.89	12.00	25	267.00	
10	0.62	3.10	385	739.97	
Total of Columns Reinforcement Steel (kg)				**30,671.84**	
30.67184 Tons					

In Table 4.12, we calculated the weight of steel reinforcement that we used in the beams of the project, and it was seven types (B1, B2, B3, B4, B5, B6, B7), by using REVIT program.

Overall, the total steel reinforcement required in this project according to the numerical cost-estimation method of the REVIT software can be represented in Table 4.13.

Table 4.13: The overall steel reinforcement needed for this project according to the numerical cost-estimation approach of REVIT.

Part	Weight (kg)
Raft Foundation Steel Reinforcement	26,566.05
Columns Steel Reinforcement	40,123.40
Walls Steel Reinforcement	24,936.53
Slabs Steel Reinforcement	40,523.30
Beams Steel Reinforcement	30,671.84
Total Steel Reinforcement in this project (kg):	**162,821.12**
162.82112 Tons	

In Table 4.13, we calculated the total weight of steel reinforcement that we used in this project, by using REVIT program.

4.2.3 Numerical Quantity Estimation of Architectural Elements

The total quantity of the project's architectural components is computed using the numerical quantity take-off via the REVIT in Table 4.14.

Table 4.14: The total quantity of the project's architectural components using the REVIT software.

Category	Quantity
External Blocks	1036.48 m^2
External Glass Wall Area	72.93 m^2
External Plaster	1570.68 m^2
External Stones	1690.59 m^2
Internal Blocks	1868.96 m^2
Internal Glass Wall Area	494.69 m^2
Internal Plaster and Paint	4869.58 m^2

In Table 4.14, we calculated the total area of architectural components using the REVIT software.

Also, the internal tiles area was evaluated using the REVIT software, which is described in Table 4.15.

Table 4.15: The quantity survey of the project's internal tiles using the REVIT software.

Floor	Area
GR	413.36
1st	473.29
2nd	473.29
Roof	513.97
Total Area of Tiles (m^2)	1,873.91 m^2

In Table 4.15, we calculated the area of internal tiles by using the REVIT software

4.3 THE RESULTS OF THE RESEARCH'S COMPARATIVE ANALYSIS

Based on the manual and numerical calculation processes of the construction project cost of this case study (hospital building), a comparative analysis was developed to validate which method (hand cost calculations or numerical cost estimation using the REVIT software) would be more cost-effective, reliable, and practical in terms of accuracy, performance, the number of errors, amount of human effort in cost evaluation, the time required for estimation, and budget required to make the cost estimation. Table 4.14 represents the results of the comparative analysis between the two cost calculation methods employed in this work regarding concrete and steel quantity take-off.

Table 4.16: A comparison between the manual cost estimation approach and the REVIT software computation related to concrete and steel quantity take-off.

Comparison		Manual Results	REVIT Results
Concrete (m^3)	Blinding	347.26	349.59
	Raft concrete	362.53	364.01
	Slabs concrete	106.76	106.37
	Columns concrete	182.57	183.79
	Beams concrete	125.85	126.48
	Walls	25,950.88	26,566.05
Steel (kg)	Raft steel	41,504.90	40,523.30
	Slabs steel	39,699.80	40,123.40
	Columns steel	31,335.20	30,671.84
	Beams steel	24,534.70	24,936.53
	Walls steel	347.26	349.59

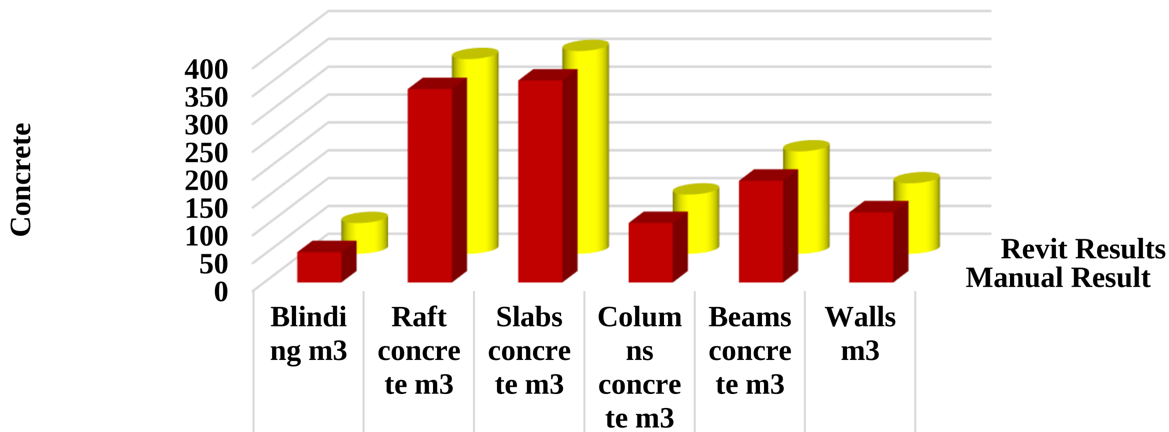
At the same time, the comparative analysis outputs related to the comparison between the manual cost estimation technique and the REVIT software computation process regarding architectural elements quantity take-off are represented in Table 4.17.

Table 4.17: A comparison between the manual cost estimation technique and the REVIT software computation process related to architectural elements quantity take-off.

Comparison	Manual Result	REVIT Results
Cut (m^3)	968.80	1,036.48
External Blocks (m^2)	1,688.32	1,868.96
Internal Blocks (m^2)	1,468.17	1,570.68
External plaster (m^2)	4,611.00	4,869.58
Internal plaster and paint (m^2)	1,468.17	1,690.59
Stones (m^2)	1,823.77	1,873.91
Floor Tiles (m^2)	440.31	494.69
Internal Glass (m^2)	75.05	72.93
External Glass (m^2)	968.80	1,036.48

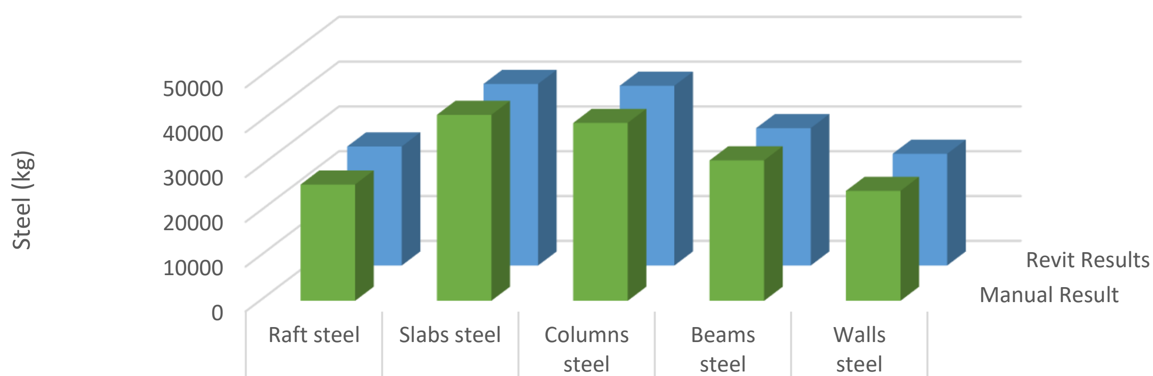
It can be concluded from Tables 4.16 and 4.17 that there are excellent agreements between the conventional cost-estimation method and the ANSYS numerical calculation associated with all construction elements and components. These results can indicate and explain that BIM technology can offer a remarkably reliable solution to determine the construction project cost with higher complexity and components. In addition, the employment of REVIT software has cut a significant number of human errors that occurred during the estimation process and quantity take-off for the project cost. Furthermore, the REVIT software has saved much time and effort needed for engineers to estimate the budget related to this challenging case study that represents a hospital building with various structural components.

Figures 4.4, 4.5, and 4.6 provides a graphical representation of the data illustrated in Tables 4.16 and 4.17.



	Blinding m3	Raft concrete m3	Slabs concrete m3	Columns concrete m3	Beams concrete m3	Walls m3
Manual Result	54.4	347.26	362.53	106.76	182.57	125.85
Revit Results	55.12	349.59	364.01	106.37	183.79	126.48

Figure 4.5: A graphical representation of the comparative analysis between hand calculations and the REVIT software in terms of concrete quantity.



	Raft steel	Slabs steel	Columns steel	Beams steel	Walls steel
Manual Result	25950.88	41504.9	39699.8	31335.2	24534.7
Revit Results	26566.05	40523.3	40123.4	30671.84	24936.53

Figure 4.6: A graphical representation of the comparative analysis between hand calculations and the REVIT software in terms of steel quantity.

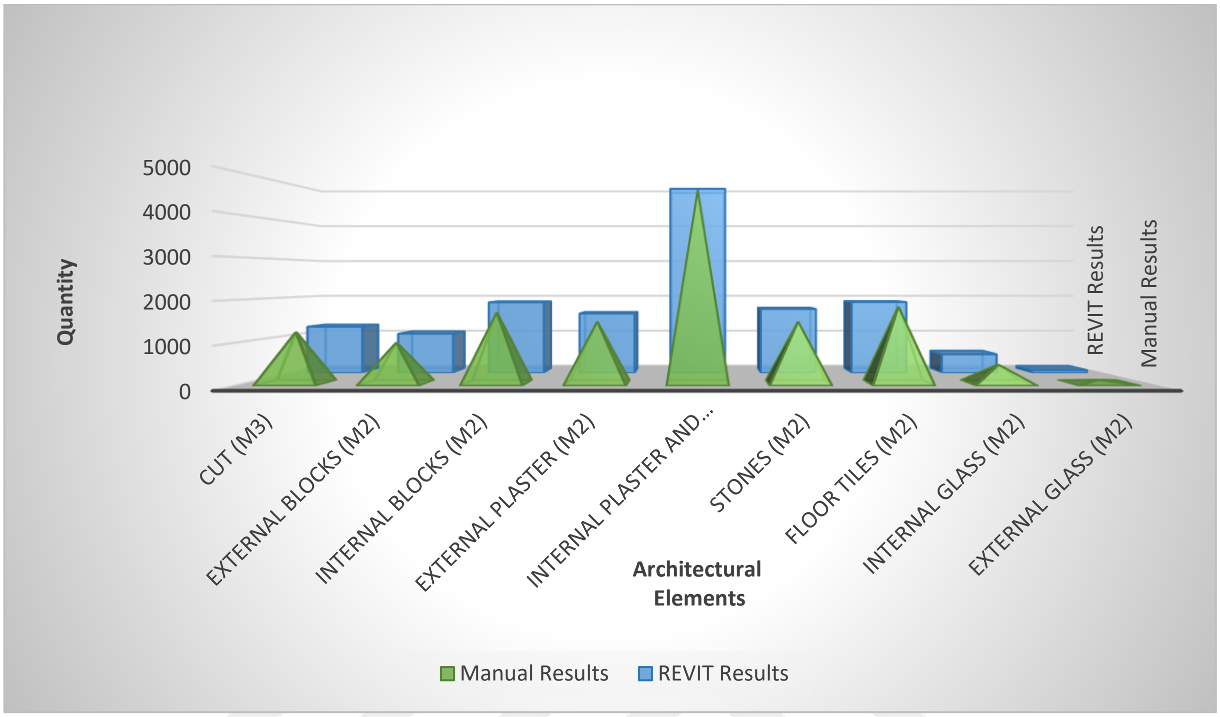


Figure 4.7: A graphical representation of the comparative analysis between hand calculations and the REVIT software in terms of architectural elements quantity.

Through the analysis of manual quantities calculation, which is the most used method by (engineers, contractors and old experts) who find it difficult to learn technical programs such as BIM applications, including the REVIT software package, and through this case study, it was found that BIM applications, including REVIT, contributed to the completion of the required work quickly and efficiently without calculated or human mistakes. Therefore, different BIM applications, such as the REVIT software, are the future of modern construction.

Furthermore, it can be seen that the results are close to each other. Nonetheless, the results of REVIT are more accurate due to the accuracy in the modeling and the few personal mistake in calculating quantities manually. As a result, it can be inferred that BIM applications and especially REVIT software are the future for controlling the modern building from design to the end of construction.

4.4 DISCUSSION

The results of this work revealed that there are excellent agreements between the conventional cost-estimation method and the ANSYS numerical calculation associated with all construction elements and components, explaining that employing the BIM technology is beneficial and practical in providing a reliable cost-estimation solution and making accurate quantity take-off on different construction materials of the project which has significant levels of complexity and high number of construction elements. The results also indicated that the utilization of the REVIT software had reduced a significant number of human errors throughout the quantity take-off of the project's cost. The research outcomes also affirmed that the REVIT software could minimize much effort and time required by engineers to assess the budget related to challenging construction projects with higher complexity and components, like this case study. These results linked to this research are consistent with the research findings of [9], [20], [24], [60], who stated that BIM technology and the REVIT software tool could minimize much of human errors and achieve a higher degree of precision. Also, these results are consistent with the findings of [29], [61], [62], who reported that the REVIT program could save considerable effort and time that would be significantly consumed by engineers to estimate the construction project cost. Also, the results of this study are compatible with [17]–[19], who analyzed the critical role of the BIM technology and REVIT software in estimating project costs and found that using the REVIT program can significantly cut effort, time, and cost required to calculate the construction projects costs that have higher complexity. Also, they found that employing BIM technology could enhance cost-calculation accuracy.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CHAPTER GOAL

Chapter five represents the major research conclusions related to the findings obtained from the manual and numerical cost estimation in this work. Furthermore, this chapter describes critical recommendations and future work suggestions to help project managers, designers, and civil engineers conduct further improvements and investigations on the BIM technology and promote its active role in effectively and accurately estimating the budget of several construction projects.

5.2 CONCLUSIONS

This research is conducted to shed light on the critical role of the BIM technology and the REVIT software package in evaluating the construction projects' cost with significant levels of effectiveness and accuracy. A case study is taken into account, representing a construction project of a hospital building. The budget of this building is calculated and analyzed using two techniques. Also, a comparative analysis between these two approaches is guided in terms of accuracy, performance, human effort, the time required, and the budget needed to make a cost estimation. These two approaches include manual quantity surveying and numerical project take-off, which depends on the REVIT software package that employs BIM principles. The quantity take-off of steel, concrete, and other vital architectural elements and structural building components was considered. The results of this work revealed the following aspects:

a. There are excellent agreements between the conventional cost-estimation method and the ANSYS numerical calculation associated with all construction elements and components, indicating that BIM technology can offer a reliable solution to determine the construction project cost with higher complexity and diverse project elements.
b. The employment of the REVIT software could cut a significant number of human errors that occurred during the estimation process and quantity take-off for the project cost.

c. The REVIT software has saved much time and human effort needed for engineers to estimate the budget related to this challenging case study that represents a hospital building with various structural components.
d. The numerical method of cost estimation was more economically feasible and provided a cost-effective approach for evaluating construction projects' budgets compared with conventional methods.

5.3 RECOMMENDATIONS

After executing the comparative analysis of the two research methods and attaining the research outcomes, it is suggested to follow a set of vital recommendations that can promote the outputs of this study regarding the importance of the BIM technology and the REVIT software in calculating the costs of various construction projects. These recommendations are:

a. To conduct training courses and educational sessions for junior engineers and BIM technology beginners, and other employees in the construction sector to increase their experience in the REVIT software.
b. To increase the level of awareness and knowledge associated with the importance of BIM technology and the REVIT software among project managers.
c. To encourage construction companies to offer effective and high-efficient hardware and software tools that employ BIM principles in their projects.

5.4 FUTURE WORK

Depending on the research findings attained from the two research techniques to estimate the construction project cost, the researcher proposes a number of future work aspects that could help chief civil engineers, project managers, and planners carry out more enhancements and explorations on the BIM technology and improve its beneficial role in effectively and accurately predicting the budget of several construction projects. These future work aspects include:

a. To conduct a comparative analysis of cost estimation using hand calculations and the REVIT software to calculate other construction project elements that are not analyzed in this work, such as plumbing, water fixtures, electrical wires, hot water supply, domestic water piping, and water network.
b. To analyze other case studies that represent large-scale construction projects that are bigger than the hospital building investigated in this work, such as skyscrapers, and predict the REVIT software cost-estimation accuracy.

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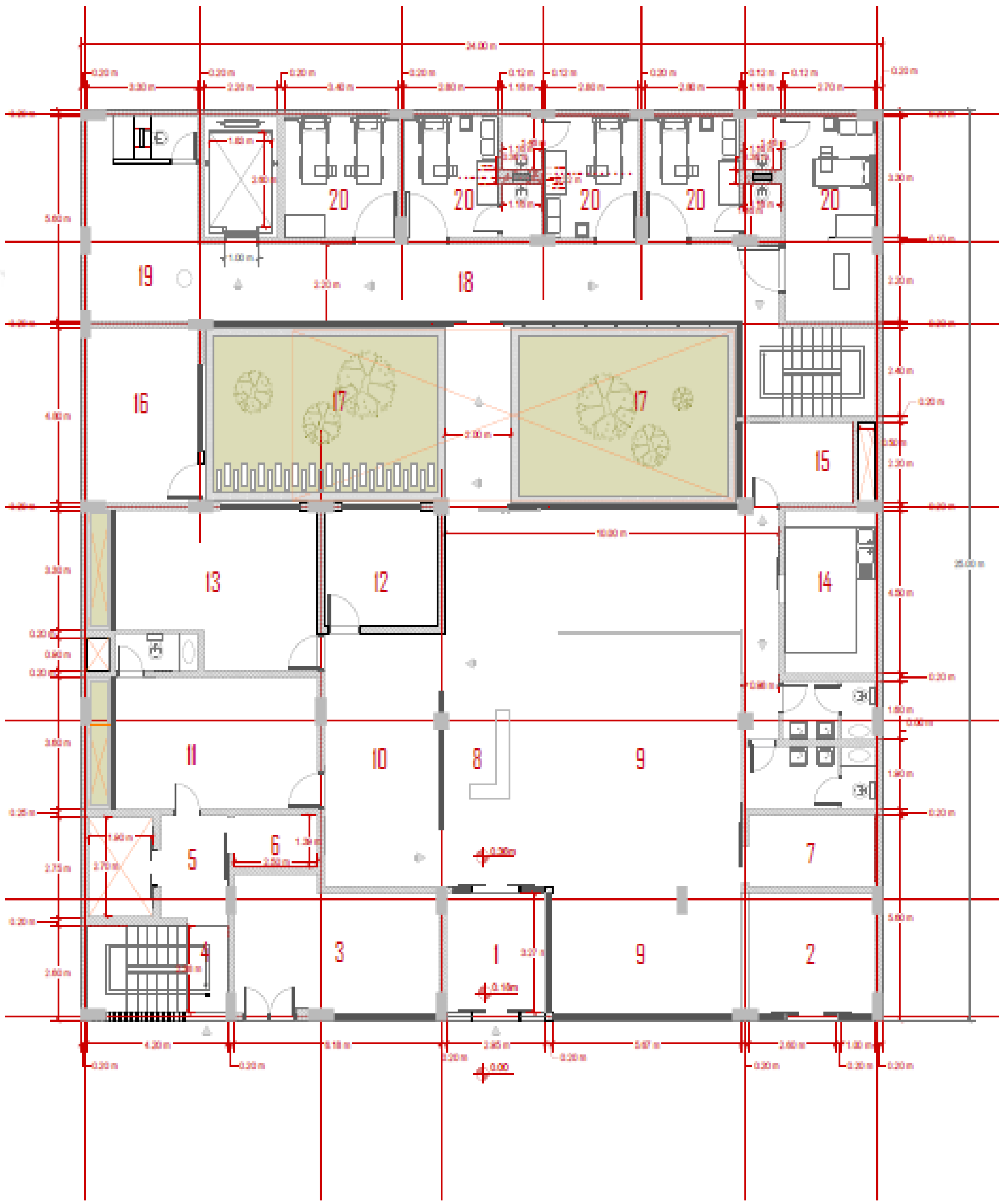
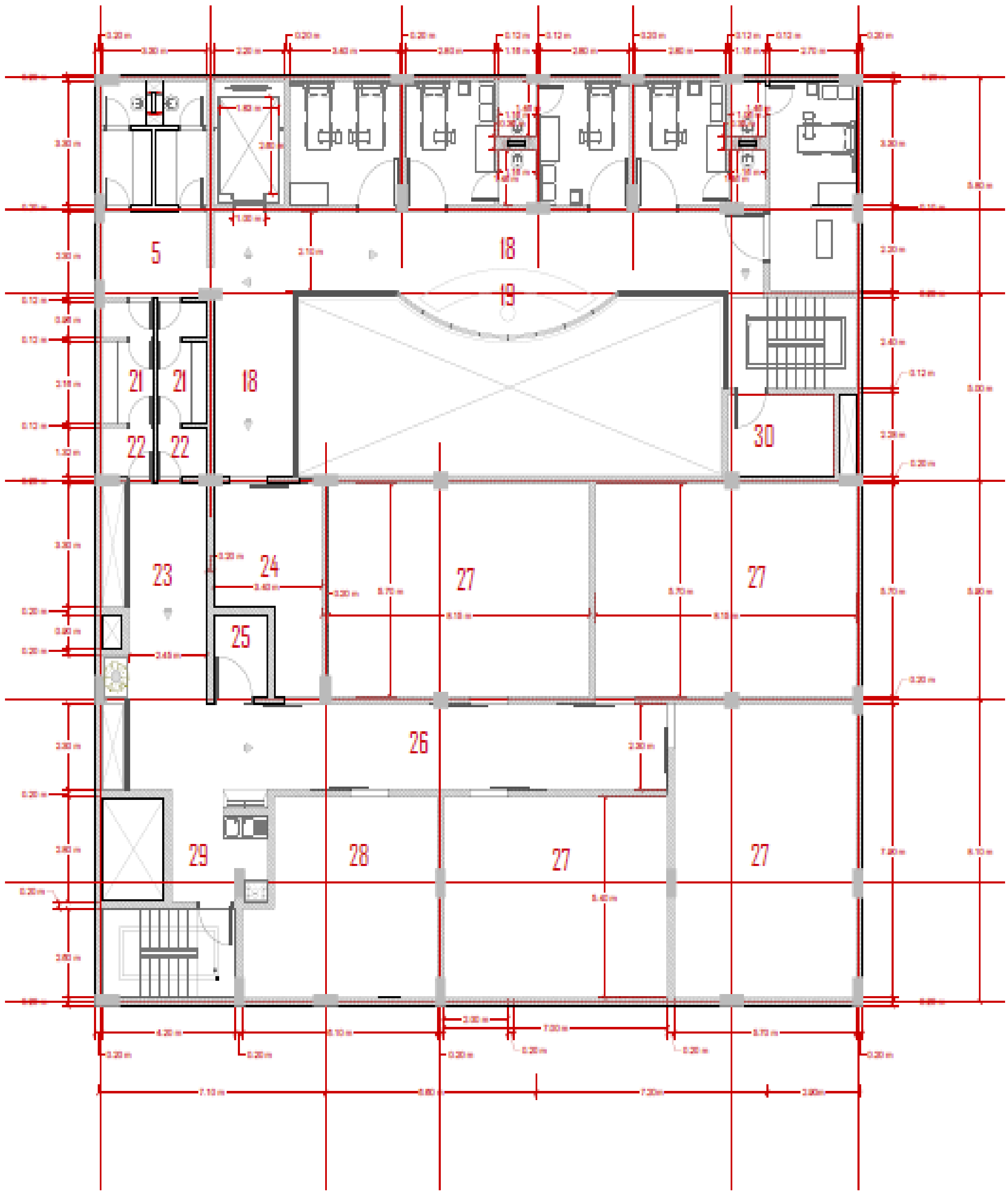
APPENDIX A

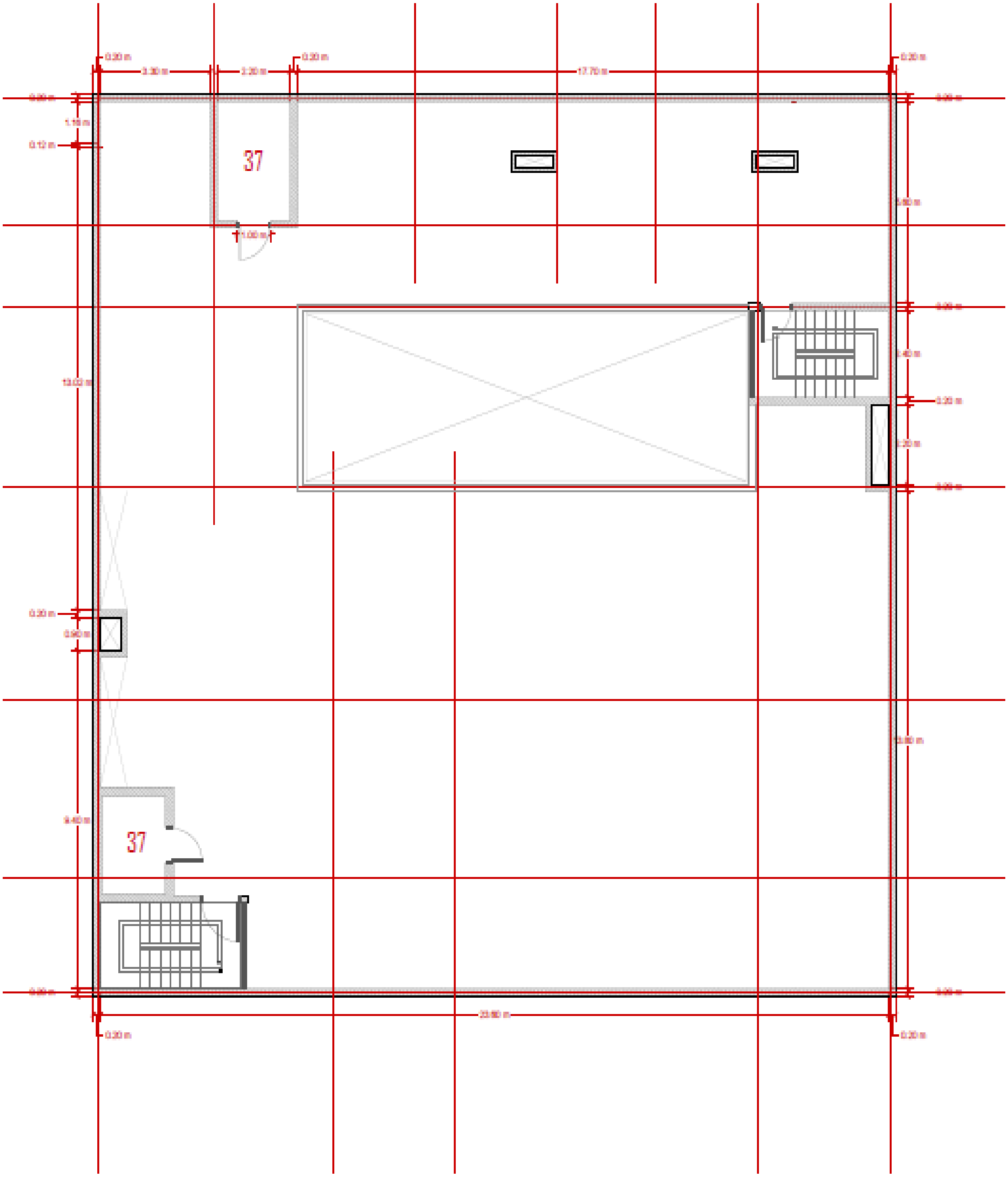
PROJECT PLANS AND INFORMATION



Ground plan



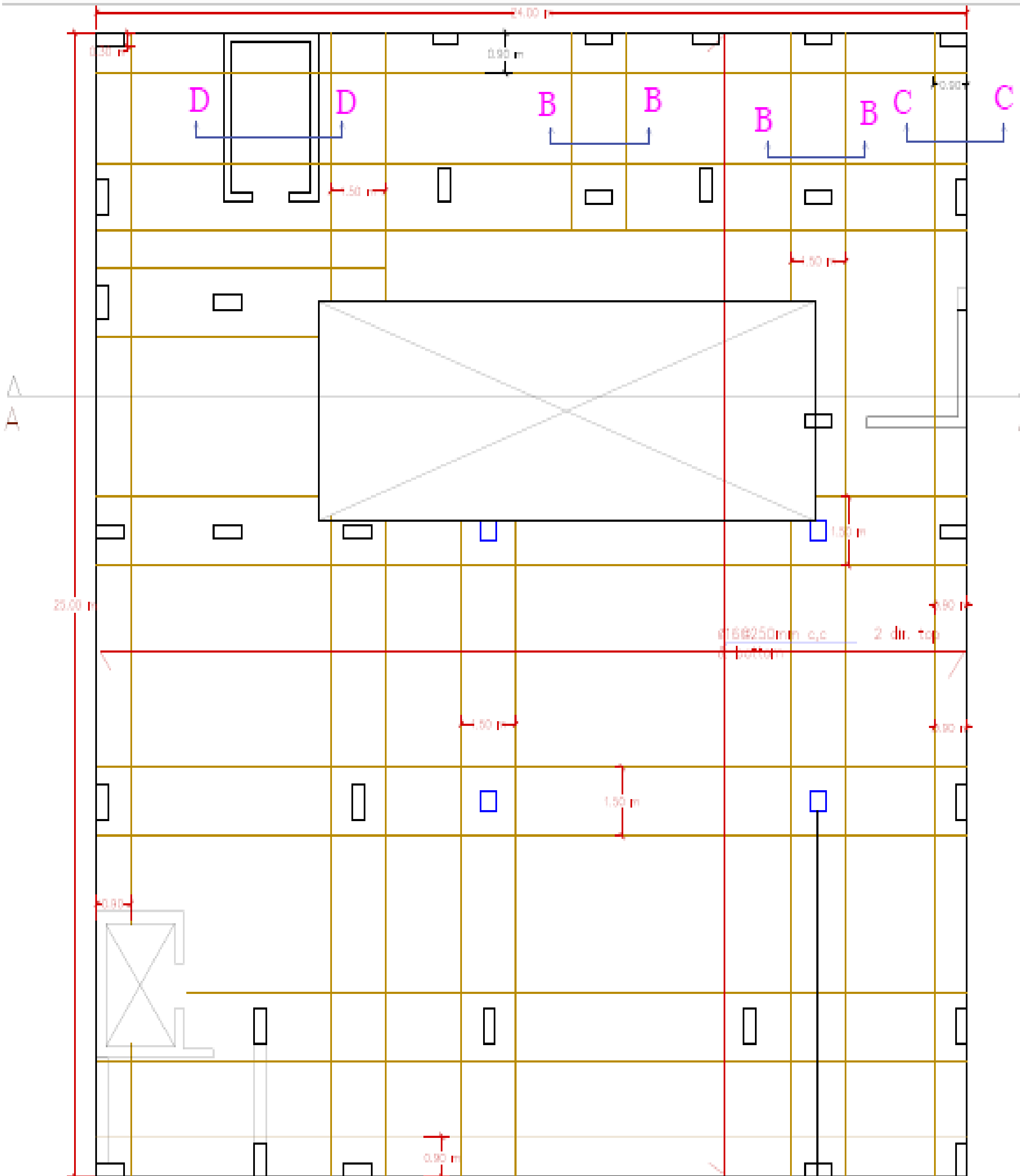
First plan
Second Plan



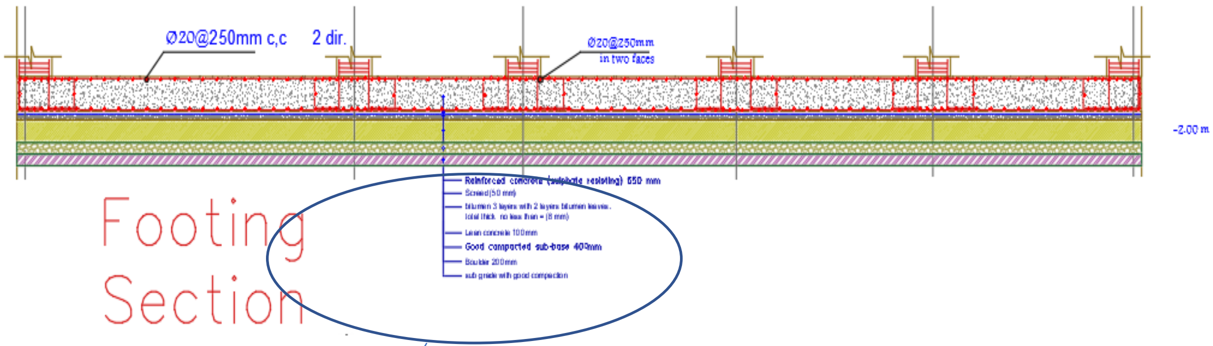
Roof plan

BUILDING COMPONENTS:

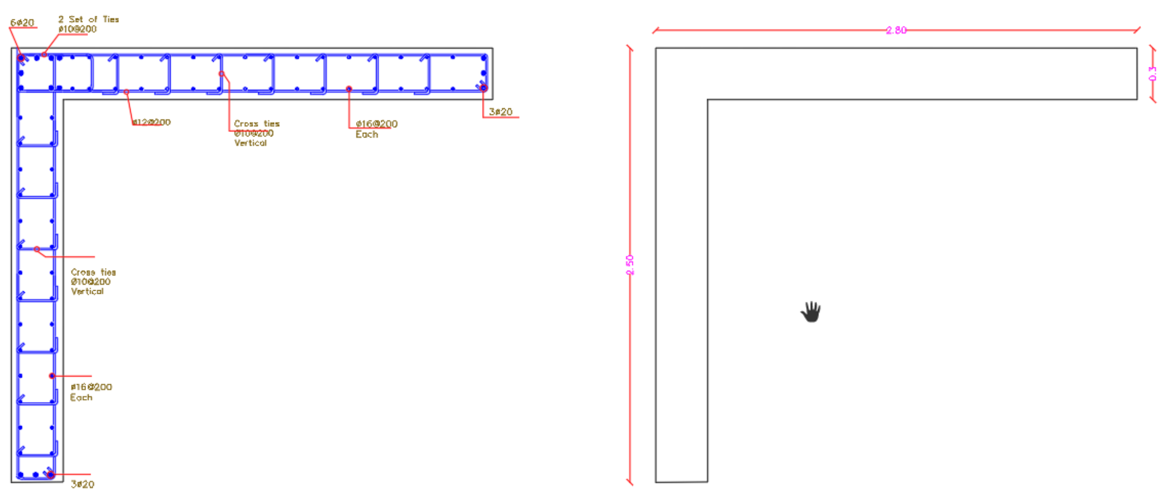
1 Main entrance
2 Optical
3 Pharmacy
4 Secondary entrance
5 Lobby
6 Healthy gas system
7 Electrical Roards Room
8 Main reseption
9 Waiting
10 Special Waiting
11 Doctor room
12 General Examination
13 Special Examination
14 Cafeteria
15 Prayer
16 Laboratory
17 Garden
18 Special corridor
19 Nursing
20 Inpatient room
21 Locker
22 Change Clothe
23 Doctors Break
24 Patient sterilization room
25 Medical sterilization room
26 Sterile corridor
27 Operations hall
28 Lasik Operation
29 Kitchenette
30 UBS Room
37 Elevator room



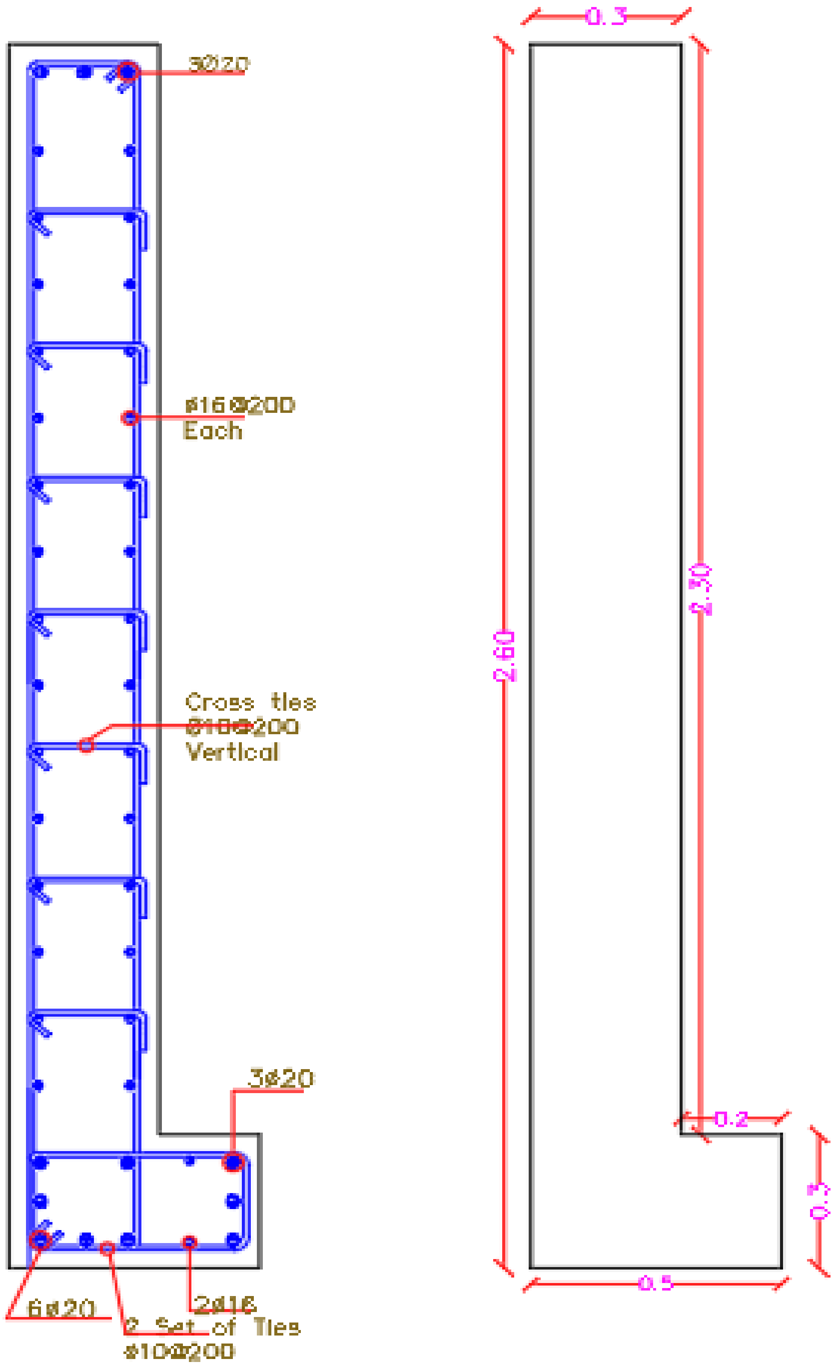
Footing Plan



- Reinforced concrete (sulphate resisting) 650 mm
- Screed (50 mm)
- bitumen 3 layers with 2 layers bitumen leaves .
  total thick no less than = (8 mm)
- Lean concrete 100 mm
- Good compacted sub-base 400mm
- Boulder 200 mm
- sub grade with good compaction



SW2


3Ø20
ø16@200
Each
Cross ties
Ø10@200
Vertical
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2 Set of Ties
ø10@200
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2.30
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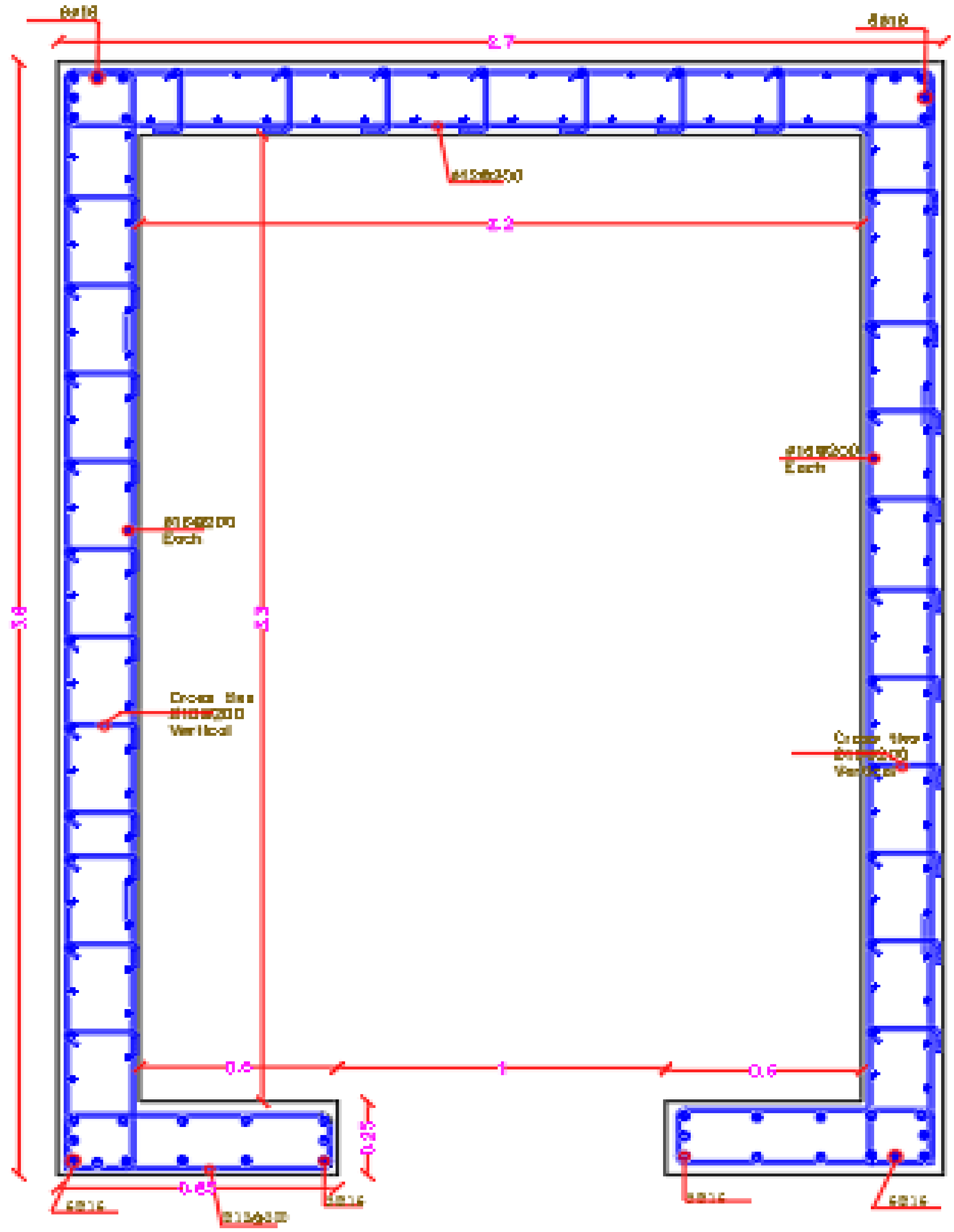
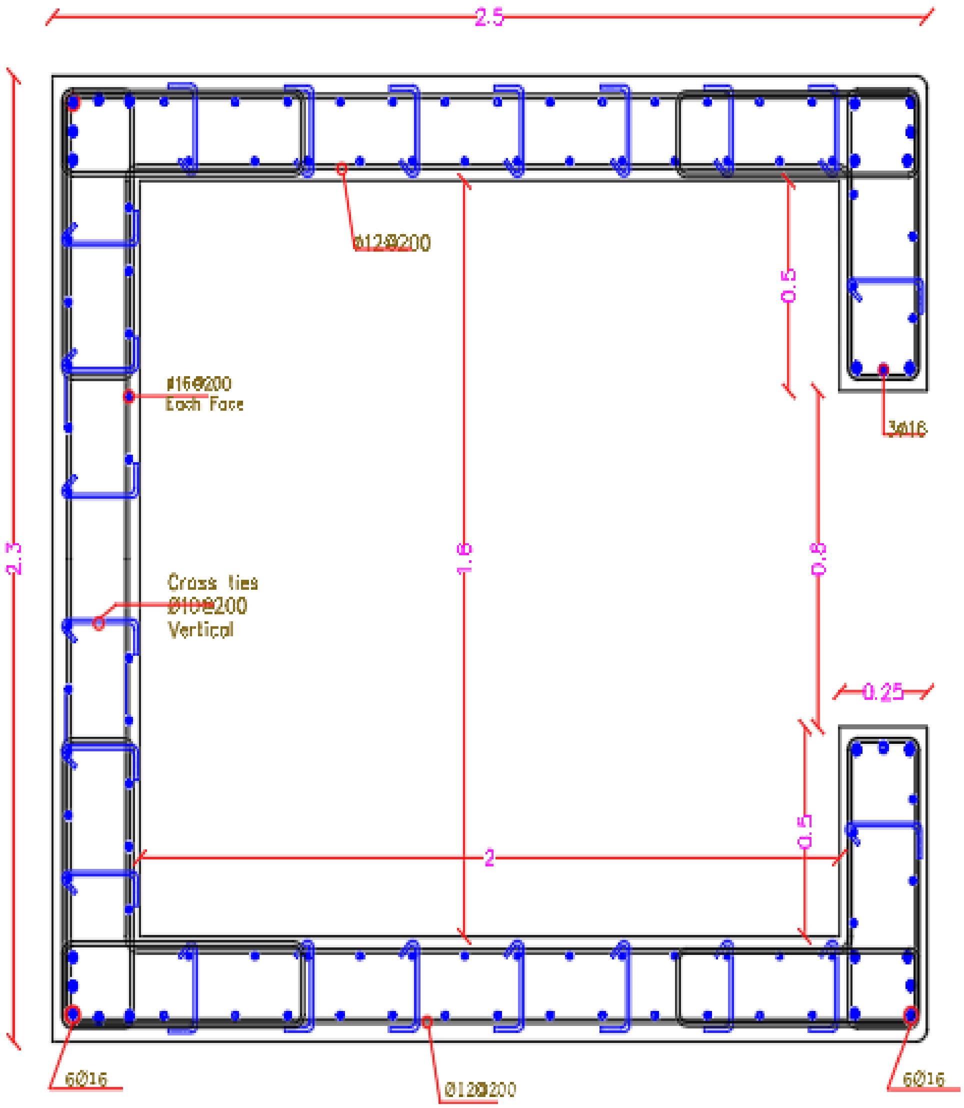
0.3
0.5

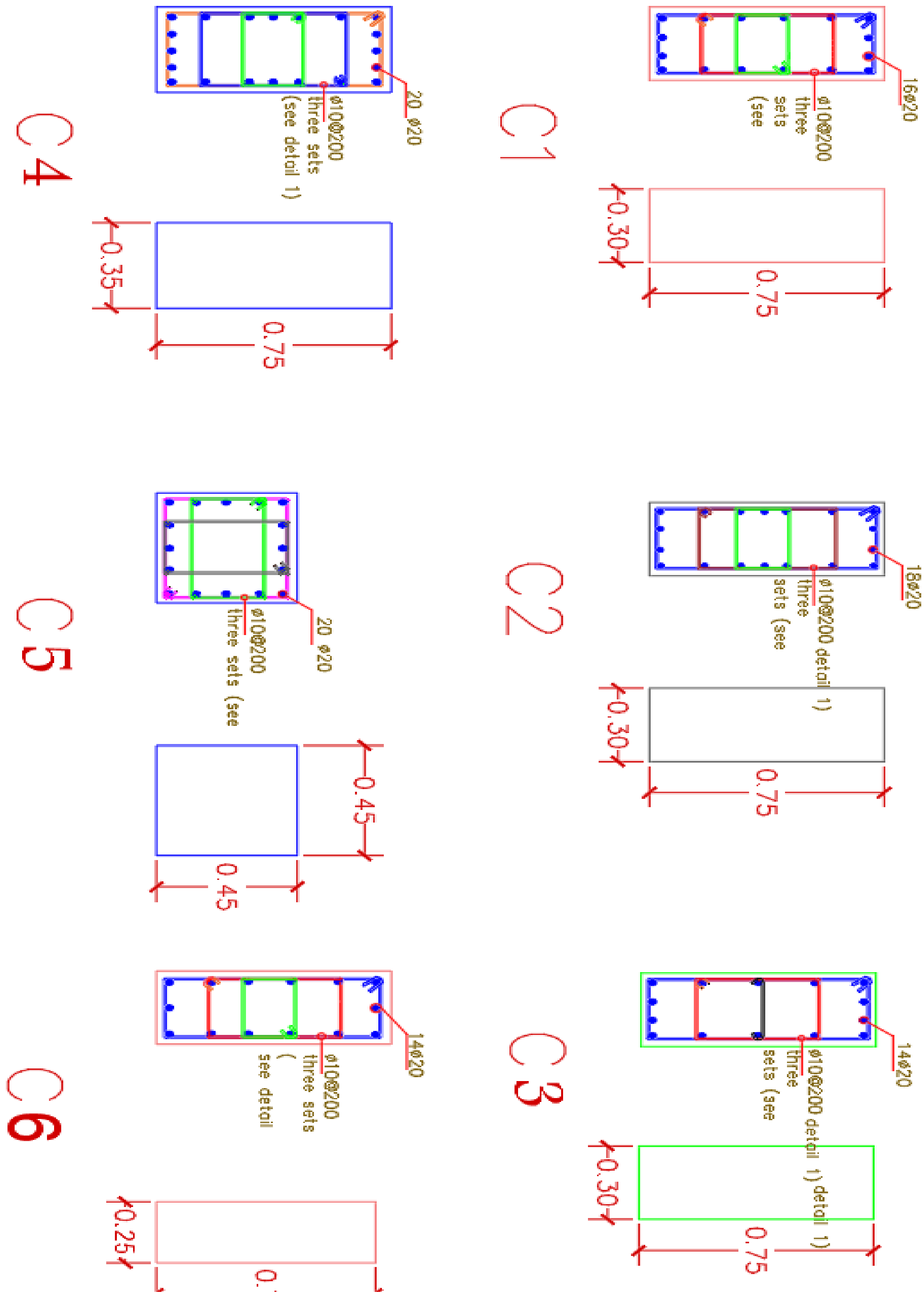
SW1



Elevator 1


2.5
2.3
Ø12@200
0.5
Ø16@200
Each Face
3Ø16
1.8
0.8
Cross ties
Ø10@200
Vertical
0.25
0.5
2
6Ø16
Ø12@200
6Ø16

Elevator 2


C1
16ø20
ø10@200
three
sets
(see
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(see detail 1)
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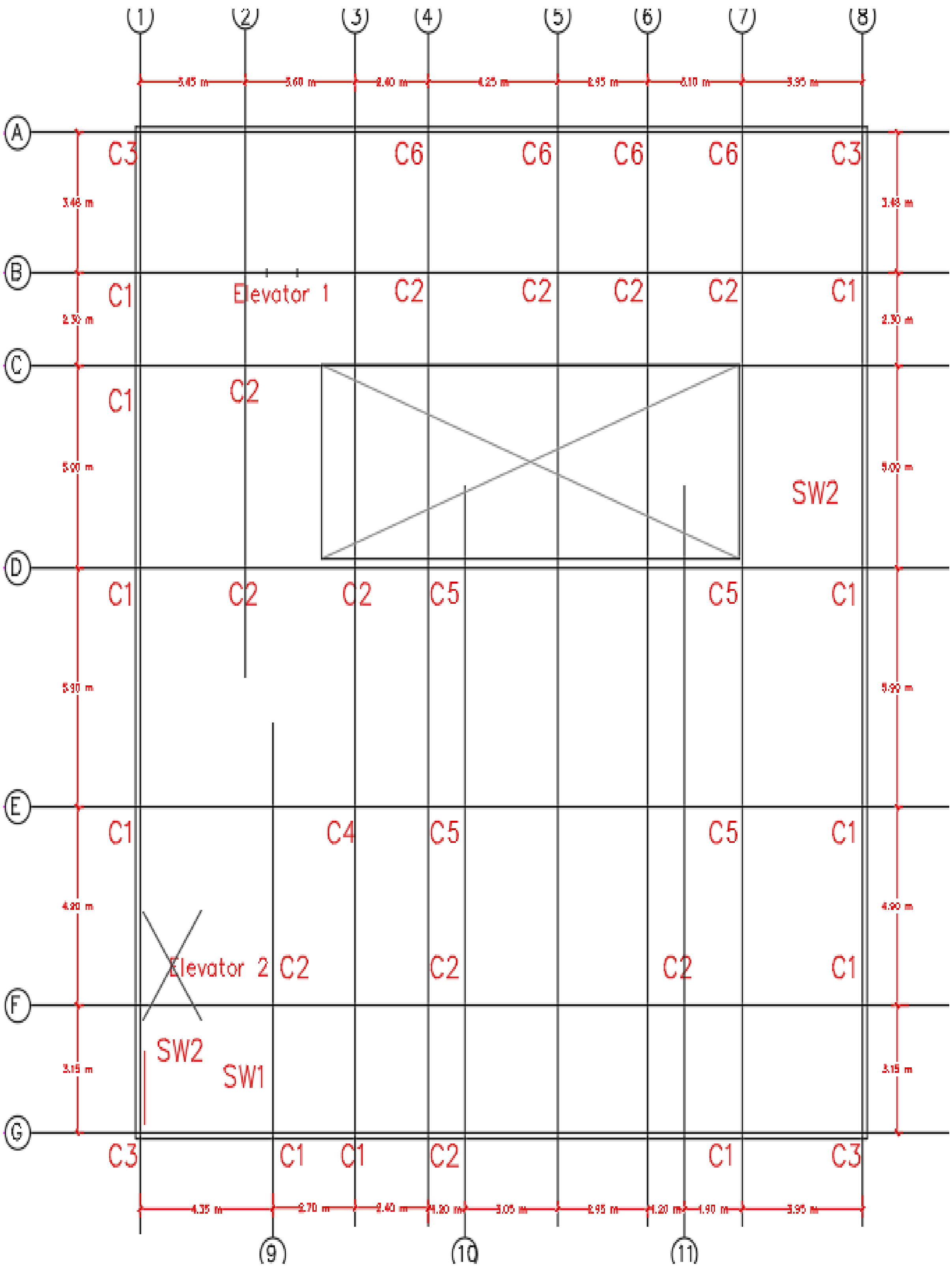
1
2
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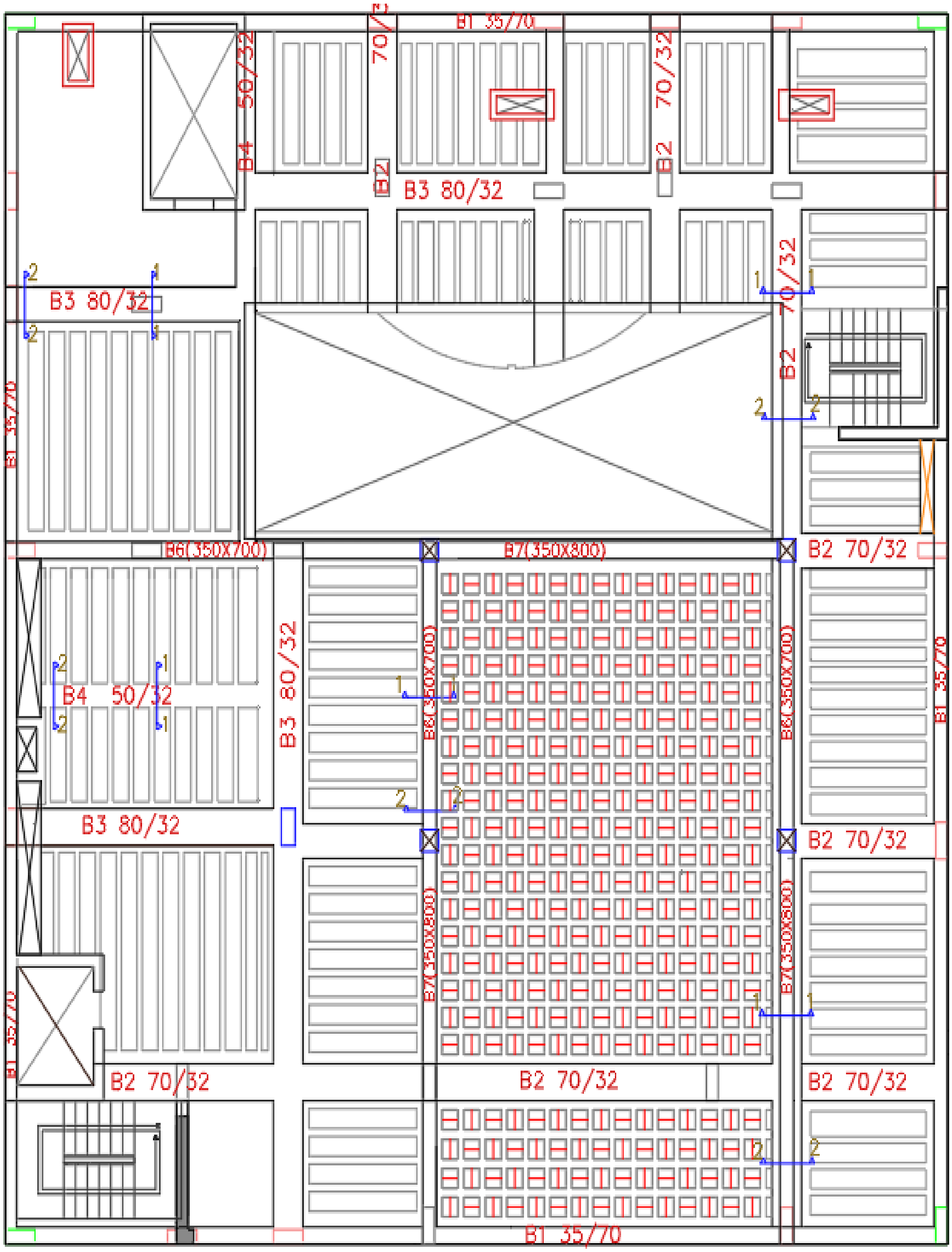
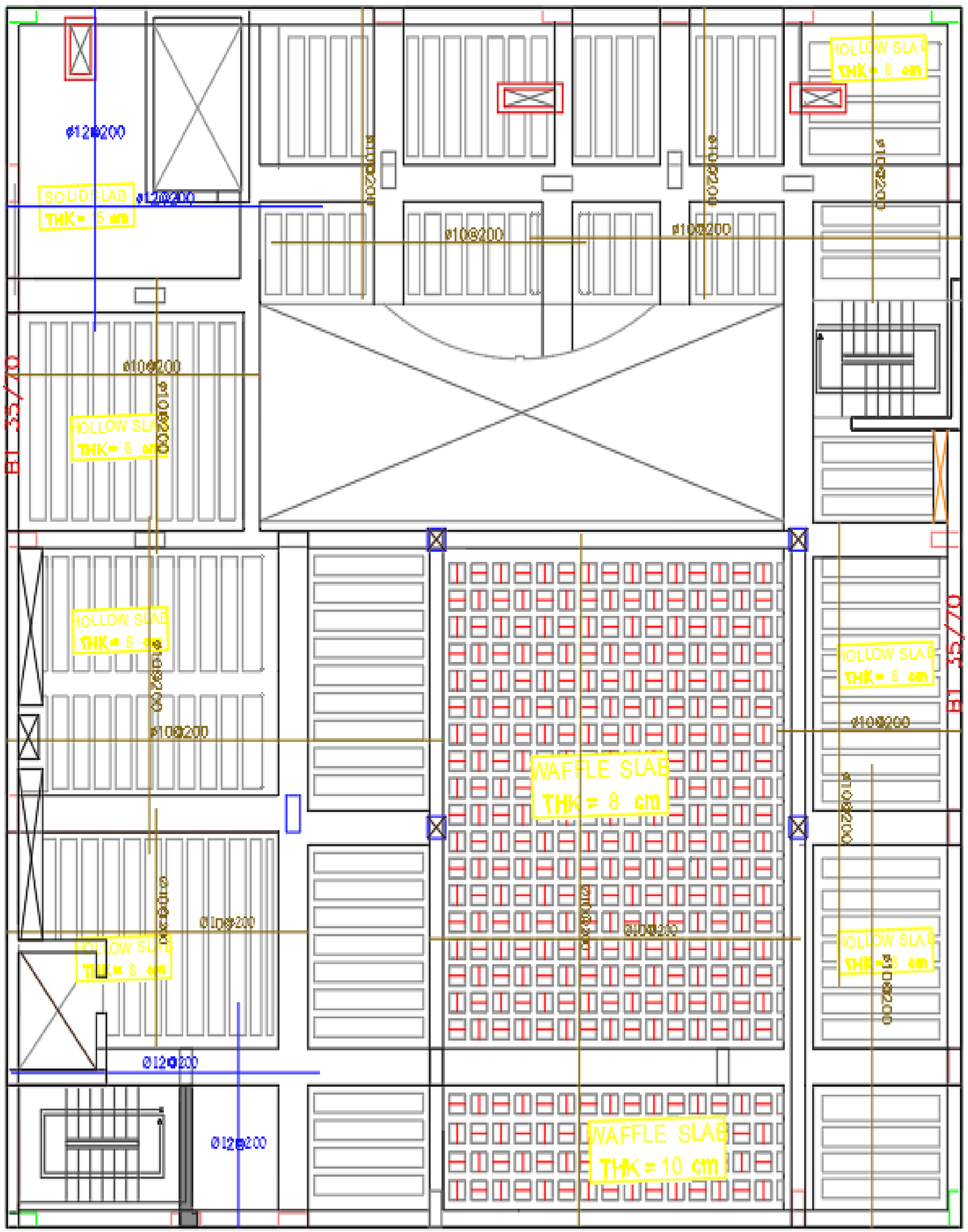
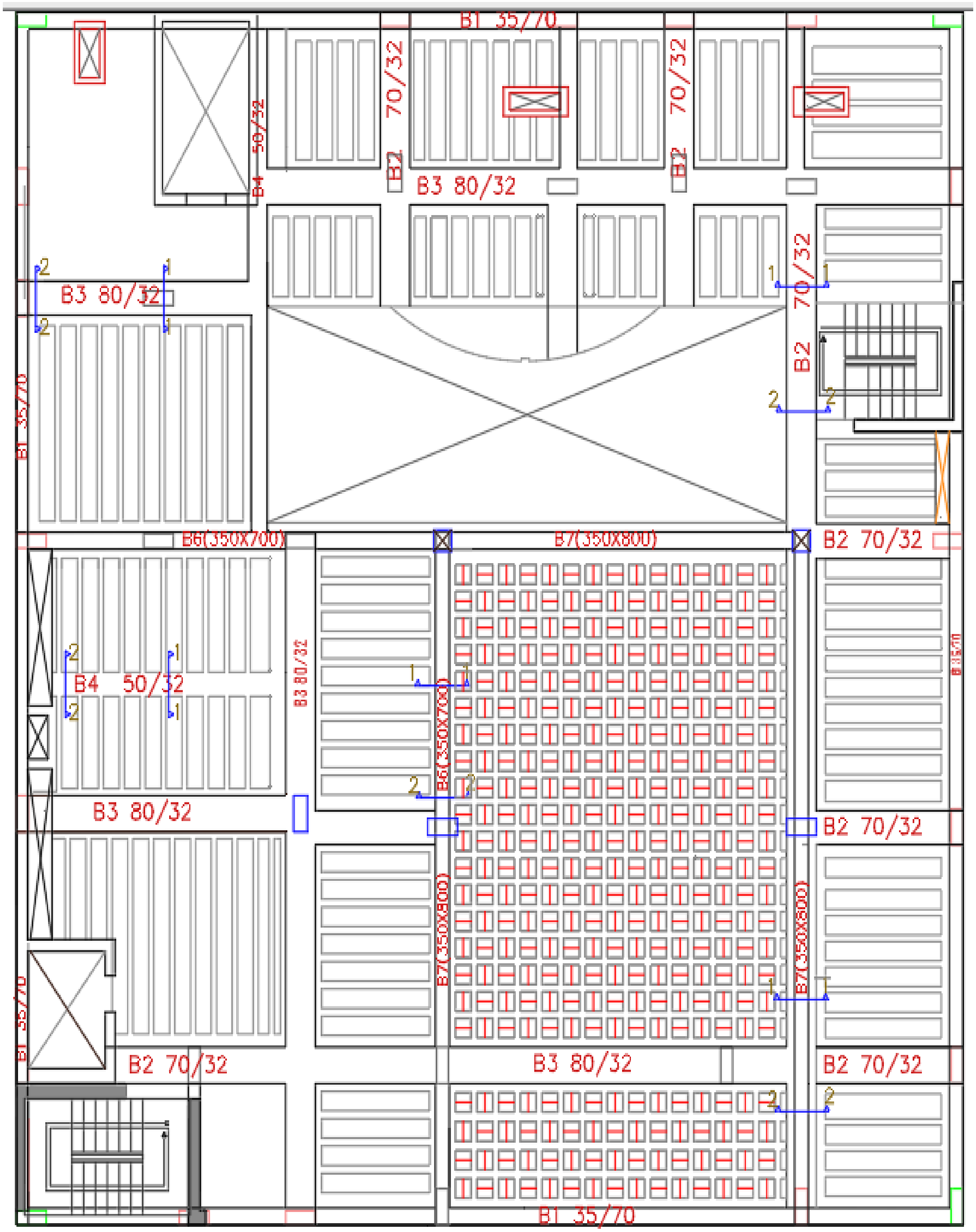
4
5
6
7
8
3.45 m
3.60 m
2.40 m
4.25 m
2.95 m
3.10 m
3.95 m
A
B
C
D
E
F
G
C3
C6
C6
C6
C6
C3
C1
Elevator 1
C2
C2
C2
C2
C1
C1
C2
SW2
C1
C2
C2
C5
C5
C1
C1
C4
C5
C5
C1
Elevator 2
C2
C2
C2
C1
SW2
SW1
C3
C1
C1
C2
C1
C3
4.35 m
2.70 m
2.40 m
1.20 m
3.05 m
2.95 m
1.20 m
1.90 m
3.95 m
9
10
11



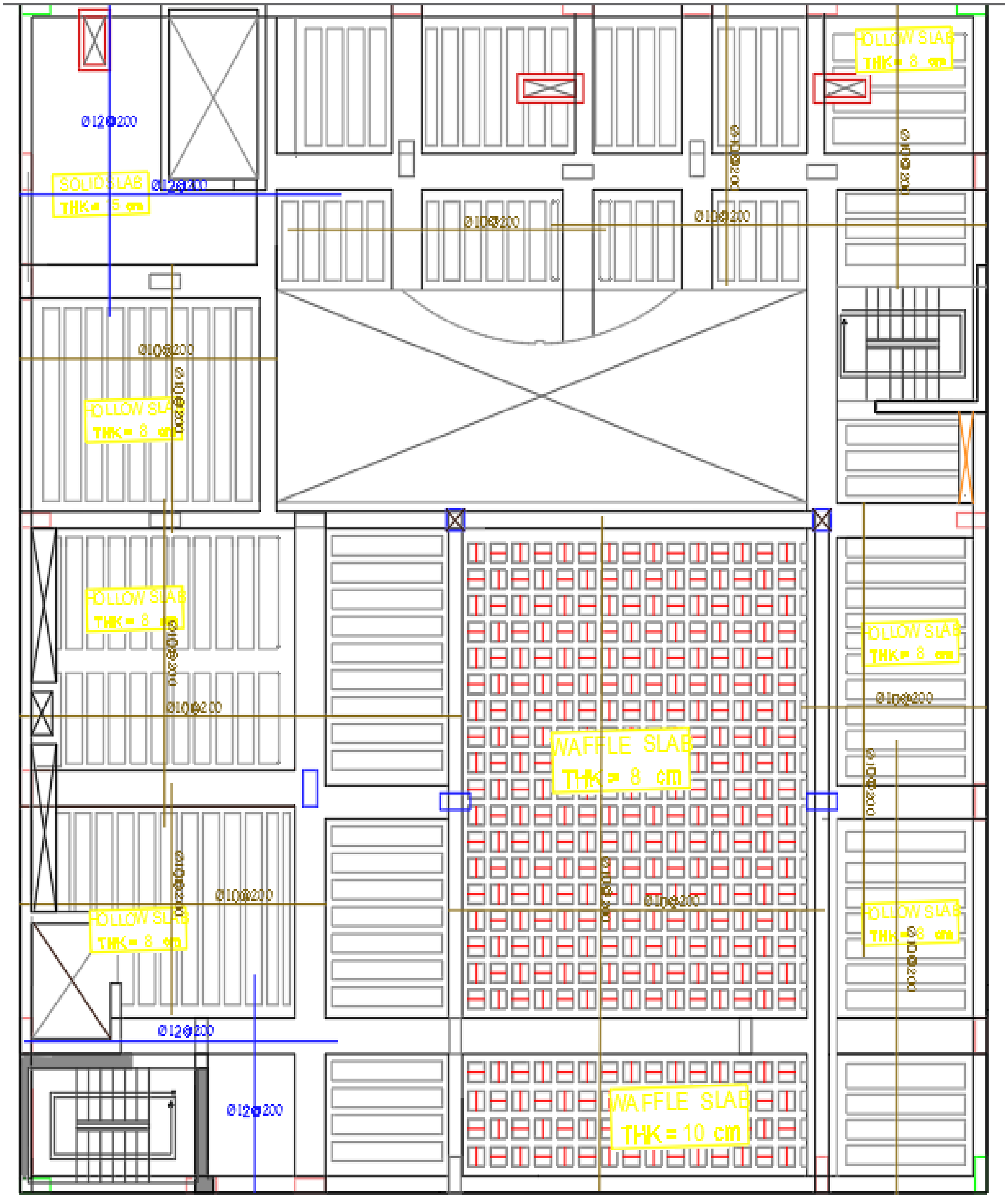
Beams Plan Ground floor



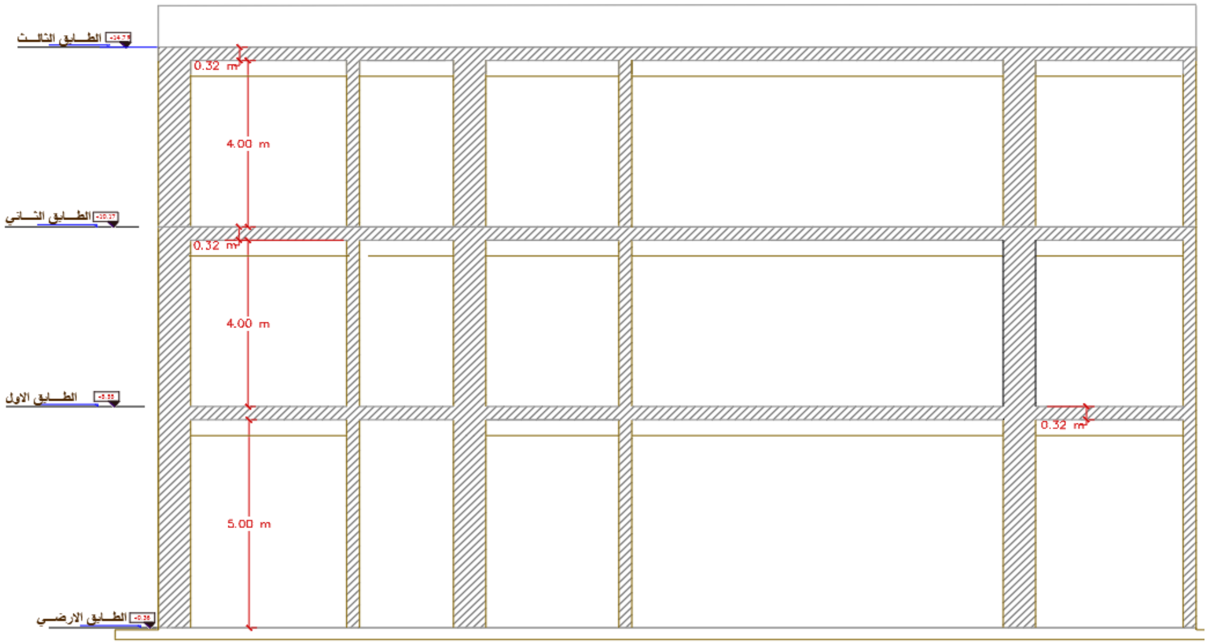
Slab Reinforcement   Ground floor



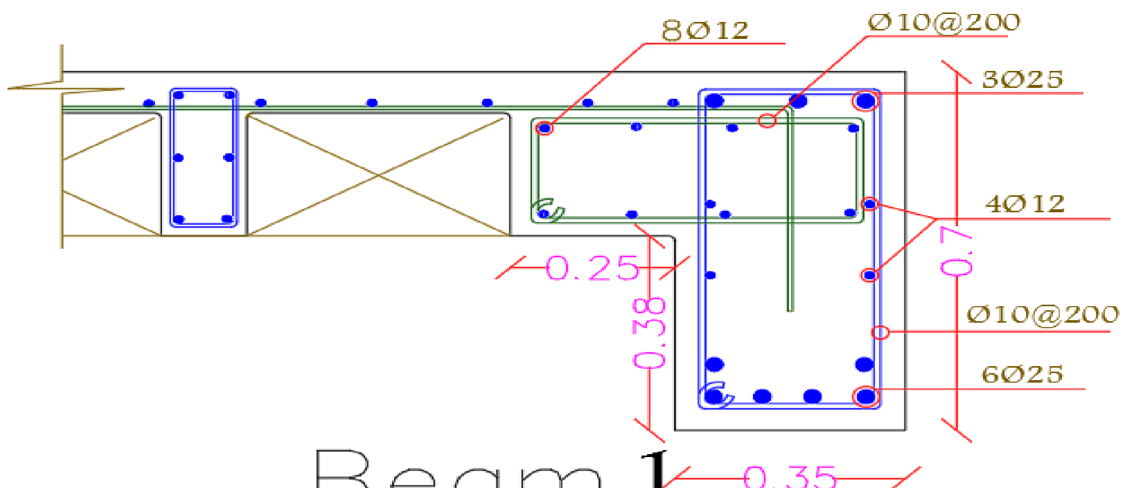
Beams Plan First and second



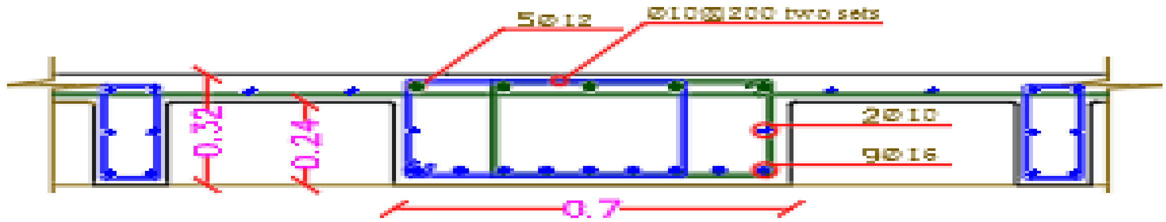
Slab Reinforcement First and second floors



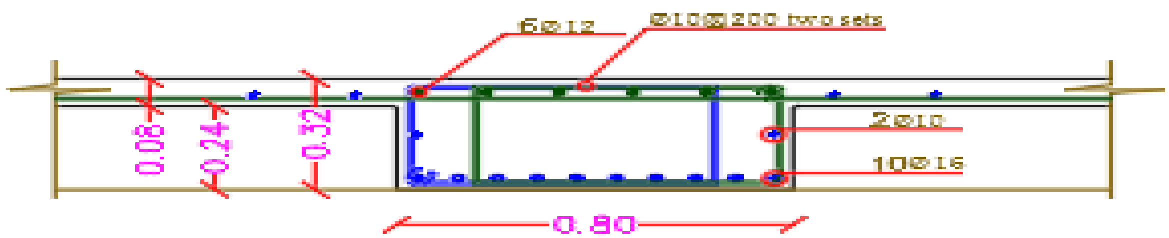
Long. Sections Front View



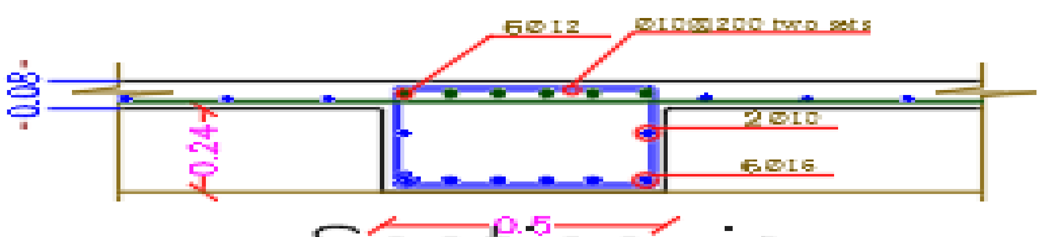
Beam 1 section in +ve Mo



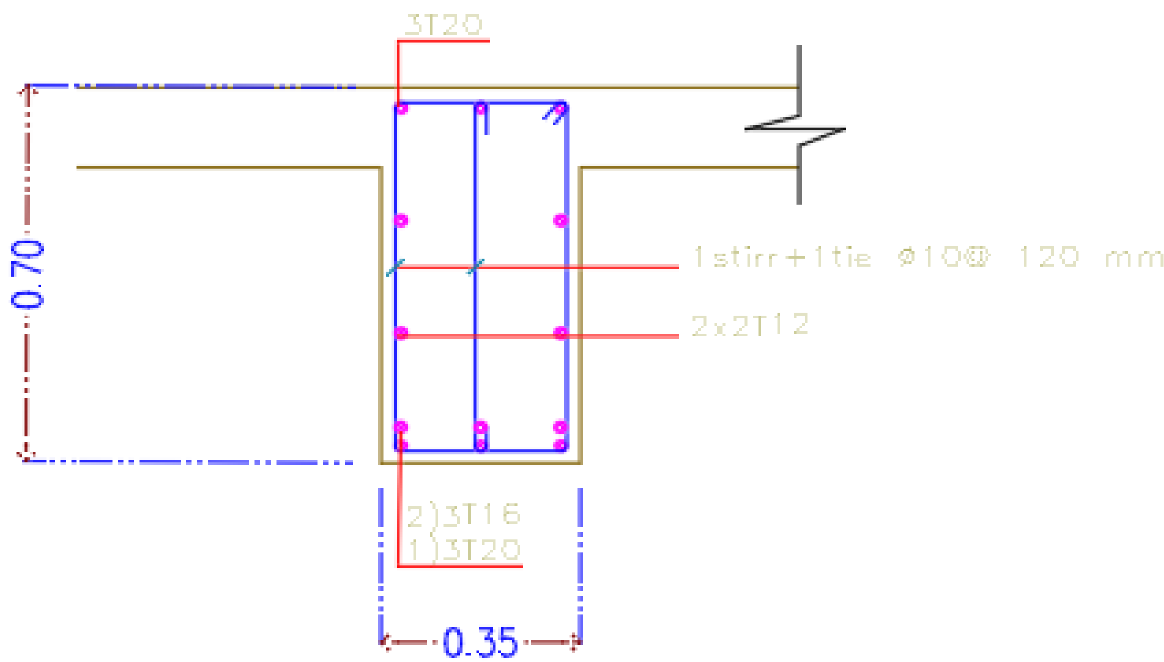
Sec 1-1.
Beam 2



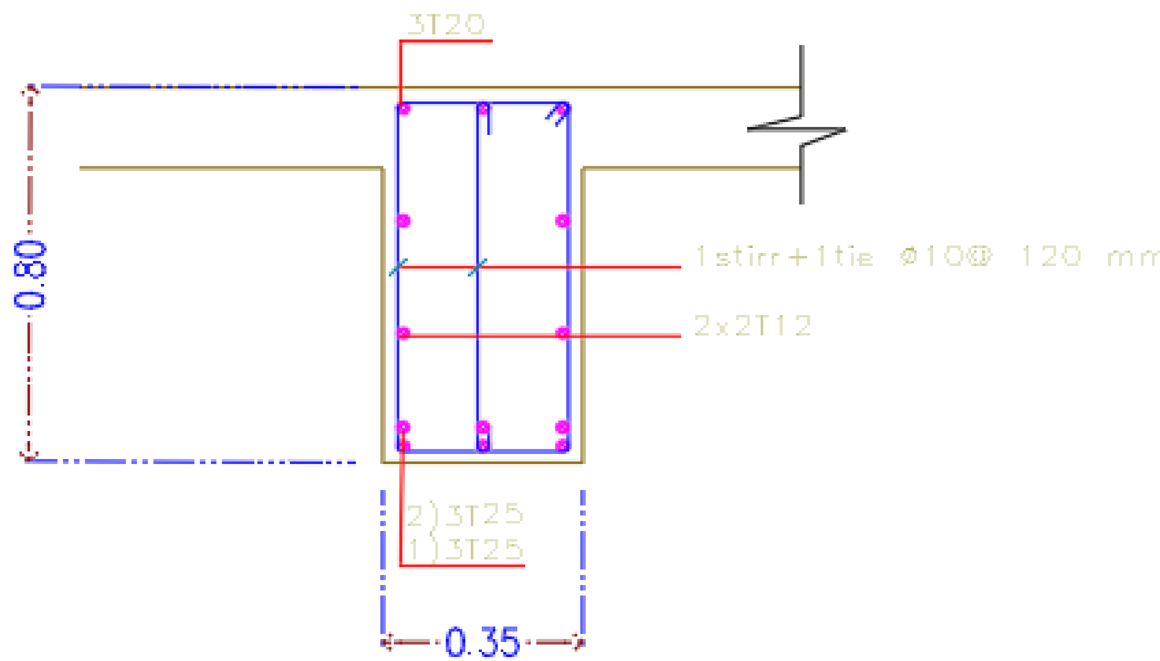
Sec 1-1.
Beam3



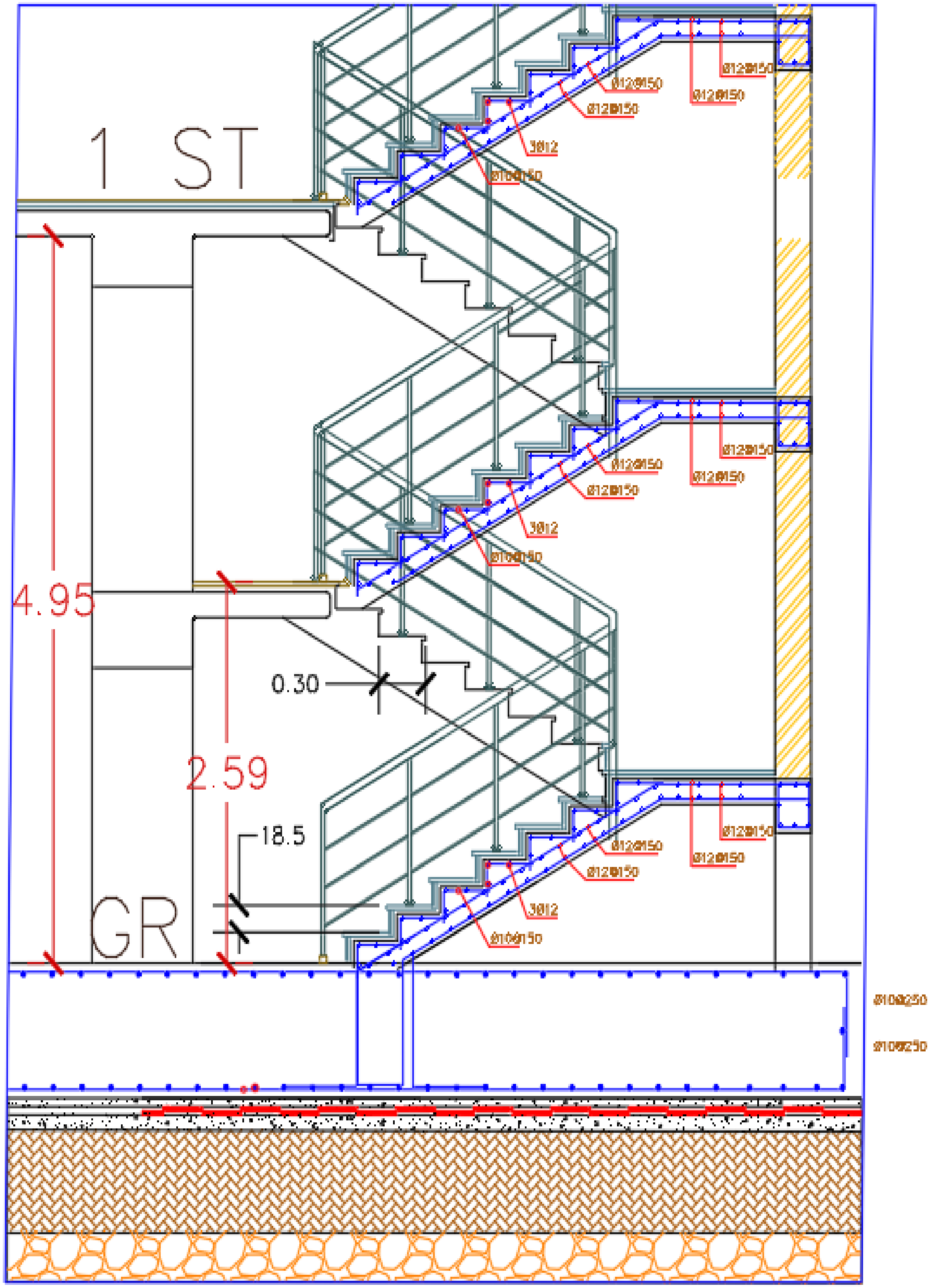
Section in sub
Beam4



SECTION 1-1 (B6)



SECTION 1-1 (B7)



1 ST
GR
4.95
2.59
0.30
18.5
3Ø12