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MASTER THESIS

A NOVEL COMPUTATIONAL APPROACH IN QUANTITY TAKE-OFF TO SUPPORT EARLY DESIGN ESTIMATIONS

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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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ABSTRACT

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In recent years, architects have adopted computational design tools (CDT), which significantly improves efficiency and speed of their practice. CDT offer great potential in not only the discovery of different design alternatives, but also rapid and accurate calculation of such crucial information as building quantities, which forms a foundation for and substantially influence the accuracy of cost estimations. However, using such benefits requires the architect to establish mathematical definitions in the early design stages where time is restricted. Therefore, the task is arduous to many. Building information modelling (BIM) software have been proposed to address such issues along many. Yet, BIM's quantity take-off (QTO) capacity is limited in accuracy and results are highly dependent on the modelling skills of the architect. In addition, to enjoy solutions provided by BIM, architectural offices must pay a financial cost which can be a significant issue especially for small ones. Arguably, developing standard mathematical definitions, which can be applied to given building project, using CDT may propose a strong alternative to BIM. Despite of its potential benefits, very few studies in the literature have addressed using CDT in building QTO practice. More, an empirical study that compares results obtained from using CDT vs. BIM vs. traditional labour-intensive approach has been highly missing. The current work aims to fill this gap. To achieve, first standard mathematical definitions of building quantity take-off were developed using parametric CDT, namely Grasshopper. Next, ten real building cases were selected. Quantities of these buildings were computed with three different methods, and the results were compared using formal test of hypothesis. The evidence is conclusive to suggest that no significant difference exists between actual values and estimations obtained from computational methods. More, the findings suggest computational methods provided results that are significantly higher in prediction accuracy compared to results obtained from BIM and traditional approaches.

Key Words: Computational design, quantity take-off, estimation, building information modelling (BIM), comparison, parametric

ÖZ

ÖN TASARIM AŞAMASI METRAJ HESAPLAMALARI İÇİN ÖZGÜN BİLİŞİMSEL BİR YÖNTEM

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Son yıllarda mimarlar, meslek pratiklerindeki uygulamalarının verimliliğini ve hızını önemli ölçüde artıran bilişimsel tasarım araçlarını (CTD) benimsemişlerdir. CDT sadece farklı tasarım alternatiflerinin keşfi ve analizlerinde değil, aynı zamanda yapı metraj hesabı gibi maliyet tahminlerinin doğruluğunu da önemli ölçüde etkileyecek önemli aktivitelerin hızlı ve doğru bir şekilde hesaplanmasında da büyük bir potansiyel sunmaktadır. Fakat, bu tür faydaları kullanmak mimarların zamanın kısıtlı olduğu erken tasarım aşamalarında matematiksel tanımlar oluşturmasını gerektirir. Bu nedenle, sektörde çalışan mimarların birçoğu için bu aktivite son derece zordur. Bina modelleme bilgisi (BIM) yazılımı, bu konulara ve daha fazlasına, çözüm önerileri sunmaktadır. Buna karşın, BIM sisteminin metraj alma kapasitesi, doğruluğu ve sonuçları sınırlıdır. Bunun sebebi, BIM çıktılarının mimarın modelleme becerilerine bağlı olmasıdır. Dahası, BIM sisteminin sunduğu çözümlerinden yararlanmak için, mimarlık ofislerin ciddi bir maliyet ödemesi gereklidir. Özellikle küçük ölçekli mimarlık ofisleri için maliyet önemli bir sorundur. Mevcut sorunlar ele alındığında BIM yöntemine alternatif olarak standart matematiksel tanımların CDT kullanarak geliştirilmesi önerilebilir. Potansiyel faydalarına rağmen, literatürde çok az sayıda çalışma CDT yöntemi kullanılarak metraj hesabı uygulamalarına odaklanmıştır. Ek olarak, CDT, BIM ve geleneksel yoğun iş gücü gerektiren yaklaşımlardan elde edilen sonuçları karşılaştıran ampirik çalışmaların sayısında fazlaca eksiklik görülmüştür. Mevcut çalışma bu boşluğu doldurmayı amaçlamaktadır. Çalışma kapsamında ilk olarak parametrik bir CDT olan Grasshopper kullanılarak matematiksel tanımlamalar geliştirilmiştir. Ardından, on gerçek bina projesi seçilmiştir. Bu yapıların metraj hesapları çalışma kapsamında ele alınan üç farklı yönteme göre hesaplanmış ve sonuçlar hipotez testi kullanılarak karşılaştırılmıştır. Elde edilen bulgular, önerilen bilgisayımsal yöntem sonuçları ve gerçek değerler arasında anlamlı bir fark olmadığını önermektedir. Dahası, bilgisayımsal yöntem BIM ve geleneksel yöntemlerden elde edilen sonuçlara kıyasla, tahmin doğruluğunda anlamlı olarak daha yüksek sonuçlar vermektedir.

Anahtar Kelimeler: Bilişimsel tasarım, metraj hesabı, tahmin, bina modelleme bilgisi (BIM), karşılaştırma, parametrik

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Alattin Çağlar ŞENDİKİCİ

Izmir, 2018

TEXT OF OATH

I declare and honestly confirm that my study, titled “A NOVEL COMPUTATIONAL APPROACH IN QUANTITY TAKE-OFF TO SUPPORT EARLY DESIGN ESTIMATIONS” presented as a Master of Science Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Şendikici, Alattin Çağlar

Signature

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September 26, 2018

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

CDT	Computational Design Technique
BIM	Building Information and Modelling
m	Meter
m^2	Meter Square
m^3	Cubic Meter
cm	Centimetres
2D	Two Dimensional
3D	Three Dimensional
CAD	Computer Aided Design
QTO	Quantity Take-off
EPW	EnergyPlus Weather Data
CPM	Critical Path Methods
ML	Machine Learning
CBR	Case Base Reasoning
KBS	Knowledge Based System
ES	Evolutionary System
ANN	Artificial Neural Network
IFC	Industry Foundation Classes
APE	Absolute Percentage Error
MIX-1	Selected Case-1 is function of Mix-used
MIX-2	Selected Case-2 is function of Mix-used
MIX-3	Selected Case-3 is function of Mix-used
RES-1	Selected Case-4 is function of residential used

RES-2	Selected Case-5 is function of residential used
RES-3	Selected Case-6 is function of residential used
RES-4	Selected Case-7 is function of residential used
RES-5	Selected Case-8 is function of residential used
PLB-1	Selected Case-9 is function of public used
COM-1	Selected Case-10 is function of commercial used

SYMBOLS:

%	Percentage

CHAPTER ONE
INTRODUCTION

1.1. BACKGROUND

Costs of buildings have an essential place in the design phase and afterwards. Traditionally, project estimates use plans and other 2D plans. Each page of the project plans should be carefully examined, and care should be taken not to count any material repeatedly while calculating the number of specific materials needed. However, the recent technological developments, the 3D modelling system has become better at a designing process, estimating and delivering projects. Building information modelling software allowed the industry to progress and forecast to BIM-based quantities.

Some of these data can be exemplified as wall, door, window, door, slab and column system. This calculation significantly affects the progress of the progeny when it is carried out in the design phase. According to the results, it is possible to make changes to the project. Project account has an essential place among architects. They can make changes to the designs made according to the results. Generally, these values calculated at the end of the project may cause a later change. So, it is important to reach, these values during the design phase of the project. These values areas also used in the project commitments and in the preparation of the tender dossier. It is crucial that the results of these values are correct.

When doing this calculation, primarily two methods are used. The first system is the traditional method. The second method is defined as a computer-aided system. The conventional method is done by an architect, engineer or professional. To implement this method, the project must be completed. Later, the drawings should be calculated individually by the professionals and collected under the headings. This system is likely to be mistaken for being a human-based system.

The second method is the computer-aided system. In this system, there is the possibility of error in the program even if the error ratio is low because the work process is computer based. However, this system yields results in the design phase of the project. This is allowed the progeny to be modified during the design phase. This is the most significant difference between the traditional method.

As a result, the construction of the building's quantity take-off is an essential point for projects. One of the most critical steps for a project survive is the cost of the project. To calculate the cost of a project, quantity take-off is needed.

1.2. PROBLEM STATEMENT

The architectural design elements are diverse, and they include many items. This makes it possible to make a mistake especially when quantity take-off amount. On the other hand, new computational approaches are evolving along with improvements in computer technology. Researchers have gained skills in solving such computational problems. Although there are many methods and techniques. There is a lack of an accepted approach to the quantity take-off of the buildings. BIM-based and 3-D design systems are helping for quantity take-off on the early design stage. However, most of the BIM-based software and 3-D modelling software are expensive.

When comparing the conventional method with the computational method, the QTO is much more successful in terms of both time and error probability. A critical review of the literature on the QTO that in the majority of studies the traditional QTO method has a high margin of error and long processing times. (Firat, Stenstrand, & Engineer, 2010; Günaydin & Doğan, 2004; Ko et al., 2014; Mohamed & Celik, 2002; Monteiro & Poças Martins, 2013)

In the computer-aided system that develops after the traditional method, the human factor is one of the methods with a high probability of error because it is the front panel. Different projects than traditional methods are not output. In this system, the calculation is done by computer. (Arayici & Aouad, 2015; Eastman, Liston, Sacks, & Liston, 2008)

In the architectural and engineering world, building information modelling is one of the evolving technologies of today. Through this system, work is being done in many different subjects such as building modelling, building planning, QTO. BIM is the massive development of the quantity take-off method by automated. 3D BIM-based drawings given some details of the projects such as a type of materials, dimensions, and quantities by doing automatically. (Monteiro & Poças Martins, 2013; Sattineni &

Bradford, 2011) Due to this problem, the accuracy of the cost estimation made through the BIM system has not been proved. (Firat et al., 2010).

In recent years, there has been considerable progress in computer-aided architectural design programs. The main reason for the widespread use of parametric design tools is that they can quickly produce different variations. Developing a computational design method is applied in many different disciplines. Most of the studies that have been carried out are the performance analyses of the buildings, the structural analysis of the buildings, environmental studies.(Eltaweel & SU, 2017; Henriques, Duarte, & Leal, 2012; Hudson, 2010; Zarei, 2012).

There is not much research about the quantity take-off of the buildings. On the other hand, QTO made using the computational design tool can be an alternative to the BIM-based design system and the conventional method. An example of this is the Cash Back 1.0 project, which is based on some of the research tools that have been developed using computational design tools.(Gerber, Elsheikh, & Solmaz, 2012).

As a result of all these researches, it is seen that QTO is an essential point for the building design process. However, none of these studies has discussed the accuracy of the results of the QTO.

We investigate the following questions during the research:

- How much can the computational design method reduce the amount of error in the QTO results when the present study is done with the quantity calculations of the buildings?
- Is there any difference in the error rates in the computational design method when comparing the conventional method with the BIM-based method?

1.3. AIM, OBJECTIVES, & HYPOTHESES

To tackle with the issues the current study aims to conduct an empirical research that compares results obtained from CDT vs. BIM vs. traditional labour-intensive approach. To achieve, the first objective is to develop standard mathematical definitions of building quantity take-off using parametric CDT, namely Grasshopper. An important point to emphasize on developed computational definition is its global implement ability. That is, such definition should have the capacity to calculate quantities of any architectural design which is introduced to the definition in adequate way. Using developed definitions, second objective is to investigate whether the results obtained from proposed definition outperform the results by BIM and traditional approach. Based on second objective, the present study poses two major hypotheses as follows:

- No significant difference exists in building quantity take-off values between actual values and estimations obtained from computational method proposed in the current work
- Computational method, offered in the present study, provides results that are significantly higher in prediction accuracy compared to results obtained from BIM and traditional approaches.

1.4. METHODOLOGY

The research employs quantitative approach to assess the performance of the proposed computational method on building quantity take-off. It develops a set of parametric definitions which estimates the building element quantities in an automated fashion. Grasshopper (a visual algorithm plug-in for Rhinoceros) is used as a computational design tool. Microsoft Excel and Minitab is used in combination for subsequent data analysis and to obtain statistical inferences.

In the proposed parametric definition, the first step is to prepare and/or transfer the design of a building into computer-aided design (CAD) environment. Among others, AutoCAD, which is arguably one of the most popular and industry standard commercial CAD software for technical drawings, is preferred. The drawings, which are introduced as closed curves, are divided into several layers. These layers are: Walls, windows, doors, columns and slabs. These layers are referred to as building elements.

Next, a drawing that is adequately prepared in CAD environment is transferred to Rhinoceros. The current work intents to translate CAD design into a parametric one. Since selected parametric design tool, Grasshopper, is a plugin working along only with Rhinoceros, we choose to employ Rhinoceros in the current work. Once the layer system of the transferred drawing is checked, a parametric design plug-in Grasshopper is initiated. Any design process done with Grasshopper is called "definition" since parametrization of design requires to define variables and their interactions among. The definitions of proposed building elements, namely walls, windows, doors, columns, and slabs are developed at this stage to perform subsequent parametric quantification.

Through quantity estimation of building elements, a simple hierarchy that present a practical relevance is proposed. Accordingly, wall and column elements are calculated under three different sub-headings: (1)area covered by volume, (2)surface of the mass and base area of (3)mass unit. Window and door elements are studied under two different sub-headings: (1)surface area of the openings and (2)area covered by the open space. The slab element is reported under three different sub-headings as (1)volume of the slab, (2)gross area of the slab and (3)net area of the slab. All computed values obtained from this parametric workflow are then exported to a datasheet

The current study hypotheses results obtained from proposed parametric pipeline will yield better results than the other methods considered in the present work, BIM and traditional labour-intensive approach. The empirical analysis of the proposed approach, 10 random building case, each consists of hundreds of different building elements are selected. For each building element in each building case, the quantities are estimated using computational, BIM, and traditional methods. 3 architectural offices agreed to participate the study. The cases are distributed to these offices, and they estimate the building quantities for each element. The average of their estimation is recorded as the result obtained from traditional method.

The obvious pitfall of such study design is the lack of reference value. All values were estimations, and one cannot argue on which estimation method provides more accurate results compared to others. To tackle with the issue, 30 random building elements are sampled out of hundreds of building elements from 10 building cases. With extreme caution and effort, the quantities of these 30 randomly sampled building elements are calculated which are assumed to be actual measurements of sampled building quantities. Test of hypotheses are conducted using these manual calculations as reference (actual) values using paired t-test.

1.5. SCOPE & LIMITATIONS

Design of the empirical study draws the main borders and plausibility of the results of the present work. Notably, the current work neglects calculating the quantities of beam elements. Arguably, the study provides a framework which can easily be adopted to any measurement practice. Therefore, considering building elements is of no practical value for the sake of time and clarity of this manuscript. The results are also restricted due to the nature of selected building cases. Since all building cases are located in Izmir, the study results cannot be generalized globally in theory. However, since quantity estimation, especially the pipeline that is proposed in the current work, does not possess any technical limitation, this limitation does not imply a significant drawback in practice. That is, in theory, the current work results are not conclusive for global implementation due to sample, while in practice it is not. Yet, we acknowledge this as a limitation to this work.

CHAPTER TWO
LITERATURE REVIEW

This chapter presents the main findings obtained from a critical review of the literature. Since quantity take-off process is highly associated with cost estimation practices, the literature review initiates with a general review of cost estimation techniques, significant factors to predict building construction costs etc. Following, studies directly related to quantity take off are examined. The primary focus of the second section is to review major quantity take-off methods in their historical development sequence. That is, the review initiates with traditional methods, carries on with BIM-based approaches and finalized with computational methods. A special concern is given to parametric computational methods as this method seem the most adequate towards increasing accuracy and decreasing overhead costs of architectural studios.

2.1. COST ESTIMATION VS. QUANTITY TAKE OFF

2.1.1. IN A NUTSHELL

Cost estimation, which is performed at the conceptual design phase of a building project, forms a foundation for budgeting, planning, executing, monitoring and even for any litigation aims. Kouskoulas and Koehm (1974) argued that design plans and features are the significant roles for project cost estimation. Therefore, in the absence of these features, it was stated that conceptual estimates might establish impairing to the owners and financiers of the project.

Nowadays, many methods are used to cost estimation in the early design stage. These methods used in the initial design phase is a conventional method, computer-aided design based, artificial neural network, case-based reasoning, ruled based method, evolutionary system, agent-based system and using software programs. On the other hand, quantity take-off is one of the most significant parts of the cost estimation in the early design phase. Quantity take-off exploits real data to make an accurate estimate of the most significant difference from other methods and systems in the early design stage.

Designers use different cost estimating techniques and methods by their experiences and their previous work of data. Although there are various methods used by different experiences of architects, the traditional way is still valid today. The conventional way of cost estimation is based on comparative cost estimation which is the unit cost per square meter. It uses historical data which is saved by averaging different building data such as height and materials. Building cost estimating comprises of multiple items such as a structural system, the walls, the doors, and windows, the mechanical system, finishing, etc.

Several initiatives are underway to improve the accuracy of construction cost estimates. For instance, some of them use neural networks. Günaydin & Doğan, (2004) proposed the use of neural networks to calculate the initial cost of structure systems. The cost estimation process is based on nine project parameters. Kim, An, & Kang, (2004) researched by adding a total of 12 parameters to the calculation of genetic algorithms and neural networks. Similarly,(Juszczyk, Kozik, Lešniak, Plebankiewicz, & Zima, 2014) used neural networks to calculate the cost of erection of multi-family buildings in the first phase of planning. These methods are based on estimation. Because of progress in the construction sector, computer-aided calculation methods have improved. Elfaki, Alatawi, & Abushandi, (2014), Information technology has a significant role in construction projects. In parallel, Computer Aided Design (CAD) technologies are used in cost estimation for building design stage. The cost estimate is one of the essential details that must be foreseen in the early stage of design. Because of a correct cost estimate, problems to be encountered in the project process can be predicted. There are several different methods for cost estimation. These are statistical based cost estimation and techniques, historical based and quantity take-off. The methods for cost estimation-based quantity take-off will be examined. These methods are conventional methods, CAD-based, BIM-based and parametric design technique-based quantity take-off.

Elfaki et al., (2014) indicated cost estimation is the most significant role in the preliminary process in the construction projects. Construction cost is an example of the expertise of the architecture task which depends on human professional. In general, architects need to more and more years to develop their knowledge for the cost estimation process. However, the main problem is that the accuracy of the cost estimation performed by architects' is not always authenticated. According to Shane, Molenaar, Anderson, & Schexnayder, (2009), the cost estimation can easily be affected by many parameters. Albogamy, Scott, & Dawood, (2013), cost estimation can cause many problems such as construction delay, change order or even bankruptcy. Generally, two factors can create these adverse situations. The first factor is that manual cost estimation is impossible to find the right result. Incorrect cost estimation effects are the second factor of these adverse situations. Therefore, researchers and construction companies are conducting new researches to solve these problems. There are some current users of the intelligent solution in the construction industry. Elfaki et al., (2014) has reviewed the latest technological methods to evaluate the importance of smart solutions at project cost estimation.

Dursun & Stoy, (2016) argued, there is a dataset consisting of historical project information in the cost estimates. These values are collected or obtained according to the type of the research. The variables that respond to the variables in the hypothesis form the input set. In the next step, sufficient analysis methods should be established to form accurate cost estimation models. Finally, these developed models are confirmed by the invisible data.

After investigating the literature, there are some studies about the cost estimation studies in different regions. For instance, Lowe, Emsley, & Harding, (2006) and Emsley, Lowe, Duff, Harding, & Hickson, (2002), both of which have researched construction projects in the United Kingdom. Günaydin & Doğan, (2004) determined certain conclusions regarding the console aspects and foundation systems in the early stages of building projects in Turkey. Kim et al., (2004) suggested independent variables that provide limited design details for their multi-stage residential projects in Korea. It is possible to come across studies using similar methods in different regions.

Cost estimating factors and techniques has a significant role for cost estimation in the early design stage. Cost estimation factors are investigated under many conditions.

2.1.2. INFLUENCING FACTORS

Shane et al., (2009), and Oberlender & Trost, (2001), indicate unique parameters are being developed for construction cost estimation such as material cost, likely design and project changes, land conditions, time of a construction, size of a project, type of constructor or client, type of a project.

Several factors impress cost estimation in construction projects. Akinci & Fischer, (1998) argued these factors could be divided into two different groups. These are estimator-specific factors and design and project-specific factors. Cost factors directly connected to building information base system.

Estimator specific factor is a part of the construction cost factor. In this factor, one of the contractors, consultant or owner can be a cost estimator. Akinci & Fischer, (1998) argued errors in the cost estimation could be due to the result of the estimator's background and experiences in this factor.

Design and project factor is another part of the construction cost factor. Shane et al., (2009),and Oberlender & Trost, (2001)indicate this factor contains the size of the project, type of project, land condition, type of client, material cost, project duration and tendering methods. The scope of the project is a healthy relationship between project size and square meter or meter and the number of labours.Doyle & Hughes, (2000) and Mahamid, (2011) applied many experimental studies on how project size can influence cost estimation. Project types can be classified into various categories which are building construction, particular purpose construction and heavy construction. Before making cost estimation, the ground condition should be one of the essential concerns in construction projects. Cost estimation made without knowing the ground conditions can be mistaken. If there are poor ground conditions, there may be additional costs. Donyavi & Flanagan, (2009) described materials can affect up to 70% of the construction project cost. The material cost has a significant role in the cost estimation for construction projects. Also, the material-selection, material types, and their availability in the local market is an influential role for cost estimation. Therefore, using material cost with any methods gives cost and time advantages for significant project's cost.

2.1.3. TECHNIQUES

Cost estimation techniques divide into two different alternatives. These are conventional single step and multistep database cost estimation. The levels used in the traditional one-step method are as follows: data analysis, model validation and cost estimation model preparation. The steps used in the multistep method are as follows:

data analysis, model validation, building element quantities and cost estimation model. There are some systems which are applying to cost estimation techniques such as machine learning, ANN technique, rule-based system, evolutionary system and agent-based system.

Artificial intelligence tools have a significant role in cost estimation such as neural networks. In today's practice, cost control is a substantial role for building design stage. Mohamed & Celik, (2002) indicated since the late 1950s, a computer-based program analysis for management of projects introduced Critical Path Methods (CPM). Before this system, the client's wanted to more detail about their design and drawings for cost estimation.

Machine learning is a system which can learn from data such as work with uncertainty, work with incomplete data and do similar work using the experiences. These examples are main strengths of ML system. On the other hand, the main weakness of the ML system is the lack of technical reasons. There are two common ML techniques such as Artificial neural network and the support vector machine. Kartam, et al. (1994) are published to introduce the benefits of the Artificial neural network system. Through this research, ML has been identified as the prefered method to overcome various problems in the construction industry.

ANN technique was introduced by Petroutsatou, Georgopoulos, Lambropoulos, & Pantouvakis, (2012) for early cost estimation of road tunnel construction. The main idea of this research is based on data collection strategy from different tunnel construction data. Questionnaires and interviews are strategies for data collection. Cheng & Hoang, (2014) got information about 13 reinforced concrete building projects between 2000 and 2007 in Taiwan

Ruled based system use rules for inferences the conclusions. This system called knowledge-based system (KBS). There are two main subjects for this system such as work to justify any result, work to simple methods that mean is easy to develop KBS. On the other hand, this system has an adverse effect on the cost estimating such as learning difficulty and time consumption to learning the rules. K. J. Kim & Kim, (2010) used a CBR system for a cost estimation model. This research defeats the suspense in preferring the actual case by using a genetic algorithm. In this research, they analysed to constructed 585 bridge over five years' period. A. E. Yildiz, Dikmen, Birgonul, Ercoskun, & Alten, (2014) created a knowledge-based risk mapping program to cost estimates for construction projects. Because of the interviews with experts, the approval process was carried out.

An evolutionary system is a group of intelligent systems related to continuous optimisation with experiential. The ability to solve complex and to challenge to solve problems encourages the use of ES for researchers. Rogalska, Bozejko, & Hejducki, (2008) determined a method based on genetic algorithm to attend to the problem of the construction project.

The agent-based system is a main part of the artificial intelligence. This system is simulating the action and interaction of automatic agents with a view of the valuation of their effects on the system. Karakas, Dikmen, & Birgonul, (2013) developed a multi-agent system. This system is working on the negotiation process between client and contractor. The main idea of this system is regarding risk division and sharing of cost overflow.

Zima, (2015) argued the case-based reasoning system is the method used when the solutions of the cases that are predicted to have the same result are similar. The most important distinguishing feature of the CBR system from other systems is that it works independently from the expert as it is continuous learning.

Quantity take-off is one of the significant tasks in the construction projects. The building components are measured and then used to estimate their costs and associated workload. Quantity calculation can be examined in different sections within itself such as conventional, CAD-based, BIM-based and software based.

2.2. QUANTITY TAKE OFF METHODS

2.2.1. TRADITIONAL

Quantity take-off is the part of the cost estimation methods. Traditional quantity take-off method is based on 2D hand drawings and calculates to building quantities. Next stage of the development is 2D software-based drawings and calculate to building quantities. Mohamed & Celik, (2002) argued the traditional quantity take-off method is that constructors focus on costs after the design decision. Because of, Firat, Stenstrand, & Engineer, (2010.) reported on the existing system, quantities are calculated either manually or via Excel using 2D drawings. Generally, traditional methods based on the layout of the projects which are plans, sections and elevation drawings. They are given necessary information about the design project. Günaydin & Doğan, (2004) was concerned about traditional quantity take-off based on 2D software-based drawings and specifications. A linear relationship between the final cost and the fundamental design change for the building projects. Traditional quantity take-off method is manual progress on 2D hand drawings such as floor plans, elevations cross-sections and another similar type of the documents. Ko et al., (2014) has demonstrated until the early 1980s, quantity take-off and building cost estimation made by hand. In this method, designers had to have calculated to every detailed on the projects by hand. In this case, it raises the possibility of making mistakes. This method is the first system applied for quantity take-off. Monteiro & Poças Martins, (2013) was concerned with the traditional quantity take-off method is very error-prone because of the human interpretation of this approach.

2.2.2. CAD-BASED

Next generation of the traditional quantity take-off is that 2-dimensional CAD (Computer-Aided-Design) software used for the quantity take-off. CAD software-based quantity take-off is more useful than 2D hand drawing quantity take-off. CAD software-based quantity take-off method saves times of the quantity take-off progress. Results by such recent works as Eastman et al., (2008), and Arayici & Aouad, (2015) discussed the disadvantages of CAD-based quantity take-off. There are some problems in this process such as human errors, less detailed quantity specifications, quantity surveyor is less qualified than the architects. The advantage of this quantity take-off method is that this method can still use without good computer knowledge. Therefore, this method still used today. The disadvantage of this method is that the error rate is high because it is a human-focused system. Since the mid-1980s, CAD software used for automated estimation and quantity.

Next generation of the CAD-based manually quantity take-off is BIM-based quantity take-off. This system is calculated from the quantities automatically.

2.2.3. BIM-BASED

Eastman et al., (2008) argued Building Information Modelling is one of the most developing areas of architecture, engineering and construction. One or more virtual models can be built in the digital environment using BIM technology. By taking advantage of these digital designs, the design process can be better analysed and controlled. Also, the use of these models, data can be prepared to support the construction, manufacturing and supply activities of the building.

Firat et al., (2010) indicated during the use of BIM tools; there is a problem of information sharing between the designer and production teams. Due to this problem, the accuracy of the cost estimation made through the BIM system has not been proved. Estimating building cost using only BIM tools is impossible. BIM tools can just report for quantity take-off automatically.

3D BIM is the massive development of the quantity take-off method by automated. 3D BIM-based drawings given some details of the projects such as a type of materials, dimensions, and quantities by doing automatically. Monteiro & Poças Martins, (2013) argued automation had improved the level of architecture, engineering and construction industry over the last 30 years in the academic community. On the other hand, the technical community has not been improved to the same extent. Generally, the risk and benefit ratio is learned in mid to long terms. In general, construction automation is related to building technology or information management. The second area of the automation concerning is mostly around software. The software is used from engineering calculation, construction and project management, planning and various type of construction documents.

One of the most useful parts of the BIM system is that quantity take-off which can be automated through BIM. The BIM-based quantity take-off is ensured more detailed and truth cost estimate than traditional cost estimation in the projects. Also, BIM-based quantity take-off is reducing time and expenses. Sattineni & Bradford, (2011) indicate favourite BIM tools cannot handle data even though they can present quantity take-off tables. This is usually done with another type of the software. Monteiro & Poças Martins, (2013) argued information is usually changed between BIM and cost estimation software in two ways. The first way is that both systems use the same property for product and data change of description. Therefore, without any loss of data happens smoothly. The second way of the system is used in different property formats. So that, the data is converted by Industry Foundation Classes (IFC) which is a third common format.

Monteiro & Poças Martins, (2013) indicate the lack of reports focusing on BIM-based quantity output is probably a result of the use of features. Building information modelling is proposed to support the automatic extraction of quantities, counts, and measurements from a building model directly. Manual calculations are removed from the middle in this process, quantity take-off is made more straightforward, and estimates are facilitated based on geometric information obtained from the 3D building model. Sattineni & Bradford, (2011) reported how the elements are modelled and how the parameters are calculated done by BIM experts. Therefore, it requires a comprehensive understanding of the input and output variables of the application.

Research is underway to develop and improve the BIM system in quantity take-off. There is some software using for BIM-based quantity take-off. Archicad and Revit are two of the most commonly used BIM tools for architectural design. Farah, (2005) reported both contain the program to subtract quantities from the model automatically. Monteiro & Poças Martins, (2013) indicated if Revit develops software which name is Autodesk Quantity take-off created explicitly for quantity take-off, it should not be forgotten that Revit is quantifying capability is more straightforward and not as powerful as Archicad.

The operating principle of the software is that the user selects the elements to be measured and defines the measurement parameters. However, they are supported by additional programs because of the sufficiency problems of the quantities they make. Abanda, Kamsu-Foguem, & Tah, (2017) identified the most preferred programs in the market as a result of their research for the quantity take-off field. These are Navisworks, Autodesk QTO, CostX, Innovaya, iTWO, d-profiler, Vico, ProjectWise Navigator etc. First, cost estimation software does not have a specific unit of measurement. Therefore, it is unlikely that this software will be consistent with cost estimates.

2.2.4. COMPUTATIONAL TOOLS

Definition and Domains

Over the last decade, there has made remarkable progress in computer-aided architectural design programs. The main reason for the widespread use of parametric design tools is that they can produce different variations quickly. Also, the design process is considered to be adverse effects that it is longer than other design tools. Parametric design tools use several different parts of the architectural design. However, the most commonly used parts are the performance-based design and generative design. Parametric design tools have been used for building cost estimates in the light of the research done even if it is not as sophisticated. The parametric design progress is based on some definition of the building parameters. These parameters are helped to estimates of the building quantities such as the dimension of the walls, columns, slabs, windows, doors and another part of the buildings. Parametric design is based on different simulation and analysis methods such as volumetric, structural, environmental and economic simulations. In parametric design, which is a database design method, making quantity take-off gives safer and more precise results than other methods.

(Fischer, 2006) indicated the design is a social and technical process that needs to coordinate weakly connected operations and data between a wide range of team members and stakeholders. Building designs to include technical, financial, aesthetic, environmental and functional aspects. However, the multiple participants are not limited to these but are based on various targets and qualifications. Jaggar (2002) indicated according to these qualities; decisions are taken early in the design phase affect the actual value of the project. Accordingly, Gerber et al., (2012) argued parametric design tools enable designers to create more design options faster than other design methods. The generative design has not yet become the normal process in the early design stage. Therefore, economic prediction in the plan is not used to with processing and design studies.

Aish & Woodbury, (2009) expected as confident of the parametric design, although practical parametric design tools are useful, they are considered complicated and time-consuming. Many surveys of recent show the increase in the popularity of parametric design tools.

Eltaweel & SU, (2017) reported parametric design software has emerged since 2008. It is accepted as a new tool developed by many software developers and companies. Grasshopper based on Rhinoceros, Dynamo based on Autodesk Revit Architecture, 3D Maya and Autodesk 3D Max are the examples of this software. Nowadays, parametric design tools have increased in popularity. Grasshopper and Dynamo have enough features for parametric design. However, Grasshopper is a more preferred add-on in the architectural design stage. Many features are used in the architectural design with the Grasshopper plugin. Some of them is that include performance analysis, structural analysis and facade design. For instance, Ladybug and Honeybee are the plugins in Grasshopper. Ladybug with the help of a standard EPW file; he makes fielded analyses on the environment. The honeybee is an add-on to Grasshopper. This appendix is one of the familiar simulation tools such as Ladybug. It can perform many field analyses such as daylight analysis, solar radiation, wind speed, heating and cooling energy consumption. Many add-ons such as these are available for Grasshopper. There are studies about these attachments (i.e. REF).

Parametric design is used in different disciplines such as architecture, structure, urban planning, environmental studies. Eltaweel & SU, (2017) indicated the architectural design includes design features such as size, location, orientation, shape, and sun position. In the conventional design, if the designer wants to change one of these parameters after the model is created, the whole process must repeat. This process takes quite a while. Since the design of variables is integrated with the designs made with the help of parametric design tools such as Grasshopper, the changes in these parameters do not cause any problems in design.

In architecture study, parametric tools used can produce creative solutions, interact with different disciplines and provide them with parametric control. Hudson, (2010) and Zarei, (2012) discussed parametric design tools, along with algorithms designed using parameters, help the designer reach multiple solutions. In this way, it helps to produce creative solutions in the utopian design process.

In structure study, parametric design can calculate algorithmic formulas and manipulate complex links and establish complex relationships. At this point, it can make solutions to complex structures. Eltaweel & SU, (2017) have worked on a sample project and have shown that spiral columns are not required and that the beam profiles must be smaller than the standard ones. As a result of this study, structural analysis can be performed using parametric design tools.

In urban planning study, distinctive results are obtained by different alternatives produced using parametric design tools. Eltaweel & SU, (2017) argued these results could not be achieved with traditional design methods.

In the environmental study, Parametric design tools can analyse climatic and environmental changes such as sun movements, location, lighting rate, wind speed, heat changes, shadows. Also, they can also be controlled parametrically. Boake (2014) and Henriques et al., (2012) stated that the performance of the real-time building could be simulated using parametric design tools. As a result, it has been understood that many design problems can be predicted and solved in the early stage of design.

Cost estimation is a significant part of the early stage of building design. However, there are not many studies about building cost estimation in the parametric design field. Parametric design tools can make building cost estimate.

Parametric tools as an alternative

Quantity take-off using the parametric design tools can be an alternative to other BIM-based systems and traditional systems. There are few examples of the cost estimation process in parametric design tools such as Cash Back 1.0 project by Gerber et al., (2012). It is a research that prepares real-time results on the cause, effect and financial characteristics of geometric design alternatives in the early design stage of the buildings.

2.3. SUMMARY

Quantity takeoff is one of the most significant tasks in the architectural design process, as it forms the foundation for subsequent cost estimation and project planning & programming activities. Cost estimation is examined under several headings. One of these is the quantity take-off. Quantity take-off has also been studied under different headings. These are the conventional method, BIM-based and parametric based quantity take-off. Firat et al., (2010) indicated to the traditional method of quantity take-off, quantities are calculated either manually or via Excel using 2D drawings. BIM-based quantity take-off is provided more detailed and truth cost estimate than traditional cost estimation in the projects.

Parametric design-based quantity take-off is expected to work more efficiently than other methods. Firat et al., (2010) as a result of the studies carried out, BIM-based programs have a margin of error. The error rate in calculating the parametric basis quantity take-off is lower than the other systems.

CHAPTER THREE
METHODOLOGY

This thesis is in the category of technology and design knowledge as a working principle. Research on technology and design can be regarded as "artificial" because of innovations produced in contrast to natural sciences. Designing and evaluation of an artwork play an essential role in design-oriented studies. Hevner et al. (2004) argued work must be about an unresolved problem, construct and prove that the problem should theoretically contribute and be tested. On the other hand, the solutions found in work must be developed or tried to solve the problem.

In this research, a quantitative approach was used to evaluate quantity take-off during the early design phase of buildings in conceptual design phases. A new calculation framework has been proposed for the building quantity take-off. The framework has been applied as a comparative study between the traditional quantity take-off method, the BIM-based quantity take-off system and the new parametric based quantity take-off method. It is assumed that parametric-based quantity take-off method will yield better results in early-stage building quantity take-off than other methods. To test the hypothesis, we used the results of the projects, which was generated by using the parametric-based design tool which name is Grasshopper.

This study used computational design tools and techniques for the establishment. Projects implemented in the real world create a new framework for finding the accuracy rates of the quantitative calculations. Firstly, parameters are defined for the definitions are made in the computational design tool. The first variables were derived from the building plan, and the variables for this are walls, windows and doors. The second set of variables are the structural elements of the building such as columns, beams and slabs. Thirdly, the building roof system is defined by the system. Fourth, mathematical connections were made as variables of the system. Finally, the results are automatically combined and transferred to electronic spreadsheets. The most significant difference between the computational design system and the other systems is that all changes made parametrically are automatically reflected in the system.

Because of this study, a new tool will be created using computational design tools. This will be a quantity take-off tool that can be used in professional life as well as contributing to the literature.

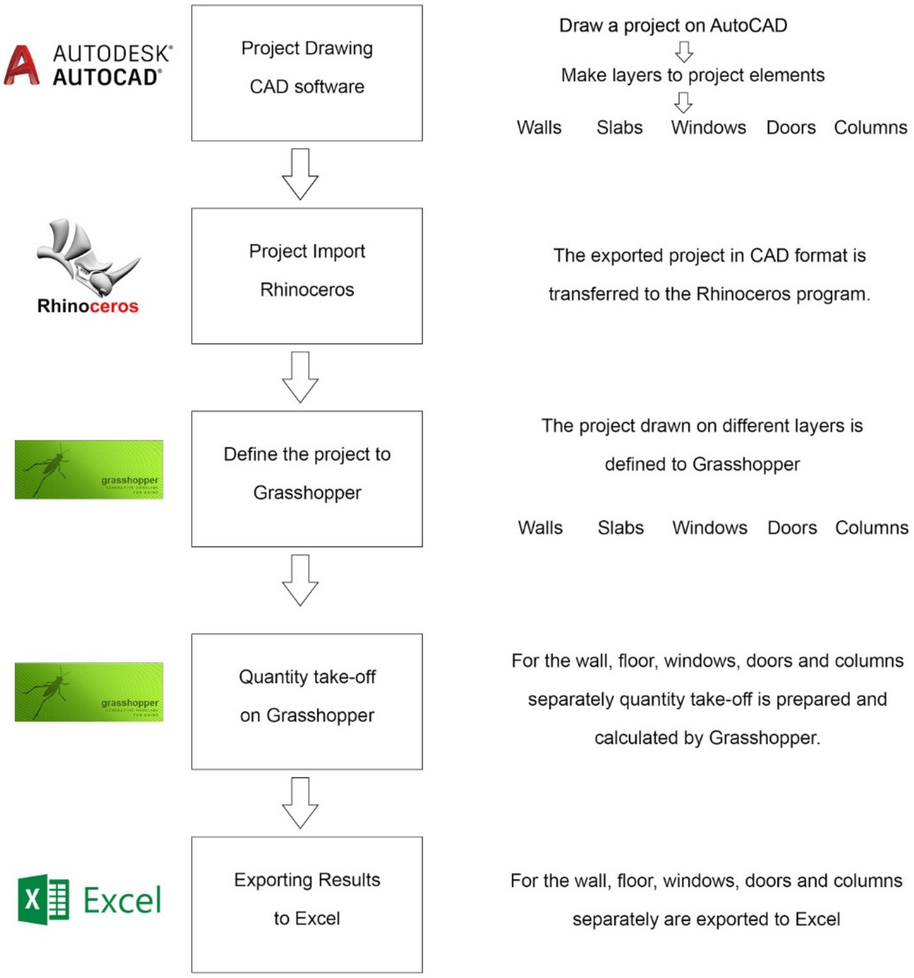

Figure 3.1 Flowchart of the method

First, the drawings of the project must be prepared in the CAD environment. Later, this drawing is exported in ".dwg" format, and it needs to be imported into Rhinoceros software. In the next step, drawings are transferred to Grasshopper which is a parametric design program. Calculations in Grasshopper are assigned to the Excel, and the result of the project's quantity take-off is found. The process is outlined in Figure 3.1. The remainder of the chapter provided computational steps presented in Figure 3.1.

3.1. INTRODUCING BUILDING PLAN

A parametric infrastructure has been defined to transfer the building plan to the computational design system. There is much computational design software. The software to be used for this work is Grasshopper which is a plugin in Rhinoceros. This software allows the whole design to be made, as well as other CAD software projects can use. Grasshopper can be used in any CAD-based design project. Nowadays, Autodesk AutoCAD is one of the most preferred CAD-based design software. Because of this, AutoCAD is preferred as our CAD-based design software in our work.

One of the most critical points in the CAD-based design system is to work systematically in layers. Primarily, the required wall, column, beam, floor, roof, window and door layers must be created and processed correctly during the design phase.

Another important point is that each layer must have closed curves or polyline. The reason for this draw is to help the process to work better in later computational design software, for example, if a wall is to be drawn, this drawing must be in one closed curves or polyline, not in separate lines. In the CAD-based design program, the project completed as polyline needs to be exported in ".dwg or. dwf" format. These two formats represent projects exported from the AutoCAD program.

Rhinoceros is a software that can do much work such as design, modelling, presentation, project analysis by Robert McNeel & Associates. Different disciplines can design using this software. Among these disciplines are found architecture. Rhinoceros supports the use of files in various formats. These formats can be 2D layout-drawings or 3D modelling projects. These formats also include "dwg and dwf" formats. For this reason, 2D drawings designed via AutoCAD can efficiently work in the Rhinoceros. The project designed using AutoCAD can be imported into Rhinoceros using import command. All layers in CAD work are visible in Rhinoceros. The next step is to transfer the project to a computational design tool which name is Grasshopper.

Grasshopper is a parametric-based design tool, it allowed to work on different topics such as generative design, performance-based design, structural analysis and ruled based design. Grasshopper will enable changes to projects made on CAD-based design tools. At this point, it is not necessary to design the project on the Grasshopper. 2D drawings prepared using closed curves or polylines are easily transferred to the Grasshopper. The next step of the project transferred to the Grasshopper is to define the variables.

3.2. CAD DESIGN

In the first step of the Flowchart (Figure 3.1) drawings can be prepared in a CAD environment. Among them, AutoCAD which is one of the most used programs for project drawings is preferred. Projects plotted as closed curves are divided into layers. These layers are defined as walls, floors, windows, doors and columns. In this way, the calculation applied in the conventional method can be done in the digital environment. These layers help to the next phase of the process. Therefore, working in layers is the most crucial part of the system. Drawings prepared in layers are exported in ".dwg" format. The calculation for the second step is prepared.

3.3. COMPUTATIONAL DESIGN STAGE

In the second step of the quantity take-off, the drawing prepared in a CAD environment is defined to Rhinoceros. Once the layer system of the transmitted drawing is checked, it is defined to Grasshopper, which is a parametric design add-on. The reason why Rhinoceros is used is that the Grasshopper plugin works in the Rhinoceros program. So, this step is necessary. The design process made through Grasshopper is called "definition". In this step, the definition must be prepared separately for walls, floors, windows, doors and columns to perform the quantity take-off parametrically. At the end of this process, wall, floor, doors, windows and columns are obtained separately for each quantity. These results are transferred to Excel. This step constitutes the third step of the process.

3.3.1. ON WORKING PRINCIPLE OF GRASSHOPPER

In this phase, when variables are determined, it is necessary to determine the area calculation of the layers mathematically. Grasshopper automatically computes the fields of the curves defined as closed. Therefore, after finding the fields of the curves defined as closed to the system, the variables required to make the counting account must be determined. In turn, the necessary mathematical connection for wall calculation is between the length and height of the wall. The mathematical relationship that must be made for the windows and doors is the height from the floor except for the width and the height. The mathematical calculation for the flooring is to find the area covered and determined the height of the upholstery. The required parameter for the column system is height. The variable required for the beam system is the height and the area of the system. After these variables are determined, it is necessary to establish a mathematical context between the floor height, which is the primary variable. The reason for this is the automatic change of the whole system in case of a difference in floor height.

In this phase, the step-by-step parametric definition is explained. CAD-based drawings are transferred via Grasshopper using curve command. The working principle of Grasshopper is based on numerical operations, unlike traditional architectural design programs. Grasshopper's working principle is the point, curve, surface and dependable ordering. If we want to create a curve, the first step is to define the points. This sorting is essential if we're going to do something on the Grasshopper. By examining the items required for designing in Grasshopper one by one, it is necessary to start with the point settlement which is the smallest unit of design.

The first step to designing on Grasshopper is to create a point. Many methods can be used to generate points for Grasshopper. One of these is construct point command. Its working principle is to find the correct value (x, y and z unit) of the points by using the coordinate system. The points prepared via Rhinoceros can be transferred to Grasshopper.

The second step on designing on Grasshopper is to make a curve or line. A curve can be drawn between the two points of interest. There are two different methods for creating curves. The first method is the curves already prepared from the CAD-based design programs. The second method is to prepare the curve grasshopper. For example, if we want to draw a curve of length ten units on the X axis on Grasshopper, we have to create two points to do. In this process, which will be done using the Construct point command, the x, y and z values of the first point are assumed to be zero. The x value of the second point is ten units, and the y and z values are assumed to be zero. The next step is to use the line command to combine these two points. Thus, the line operation is completed parametrically on the grasshopper. The most significant benefit of this system is that it can quickly change the design by changing parametric values.

The third step is to create the surface. If the surface is to be created in Grasshopper, it is necessary to work on curves. There are many ways to create surfaces in Grasshopper. The most common ones are a loft, sweep and extrude curve. For the Loft command to work, at least two curves must be combined. In the Loft command, it is necessary to specify the directions of the curves to determine which axis the surface will be on. One of the best ways to describe this is to move the curve in the desired axis. It would be better to use the extrude curve command for a surface to be created over a single axis. What we need to apply for this command is to determine the curve, define the axis, and determine the length of the surface.

The fourth step is to create mass or solid. Surface or surfaces are needed to create stable on Grasshopper. The surface can be transformed into a mass by extruded surface command after it is determined which mass is to be built on the axis.

If it is necessary to explain the system on an example, the method can be described by a sample of 30 cm wide, 20 cm high and 10 cm thick on the y-axis. The first step is to create points. For this, the construct point command is used. The coordinates of the first point are zero for x, y, and z. The x value of the second point is zero, the y value of the second point is 30 cm, and the z value is zero. If no value is entered in the command input, that value is assumed to be zero.

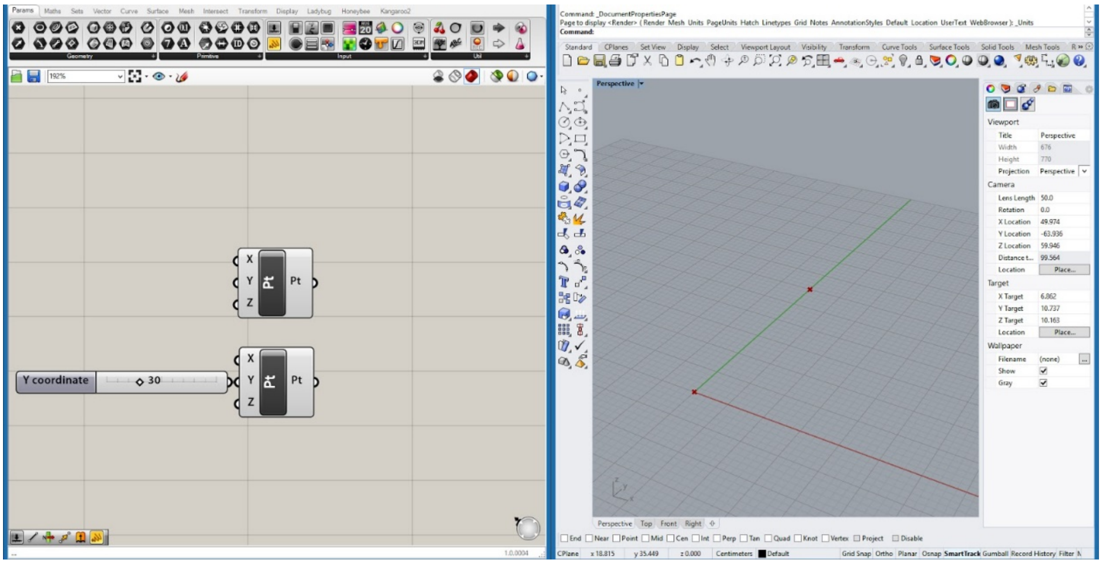

Figure 3.2 Computational design process-1

The second step in design is creating a curve. What we need to do for this is to combine these two points that have already been established. The line command is used for this operation. The feature of this command is to create a line between two points. The input values are appearing as A and B are defined as the output values of the first and second points.

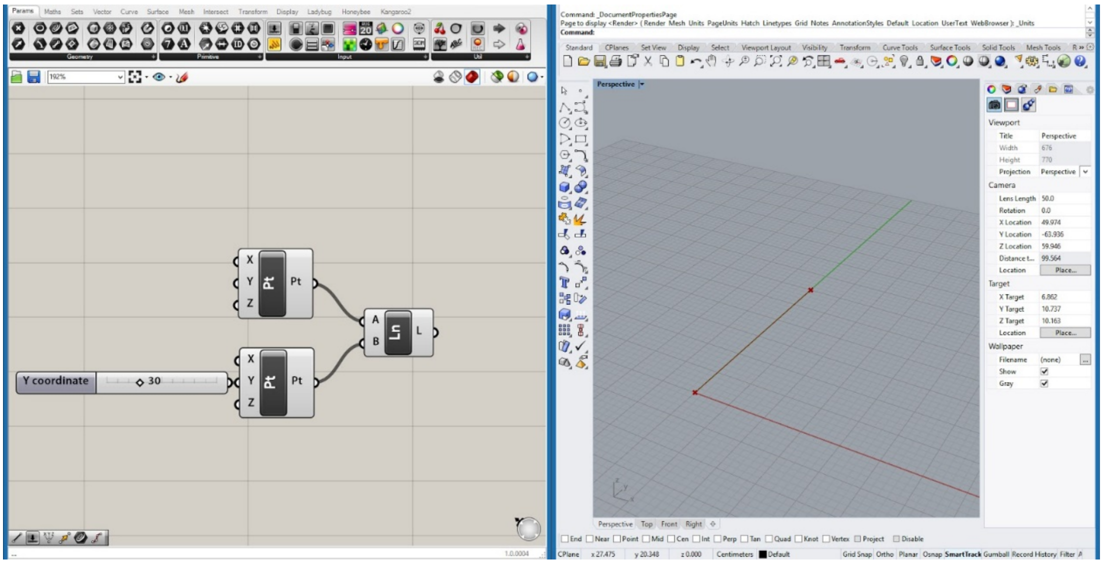

Figure 3.3 Computational design process-2

The third stage of design is to form the surface. It is necessary to raise 20 centimetres above the z-axis of the curve created for this. This is done using the extrude curve command. There are two input values in the Extrude curve command. While the output value of the curve command is used for the B input, the output value of the unit Z command is used for the D input. The input value of the Unit Z command is the height of the system.

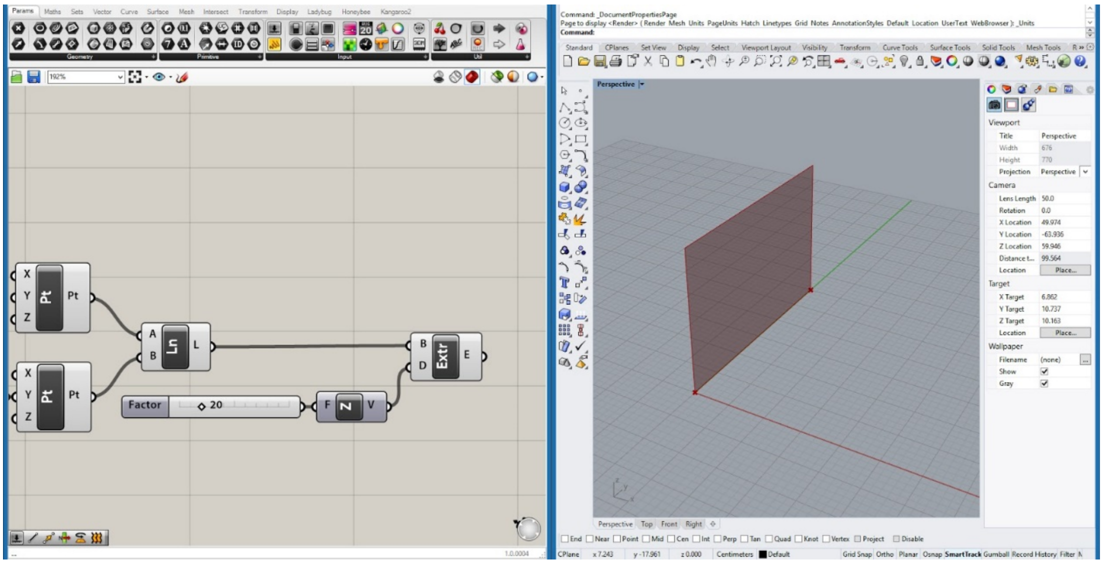

Figure 3.4 Computational design process-4

The final step of the design is to create mass. The extrude surface command is used for this step. There are two input values in the Extrude surface command. While the output value of the extrudes curve, the command is used for the B input, the output value of the unit X command is used for the D input. The input value of the Unit X command is the thickness of the system.

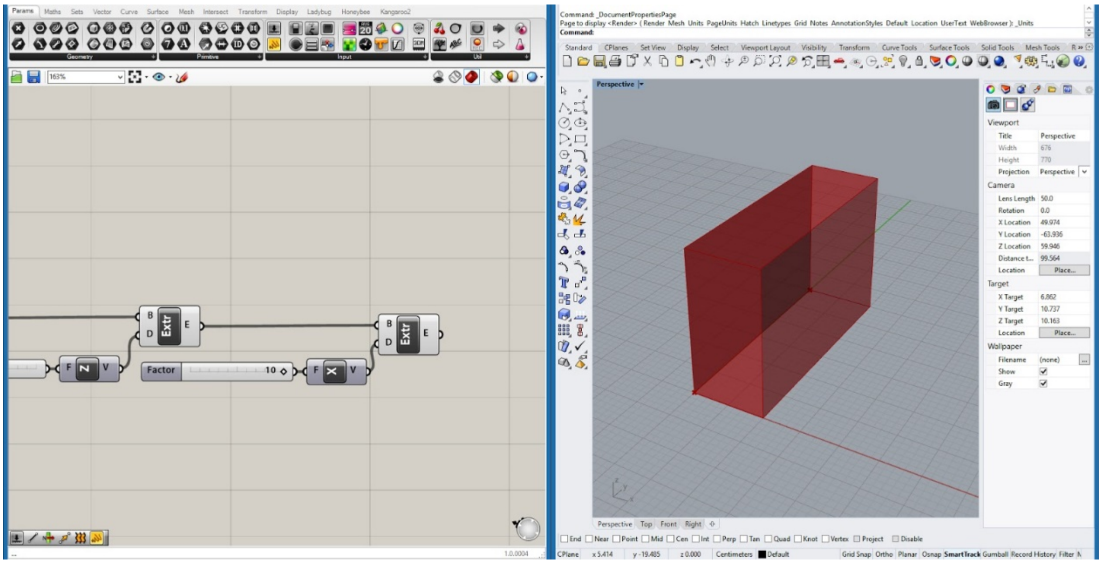

Figure 3.5 Computational design process-4

There are many variables in the system. These are the length, width and height of the system. One of the essential features of the parametric design is that changes are made quickly after the design is realised.

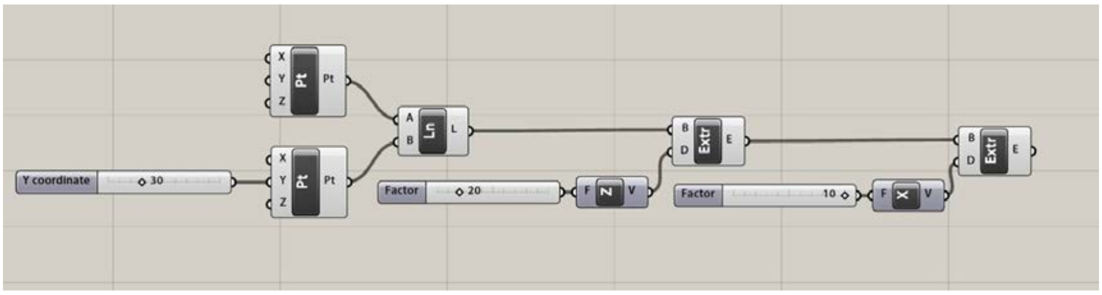

Figure 3.6 Computational design process-5

In the first example, the system has a length of 10 cm, a width of 15 cm and a height of 20 cm.

In the second example, the system has a length of 30 cm, a width of 15 cm and a height of 10 cm.

In the third example, the system has a length of 10 cm, a width of 40 cm and a height of 20 cm.

The production speed of a three-dimensional form in other design programs is better than that of Grasshopper, which is a parametric design program. However, Grasshopper's alternative generation speed is faster than other programs. In this case, it shows that the working principle of parametric-based design programs is different from other design programs. The working principle of parametric design is convenient to make the quantity take-off. The reason for this is that the changes to be made to the system are the effect on the associated design elements.

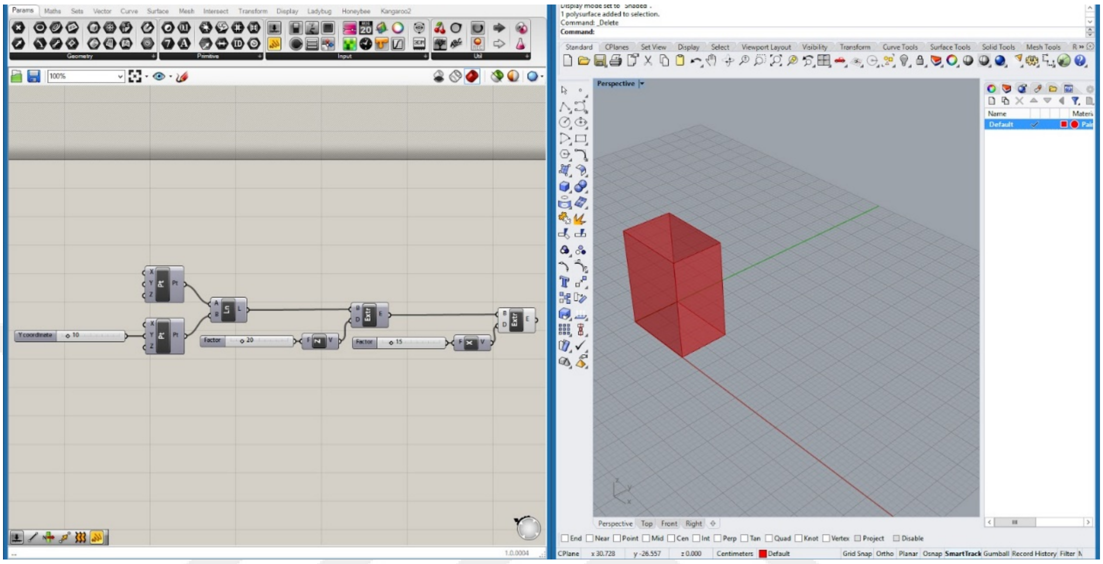

Figure 3.7 Computational design process-6

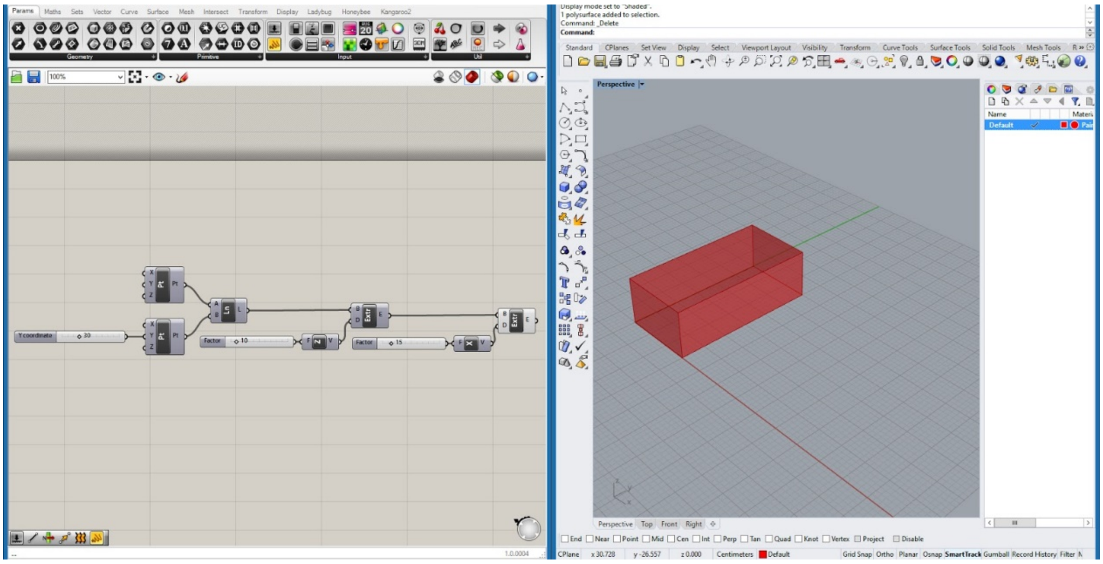

Figure 3.8 Computational design process-7

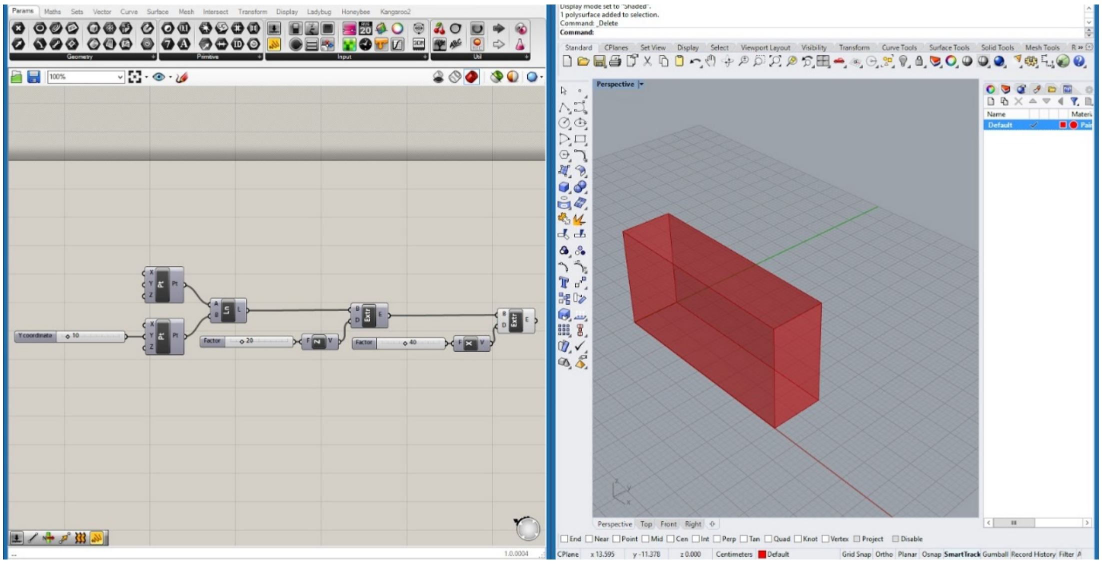

Figure 3.9 Computational design process

3.3.2. DEFINITION FOR FLOOR QUANTITIES

It is easy to make a zone account in Grasshopper, which is a computational design method. For this, there is an area command in Grasshopper. This command is used to make all kinds of zone accounts. The point to be noted is that the geometry to be computed must be a closed curve. This geometry can be prepared on Grasshopper as well as on a CAD-based design program.

If it is to be explained step by step, the process of this definition has progressed as follows. The first step is to draw a rectangle by 40 meters to 30 meters in AutoCAD. This geometry is drawn using the polyline command on the AutoCAD. Later, this drawing was exported via AutoCAD. The file format is “dwg”. Then, this drawing was imported into the Rhinoceros. In the next step, the drawing in Rhinoceros was transferred to Grasshopper. This closed curve was introduced to Grasshopper using the geometry command. In the next step, the area command was used to find the area of the geometry. Panel command determined the result.

In the second example, the same system is designed on Grasshopper. The general operating principle of Grasshopper is point, curve, surface and stable ordering should not be forgotten. In the Grasshopper, there is a need for points to create a closed curve. To create this geometry, four points are needed. The construct point command is used to develop these points. The working principle of the Construct Point is by the coordinate system. Therefore, the coordinates of these four points are needed. The coordinates of the first point are assumed to be zero for x, y, and z values. The coordinates of the second point are assumed to be 30 meters for the x value and zero for the y and z values. The coordinates of the third point are considered to be 30 meters for x value, 40 meters for y value and 0 for z value. The coordinates of the fourth point are expected to be zero for the x value, 40 meters for the y value, and zero for the z value. The next step is to create a closed curve for these created points. For this step, the polyline command is used. The specified points are added to the input of the polyline command, respectively. The next step is to find the area of this closed curve. The area command is used for this step. The panel command was used to determine the result.

3.3.3. DEFINITION FOR WALL QUANTITIES

First, a few different methods can be used to make a wall quantity take-off. In the traditional process, the result obtained by calculating the area of the wall and multiplying it by the height of the wall gives us the quantity take-off for the wall. To apply this system in the computational design method, what is needed to be done is to draw the wall as a closed curve and calculate the area and then multiplying it by floor height. With this method, both the calculation of the wall area and the 3D model of the wall are the primary objective.

This system can be done directly from the Grasshopper or CAD-based design program. The system to be made via Grasshopper can use a parametric design which will be prepared firstly about a point, curve, surface and solid. In the case of the CAD-based design program AutoCAD, the same process can be performed by introducing Grasshopper, which is a wall curve drawing as a closed curve. The principle of working in two systems gives the same result. So, it is explained in two cases with an example.

It was worked on an L shaped wall example with a long side of 5 meters and a short side of 4 meters. First, this shape was created to a closed curve through AutoCAD. Wall height was determined as the second parameter. This value was used as 3 meters. If the wall quantity take-off is to be done over square meters, what is needed is the wall length and the height of the wall. If the wall quantity take-off is to be made over a cubic meter, what is required is the result of wall length, wall height and wall thickness. Wall thickness was defined as the third parameter. This value was used as 25 centimetres.

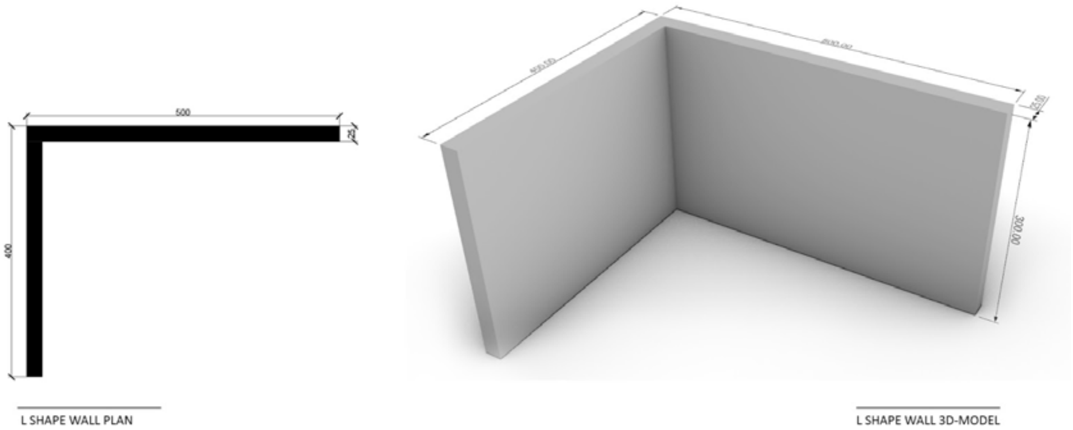

Figure 3.10 Parametric quantity take-off a sample for wall elements

The prepared drawing is saved in “.dwg” format and imported into Rhinoceros. In the next step, the drawing is imported to Grasshopper using the curve command. At this stage, the shape field can be found using the area command. Using the panel command, the field can be seen on Grasshopper. If a cubic meter is to be calculated, the next step is multiplied by the height of the wall, which is 3 meters, and the result is obtained.

3.3.4. DEFINITION FOR SLAB QUANTITIES

There are many different methods for quantity take-off of flooring. One of the types of quantity take-off is the square meters. A different kind of quantity take-off is the cubic meter. The feature that separates these quantity take-off methods from one another is the purpose of the system. If a quantity take-off method is used over the square meters, the area occupied by the upholstery is calculated here. If a cubic meter quantity take-off is being created, the system will find the area covered in three-dimensional. Traditionally, a quantity take-off method is used on the square meter account. In Grasshopper, it is possible to make this account quickly. By using area command in Grasshopper, any closed curve area can be calculated. The area of geometry can also be calculated through AutoCAD. However, when this calculation is made, the result is not in written form. It is only visible on the screen as information. In Grasshopper, the calculated area can be seen in written form.

To illustrate this account with an example, a polygon-shaped account has been created. The first thing to do is to draw a calculated curve through AutoCAD as a closed curve. The polygon in the figure is used for this operation. In the next step, the geometry drawn as a closed curve is exported. Rhinoceros software is imported. It is then transferred to the Grasshopper using the curve command. The output of the curve command is connected to the input of the area command. In the next stage, the output of the area command is connected to the panel command to obtain the area of the geometry, and the area of the geometry is obtained. If the cubic meter of the same geometry is to be learned, the curve command is raised on the z-axis using the extrude command as much as the thickness of the slab. Later, it is determined how many cubic meters of flooring it is as a result of the collapse of the area and the thickness. More then, it is learned how many cubic meters of flooring it is because of the collapse of the area and the thickness. Thus, both square meters and cubic meters are absorbed in Grasshopper. These values are transferred to Excel. The same process can be done by determining the different spaces in the building such as a living room, kitchen, bathroom and rooms.

3.3.5. DEFINITION FOR WINDOW QUANTITIES

The quantity take-off of the windows is calculated on the square meters. For this, the length and height of the window are needed. Thickness is only required in the production phase. This calculation is recorded after the long side of the window is taken, and the height is determined in the measurement system to be made via a CAD-based design program.

Using an example, it is explained how the system was made through Grasshopper. In the first stage, the window should be located on the wall. In the next step, both the wall and the window should be drawn as a closed curve. This system should be exported after it has been defined as two separate layers which names are windows and walls.

An example of a drawing is a 1-meter window on a 2.5 meters wall. The height of the wall was assumed to be 3 meters. The height of the window was assumed to be 2 meters.

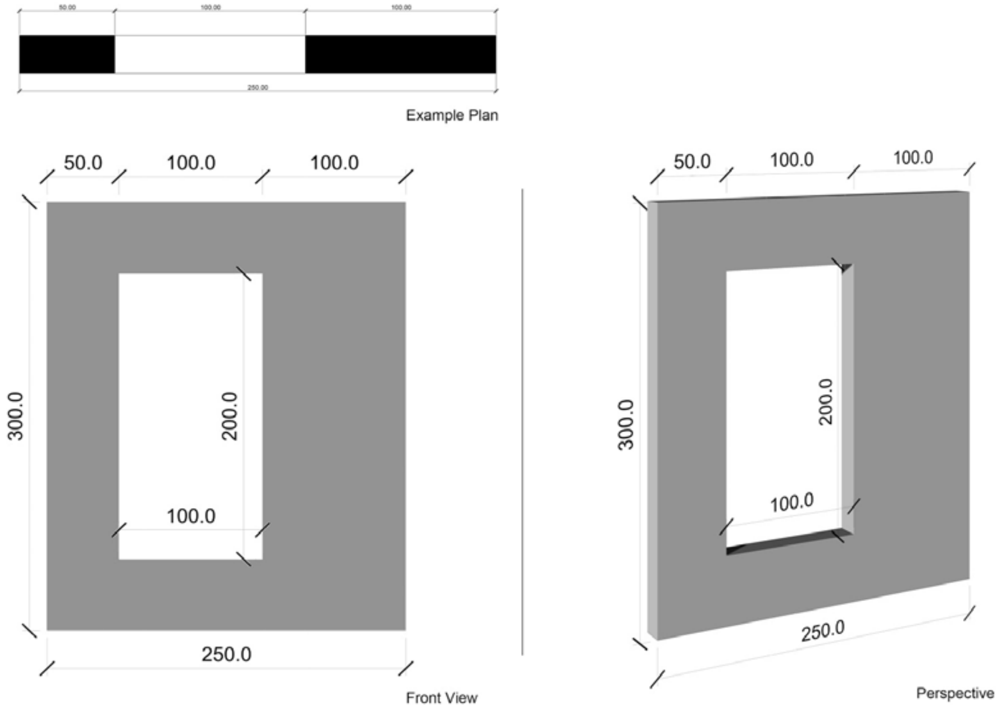

Figure 3.11 QTO window sample visualization

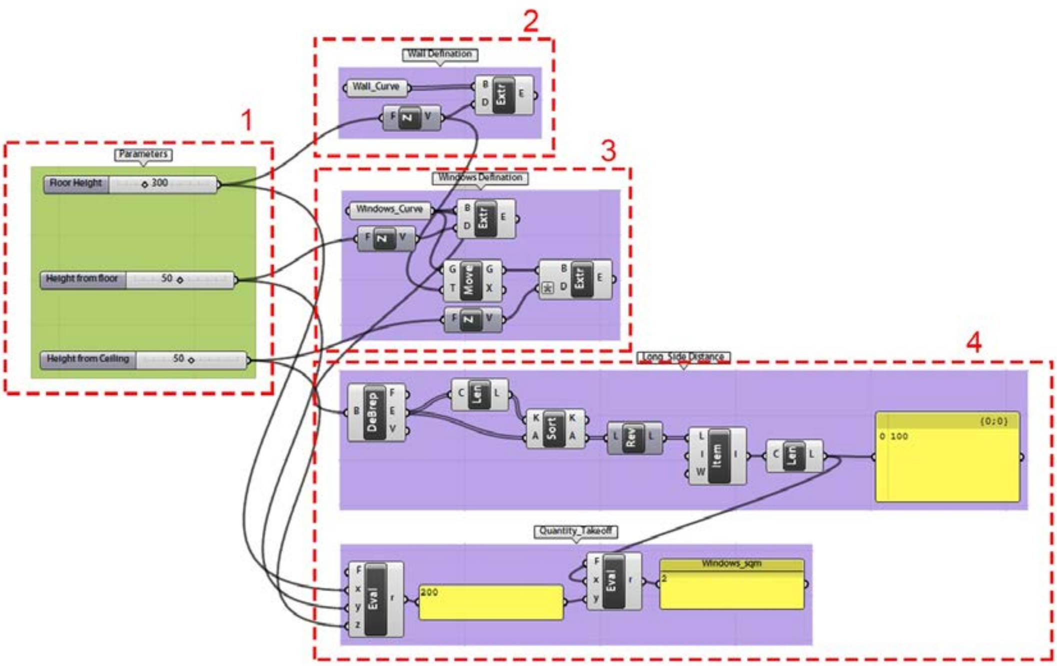

Figure 3.12 QTO window Grasshopper definition

In the Grasshopper definition shown in the figure, the window is written for the quantity take-off. In the next phase, step by step is explained. The part that appears in the first step is the variables of the system. These variables include the height of the floor, the height of the window from the floor, and the distance from the window to the ceiling.

In the second step, the closed curve in the wall layer is transferred to the system using the curve command. Then the curve command is connected to the B of the extrude command. The Unit Z command is connected to the D input of the Extrude command. The reason is that it is raised in the Z direction. The data of the Unit Z command is connected to 300 values of floor height. At the end of these operations, 3-meter-high walls were introduced to the system.

The final stage is the mathematical operations. The purpose here is to specify the height of the window using the function command. The expansion of the function is (X-Y-Z). X value is floor height, Y is the height of the window from the floor, and Z is the distance from the window to the ceiling. The result is 2 meters for the drawing. In the second step, the function (X * Y) is used. The X value is the long edge of the window. The Y value is defined as the result of the first function. The result of this process is 2 square meters.

3.3.6. DEFINITION FOR DOOR QUANTITIES

The door's quantity take-off is based on the unit account number. For this, firstly the doors drawn in closed curves of the plot drawn in CAD programs must be drawn. The next step should be added to the door layer. If the doors have different measures, these doors must be identified in the lower layers. In addition to the number of doors, the height of the door from the ground and the distance between the ceiling and floor is needed for the system to determine the places of the doors. It should be exported in dwg format after the project layers are prepared. This format should then be introduced to the Rhinoceros program as described in other topics. The door defined as closed curves of the project drawn in CAD programs must be introduced to the Grasshopper using the curve command. After this is done, the longest edge of the closed curve must be found. The height of the door should be determined after this value is found. It is determined by how many square meters the door is because of the long side and height of the door. Later, this value is instantly transferred to excel.

3.4. SELECTED CASES

This part of the thesis introduces the results of the process described in the previous section. 10 projects are selected to determine these results. Selected projects have different structures and different types. The following table features the features of the project. Project information can be seen at Table 3.1

Table 3.1 Information on selected validation cases

Project Type	BUILDING TYPE	NUMBER OF floors	BUILDING HEIGHT / m	TOTAL AREA / m2
MIX-1	Residential& Commercial	5	14,30	861,526
MIX-2	Residential& Commercial	3	9,63	561,73
MIX-3	Residential& Commercial	6	13,80	1846,06
RES-1	Residential	2	6,80	558,58
RES-2	Residential	2	6,80	221,12
RES-3	Residential	2	6,80	315,72
RES-4	Residential	4	12,80	1588,76
RES-5	Residential	6	18,80	2100,56
PLB-1	Public	1	5,40	509,53
COM-1	Commercial	2	12,80	1263,46

The first part of this section contains information about the projects. The projects are primarily the results of traditional quantity take-off by three different architects. Secondly, BIM-based quantity take-off results are examined. Lastly, computational based quantity take-off results are examined. In the next part, the comparison of these results takes place.

3.4.1. INFORMATION ON SELECTED CASE 1: MIX-1

This project location is in Izmir, Narlıdere. The project is used as a property for both residential and commercial purposes (Table 3.2). On the ground floor of the building, there is a store for commercial purposes (Figure 3.13).

Figure 3.13 MIX-1 3D visualization

Table 3.2 MIX-1 Project Information

FLOOR ID	**FLOOR HEIGHT / m**	**FLOOR AREA /m2**	**ROOF SLOPE %**	**33**
GROUND FLOOR	3,54	156,04	MAX ROOF HEIGHT / M	2,8 9
FIRST FLOOR	2,62	172,85	PROJECT CODE: MIX-1	
SECOND FLOOR	2,62	172,85	PROJECT TYPE RESIDENTIAL & COMMERCIAL	
THIRD FLOOR	2,62	179,89		
ROOF FLOOR	2,89	179,89		

The remaining floors are used for residential purposes. There are four flats on the first and second floors of this project. There are two duplex apartments on the third and roof floors. The total number of floors is five, and these floors are as follows; ground floor, first floor, second floor, third floor and roof floor. MIX-1 ground floor plan can be seen at Figure 3.14

The total height of the building is determined as 15.80 meters. The total building area is 861,526 square meters. The ground floor height of the building is 3.54 meters. The first, second and third floor heights are 2.62 meters. The roof ridge height is 2,89 meters. MIX-1 first floor plan can be seen at Figure 3.15.

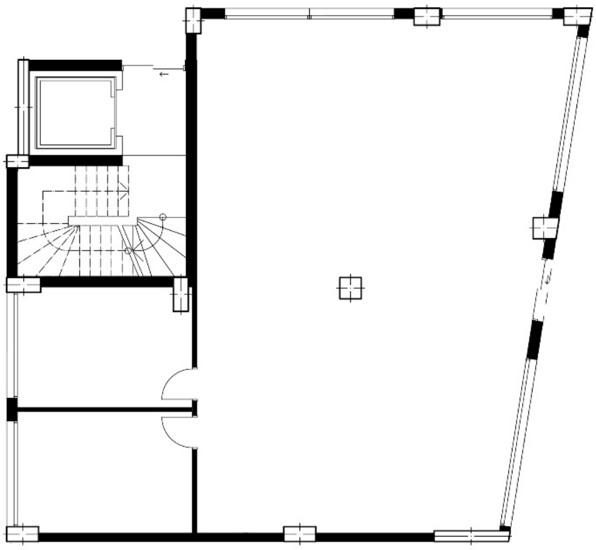

Figure 3.14 Ground floor plan of MIX-1

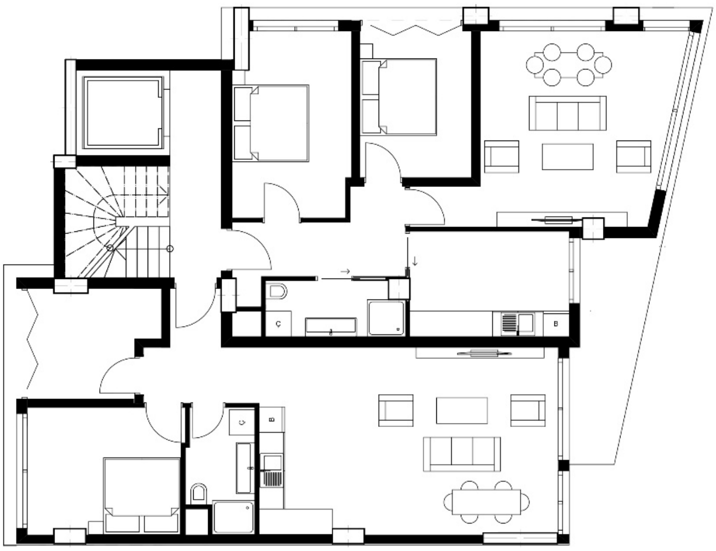

Figure 3.15 First and second-floor plan of MIX-1

3.4.2. INFORMATION ON SELECTED CASE 2: MIX-2

This project location is in Izmir, Limanreis district of Narlıdere. The project is being used for both residential and commercial purposes (Table 3.3). On the ground floor of the building, there is a restaurant for commercial purpose (Figure 3.16)

The remaining floors are used for residential purposes. There are two duplex apartments on the first and roof floor. The total number of floors is three and these floors are as follows; ground, first and roof floors. MIX-2 ground floor plan can be seen at Figure 3.17.

The total height of the building is 9,63 meters. The total building area is 561,7 square meters. The ground floor height of the building is 2,85 meters. The first-floor height is 2,53 meters. The roof ridge height is 4,25 meters. MIX-2 first floor plan can be seen at Figure 3.18**.**

Figure 3.16 MIX-2 3D visualization

Table 3.3 MIX-2 project information

FLOOR ID	**FLOOR HEIGHT / m**	**FLOOR AREA /m2**	**ROOF SLOPE %**	**25**
GROUND FLOOR	2,85	179,98	MAX ROOF HEIGHT / M	4,2 5
FIRST FLOOR	2,53	188,5	PROJECT CODE: MIX-2	
ROOF FLOOR	4,25	193,25	PROJECT TYPE RESIDENTIAL & COMMERCIAL	

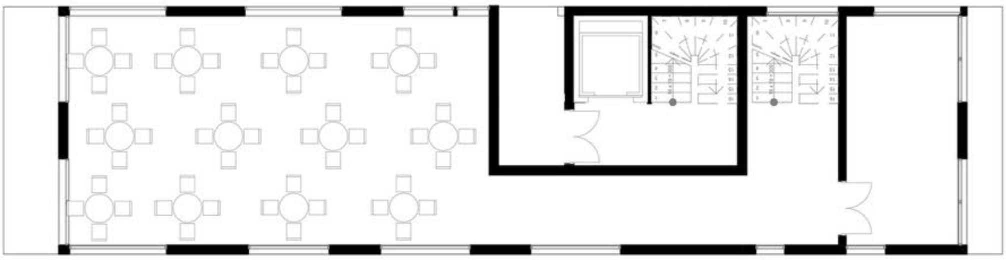

Figure 3.17 Ground floor plan of MIX-2

Figure 3.18 First floor plan of MIX-2

3.4.3. INFORMATION ON SELECTED CASE 3: MIX-3

This project location is in Izmir, Yenikale district of Narlıdere. This project purpose is residential and commercial (**Table 3.4**). On the ground floor of the building, there is a store for commercial purpose (**Figure 3.19**).

Figure 3.19 MIX-3 3D visualization

The remaining floors are used for residential purposes. There are sixteen flats on the first, second and third floors. There are four duplex apartments on the third and roof floor. The total number of floors is six, and these floors are as follows; ground, first, second, third, fourth and roof floors. MIX-3 ground floor plan can be seen at Figure 3.20.

Table 3.4 MIX-3 Project information

FLOOR ID	FLOOR HEIGHT / m	FLOOR AREA /m2	ROOF SLOPE %	30
GROUND FLOOR	2,7	272,36	MAX ROOF HEIGHT / M	3
FIRST FLOOR	2,7	367,37	PROJECT CODE: MIX-3	
SECOND FLOOR	2,7	367,4	PROJECT TYPE RESIDENTIAL & COMMERCIAL	
THIRD FLOOR	2,7	367,37		
FOURTH FLOOR	2,7	367,5		
ROOF FLOOR	3	104,06		

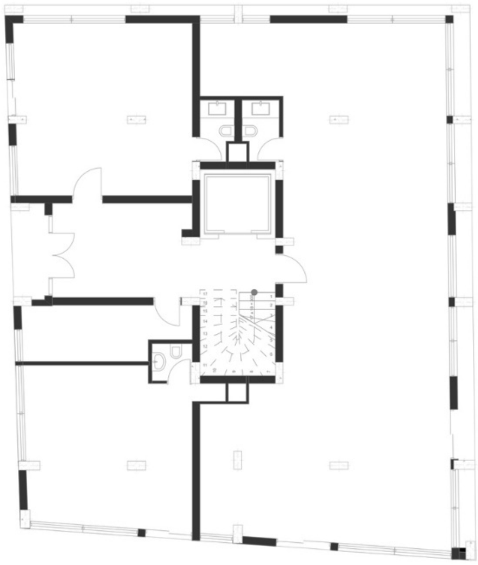

Figure 3.20 Ground floor plan of MIX-3

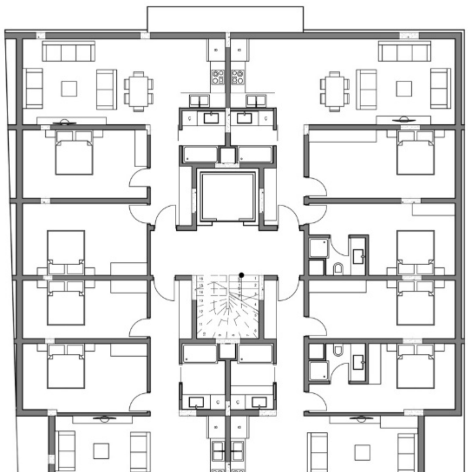

Figure 3.21 First floor plan of MIX-3

The total height of the building is 13,80 meters. The total building area is 1846,06 square meters. The ground floor height of the building is 2,70 meters. The first, second, third and fourth-floor height is 2,70 meters. The roof ridge height is 3,00 meters. MIX-3 first floor plan can be seen at Figure 3.21

3.4.4. INFORMATION ON SELECTED CASE 4: RES-1

Figure 3.22 RES-1 3D visualization

This project location is in Izmir, Sahilevleri district of Narlıdere. This project purpose is residential (Table 3.5 RES-1 project information. The project is a two-storey villa project (Figure 3.22).

Table 3.5 RES-1 project information

FLOOR ID	**FLOOR HEIGHT / m**	**FLOOR AREA /m2**	**ROOF SLOPE %**	**0**
GROUND FLOOR	2,55	274,325	MAX ROOF HEIGHT / M	0
FIRST FLOOR	2,55	284,26	PROJECT CODE: RES-1	
ROOF FLOOR	0	284,26	PROJECT TYPE RESIDENTIAL	

The total number of floors is two, and these floors are as follow; ground and first floor. The total height of the building is 6,80 meters. RES-1 ground floor plan can be seen at Figure 3.23

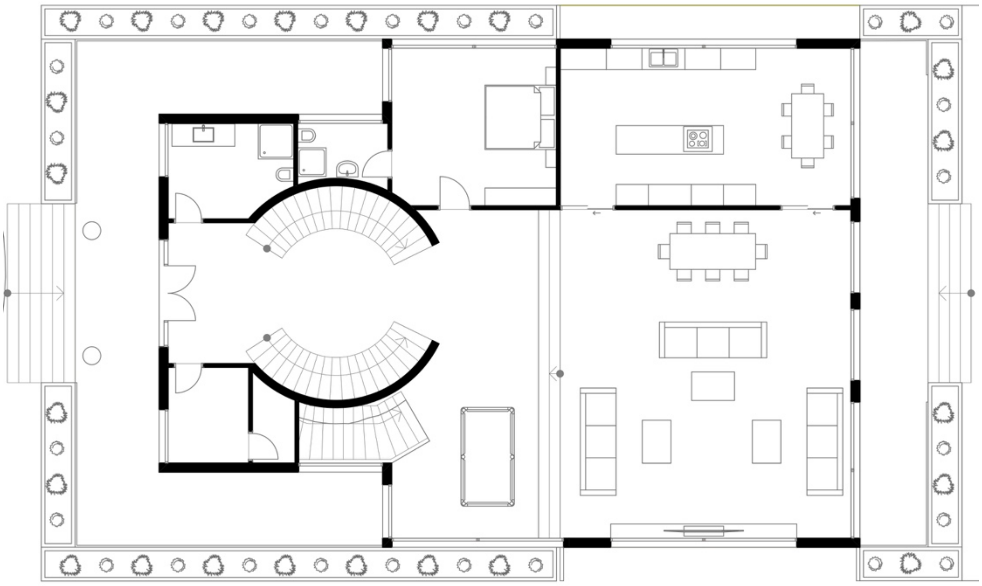

Figure 3.23 Ground floor plan of RES-1

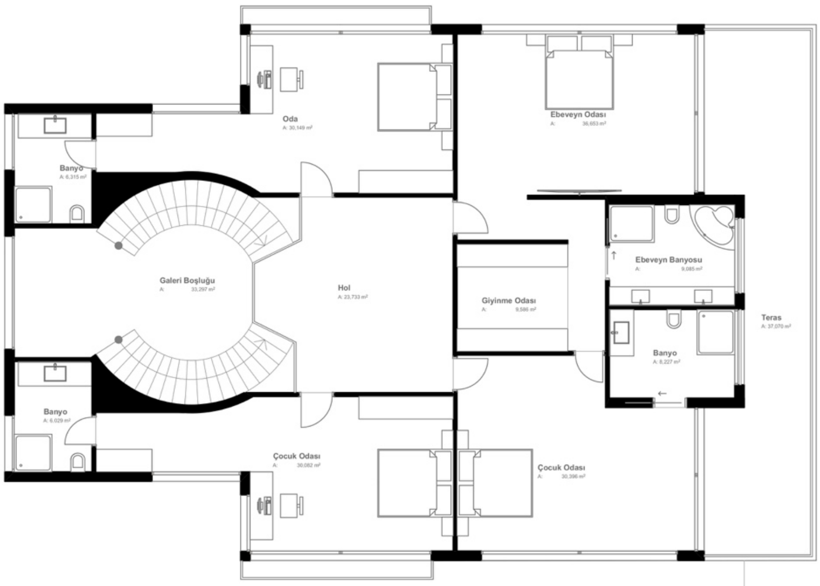

Figure 3.24 First floor plan of RES-1

The total building area is 558.85 square meters. The ground floor and first-floor height of the building are 2.55 meters. RES-1 first floor plan can be seen at Figure 3.24.

3.4.5. INFORMATION ON SELECTED CASE 5: RES-2

Figure 3.25 RES-2 3D visualization

This project location is in Izmir, Limanreis district of Narlıdere. The project is being used for residential purpose. The project is a two-storey twin-villa project (Figure 3.25) RES-2 project information can be seen at Table 3.6

Table 3.6 RES-2 project information

FLOOR ID	**FLOOR HEIGHT / m**	**FLOOR AREA /m2**	**ROOF SLOPE %**	**33**
GROUND FLOOR	3	114,97	MAX ROOF HEIGHT / M	2,3 8
FIRST FLOOR	3	106,18	PROJECT CODE: RES - 2	
ROOF FLOOR	2,3	104,16	PROJECT TYPE RESIDENTIAL	

The total height of the building is 8,30 meters. RES-2 ground floor plan can be seen at Figure 3.26. Total building area is 325,31 square meters. The ground floor and first-floor height of the building are 3 meters. The roof ridge height is 2,30 meters, and the slope is 33 percentage. RES-2 first floor plan can be seen at Figure 3.27.

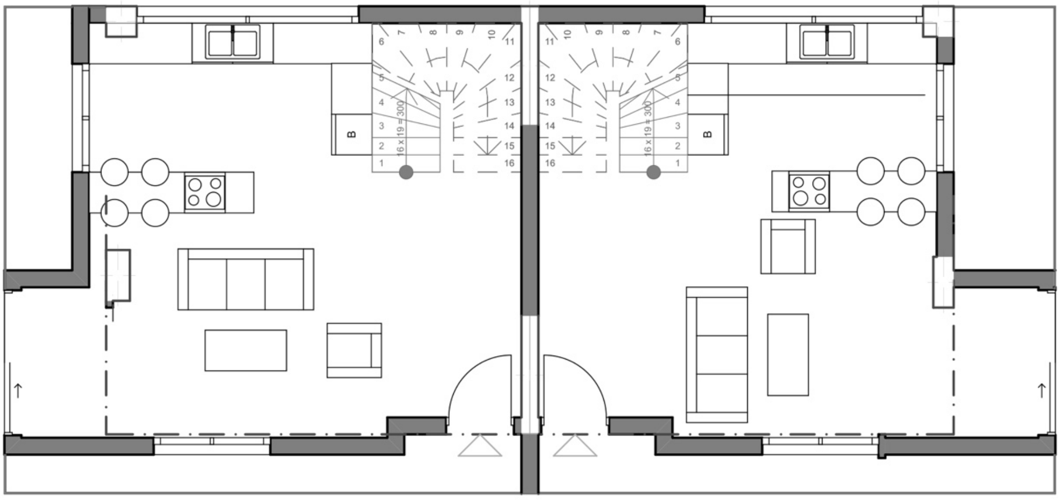

Figure 3.26 Ground floor plan of RES-2

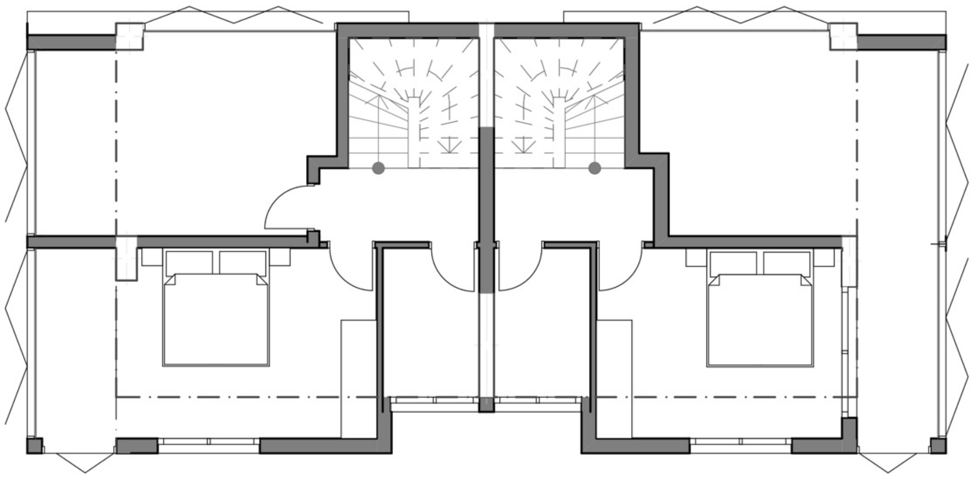

Figure 3.27 First floor plan of RES-2

3.4.6. INFORMATION ON SELECTED CASE 6: RES-3

This project location is in Izmir, Altıevler district of Narlıdere. The project being used for the residential purpose (Table 3.7). The project is two-storey housing project as can be seen in Figure 3.28

The total height of the building is 6,80 meters. Total building area is 315,72 square meters. The ground floor height of the building is 3 meters. RES-3 ground floor plan can be seen at Figure 3.29

The height of the first floor is 4,50 meters. The roof ridge height is 4,5 meters, and the slope is 25 percentage. RES-3 first floor plan can be seen at Figure 3.30

Figure 3.28 RES-3 3D visualization

Table 3.7 RES-3 project information

FLOOR ID	**FLOOR HEIGHT / m**	**FLOOR AREA /m2**	**ROOF SLOPE %**	**25**
GROUND FLOOR	3	143,99	MAX ROOF HEIGHT / M	4,53
FIRST FLOOR	4,53	171,73	PROJECT CODE: RES - 3	
ROOF FLOOR			PROJECT TYPE RESIDENTIAL	

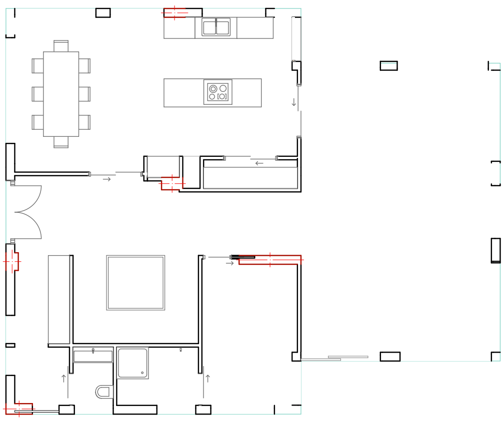

Figure 3.29 Ground floor plan of RES-3

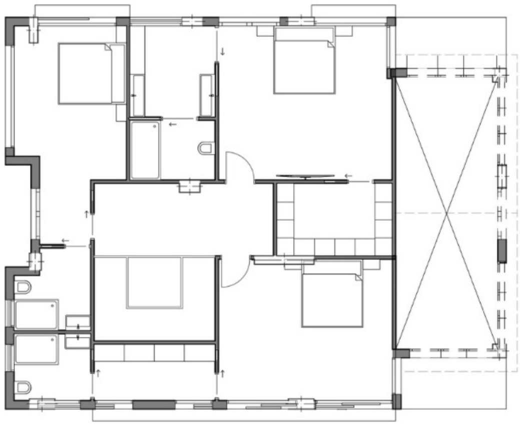

Figure 3.30 First floor plan of RES-3

3.4.7. INFORMATION ON SELECTED CASE 7: RES-4

This project location is in Izmir, Limanreis district of Narlıdere. The project being used for the residential purpose (Table 3.8). The project is a multi-storey building (Figure 3.31)

Figure 3.31 RES-4 3D visualization

Table 3.8 RES-4 project information

FLOOR ID	FLOOR HEIGHT / m	FLOOR AREA /m2	ROOF SLOPE %	25
GROUND FLOOR	2,5	357,83	MAX ROOF HEIGHT / M	2. 8
FIRST FLOOR	2,5	410,31	PROJECT CODE: RES - 4	
THIRD FLOOR	2,5	410,31	PROJECT TYPE RESIDENTIAL	
ROOF FLOOR		0		

There are four floors on this project. Also, there are eight duplex apartments between ground and first floor, third and roof floor. The total number of floors is four, and these floors are as follows; ground, first, second and roof floors. RES-4 ground floor plan can be seen at Figure 3.32.

Figure 3.32 Ground floor plan of RES-4

Figure 3.33 First floor plan of RES-4

The total height of the building is 12,80 meters. The total building area is 1518,76 square meters. The ground, first and second-floor height of the building is 2,50 meters. The roof ridge height is 2,80 meters. RES-4 first floor plan can be seen at Figure 3.33.

3.4.8. INFORMATION ON SELECTED CASE 8: RES-5

This project is in Izmir, Ilıca district of Narlıdere. The project is being used for residential purpose (Table 3.9). There are four duplex apartments on the ground and mezzanine floor (Figure 3.34).

Figure 3.34 RES-5 3D visualization

Table 3.9 RES-5 project information

FLOOR ID	FLOOR HEIGHT / m	FLOOR AREA /m2	ROOF SLOPE %
GROUND FLOOR	2,5	305,96	MAX ROOF HEIGHT / M
MEZZANINE FLOOR	2,5	324,49	PROJECT CODE: RES - 5
FIRST FLOOR	3	366,08	PROJECT TYPE RESIDENTIAL
SECOND FLOOR	3	366,08	
THIRD FLOOR	3	366,08	
ROOF FLOOR	3	371,87	

Also, there are 12 flats on the first, second and third floors. There are four duplex apartments on the third and roof floor. The total number of floors is six, and these floors are as follows; ground, mezzanine, first, second, third, and roof floors. RES-5 ground floor plan can be seen at Figure 3.35.

Figure 3.35 Ground floor plan of RES-5

Figure 3.36 First floor plan of RES-5

The total height of the building is 18,80 meters. The total building area is 1846,06 square meters. The ground floor height of the building is 2,70 meters. The first, second, third and fourth-floor height is 2,70 meters. The roof ridge height is 3,00 meters. RES-5 first floor plan can be seen at Figure 3.36

3.4.9. INFORMATION ON SELECTED CASE 9: PLB-1

Figure 3.37 PLB-1 3D visualization

Table 3.10 PLB-1 project information

FLOOR ID	FLOOR HEIGHT / m	FLOOR AREA /m2		0
GROUND FLOOR	3,1	509,53	MAX ROOF HEIGHT / M	0
ROOF FLOOR	5,3	509,53	PROJECT CODE: PLB - 1 PROJECT TYPE PUBLIC	

This project location is in Izmir, Çamdibi. The project is being used for the fire station building which is a public purpose (**Table 3.10**) There are two different part of the building **Figure 3.37**.

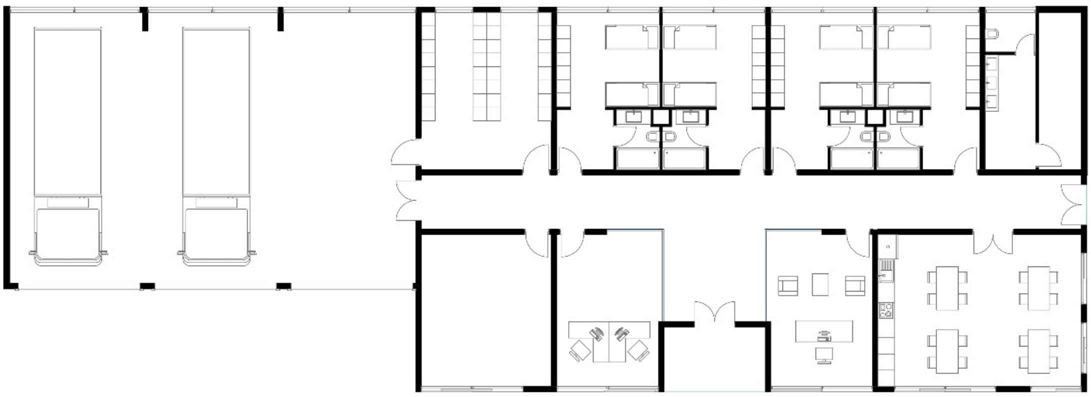

Figure 3.38 Ground floor plan of PLB-1

The first part of the building is a fire truck. Also, this part of the building height is 5,30 meters. The second part of the building is fireman staying part and administration. This part of the building height is 3,10 meters. The total building area is 509,53 square meters. COM-1 ground floor plan can be seen at Figure 3.38

3.4.10. INFORMATION ON SELECTED CASE 10: COM-1

Figure 3.39 COM-1 3D visualization

Table 3.11 COM-1 project information

FLOOR ID	FLOOR HEIGHT / m	FLOOR AREA /m2	ROOF SLOPE %	0
GROUND FLOOR	5,5	631,73	MAX ROOF HEIGHT / M	0
FIRST FLOOR	3,1	631,76	PROJECT CODE: COM-1	
ROOF FLOOR	0	631,73		
			PROJECT TYPE COMMERCIAL	

This project location is in Izmir, Sarnıç. The project is being used for commercial purpose (Table 3.11). There are two different part of the building (Figure 3.39). The first part of the building is storage on the first floor.

Also, this part of the building height is 5,50 meters. The second part of the building is administration on the second floor. PLB-1 ground floor plan can be seen at Figure 3.40.

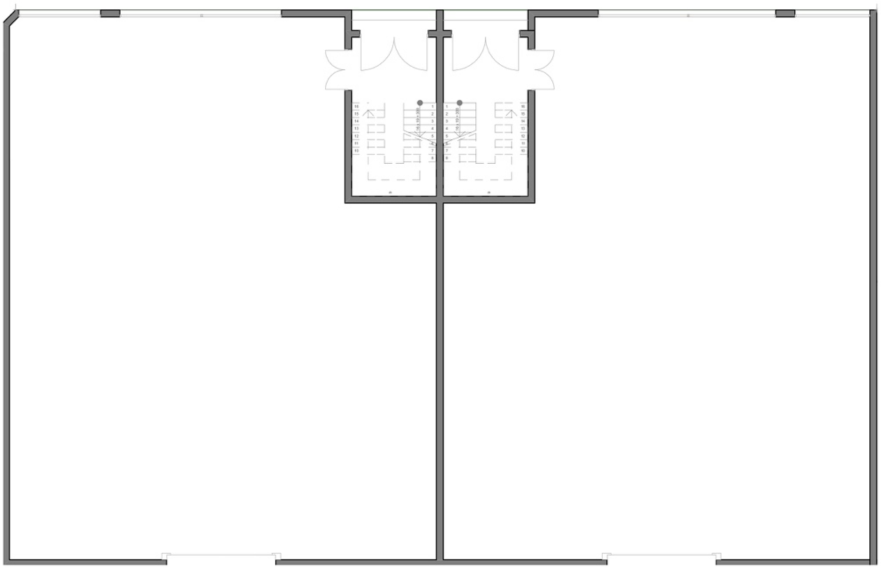

Figure 3.40 Ground floor plan of COM-1

3.5. HYPOTHESES

Three hypotheses were assumed in the current work. Although, they have been summarized in Section 1.3, formal statement is required. After calculating the quantities from 10 sampled building cases using three different methods, namely traditional, BIM, and parametric-computational, the results were compared.

The current study assumed that no significant difference exists in building quantity take-off values between actual values and estimations obtained from computational method proposed in the current work. The formal hypothesis is constructed as follows:

$H_{0,1}$ = NO significant differences observed in building quantity take-off values between actual values and estimations obtained from proposed computational method

against

$H_{alt,1}$ = Significant differences observed in building quantity take-off values between actual values and estimations obtained from proposed computational method

In addition, the current study hypothesized that results obtained from proposed approach outperforms those obtained from traditional and BIM approaches. This assumption requires two hypotheses.

Accordingly, null hypothesis of

$H_{0,2}$ = Accuracy of estimations obtained from proposed computational method is NOT significantly greater than those provided by traditional labour-intensive method.

Will be tested against alternative hypothesis of

$H_{alt,2}$ = Accuracy of estimations obtained from proposed computational method is significantly greater than those provided by traditional labour-intensive method.

Similarly,

$H_{0,3}$ = Accuracy of estimations obtained from proposed computational method is NOT significantly greater than those provided by BIM-based method.

Will be tested against alternative hypothesis of

$H_{alt,3}$ = Accuracy of estimations obtained from proposed computational method is significantly greater than those provided by BIM-based method.

In the current work, the accuracy of estimations was measured using the metric of Absolute Percentage Error, which is computed as:

$$APE = \left| \frac{(Actual\ Value - Estimated\ Value)}{Actual\ Value} \right| \times 100$$

where, the actual value corresponds to the calculations made in person with extreme care and effort. These served as the reference values in formal test of hypotheses under study.

Appropriate statistics to conduct the formal test of hypothesis is paired t-test since in all three hypotheses, the methods under study were applied to the identical sample. That is, the observations in the sample were constant while intervention, method of quantity take off, changes. In this test, one can determine the probability of the mean difference for the population is different from a reference value (usually zero). An advantage of analyzing paired observations rather than independent samples is that the variability in the observations that is due to differences between the objects sampled is factored out, resulting in a more powerful test (Arnold, 2006).

CHAPTER FOUR
RESULTS

4.1. MIX-1 QTO RESULTS

4.1.1. MIX-1 WALL QUANTITY TAKE-OFF RESULTS

The wall comparison charts of the project are below. The table is also created as to display both the method of computational and the method of BIM-based. The results are shown below (**Table 4.1**).

Table 4.1 MIX-1 Wall QTO results of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Volume m3	34,18	40,7	40,7	38,63	49,48	203,69
BIM- Based Method		28,99	39,75	39,62	35,98	47,61	191,95
APE	%	17,90	2,39	2,73	7,37	3,93	6,12
Computational Method	Surface Area m^2	159,34	200,7	200,7	199,45	200,55	960,74
BIM- Based Method		151,33	212,53	208,78	198,03	202,94	973,61
APE	%	5,29	5,57	3,87	0,72	1,18	1,32
Computational Method	Area m2	14,06	22,07	22,07	20,24	28,99	107,43
BIM- Based Method		15,67	24,14	23,82	20,99	24,01	108,63
APE	%	10,27	8,57	7,35	3,57	20,74	1,10

As can be seen in the table, there is a percentage of the difference between the two methods for total volume result. The most significant difference between the wall volume is on the third floor. The percentage of this value is 17,90%. The least difference of the wall volume is on the ground floor. This value is 2,39 %. There is a difference of 6,12 % in the overall total.

As can be seen in the table, there is a minimum of 0,72% variation of wall surface area results with a maximum of 5.57%. The minimum value is found on the third floor, and the maximum amount is on the second floor. The overall result is 1,32 % When we look at this result; the total result value shows a close relationship between two different methods. However, when analyzed on a floor-by-floor basis, it is understood that it is 5% above the results on the first and second floors.

When the values of the wall floor area seen in the table are compared, it is observed that there is an enormous difference in the ground floor. The absolute percentage error in this area is 10,27%. The lowest difference is between the third floor and roof floor. The difference found here is slightly above 3%. Looking at the overall result, it is seen that the result is above 6%. The results are shown below (**Table 4.2**).

Table 4.2 MIX-1 Wall QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Volume m3	34,18	40,7	40,7	38,63	49,48	203,69
Traditional Method		29,54	39,59	39,59	37,19	47,84	193,75
APE	%	15,71	2,80	2,80	3,87	3,43	5,13
Computational Method	Surface Area m2	159,34	200,7	200,7	199,45	200,55	960,74
Traditional Method		140,87	199,35	199,35	194,38	197,19	931,14
APE	%	13,11	0,68	0,68	2,61	1,70	3,18
Computational Method	Area m2	14,06	22,07	22,07	20,24	28,99	107,43
Traditional Method		8,02	14,51	14,51	13,69	23,23	73,96
APE	%	75,31	52,10	52,10	47,85	24,80	45,25

On average, there is a difference of 3% in the wall volume quantity take-off. The overall result of the wall volume is 3,25%.

In the wall surface quantity take-off, the minimum difference is determined as 0,6% with the first and second floor. The total result is 3,08%.

4.1.2. MIX-1 WINDOWS QUANTITY TAKE-OFF RESULTS

The window quantity take-off method is based on examining the surface area of the window and the base area of the window. However, BIM-based quantity take-off method, the area of the window cannot be calculated. For this reason, the comparison of the computational method and BIM-based method is only seen over the surface area.

The table below also shows the windows overall result of a comparison between BIM-based method and the computational method. The results are shown below (**Table 4.3**).

Table 4.3 MIX-1 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	64,79	42,28	42,28	45,31	12,66	207,32
BIM- Based Method		63,71	42,12	42,12	44,94	14,96	207,85
APE	%	6,40	0,38	0,38	0,82	15,37	0,25
Computational Method	Area m2	3,70	4,40	4,40	4,71	1,18	18,39
BIM- Based Method		-	-	-	-	-	-
APE	%	-	-	-	-	-	-

Table 4.4 MIX-1 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	64,79	42,28	42,28	45,31	12,66	207,32
Traditional Method		55,11	42,24	42,24	47,35	9,20	196,14
APE	%	17,56	0,09	0,09	4,31	37,60	5,73
Computational Method	Area m2	3,70	4,40	4,40	4,71	1,18	18,39
Traditional Method		4,82	4,50	4,50	4,78	1,17	19,77
APE	%	23,24	2,22	2,22	1,46	0,85	6,98

As can be seen in the table, there are two significant differences. They are found on the roof floor quantity take-off. There is a most significant difference of 70 % in the roof floor. The results seen on the other floors are close. The overall effect is approximately 4%. The results are shown below (**Table 4.4**)

Through comparison between the methods, a huge difference is observed on roof floor. This difference is seen as 37,60%. For the other floors, the results are close to each other and the difference between the first and second floors is almost 0%. The overall result of the surface area is 5,73%.

When we look at the area of the window covered by the floor, the most noticeable difference is captured on the ground floor. This value is 6,329%. On the other floors, the difference is meagre. The overall result of the total area is 2,70%.

When the data are interpreted, the results between the computational method and the traditional method are close to each other. In the BIM-based quantity take-off results, there is a difference, especially on the roof floor

4.1.3. MIX-1 DOOR QUANTITY TAKE-OFF RESULTS

Table 4.5 MIX-1 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	18,45	34,74	34,74	21,35	4,88	114,16
BIM- Based Method		17,82	33,84	33,84	21,36	3,12	109,98
APE	%	3,54	2,66	2,66	0,05	56,41	3,80
Computational Method	Area m2	1,02	2,73	2,73	1,28	0,28	8,04
BIM- Based Method		-	-	-	-	-	-
APE	%	-	-	-	-	-	-

The door quantity take-off method is based on examination of the surface area of the window and the base area of the window. However, via BIM-based quantity take-off method, the area of the window cannot be calculated. For this reason, the comparison of the computational method and BIM-based method is only seen over the surface area.

The results are shown below (**Table 4.5**).

As can be seen in the table, there is one significant difference. It is captured at the roof floor quantity take-off. There is a very considerable difference of 56,41 % in the roof floor. The results seen on the other floors are close. Primarily, the surface results of the doors on the third floor are precisely the same. The overall effect is approximately 4%.

The table below also shows the overall door result of the comparison between BIM-based method and the traditional method

The results are shown below (**Table 4.6**).

Table 4.6 MIX-1 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	18,45	34,74	34,74	21,35	4,88	114,16
Traditional Method		17,88	34,12	34,12	21,36	3,84	111,32
APE	%	3,19	1,82	1,82	0,05	27,08	2,55
Computational Method	Area m2	1,02	2,73	2,73	1,28	0,28	8,04
Traditional Method		0,99	2,67	2,67	1,31	0,28	7,92
APE	%	3,23	2,25	2,25	2,29	0,00	1,51

During the comparison of the door surface area between traditional and computational method, an enormous difference is observed on the roof floor. This difference is seen as 27,08%. For the other floors, the results are close to each other. The third-floor result is almost 0%. The overall effect of the surface area is 2,55%. When we look at the area of the door covered by the floor, the most noticeable difference is determined on the first and second floors. This value is 2,25%. On the other floors, the difference is meagre. The overall result of the total area is 1,51%. When the data are interpreted, the results between the computational method and the traditional method are close to each other. For the first-floor and roof floor results, the BIM-based method appears to be more similar to the traditional method. The results of the second and third floors provide close results to each other in all methods.

4.1.4. MIX-1 COLUMNS QUANTITY TAKE-OFF RESULTS

The column quantity take-off also consists of three different stages, such as a wall quantity take-off. These stages are composed of the area of the column, the volume of the column and the floor area of the column. The results are shown below (**Table 4.7**).

Table 4.7 MIX-1column QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Volume m3	12,65	9,06	9,06	9,06	0,00	39,83
BIM- Based Method		15,54	12,31	12,31	12,31	0,00	52,47
APE	%	18,60	26,40	26,40	26,40	0,00	24,09
Computational Method	Surface Area m2	38,16	27,30	27,30	27,30	0,00	120,06
BIM- Based Method		135,17	104,60	104,60	104,60	0,00	448,97
APE	%	71,77	73,90	73,90	73,90	0,00	73,26
Computational Method	Total Area m2	3,57	3,46	3,46	3,46	0,00	13,95
BIM- Based Method		4,39	4,69	4,69	4,69	0,00	18,46
APE	%	18,68	26,23	26,23	26,23	0,00	24,43

According to the results in the table, the column volume absolute percentage error on the first floor is observed to be closer to that of the other floors. The percentage of the first-floor result is 18,60%. Another floors result is 26,40%. On the roof floor, there are no columns.

As can be seen in the table, there is an extreme difference in the results of the BIM-based method in the surface area of the columns. According to the result, there is a difference of over 70%.

According to the column floor area results, there is a difference of 18,68% on all floors.

The table below also shows the columns overall result of the comparison between traditional method and computational method (**Table 4.8**).

Table 4.8 MIX-1 column QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Volume m3	12,65	9,06	9,06	9,06	0,00	39,83
Traditional Method		12,63	9,35	9,35	9,35	0,00	40,68
APE	%	0,16	3,10	3,10	3,10	0,00	2,09
Computational Method	Surface Area m2	38,16	27,30	27,30	27,30	0,00	120,06
Traditional Method		38,02	27,30	27,30	27,30	0,00	119,92
APE	%	0,37	0,00	0,00	0,00	0,00	0,12
Computational Method	Total Area m2	3,57	3,46	3,46	3,46	0,00	13,95
Traditional Method		3,57	3,57	3,57	3,57	0,00	14,28
APE	%	0,00	3,08	3,08	3,08	0,00	2,31

The comparison results of the traditional method and the computational method are closer than the BIM-based method. In comparing the volume results, the lowest difference is captured at the ground floor. This result is 0,15%. On the other floors, the difference was determined as 3,20%. The overall effect of the volume is 2,33%.

The closest difference in the surface area results is spotted on the ground floor. This value is determined as 0,37%. On the other floors, the difference is defined as 0,00%. The overall result of the surface area is 0,12%.

In the floor area of the columns, the results are the same on all the floors.

According to the comparison results, the results of the computational method and the traditional method are close to each other. Primarily, the results of the floor area of the columns are determined to be precisely the same. On the other hand, BIM-based method results seem to have different values in comparison.

4.1.5. MIX-1 SLAB QUANTITY TAKE-OFF RESULTS

The table below also shows the slabs overall result of the comparison between computational method and BIM-based method (**Table 4.9**).

Table 4.9 MIX-1 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Volume m3	49,93	51,87	51,87	54,07	51,75	259,49
BIM- Based Method		46,89	50,38	50,38	50,69	49,07	247,41
APE	%	6,48	2,96	2,96	6,67	5,46	4,88
Computational Method	Gross Area m2	156,05	172,85	172,85	179,89	179,89	861,53
BIM- Based Method		156,29	178,84	178,84	179,89	181,76	875,62
APE	%	0,16	3,35	3,35	0,00	1,03	1,61
Computational Method	Net Area m2	156,05	162,11	162,11	168,96	161,74	810,97
BIM- Based Method		156,29	167,94	167,94	168,98	163,58	824,73
APE	%	0,16	3,47	3,47	0,01	1,12	1,67

According to the result in the table, the most significant difference between the computational and BIM-based method is spotted on the third floor. This value is 6,67%.

Table 4.10 MIX-1 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Roof Floor	Total Result
Computational Method	Volume m3	49,93	51,87	51,87	54,07	51,75	259,49
Traditional Method		49,92	51,84	51,84	54,10	51,73	259,43
APE	%	0,02	0,06	0,06	0,06	0,04	0,02
Computational Method	Gross Area m2	156,05	172,85	172,85	179,89	179,89	861,53
Traditional Method		156,03	172,85	172,85	179,89	179,89	861,51
APE	%	0,01	0,00	0,00	0,00	0,00	0,00
Computational Method	Net Area m2	156,05	162,11	162,11	168,96	161,74	810,97
Traditional Method		156,06	162,02	162,02	169,06	161,68	810,84
APE	%	0,01	0,06	0,06	0,06	0,04	0,02

The least difference is seen in the third-floor gross area. The results are the same value.

When the results are compared, the final value difference in the volume results is determined as 4,88%. Result of the gross area is 1,61%. The result of the net area is 1,67%.

When the results are taken into consideration, it is determined that the results are close to each other.

The table below also shows the slabs overall result of the comparison between traditional method and computational method (**Table 4.10**).

The second comparison of the main title is between computational method and traditional method.

According to the comparison results examined in the three different main sections, all the results seem to be close to 0%.

4.2. MIX-2 QTO RESULTS

The results of the MIX-2 project are examined under five main titles. These titles are as follows; wall, window, door, column and slab. while comparing the computational method results are regarded as the actual result.

4.2.1. MIX-2 WALL QUANTITY TAKE-OFF RESULTS

The results are shown below (**Table 4.11**).

As seen in Table, it is seen that the maximum difference in the volume result is 28,97% on the ground floor. According to the volume comparison result, the least difference is seen as the result of the second floor. This result is determined to 6,30%. The total result is determined as 6,35%.

Because of the surface area, the maximum difference is 26,17% on the ground floor. The least difference is 0,29% on the second floor. The total result of the surface area is 6,06%.

According to the result of the floor area, the maximum difference is 49,62% on the second floor. The least difference is 6,34% on the ground floor. The total result of the floor area is 25,06%.

Table 4.11 MIX-2 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	23,33	27,9	31,7	82,93
BIM- Based Method		18,09	26,06	33,83	77,98
APE	%	28,97	7,06	6,30	6,35
Computational Method	Surface Area m2	99,36	162,75	198,64	460,75
BIM- Based Method		78,75	157,63	198,06	434,44
APE	%	26,17	3,25	0,29	6,06
Computational Method	Area m2	18,16	19,87	12,5	50,53
BIM- Based Method		19,39	23,23	24,81	67,43
APE	%	6,34	14,46	49,62	25,06

According to the comparison results, the surface area results and the volume results are different from each other even though the ground floor walls have the closest result on the ground floor. This may be due to a fault for floor height differences. The results are shown below (**Table 4.12**).

Table 4.12 MIX-2 wall QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	23,33	27,9	31,7	82,93
Traditional Method		23,16	29,875	32,15	85,185
APE	%	0,73	6,61	1,40	2,65
Computational Method	Surface Area m2	99,36	162,75	198,64	460,75
Traditional Method		100,985	164,33	199,65	464,965
APE	%	1,61	0,96	0,51	0,91
Computational Method	Area m2	18,16	19,87	12,5	50,53
Traditional Method		14,69	20,2	12,7	47,59
APE	%	23,62	1,63	1,57	6,17

On this table, computational and traditional method comparison are displayed. There are three different parts in comparing these methods such as volume, surface area and base area of the wall.

First comparison result for volume is as follows; The maximum difference is 6,61% on the first floor. The least difference is 0,73% on the ground floor. The overall result of the volume is 2,65%.

The second part of the comparison is the surface area. The maximum value of the difference is 1,61% on the ground floor. The least value of the difference is 0,51% on the second floor. The overall result is 0,91%.

Last part of the comparison is a base area of the wall. The maximum difference is 23,62% on the ground floor. The least difference is 1,57% on the second floor. The overall result of the floor area of the wall is 6,17%.

4.2.2. MIX-2 WINDOWS QUANTITY TAKE-OFF RESULTS

The window quantity take-off method is based on examination of the surface area of the window and the base area of the window. However, with BIM-based quantity take-off method, the area of the window cannot be calculated. For this reason, the comparison of the computational method and BIM-based method is only seen over the surface area.

The table below also shows the windows overall result of the comparison between BIM-based method and the computational method (**Table 4.13**).

Table 4.13 MIX-2 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m3	110,23	104,08	86,85	301,16
BIM- Based Method		97,57	101,22	91,38	290,17
APE	%	12,98	2,83	4,96	3,79
Computational Method	Area m2	10,44	10,47	9,24	30,15
BIM- Based Method		-	-	-	-
APE	%	-	-	-	-

As can be seen in the table, there is a significant difference on the ground floor. There is a highly significant difference of 12,98% on the ground floor. The least value of the surface area is 2,83% on the first floor. The overall result of the surface area is 3,79%.

The table below also shows the windows overall result of the comparison between computational and traditional method (**Table 4.14**).

Table 4.14 MIX-2 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m3	110,23	104,08	86,85	301,16
Traditional Method		102,98	112,15	89,21	304,34
APE	%	7,05	7,20	2,65	1,04
Computational Method	Area m2	10,44	10,47	9,24	30,15
Traditional Method		10,29	11,22	9,75	31,26
APE	%	1,46	6,64	5,23	3,54

As can be seen in the table, the maximum difference is 7,20% on the first floor. The least value of the surface area is 2,65% on the second floor. The overall result of the surface area is 1,04%

The second part of the comparison is the base area. The maximum difference is 6,64% on the first floor. The least difference is 1,46% on the ground floor. The overall result is 3,54%.

Computational and traditional methods results are close to each other.

4.2.3. MIX-2 DOORS QTO RESULTS

The table below also shows the overall door result of the comparison between BIM-based method and the computational method (**Table 4.15**).

As can be seen in the table, there is one significant difference. It is spotted on the ground floor. There is a considerable difference of 155,10 % in the ground floor. The least difference is 19,05% on the first floor. The overall effect is approximately 34,48%.

The table below also shows the overall door result of the comparison between computational and traditional methods (**Table 4.16**).

Table 4.15 MIX-2 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m2	7,5	20,75	27,1	55,35
BIM- Based Method		2,94	17,43	20,79	41,16
APE	%	155,10	19,05	30,35	34,48
Computational Method	Area m2	0,35	1,11	1,27	2,73
BIM- Based Method		-	-	-	-
APE	%	-	-	-	-

Table 4.16 MIX-2 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m2	7,50	20,75	27,10	55,35
Traditional Method		7,25	20,75	26,72	54,72
APE	%	3,45	0,00	1,42	1,15
Computational Method	Area m2	0,35	1,11	1,27	2,73
Traditional Method		0,73	1,36	1,29	3,37
APE	%	51,72	18,08	1,55	18,99

As can be seen in the table, all the results are close to each other on the surface area differences. The maximum difference is 3,45% on the ground floor. The least difference is the same result on the first floor. The overall result is 1,15% for surface area.

On the base area results, the maximum difference is 51,72% on the ground floor. The least difference is 1,55% on the second floor. The overall difference is 18,99%.

4.2.4. MIX-2 COLUMNS QTO RESULT

The column quantity take-off also consists of three different stages, such as the volume, surface area and base area.

The table below also shows the columns overall result of the comparison between computational method and BIM-based method (**Table 4.17**).

Table 4.17 MIX-2 column QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	9,73	6,89	0,00	16,62
BIM- Based Method		9,10	12,62	0,00	21,72
APE	%	6,92	45,40	0,00	23,48
Computational Method	Surface Area m2	13,39	8,98	0,00	22,37
BIM- Based Method		101,83	138,14	0,00	239,97
APE	%	86,85	93,50	0,00	90,68
Computational Method	Total Area m2	3,41	2,72	0,00	6,13
BIM- Based Method		3,41	4,99	0,00	8,40
APE	%	0,00	45,49	0,00	27,02

According to the results in the table, the column volume absolute percentage error on the first floor is observed to be closer to that of the other floors. The percentage of the first-floor result is 45,40%. The overall result is 50%.

As can be seen in the table, there is an extreme difference in the results of the BIM-based method in the surface area of the columns. According to the result, there is a difference of over 86%.

Table 4.18 MIX-2 column QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	9,73	6,89	0,00	16,62
Traditional Method		9,73	6,90	0,00	16,63
APE	%	0,00	0,14	0,00	0,06
Computational Method	Surface Area m2	13,39	8,98	0,00	22,37
Traditional Method		13,40	9,00	0,00	22,40
APE	%	0,07	0,22	0,00	0,13
Computational Method	Total Area m2	3,41	2,72	0,00	6,13
Traditional Method		3,40	2,75	0,00	6,15
APE	%	0,29	1,09	0,00	0,33

According to the column floor area results, the maximum difference is 45,49% on the first floor. The least difference is same on the ground floor. The overall result is 27,02%.

The table below also shows the columns overall result of the comparison between traditional method and computational method (**Table 4.18**).

As can be seen in the table, all comparison stage results are almost the same. On the volume results, the maximum difference is 0,14% on the first floor. The least difference is same on the ground floor.

On the surface area results, the maximum difference is 0,22%. The least difference is 0,07% on the ground floor. The overall result is 0,13%.

On the base area of the columns, the maximum difference is 1,09% on the first floor. The least difference is 0,29% on the first floor. The overall result is 0,33%.

4.2.5. MIX-2 SLAB QTO RESULTS

The table below also shows the slabs overall result of the comparison between computational method and BIM-based method (**Table 4.19**).

Table 4.19 MIX-2 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	57,59	58,68	58,30	174,57
BIM- Based Method		49,87	57,22	58,06	165,15
APE	%	15,48	2,55	0,41	5,70
Computational Method	Gross Area m2	179,98	188,50	193,25	561,73
BIM- Based Method		166,24	188,51	189,20	543,95
APE	%	8,27	0,01	2,14	3,27
Computational Method	Net Area m2	179,98	183,40	182,21	545,59
BIM- Based Method		166,24	178,83	181,43	526,50
APE	%	8,27	2,56	0,43	3,63

According to the result of the volume in the table, the maximum difference is 15,48% on the ground floor. The least difference is 0,41% on the second floor.

On the gross area results, the maximum difference is 8,27% on the ground floor. The least difference is almost the same result on the first floor. The overall result is 3,27%.

On the net area results comparison, the maximum difference is 8,27% on the ground floor. The minimum difference is 0,43% on the second floor. The overall result is 3,63%.

When the results are taken into consideration, it is determined that the results are close to each other.

The table below also shows the slabs overall result of the comparison between computational method and the traditional method (**Table 4.20**).

According to the result of the table, all results are the same value.

Table 4.20 MIX-2 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	57,59	58,68	58,30	174,57
Traditional Method		57,59	58,68	58,30	174,57
APE	%	0,00	0,00	0,00	0,00
Computational Method	Gross Area m2	179,98	188,50	193,25	561,73
Traditional Method		179,98	188,50	193,25	561,73
APE	%	0,00	0,00	0,00	0,00
Computational Method	Net Area m2	179,98	183,40	182,21	545,59
Traditional Method		179,98	183,40	182,21	545,59
APE	%	0,00	0,00	0,00	0,00

4.3. MIX-3 QTO RESULTS

4.3.1. MIX-3 WALL QTO RESULTS

Wall Quantity take-off result of the comparison between Computational Method and BIM-based method (**Table 4.21**).

The wall comparison results are examined in three stages. The first stage is the volume. The maximum difference is 66,91% on the roof floor. The least difference is 0,52% on the second floor. The overall result of the difference is 9,21%.

The second stage of the wall comparison is surface area. The maximum difference is 62,48% on the roof floor. The least difference is 0,32% on the second floor. The overall result of the difference is 8,62%.

The third stage is the base area of the wall. The maximum difference is 16,43% on the roof floor. The least difference is 5,50% on the first floor. The overall result of the difference is 10,22%.

The table below also shows the wall overall result of the comparison between traditional and computational method (**Table 4.22**).

Table 4.21 MIX-3 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	38,33	75,51	76,27	77,36	77,36	75,46	420,29
BIM- Based Method		41,08	74,54	76,67	78,62	68,71	45,21	384,83
APE	%	6,69	1,30	0,52	1,60	12,59	66,91	9,21
Computational Method	Surface Area m2	182,19	377,94	380,42	400,6	386,21	409,04	2136,43
BIM- Based Method		191,04	374,09	381,64	396,6	371,6	251,7	1966,81
APE	%	4,63	1,03	0,32	1,02	3,91	62,48	8,62
Computational Method	Area m2	25,95	43,6	42,15	42,69	41,81	34,54	230,74
BIM- Based Method		29	46,14	47,81	48,3	44,44	41,33	257,02
APE	%	10,52	5,50	11,84	11,61	5,92	16,43	10,22

The first stage of the comparison is volume. The maximum difference is 71,54% on the roof floor. The least difference is 0,52% on the first floor. The overall result of the difference is 9,79%.

The second stage of the comparison is the surface area of the wall. The maximum difference is 65,46% on the roof floor. The least difference is 1,28% on the fourth floor. The overall result of the difference is 8,12%.

The third stage is the base area of the wall. The maximum difference is 63,11% on the first floor. The least difference is 1,90% on the roof floor. The overall difference is 39,78%.

Table 4.22 MIX-3 wall QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	38,33	75,51	76,27	77,36	77,36	75,46	420,29
Traditional Method		34,77	75,12	70,8	81,45	76,68	43,99	382,81
APE	%	10,23	0,52	7,73	5,02	0,89	71,54	9,79
Computational Method	Surface Area m2	182,19	377,94	380,42	400,63	386,21	409,04	2136,43
Traditional Method		187	369,11	369,9	411,58	391,21	247,22	1976,02
APE	%	2,57	2,39	2,84	2,66	1,28	65,46	8,12
Computational Method	Area m2	25,95	43,6	42,15	42,69	41,81	34,54	230,74
Traditional Method		18,6	26,73	27,07	29,06	28,4	35,21	165,07
APE	%	39,52	63,11	55,71	46,90	47,22	1,90	39,78

4.3.2. MIX-3 WINDOWS QTO RESULTS

The table below also shows the window overall result of the comparison between BIM-based and computational method (**Table 4.23**).

Window QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window. The first stage of the windows comparison is the surface area. The maximum difference is 41,94% on the roof floor. The least difference is 1,59% on the ground floor. The overall difference is 17,58%.

The table below also shows the window overall result of the comparison between traditional and computational method (**Table 4.24**).

The first stage of the window comparison is the surface area of the window. The maximum difference is 4,60% on the ground floor. The least difference is 2,07% on the third and fourth floors. The overall result difference is 0,01%.

Table 4.23 MIX-3 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m3	91,00	126,33	106,79	102,20	102,20	56,86	585,38
BIM- Based Method		92,47	125,52	130,27	128,50	135,58	97,93	710,27
APE	%	1,59	0,65	18,02	20,47	24,62	41,94	17,58
Computational Method	Area m2	9,09	12,70	11,56	10,88	10,88	6,57	61,68
BIM- Based Method		-	-	-	-	-		-
APE	%	-	-	-	-	-		-

Table 4.24 MIX-3 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m3	91,00	126,33	106,79	102,20	102,20	56,86	585,38
Traditional Method		87,00	122,62	104,36	104,36	104,36	62,65	585,35
APE	%	4,60	3,03	2,33	2,07	2,07	9,24	0,01
Computational Method	Area m2	9,09	12,70	11,56	10,88	10,88	6,57	61,68
Traditional Method		8,63	12,50	11,45	10,75	10,75	6,57	60,65
APE	%	5,33	1,60	0,96	1,21	1,21	0,00	1,70

The second stage is the base area of the window. The maximum difference is 5,33% on the ground floor. The least difference is 0,00% on the roof floor. The overall result of the difference is 1,70%.

4.3.3. MIX-3 DOOR QTO RESULTS

The table below also shows the overall door result of the comparison between BIM-based and computational method (**Table 4.25**).

Table 4.25 MIX-3 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	38,45	56,54	48,11	58,59	54,59	0	256,28
BIM- Based Method		35,42	37,18	40,34	41,18	37,18	0	191,3
APE	%	8,55	52,07	19,26	42,28	46,83	0,00	33,97
Computational Method	Area m2	3,6	4,12	3,44	4,28	4,08	0	19,52
BIM- Based Method		-	-	-	-	-	0	-
APE	%	-	-	-	-	-	0	-

Door QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window.

The first stage of the door comparison is the surface area. The maximum difference is 52,07% on the first floor. The least difference is 8,55% on the ground floor. The overall difference is 33,97%.

The table below also shows the overall door result of the comparison between traditional and computational method (**Table 4.26**).

Table 4.26 MIX-3 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	38,45	56,54	48,11	58,59	54,59	1,25	257,53
Traditional Method		42,69	49,10	49,10	49,10	41,36	1,00	232,35
APE	%	9,93	15,15	2,02	19,33	31,99	25,00	10,84
Computational Method	Area m2	3,60	4,12	3,44	4,28	4,08	0,25	19,77
Traditional Method		3,90	4,12	3,98	3,98	3,21	0,28	19,47
APE	%	7,69	0,00	13,57	7,54	27,10	10,71	1,54

The first stage of the door comparison is the surface area. The maximum difference is 31,99% on the fourth floor. The least difference is 2,02% on the second floor. The overall difference is 10,84%.

The second stage of the door is the base area. The maximum difference is 27,10 on the fourth floor. The least difference is 0,00% on the first floor. The overall result of the difference is 1,54%.

4.3.4. MIX-3 COLUMN QTO RESULTS

The table below also shows the overall column result of the comparison between BIM-based and computational method (**Table 4.27**).

Table 4.27 MIX-3 column QTO result of the comparison between computational method and BIM-based method

QTO_METHOD	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	11,23	11,23	11,23	11,91	11,91	0,00	57,51
BIM- Based Method		12,94	12,94	12,94	12,94	9,92	0,00	61,68
APE	%	13,21	13,21	13,21	7,96	20,06	0,00	6,76
Computational Method	Surface Area m2	19,59	19,59	19,59	20,94	20,94	0,00	100,65
BIM- Based Method		137,81	137,81	137,81	137,81	107,87	0,00	659,11
APE	%	85,78	85,78	85,78	84,81	80,59	0,00	84,73
Computational Method	Total Area m2	4,16	4,16	4,16	4,41	4,41	0,00	21,30
BIM- Based Method		4,75	5,75	6,75	7,75	8,75	0,00	33,75
APE	%	12,42	27,65	38,37	43,10	49,60	0,00	36,89

The column QTO has been examined under three sub-titles. These are the volume of the column, the surface area of column and base area of the column.

The first stage is the volume of the column. The maximum difference is 13,21% on the ground, first and second floors. The least difference is 7,96% on the third floor. The second stage is the surface area of the column. The maximum difference is 85,78% on the ground, first and second floors. The least difference is 80,59% on the fourth floor.

The third stage is the base area of the column. The maximum difference is 49,60% on the fourth floor. The least difference is 12,42% on the ground floor.

The BIM-based system makes mistakes while calculating the surface area of the columns. Due to this condition, the results differ at times.

The table below also shows the overall column result of the comparison between traditional and computational method (**Table 4.28**).

Table 4.28 MIX-3 column QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	11,23	11,23	11,23	11,91	11,91	0,00	57,51
Traditional Method		12,63	9,35	9,35	9,35	9,35	0,00	50,03
APE	%	11,08	20,11	20,11	27,38	27,38	0,00	14,95
Computational Method	Surface Area m2	19,59	19,59	19,59	20,94	20,94	0,00	100,65
Traditional Method		38,02	28,13	28,13	28,13	28,13	0,00	150,54
APE	%	48,47	30,36	30,36	25,56	25,56	0,00	33,14
Computational Method	Total Area m2	4,16	4,16	4,16	4,41	4,41	0,00	21,30
Traditional Method		3,57	3,57	3,57	3,57	3,57	0,00	17,85
APE	%	16,53	16,53	16,53	23,53	23,53	0,00	19,33

The first stage is the volume of the column. The maximum difference is 12,63% on the ground, first and second floors. The least difference is 11,91% on the third floor. The second stage is the surface area of the column. The maximum difference is 48,47% on the ground, floor. The least difference is 25,56% on the third and fourth floor.

The third stage is the base area of the column. The maximum difference is 23,53% on the third floor. The least difference is 16,53% on the ground floor. The overall result of the difference is 19,33%.

4.3.5. MIX-3 SLAB QTO RESULT

The table below also shows the overall slab result of the comparison between BIM-based and computational method (**Table 4.29**).

Table 4.29 MIX-3 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	87,15	113,52	113,49	113,48	113,52	31,22	572,38
BIM- Based Method		95,19	124,46	124,46	123,97	123,98	41,20	633,26
APE	%	8,45	8,79	8,81	8,46	8,44	24,22	9,61
Computational Method	Gross Area m2	272,36	367,37	367,40	367,37	367,50	104,06	1846,06
BIM- Based Method		271,96	369,93	369,93	369,26	369,42	118,43	1868,93
APE	%	0,15	0,69	0,68	0,51	0,52	12,13	1,22
Computational Method	Net Area m2	272,36	354,77	354,68	354,65	354,77	97,58	1788,81
BIM- Based Method		271,96	355,60	355,60	354,20	354,22	117,71	1809,29
APE	%	0,15	0,23	0,26	0,13	0,16	17,10	1,13

The first stage is the volume of the slab. The maximum difference is 24,22% on the roof floor. The least difference is 8,44% on the fourth floor. The overall result of the difference is 9,61%.

The second stage is the gross area. The maximum difference is 12,13% on the roof floor. The least difference is 0,15% on the ground floor. The overall result of the difference is 1,22%

The third stage is the net area of the slab comparison. The maximum difference is 17,10% on the roof floor. The least difference is 0,13% on the third floor. The overall result of the difference is 1,13%.

The table below also shows the overall slab result of the comparison between traditional and computational method (**Table 4.30**).

Table 4.30 MIX-3 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	87,15	113,52	113,49	113,48	113,52	31,22	572,38
Traditional Method		85,36	130,09	116,36	116,36	116,36	51,73	616,26
APE	%	2,10	12,75	2,47	2,48	2,44	39,65	7,12
Computational Method	Gross Area m2	272,36	367,37	367,40	367,37	367,50	104,06	1846,06
Traditional Method		275,96	365,36	365,36	365,36	365,36	104,97	1842,37
APE	%	1,30	0,55	0,56	0,55	0,59	0,87	0,20
Computational Method	Net Area m2	272,36	354,77	354,68	354,65	354,77	97,58	1788,81
Traditional Method		275,96	351,63	351,63	351,63	351,63	98,69	1781,17
APE	%	1,30	0,89	0,87	0,86	0,89	1,12	0,43

The first stage is the volume of the slab. The maximum difference is 39,65% on the roof floor. The least difference is 2,10% on the ground floor. The overall result of the difference is 7,12%.

The second stage is the gross area. The maximum difference is 1,30% on the ground floor. The least difference is 0,55% on the first floor. The overall result of the difference is 0,20%

The third stage is the net area of the slab comparison. The maximum difference is 1,30% on the first floor. The least difference is 0,86% on the third floor. The overall result of the difference is 0,43%.

4.4. RES-1 QTO RESULTS

4.4.1. RES-1 WALL QTO RESULTS

The wall comparison of the project consists of two phases. In the first step, it is between the computational method and the BIM-based method. The second stage is between the computational method and the traditional method.

These comparisons come in three different stages. The first stage provides the volume QTO results of the wall. The second stage provides the wall surface area QTO results. The third and the final stage provides the Wall base area QTO results.

Wall Quantity take-off result of the comparison between Computational Method and BIM-based method (**Table 4.31**).

Table 4.31 RES-1 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	26,14	36,53	62,67
BIM- Based Method		28,78	39,75	68,53
APE	%	9,17	8,10	8,55
Computational Method	Surface Area m2	141,53	219,92	361,45
BIM- Based Method		151,33	212,53	363,86
APE	%	6,48	3,48	0,66
Computational Method	Area m2	19,43	23,85	43,28
BIM- Based Method		15,67	24,14	39,81
APE	%	23,99	1,20	8,72

The first comparison result concerns the wall volume results. The maximum difference between the volume results is 9,17% on the ground floor. Differences in the overall result are 8,55%.

The second comparison result concerns the wall surface area results. The maximum difference between the surface area is 6,48% on the ground floor. The difference in the overall result is 0,66%.

The third comparison result concerns the wall base area. The maximum difference in the base area is 23,99% on the ground floor. The difference in the overall result is 8,72%. The least difference between the base area is 1,20% on the first floor. Wall Quantity take-off result of the comparison between computational and traditional method (**Table 4.32**).

Table 4.32 RES-1 wall QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	26,14	36,53	62,67
Traditional Method		26,28	32,63	58,91
APE	%	0,53	11,95	6,38
Computational Method	Surface Area m2	141,53	219,92	361,45
Traditional Method		132,95	207,526	340,476
APE	%	6,45	5,97	6,16
Computational Method	Area m2	19,43	23,85	43,28
Traditional Method		6,96	13,0205	19,9805
APE	%	179,17	83,17	116,61

The first stage of the comparison is volume. The maximum difference is 11,95% on the first floor. The overall difference is 6,38%. On the other hand, the least difference is 0,53% on the ground floor.

The second stage of the comparison is the surface area of the wall. The maximum difference is 6,45% on the ground floor. The overall difference is 6,16%. Also, the least difference value is 5,97% on the first floor.

The third and the final stage of the comparison is the base area of the wall. The maximum difference is 179,17%. The overall result of the base floor is 116,61%. Also, the least difference is 83,17%. As seen in these results, there is a difference of over 80% in all the floors. These calculations are calculated by more than one architect, and the average of these calculation is taken. The difference is caused by the influence of the average result.

4.4.2. RES-1 WINDOWS QTO RESULT

Windows quantity take-off result of the comparison between computational and BIM-based method (**Table 4.33**).

The window comparison results are examined under two main stages. The first stage is the surface area difference. The maximum difference is 6,95% on the first floor. Ground floor difference of the surface area is 0,34%. The overall result difference is 3,91%. The second comparison cannot be processed since it can not be calculated in the BIM-based system. Windows quantity take-off result of the comparison between computational and traditional method (**Table 4.34**).

Table 4.33 RES-1 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	81,61	89,11	170,72
BIM- Based Method		81,89	95,77	177,66
APE	%	0,34	6,95	3,91
Computational Method	Area m2	9,10	9,87	18,97
BIM- Based Method		-	-	-
APE	%	-	-	-

Table 4.34 RES-1 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m3	81,61	89,11	170,72
Traditional Method		81,80	95,76	177,56
APE	%	0,23	6,94	3,85
Computational Method	Area m2	9,10	9,87	18,97
Traditional Method		9,06	10,52	19,58
APE	%	0,41	6,16	6,08

The window comparison results are examined under two main stages. The first stage is the surface area comparison. The maximum difference is 6,94% on the first floor. The least difference is 0,23% on the ground floor. The overall result of the difference is 3,85%.

The second stage of the comparison is the base area of the window. The maximum difference is 6,16% on the first floor. On the ground floor difference is 0,41%. The overall result of the difference is 6,08%.

According to these results, there is a significant difference on the ground floor values.

4.4.3. RES-1 DOOR QTO RESULTS

Door quantity take-off result of the comparison between computational and BIM-based method (**Table 4.35**).

Table 4.35 RES-1 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	21,52	17,38	38,9
BIM- Based Method		20,58	16,38	36,96
APE	%	4,57	6,11	5,25
Computational Method	Area m2	1,42	0,92	2,34
BIM- Based Method		-	-	-
APE	%	-	-	-

The door comparison results are examined under two stages as the surface of the door and base area of the door. The first stage difference value has three different values. The maximum difference between the door surface area is 6,11% on the first floor. The least difference is 4,57% on the ground floor. The overall result of the difference is 5,25%.

The second stage is the base area of the door. However, the BIM-based system is not able to calculate this value.

Door quantity take-off result of the comparison between computational and traditional method (**Table 4.36**).

According to the first stage results difference, the maximum difference is 6,11% on the first floor. The least difference is 0,61% on the ground floor. The overall result of the difference is 2,99%.

The second stage is the base area of the door. The maximum difference is 2,53%. The least difference is 0,55% on the first floor. The overall result of the difference is 1,74%.

Table 4.36 RES-1 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	21,52	17,38	38,90
Traditional Method		21,39	16,38	37,77
APE	%	0,61	6,11	2,99
Computational Method	Area m2	1,42	0,92	2,34
Traditional Method		1,39	0,92	2,30
APE	%	2,53	0,55	1,74

4.4.4. RES-1 COLUMN QTO RESULT

Column quantity take-off result of the comparison between computational and BIM-based method (**Table 4.37**).

Table 4.37 RES-1 column QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	6,37	6,75	13,12
BIM- Based Method		12,15	9,63	21,78
APE	%	47,57	29,91	39,76
Computational Method	Surface Area m2	12,11	12,75	24,86
BIM- Based Method		104,58	82,64	187,22
APE	%	88,42	84,57	86,72
Computational Method	Total Area m2	2,50	2,50	5,00
BIM- Based Method		3,43	2,75	6,18
APE	%	27,11	9,09	19,09

The column comparison results are examined in three stages as volume, surface area and the base area of the column.

According to the first stage result, the maximum difference is 47,57% on the ground floor. The least difference is 29,91% on the first floor. The overall result of the difference is 39,67%.

The second stage is the surface area of the column. The maximum difference is 88,42% on the ground floor. The least difference is 84,57% on the first floor. The overall result of the difference is 86,72%.

The third and the last stage is the base area of the column. The maximum difference is 27,11% on the ground floor. The least difference is 9,09% on the first floor. The overall result of the difference is 19,09%.

According to these results, it is seen that there is an error in the calculation of the BIM-based system. This error may have been caused by mistake made in the description of the columns.

Column quantity take-off result of the comparison between computational and traditional method. It can be seen at **Table 4.38**

Table 4.38 RES-1 column QTO result of the comparison between computational method and traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	6,37	6,75	13,12
Traditional Method		5,85	5,85	11,70
APE	%	8,89	15,38	12,14
Computational Method	Surface Area m2	12,11	12,75	24,86
Traditional Method		11,36	11,36	22,72
APE	%	6,60	12,24	9,42
Computational Method	Total Area m2	2,50	2,50	5,00
Traditional Method		2,10	2,65	4,75
APE	%	19,05	5,66	5,26

The first stage is the volume of the column comparison. The maximum difference is 15,38% on the first floor. The least difference is 8,89% on the ground floor. The overall result of the difference is 12,14%.

The second stage is the surface area. The maximum difference is 12,24% on the ground and first floor. The overall result of the difference is 9,42%.

The third stage is the base area of the column. The maximum difference is 19,05 on the ground floor. The least difference is 5,66% on the first floor. The overall result of the difference is 5,26%

It is seen that the comparison results of all values are close to each other.

4.4.5. RES-1 SLAB QTO RESULTS

Slab quantity take-off result of the comparison between computational and BIM-based method (**Table 4.39**).

Table 4.39 50 RES-1 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	87,78	87,07	174,85
BIM- Based Method		46,89	50,38	97,27
APE	%	87,20	72,83	79,76
Computational Method	Gross Area m2	274,33	284,26	558,59
BIM- Based Method		156,29	178,84	335,13
APE	%	75,52	58,95	66,68
Computational Method	Net Area m2	274,33	272,09	546,42
BIM- Based Method		156,29	167,94	324,23
APE	%	75,52	62,02	68,53

The slab comparison results are examined in three stages. The first stage is the volume of the slab. The maximum difference is 82,70% on the ground floor. The least difference is 72,83% on the first floor. The overall result of the difference is determined as 79,76%.

The second stage of the slab comparison is the gross area. The maximum difference is 75,52% on the ground floor. The least difference is 58,95% on the first floor. The overall result of the difference is determined as 66,68%.

The third stage is the net area of the slab results. The maximum difference value is 75,52% on the ground floor. The least difference is 62,02% on the first floor. The overall result of the difference is 68,53.

Slab quantity take-off result of the comparison between computational and BIM-based method (**Table 4.40**).

Table 4.40 RES-1 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	87,78	87,07	174,85
Traditional Method		87,78	87,07	174,85
APE	%	0,00	0,00	0,00
Computational Method	Gross Area m2	274,33	284,26	558,59
Traditional Method		274,32	284,26	558,58
APE	%	0,00	0,00	0,00
Computational Method	Net Area m2	274,33	272,09	546,42
Traditional Method		274,32	272,09	546,41
APE	%	0,00	0,00	0,00

The results of the three-stage comparisons are the same values. In this case, the QTO result using the traditional method is considered correct.

4.5. RES-2 QTO RESULTS

4.5.1. RES-2 WALL QTO RESULTS

Wall quantity take-off result of the comparison between computational and BIM-based method (**Table 4.41**).

The wall comparison results are examined in three stages. The first stage is the volume. The maximum difference is 15,29% on the second floor. The least difference is 1,98% on the first floor. The overall result of the difference is 2,60%.

The second stage of the wall comparison is the surface area. The maximum difference is 11,44% on the second floor. The least difference is 5,34% on the first floor. The overall result of the difference is 0,89%.

The third stage is a base area of the wall. The maximum difference is 35,15% on the second floor. The least difference is 15,60% on the ground floor. The overall result of the difference is 27,21%.

Table 4.41 RES-2 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	21,69	24,78	17,34	63,81
BIM- Based Method		19,76	25,28	20,47	65,51
APE	%	9,77	1,98	15,29	2,60
Computational Method	Surface Area m2	86,78	134,45	85,11	306,34
BIM- Based Method		79,91	127,63	96,1	303,64
APE	%	8,60	5,34	11,44	0,89
Computational Method	Area m2	10,71	12,37	8,32	31,4
BIM- Based Method		12,69	17,62	12,83	43,14
APE	%	15,60	29,80	35,15	27,21

When all the results considered, it appears that there are serious differences between the BIM-based method and the computational method. It is seen that the BIM drawing system and the QTO system do not work in harmony.

Wall quantity take-off result of the comparison between computational and traditional method (**Table 4.42**).

Table 4.42 RES-2 wall QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	21,69	24,78	17,34	63,81
Traditional Method		14,34	10,42	10,98	35,74
APE	%	51,26	137,81	57,92	78,54
Computational Method	Surface Area m2	86,78	134,45	85,11	306,34
Traditional Method		57,37	41,79	45,91	145,07
APE	%	51,26	221,73	85,38	111,17
Computational Method	Area m2	10,71	12,37	8,32	31,4
Traditional Method		5,24	3,41	4,57	13,22
APE	%	104,39	262,76	82,06	137,52

The first stage of the wall comparison is the volume. The maximum difference is 137,81% on the first floor. The minimum difference is 51,26% on the ground floor. The overall result of the difference is 78,54%

The second stage is surface area of the wall. The maximum difference is 221,73% on the first floor. The minimum difference is 51,26% on the ground floor. The overall result of the difference is 111,17%.

The third stage of the wall comparison is area of the floor. The maximum difference is 262,76% on the first floor. The minimum difference is 104,39% on the ground floor. The overall result of the difference is 137,52%.

4.5.2. RES-2 WINDOW QTO RESULTS

Window quantity take-off result of the comparison between computational and BIM-based method (**Table 4.43**).

Table 4.43 RES-2 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m2	36,77	66,75	26,54	130,06
BIM- Based Method		23,00	17,38	32,97	73,35
APE	%	59,87	284,06	19,50	77,31
Computational Method	Area m2	4,39	4,89	2,89	12,17
BIM- Based Method		-	-	-	-
APE	%	-	-	-	-

The first stage of the window comparison is the surface area. The maximum difference is 284,06% on the second floor. The least difference is 19,50% on the first floor. The overall result of the difference is 77,31% These comparison results are not close to each other.

Window quantity take-off result of the comparison between computational and traditional method (**Table 4.44**).

Table 4.44 55 RES-2 window QTO result of the comparison between computational method and the traditional method

QTO METHOD	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m3	36,77	66,75	26,54	130,06
Traditional Method		23,00	65,00	35,50	123,50
APE	%	59,87	2,69	25,24	5,31
Computational Method	Area m2	4,39	4,89	2,89	12,17
Traditional Method		3,28	7,01	4,38	14,66
APE	%	34,05	30,24	33,94	16,98

The first stage of the comparison is the surface area. The maximum difference is 59,87% on the ground floor. The least difference is 2,69% on the first floor. The overall results of the difference are 5,31%.

The second stage is the base area of the window. The maximum difference is 34,05% on the ground floor. The least difference is 30,24% on the first floor. The overall results of the difference are 16,98%.

4.5.3. RES-2 DOOR QTO RESULTS

Door quantity take-off result of the comparison between computational and BIM-based method (**Table 4.45**).

Table 4.45 RES-2 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m2	5	9,18	8,64	22,82
BIM- Based Method		15,7	60,64	10,50	86,84
APE	%	68,15	84,86	17,71	73,72
Computational Method	Area m2	0,5	0,32	0,34	1,16
BIM- Based Method		-	-	-	-
APE	%	-	-	-	-

The first stage of the comparison is the surface area of the door. The maximum difference is 84,86% on the first floor. The least difference is 17,71% on the second floor. The overall result of the difference is 73,72%.

Door quantity take-off result of the comparison between computational and traditional method (**Table 4.46**).

Table 4.46 RES-2 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Surface Area m2	5,00	9,18	8,64	22,82
Traditional Method		15,70	8,00	7,68	31,38
APE	%	68,15	14,75	12,89	72,72
Computational Method	Area m2	0,50	0,32	0,34	1,16
Traditional Method		1,57	0,32	0,34	2,23
APE	%	68,15	0,00	0,00	47,98

The first stage of the comparison is the surface area. The maximum difference is 68,15% on the ground floor. The least difference is 12,89% on the second floor. The overall difference is 72,72%.

The second stage is the base area of the door. The maximum difference is 68,15% on the ground floor. The least difference is 0,00% on the first and second floors. The overall difference in the result is 47,98%.

4.5.4. RES-2 COLUMN QTO RESULTS

Column quantity take-off result of the comparison between computational and BIM-based method (**Table 4.47**).

The column QTO has been examined under three sub-titles. These are the volume of the column, the surface area of column and base area of the column.

The first stage is the volume of the column. The maximum difference is 80,78% on the first floor. The least difference is 29,13% on the ground floor.

The second stage is the surface area of the column. The maximum difference is 47,32% on the ground floor. The least difference is 33,66% on the first floor.

The third stage is the base area of the column. The maximum difference is 70,59% on the first floor. The least difference is 21,47% on the ground floor.

Table 4.47 RES-2 column QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	6,96	6,96	0,00	13,92
BIM- Based Method		5,39	3,85	0,00	9,24
APE	%	29,13	80,78	0,00	50,65
Computational Method	Surface Area m2	8,99	8,99	0,00	17,98
BIM- Based Method		47,32	33,60	0,00	80,92
APE	%	81,00	73,24	0,00	77,78
Computational Method	Total Area m2	2,32	2,32	0,00	4,64
BIM- Based Method		1,91	1,36	0,00	3,27
APE	%	21,47	70,59	0,00	41,90

The BIM-based system makes mistakes while calculating the surface area of the columns. Therefore, in this condition, the results differ at times

Column quantity take-off result of the comparison between computational and traditional method (**Table 4.48**)

Table 4.48 RES-2 column QTO result of the comparison between computational method and traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	6,96	6,96	13,92
Traditional Method		5,14	5,14	10,28
APE	%	35,44	35,44	35,44
Computational Method	Surface Area m2	8,99	8,99	17,98
Traditional Method		17,02	17,02	34,04
APE	%	47,17	47,17	47,17
Computational Method	Total Area m2	2,32	2,32	4,64
Traditional Method		1,92	2,92	4,84
APE	%	20,99	20,48	4,03

The first stage is the volume of the column. The maximum and minimum differences are 5,14%

The second stage is the surface area of the column. The maximum and minimum differences are 17,02%.

The third stage is the base area of the column. The maximum and minimum difference are 20,99%.

4.5.5. RES-2 SLAB QTO RESULTS

The table below also shows the overall slab result of the comparison between BIM-based and computational method (**Table 4.49**).

Table 4.49 RES-2 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	36,79	30,88	30,11	97,78
BIM- Based Method		38,20	32,97	32,32	103,49
APE	%	3,69	6,34	6,84	5,52
Computational Method	Gross Area m2	114,97	106,18	104,16	325,31
BIM- Based Method		119,36	112,71	110,64	342,71
APE	%	3,68	5,79	5,86	5,08
Computational Method	Net Area m2	114,97	96,50	94,11	305,58
BIM- Based Method		119,36	103,03	101,01	323,40
APE	%	3,68	6,34	6,83	5,51

The slab is examined under three sub-titles. These are volume, gross area and net area of the slab.

The first stage is the volume of the slab. The maximum difference is 6,84% on the second floor. The least difference is 3,69% on the ground floor. The overall result of the difference is 5,52%.

The second stage is the gross area. The maximum difference is 5,86% on the second floor. The least difference is 3,68% on the ground floor. The overall result of the difference is 5,08%

The third stage is a net area of the slab comparison. The maximum difference is 6,83% on the second floor. The least difference is 3,68% on the ground floor. The overall result of the difference is 5,51%.

The table below also shows the overall slab result of the comparison between traditional and computational method (**Table 4.50**).

Table 4.50 RES-2 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Total Result
Computational Method	Volume m3	36,79	30,88	30,11	97,78
Traditional Method		36,79	30,88	20,78	88,45
APE	%	0,00	0,00	44,90	10,55
Computational Method	Gross Area m2	114,97	106,18	104,16	325,31
Traditional Method		114,97	106,18	74,77	295,92
APE	%	0,00	0,00	39,31	9,93
Computational Method	Net Area m2	114,97	96,50	94,11	305,58
Traditional Method		114,97	96,50	64,95	276,42
APE	%	0,00	0,00	44,90	10,55

The first stage is the volume of the slab. The maximum difference is 44,90% on the second floor. The least difference is 0,00% on the ground and first floors. The overall result of the difference is 10,55%.

The second stage is the gross area. The maximum difference is 39,31% on the second floor. The least difference is 0,00% on the ground and first floors. The overall result of the difference is 9,93%

The third stage is the net area of the slab comparison. The maximum difference is 44,90% on the second floor. The least difference is 0,00% on the ground and first floors. The overall result of the difference is 10,55%.

4.6. RES-3 QTO RESULTS

4.6.1. RES-3 WALL QTO RESULT

The table below also shows the wall overall result of the comparison between computational method and BIM-based method (**Table 4.51**).

Table 4.51 RES-3 wall QTO of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	20,87	61,21	82,08
BIM- Based Method		19,13	31,22	50,35
APE	%	9,10	96,06	63,02
Computational Method	Surface Area m2	131,98	366,79	498,77
BIM- Based Method		126,09	222,44	348,53
APE	%	4,67	64,89	43,11
Computational Method	Area m2	14,36	16,1	30,46
BIM- Based Method		16,49	15,43	31,92
APE	%	12,92	4,34	4,57

As can be seen in the table, there is a percentage difference between the two methods for total volume result. The most significant difference between the wall volume is on the first floor. The percentage of this value is 96,06%. The least difference of the wall volume is on the ground floor. This value is 9,10 %. There is a difference of 63,02 % in the overall total.

The first stage of the wall comparison is the surface area of the wall. The maximum difference is 64,86% on the first floor. The least difference is 4,67% on the ground floor. The overall results of the differences are 43,11%

The second stage of the wall comparison is the base area of the wall. The maximum difference is 12,92% on the ground floor. The least difference is 4,34% on the first floor. The overall result of the difference is 4,57%.

When the ground area values are examined, it is seen that the results are close to each other. In view of the results of these data, it is seen that the BIM-based system is massive in terms of the floor height data.

The table below also shows the wall overall result of the comparison between traditional method and computational method (**Table 4.52**).

Table 4.52 RES-3 wall QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	20,87	61,21	82,08
Traditional Method		18,65	56,69	75,34
APE	%	11,90	7,97	8,95
Computational Method	Surface Area m2	131,98	366,79	498,77
Traditional Method		127,98	354,79	482,77
APE	%	3,13	3,38	3,31
Computational Method	Area m2	14,36	16,1	30,46
Traditional Method		15,69	15,75	31,44
APE	%	8,48	2,22	3,12

The first stage of the wall comparison is volume. The maximum difference is 7,79% on the first floor. The least difference is 11,90% on the ground floor. The overall results of the difference are 8,95%.

The second stage is the surface area of the wall. The maximum difference is 3,38% on the first floor. The least difference is 3,13% on the ground floor. The overall results of the difference are 3,31%.

The third stage is the base area. The maximum difference is 8,48% on the ground floor. The least difference is 2,22% on the first floor. The overall difference is 3,12%.

According to the comparison data, the results of both methods are close to each other. Slight differences are seen in some cases regarding certain values; these changes take place because they are based on the average in the traditional method.

4.6.2. RES-3 WINDOW QTO RESULT

The table below also shows the window overall result of the comparison between BIM-based method and the computational method (**Table 4.53**).

Table 4.53 RES-3 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m3	85,05	74,08	159,13
BIM- Based Method		109,36	59,86	169,22
APE	%	22,23	23,75	5,96
Computational Method	Area m2	8,36	5,48	13,84
BIM- Based Method		-	-	-
APE	%	-	-	-

Window QTO has been examined two under sub-titles. These are the surface area of the window and the base area of the window. However, the with BIM-based method it is not possible to calculate the base area of the window.

The first stage of the windows comparison is the surface area. The maximum difference is 23,75% on the first floor. The least difference is 22,23% on the ground floor. The overall difference is 5,96%.

The table below also shows the window overall result of the comparison between traditional and computational method (

Table 4.54).

The first stage of the window comparison is the surface area of the window. The maximum difference is 13,23% on the ground floor. The least difference is 5,40% on the first floor. The overall result difference is 8,91%.

The second stage is the base area of the window. The maximum difference is 3,01% on the first floor. The least difference is 0,00% on the ground floor. The overall result of the difference is 1,21%.

Table 4.54 RES-3 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m3	85,05	74,08	159,13
Traditional Method		80,69	65,42	146,11
APE	%	5,40	13,23	8,91
Computational Method	Area m2	8,36	5,48	13,84
Traditional Method		8,36	5,65	14,01
APE	%	0,00	3,01	1,21

4.6.3. RES-3 DOOR QTO RESULT

The table below also shows the overall door result of the comparison between BIM-based method and the computational method (**Table 4.55**).

Table 4.55 RES-3 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	22,25	31,94	54,19
BIM- Based Method		22,25	20	42,25
APE	%	0,00	59,70	28,26
Computational Method	Area m2	1,16	0,79	1,95
BIM- Based Method		-	-	-
APE	%	-	-	-

Door QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

The first stage of the door comparison is the surface area. The maximum difference is 59,70% on the first floor. The least difference is 0,00% on the ground floor. The overall difference is 28,26%.

Although the values on the ground floor are the same, the value difference on the first floor is dramatically higher.

The table below also shows the overall door result of the comparison between traditional and computational method (**Table 4.56**).

Table 4.56 RES-3 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	22,25	31,94	54,19
Traditional Method		22,25	31,90	54,15
APE	%	0,00	0,13	0,07
Computational Method	Area m2	1,16	0,79	1,95
Traditional Method		1,15	0,79	1,94
APE	%	0,87	0,00	0,52

The first stage of the door comparison is the surface area. The maximum difference is 0,13% on the first floor. On the ground floor, the difference value is the same with each other. The overall result of the difference is 0,07%

The second stage is the base area of the door. The maximum difference is 0,87% on the ground floor. On the first floor, the difference value is the same with each other. The overall result of the difference is 0,52%.

The values in the comparison result data seem to be close with the difference between the methods.

4.6.4. RES-3 COLUMN QTO RESULT

The table below also shows the overall column result of the comparison between BIM-based and computational method (**Table 4.57**).

The column QTO has been examined under three sub-titles. The first stage is the volume of the column comparison. All results are the same value.

The second stage is the surface area of the column. The maximum difference is 85,04% on the ground and first floor. The overall difference of the column is 85,04%.

The third stage is the base area of the column. The maximum difference is 0,88% on the ground and first floor. The overall difference is 0,88%.

Table 4.57 RES-3 column QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	6,80	6,80	13,60
BIM- Based Method		6,80	6,80	13,60
APE	%	0,00	0,00	0,00
Computational Method	Surface Area m2	10,05	10,05	20,10
BIM- Based Method		67,20	67,20	134,40
APE	%	85,04	85,04	85,04
Computational Method	Total Area m2	2,26	2,26	4,52
BIM- Based Method		2,28	2,28	4,56
APE	%	0,88	0,88	0,88

The BIM-based system makes mistakes while calculating the surface area of the columns. Due to this condition, the results differ at times

The table below also shows the overall column result of the comparison between traditional and computational method (**Table 4.58**).

The first stage is the volume of the column comparison. The maximum difference is 4,62% on the first floor. The least difference is 0,00% on the ground floor. The overall result of the difference is 2,26%.

The second stage is the surface area. The maximum difference is 4,69% on the ground and first floor. The overall result of the difference is 4,69%.

The third stage is the base area of the column. The maximum and minimum difference are the same results of 0,00%. The overall result of the difference is 0,00%.

It is seen that the comparison results of all values are close to each other.

Table 4.58 RES-3 column QTO result of the comparison between computational method and the traditional method

QTO METHODS	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	6,80	6,80	13,60
Traditional Method		6,80	6,50	13,30
APE	%	0,00	4,62	2,26
Computational Method	Surface Area m2	10,05	10,05	20,10
Traditional Method		9,60	9,60	19,20
APE	%	4,69	4,69	4,69
Computational Method	Total Area m2	2,26	2,26	4,52
Traditional Method		2,26	2,26	4,52
APE	%	0,00	0,00	0,00

4.6.5. RES-3 SLAB QTO RESULT

The table below also shows the overall slab result of the comparison between BIM-based and computational method (**Table 4.59**).

The slab is examined under three sub-titles. These are as follows; volume, gross area and net area of the slab.

The first stage is the volume of the slab. The maximum difference is 12,35% on the first floor. The least difference is 8,41% on the ground floor. The overall result of the difference is 0,86%.

The second stage is the gross area. The maximum difference is 19,13% on the first floor. The least difference is 0,19% on the ground floor. The overall difference is 9,68%.

The third stage is the net area of the slab comparison. The maximum difference is 5,34% on the first floor. The least difference is 0,19% on the ground floor. The overall result of the difference is 2,69%.

The table below also shows the overall slab result of the comparison between traditional and computational method (**Table 4.60**).

Table 4.59 RES-3 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	46,07	45,59	91,66
BIM- Based Method		50,30	40,58	90,88
APE	%	8,41	12,35	0,86
Computational Method	Gross Area m2	143,99	171,73	315,72
BIM- Based Method		143,71	144,15	287,86
APE	%	0,19	19,13	9,68
Computational Method	Net Area m2	143,99	142,49	286,48
BIM- Based Method		143,71	135,27	278,98
APE	%	0,19	5,34	2,69

Table 4.60 RES-3 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	46,07	45,59	91,66
Traditional Method		43,87	45,59	89,46**100
APE	%	5,01	0,00	2,40
Computational Method	Gross Area m2	143,99	171,73	315,72
Traditional Method		144,00	171,73	315,73
APE	%	0,00	0,00	0,00
Computational Method	Net Area m2	143,99	142,49	286,48
Traditional Method		144,00	142,58	286,58
APE	%	0,00	0,06	0,03

The first stage comparison is the volume of the slab. The maximum difference is 5,01% on the ground floor The overall difference is 2,40%.

The second stage is a gross area of the slab. All the results are the same value.

The third stage is the net area. The maximum difference is 0,06%. The least difference is 0,00% on the ground floor. The overall result of the difference is 0,03%.

4.7. RES-4 QTO RESULTS

4.7.1. RES-4 WALL QTO RESULT

The table below also shows the wall overall result of the comparison between BIM-based and computational method (**Table 4.61**).

Table 4.61 RES-4 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Volume m3	68,13	86,64	85,53	96,28	336,58
BIM- Based Method		64,49	79,56	62,87	85,74	292,66
APE	%	5,64	8,90	36,04	12,29	15,01
Computational Method	Surface Area m2	286,34	486,04	390,35	554,46	1717,19
BIM- Based Method		319,11	475,53	317,77	513,07	1625,48
APE	%	10,27	2,21	22,84	8,07	5,64
Computational Method	Area m2	36,96	45,49	44,31	44,49	171,25
BIM- Based Method		42,91	50,47	52,07	50,06	195,51
APE	%	13,87	9,87	14,90	11,13	12,40

The wall comparison results are examined in three stages. The first stage is the volume. The maximum difference is 36,04% on the second floor. The least difference is 5,64% on the first floor. The overall result of the difference is 15,01%.

The second stage of the wall comparison is the surface area. The maximum difference is 22,84% on the second floor. The least difference is 2,21% on the first floor. The overall result of the difference is 5,64%.

The third stage is the base area of the wall. The maximum difference is 14,90% on the second floor. The least difference is 4,70% on the second floor. The overall result of the difference is 12,40%.

The table below also shows the wall overall result of the comparison between traditional and computational method (**Table 4.62**).

Table 4.62 RES-4 wall QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Volume m3	68,13	86,64	85,53	96,28	336,58
Traditional Method		68,36	85,05	67,5	94,31	315,22
APE	%	0,34	1,87	26,71	2,09	6,78
Computational Method	Surface Area m2	286,34	486,04	390,35	554,46	1717,19
Traditional Method		334,33	505,64	342,72	517,55	1700,24
APE	%	14,35	3,88	13,90	7,13	1,00
Computational Method	Area m2	36,96	45,49	44,31	44,49	171,25
Traditional Method		25,71	32,04	25,33	31,77	114,85
APE	%	43,76	41,98	74,93	40,04	49,11

The first stage of the comparison is volume. The maximum difference is 26,71% on the second floor. The least difference is 0,34% on the ground floor. The overall result of the difference is 6,78%.

The second stage of the comparison is the surface area of the wall. The maximum difference is 14,35% on the ground floor. The least difference is 3,88% on the first floor. The overall result of the difference is 1,00%.

The third stage is the base area of the wall. The maximum difference is 74,93% on the second floor. The least difference is 40,04% on the third floor. The overall difference is 49,11%.

4.7.2. RES-4 WINDOW QTO RESULT

The table below also shows the window overall result of the comparison between BIM-based and computational method (**Table 4.63**).

Table 4.63 RES-4 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Surface Area m3	75,34	70,92	79,10	67,31	292,67
BIM- Based Method		81,84	87,56	84,46	85,38	339,24
APE	%	7,94	19,00	6,34	21,16	13,72
Computational Method	Area m2	9,10	8,61	8,83	8,83	35,37
BIM- Based Method		-	-	-	-	-
APE	%	-	-	-	-	-

Window QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

Table 4.64 RES-4 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Surface Area m3	75,34	70,92	79,10	67,31	292,67
Traditional Method		83,99	81,26	81,26	92,49	339,00
APE	%	10,29	12,72	2,65	27,22	13,66
Computational Method	Area m2	9,10	8,61	8,83	8,83	35,37
Traditional Method		9,10	8,61	8,83	8,83	35,37
APE	%	0,00	0,00	0,00	0,00	0,00

The first stage of the windows comparison is the surface area. The maximum difference is 21,16% on the third floor. The least difference is 6,34% on the second floor. The overall difference is 13,72%.

The table below also shows the window overall result of the comparison between traditional and computational method (**Table 4.64**).

The first stage of the window comparison is the surface area of the window. The maximum difference is 27,22% on the third floor. The least difference is 2,65% on the first floor. The overall result difference is 13,66%.

The second stage is the base area of the window. The maximum and minimum difference is the same value. Both of them is 0,00%. The overall result of the difference is 0,00%.

4.7.3. RES-4 DOOR QTO RESULT

The table below also shows the overall door result of the comparison between BIM-based and computational method (**Table 4.65**).

Table 4.65 RES-4 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Surface Area m2	24,49	76,44	34,86	90,62	226,41
BIM- Based Method		22,85	57,47	31,05	60,87	172,24
APE	%	7,18	33,01	12,27	48,87	31,45
Computational Method	Area m2	2,15	4,82	2,84	4,41	14,22
BIM- Based Method		-	-	-	-	-
APE	%	-	-	-	-	-

Door QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

The first stage of the door comparison is the surface area. The maximum difference is 33,01% on the first floor. The least difference is 7,18% on the ground floor. The overall difference is 31,45%.

The table below also shows the overall door result of the comparison between traditional and computational method (**Table 4.66**).

Table 4.66 RES-4 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Surface Area m2	24,49	76,44	34,86	90,62	226,41
Traditional Method		24,49	76,72	33,35	68,93	203,49
APE	%	0,00	0,36	4,53	31,47	11,26
Computational Method	Area m2	2,15	4,82	2,84	4,41	14,22
Traditional Method		2,14	4,82	2,84	4,41	14,21
APE	%	0,47	0,00	0,00	0,00	0,07

The first stage of the door comparison is the surface area. The maximum difference is 31,47% on the first floor. The least difference is 0,00% on the ground floor. The overall result of the difference is 11,26%.

The second stage is the base area of the door. The maximum difference is 0,47% on the ground floor. The least difference is 0,00% on the first, second and third floor. The overall result of the difference is 0,07%.

The values in the comparison result data seem to be close with the difference between the two methods.

4.7.4. RES-4 COLUMN QTO RESULT

The table below also shows the overall column result of the comparison between BIM-based and computational method (**Table 4.67**).

Table 4.67 RES-4 column QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Volume m3	14,02	14,02	14,02	0,00	42,06
BIM- Based Method		27,56	27,56	27,56	0,00	82,68
APE	%	49,13	49,13	49,13	0,00	49,13
Computational Method	Surface Area m2	19,87	19,87	19,87	0,00	59,61
BIM- Based Method		278,91	278,91	278,91	0,00	836,73
APE	%	92,88	92,88	92,88	0,00	92,88
Computational Method	Total Area m2	5,61	5,61	5,61	0,00	16,83
BIM- Based Method		11,53	12,53	12,13	0,00	36,19
APE	%	51,34	55,23	53,75	0,00	53,49

The column QTO has been examined under three sub-titles. These are the volume of the column, the surface area of column and base area of the column.

The first stage is the volume of the column. The maximum and minimum difference is the same value which is 49,13%.

The second stage is the surface area of the column. The maximum and minimum difference are 92,88%

The third stage is the base area of the column. The maximum difference is 53,75% on the second floor. The least difference is 53,49% on the ground floor.

The BIM-based system makes mistakes while calculating the surface area of the columns. Therefore, in this condition, the results differ at times

The table below also shows the overall column result of the comparison between traditional and computational method (**Table 4.68**).

The first stage is the volume of the column comparison. The maximum and minimum difference are 1,96% on all floors.

The second stage is the surface area. The maximum and minimum difference 1,39% on all floors.

The third stage is the base area of the column. The maximum and minimum difference are the same results of 0,00%. The overall result of the difference is 0,00%.

It is seen that the comparison results of all values are close to each other.

Table 4.68 RES-4 column QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Volume m3	14,02	14,02	14,02	0,00	42,06
Traditional Method		14,30	14,30	14,30	0,00	42,90
APE	%	1,96	1,96	1,96	0,00	1,96
Computational Method	Surface Area m2	19,87	19,87	19,87	0,00	59,61
Traditional Method		20,15	20,15	20,15	0,00	60,45
APE	%	1,39	1,39	1,39	0,00	1,39
Computational Method	Total Area m2	5,61	5,61	5,61	0,00	16,83
Traditional Method		5,61	5,61	5,61	0,00	16,83
APE	%	0,00	0,00	0,00	0,00	0,00

4.7.5. RES-4 SLAB QTO RESULT

The table below also shows the overall slab result of the comparison between BIM-based and computational method (**Table 4.69**).

The slab is examined three under sub-titles. These are volume, gross area and net area of the slab.

The first stage is the volume of the slab. The maximum difference is 10,74% on the third floor. The least difference is 2,76% on the ground floor. The overall result of the difference is 4,37%.

The second stage is the gross area. The maximum and minimum difference is the same value which is 0,00% on all floors.

Table 4.69 RES-4 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Volume m3	114,50	123,37	121,35	117,20	476,42
BIM- Based Method		111,42	127,73	127,73	131,30	498,18
APE	%	2,76	3,41	4,99	10,74	4,37
Computational Method	Gross Area m2	357,83	410,31	410,31	410,32	1588,77
BIM- Based Method		357,83	410,32	410,32	410,32	1588,79
APE	%	0,00	0,00	0,00	0,00	0,00
Computational Method	Net Area m2	357,83	385,55	379,24	390,65	1513,27
BIM- Based Method		357,83	399,15	399,15	410,32	1566,45
APE	%	0,00	3,41	4,99	4,79	3,39

Table 4.70 RES-4 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Total Result
Computational Method	Volume m3	114,50	123,37	121,35	117,20	476,42
Traditional Method		114,50	123,38	129,62	117,19	484,69
APE	%	0,00	0,01	6,38	0,01	1,71
Computational Method	Gross Area m2	357,83	410,31	410,31	410,32	1588,77
Traditional Method		357,83	410,32	410,32	410,32	1588,79
APE	%	0,00	0,00	0,00	0,00	0,00
Computational Method	Net Area m2	357,83	385,55	379,24	390,65	1513,27
Traditional Method		357,83	385,56	405,08	390,64	1539,11
APE	%	0,00	0,00	6,38	0,00	1,68

The third stage is the net area of the slab comparison. The maximum difference is 4,99% on the second floor. The least difference is 0,00% on the ground floor. The overall result of the difference is 3,39%.

The table above also shows the overall slab result of the comparison between traditional and computational method (**Table 4.70**).

The first stage comparison is the volume of the slab. The maximum difference is 6,38% on the second floor. The minimum difference is 0,00% on the ground floor. The overall difference is 1,71%.

The second stage is the gross area of the slab. All the results are of the same value which is 0,00%.

The third stage is the net area. The maximum difference is 6,38% on the second floor. The least difference is 0,00% on the ground and first floors. The overall result of the difference is 1,68%.

4.8. RES-5 QTO RESULTS

4.8.1. RES-5 WALL QTO RESULT

The table below also shows the wall overall result of the comparison between BIM-based and computational method (**Table 4.71**).

The wall comparison results are examined in three stages. The first stage is the volume. The maximum difference is 22,06% on the first floor. The least difference is 0,95% on the fourth floor. The overall result of the difference is 9,27%.

The second stage of the wall comparison is the surface area. The maximum difference is 19,22% on the first floor. The least difference is 4,03% on the third floor. The overall result of the difference is 4,56%.

The third stage is the base area of the wall. The maximum difference is 50,62% on the ground floor. The least difference is 1,69% on the first floor. The overall result of the difference is 19,86%.

Table 4.71 RES-5 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	57,61	56,5	73,71	78,84	78,84	79,448	424,94
BIM- Based Method		56,49	46,29	72,27	72,27	78,1	66,02	391,44
APE	%	1,98	22,06	1,99	9,09	0,95	20,34	8,55
Computational Method	Surface Area m2	363,47	356,75	439,62	478,09	489,48	493,38	2620,79
BIM- Based Method		348,47	299,5	459,56	459,56	516	423,45	2506,54
APE	%	4,30	19,12	4,34	4,03	5,14	16,51	4,56
Computational Method	Area m2	35,21	34,28	40,72	40,72	40,97	25,82	217,72
BIM- Based Method		71,3	33,71	42,16	42,16	45,41	36,93	271,67
APE	%	50,62	1,69	3,42	3,42	9,78	30,08	19,86

The wall comparison results are examined in three stages. The first stage is the volume. The maximum difference is 22,06% on the first floor. The least difference is 0,95% on the fourth floor. The overall result of the difference is 8,55%.

The second stage of the wall comparison is the surface area. The maximum difference is 19,22% on the first floor. The least difference is 4,03% on the third floor. The overall result of the difference is 4,56%.

The third stage is the base area of the wall. The maximum difference is 50,62% on the ground floor. The least difference is 1,69% on the first floor. The overall result of the difference is 19,86%.

The table below also shows the wall overall result of the comparison between traditional and computational method (**Table 4.72**).

The first stage of the comparison is volume. The maximum difference is 28,31% on the ground floor. The least difference is 0,26% on the first floor. The overall result of the difference is 12,55%.

Table 4.72 RES-5 wall QTO result of the comparison between computational method and computational method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	57,61	56,5	73,71	78,84	78,84	79,448	424,948
Traditional Method		44,9	56,65	68,09	68,09	68,56	71,28	377,57
APE	%	*28,31*	*0,26*	*8,25*	*15,79*	*14,99*	*11,46*	*12,55*
Computational Method	Surface Area m2	363,47	356,75	439,62	478,09	489,48	493,38	2620,79
Traditional Method		360,69	359,52	416,19	416,19	425,42	396,18	2374,19
APE	%	*0,77*	*0,77*	*5,63*	*14,87*	*15,06*	*24,53*	*10,39*
Computational Method	Area m2	35,21	34,28	40,72	40,72	40,97	25,82	217,72
Traditional Method		36,27	35,45	40,72	40,72	40,97	25,82	219,95
APE	%	*2,92*	*3,30*	*0,00*	*0,00*	*0,00*	*0,00*	*1,01*

The second stage of the comparison is the surface area of the wall. The maximum difference is 24,53% on the roof floor. The least difference is 0,77% on the ground and first floor. The overall result of the difference is 10,39%.

The third stage is the base area of the wall. The maximum difference is 3,30% on the first floor. The least difference is 0,00% on the second to fifth floors. The overall difference is 1,01%.

4.8.2. RES-5 WINDOW QTO RESULT

The table below also shows the window overall result of the comparison between BIM-based and computational method (**Table 4.73**).

Window QTO has been examined under two sub-titles. These are the surface area of the window and base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

The first stage of the windows comparison is the surface area. The maximum difference is 54,80% on the first floor. The least difference is 0,70% on the third floor. The overall difference is 15,14%.

Table 4.73 RES-5 window QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	100,40	115,32	126,44	155,18	155,18	70,97	723,49
BIM- Based Method		222,14	110,99	154,10	154,10	147,28	63,96	852,57
APE	%	54,80	3,90	17,95	0,70	5,36	10,96	15,14
Computational Method	Area m2	11,55	11,84	14,17	14,17	14,08	5,67	71,68
BIM- Based Method		-	-	-	-	-		-
APE	%	-	-	-	-	-		-

The table below also shows the window overall result of the comparison between traditional and computational method (**Table 4.74**).

Table 4.74 RES-5 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	100,40	115,32	126,44	155,18	155,18	70,97	723,49
Traditional Method		110,44	89,54	143,45	143,45	131,03	59,47	677,38
APE	%	9,09	28,79	11,86	8,18	18,43	19,34	6,81
Computational Method	Area m2	11,55	11,84	14,17	14,17	14,08	5,67	71,48
Traditional Method		11,55	8,17	14,17	14,17	14,07	5,67	67,80
APE	%	0,00	44,92	0,00	0,00	0,05	0,00	5,42

The first stage of the window comparison is the surface area of the window. The maximum difference is 28,79% on the first floor. The least difference is 8,18% on the third floor. The overall result difference is 6,81%.

The second stage is the base area of the window. The maximum difference is 44,92% on the first floor. The least difference is 0,05% on the fourth floor. The overall result of the difference is 5,42%.

4.8.3. RES-5 DOOR QTO RESULT

The table below also shows the overall door result of the comparison between BIM-based and computational method (**Table 4.75**).

Table 4.75 RES-5 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	32,2	44,11	38,82	38,82	42,76	0	196,71
BIM- Based Method		67,62	36,33	36,33	36,33	38,01	0	214,62
APE	%	52,38	21,41	6,85	6,85	12,50	0,00	8,34
Computational Method	Area m2	2,27	0,84	2,29	2,29	2,47	0	10,16
BIM- Based Method		-	-	-	-	-	0	-
APE	%	-	-	-	-	-	0	-

Door QTO has been examined under two sub-titles. These are the surface area of the window and base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

Table 4.76 RES-5 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Surface Area m2	32,20	44,11	38,82	38,82	42,76	42,76	196,71
Traditional Method		35,42	36,33	40,59	40,59	44,71	38,07	235,71
APE	%	9,09	21,41	4,36	4,36	4,37	12,32	16,54
Computational Method	Area m2	2,27	0,84	2,29	2,29	2,47	2,47	12,63
Traditional Method		2,27	0,84	2,29	2,29	2,47	2,19	12,35
APE	%	0,00	0,00	0,00	0,00	0,00	12,79	2,27

The first stage of the door comparison is the surface area. The maximum difference is 52,38% on the ground floor. The least difference is 6,68% on the first floor. The overall difference is 8,34%.

The table below also shows the overall door result of the comparison between traditional and computational method (**Table 4.76**).

The first stage of the door comparison is the surface area. The maximum difference is 12,32% on the roof floor. The least difference is 4,36% on the first and second floors. The overall difference is 16,54%.

4.8.4. RES-5 COLUMN QTO RESULT

The table below also shows the overall column result of the comparison between BIM-based and computational method (**Table 4.77**).

Table 4.77 RES-5 column QTO result of the comparison between computational method and BIM-based method

QTO METHOD	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	11,23	11,23	11,23	11,91	11,91	0,00	57,51
BIM- Based Method		13,54	13,54	13,54	13,54	13,54	0,00	67,70
APE	%	17,06	17,06	17,06	12,04	12,04	0,00	15,05
Computational Method	Surface Area m2	19,59	19,59	19,59	20,94	20,94	0,00	100,65
BIM- Based Method		103,69	103,69	103,69	103,69	103,69	0,00	518,45
APE	%	81,11	81,11	81,11	79,81	79,81	0,00	80,59
Computational Method	Total Area m2	4,16	4,16	4,16	4,41	4,41	0,00	21,30
BIM- Based Method		5,36	5,36	5,36	5,36	5,36	0,00	26,80
APE	%	22,39	22,39	22,39	17,72	17,72	0,00	20,52

The column QTO has been examined under three sub-titles. These are the volume of the column, the surface area of column and the base area of the column.

The first stage is the volume of the column. The maximum difference is 17,06% on the ground, first and second floors. The least difference is 12,04% on the third and fourth floors.

The second stage is the surface area of the column. The maximum difference is 81,11% on the ground, first and second floors. The least difference is 79,81% on the third and fourth floors.

The third stage is the base area of the column. The maximum difference is 22,39% on the ground, first and second floors. The least difference is 17,72% on the third and fourth floors.

The BIM-based system makes mistakes while calculating the surface area of the columns. Therefore, difference occurs in results at times.

The table below also shows the overall column result of the comparison between traditional and computational method (**Table 4.78**).

Table 4.78 RES-5 column QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	11,23	11,23	11,23	11,91	11,91	0,00	57,51
Traditional Method		11,23	11,23	11,23	11,91	11,91	0,00	57,51
APE	%	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Computational Method	Surface Area m2	19,59	19,59	19,59	20,94	20,94	0,00	100,65
Traditional Method		19,59	19,59	19,59	20,94	20,94	0,00	100,65
APE	%	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Computational Method	Total Area m2	4,16	4,16	4,16	4,41	4,41	0,00	21,30
Traditional Method		4,16	4,16	4,16	4,41	4,41	0,00	21,30
APE	%	0,00	0,00	0,00	0,00	0,00	0,00	0,00

All stages of the comparison results are the same value with each other.

4.8.5. RES-5 SLAB QTO RESULT

The table below also shows the overall slab result of the comparison between BIM-based and computational method (**Table 4.79**).

Table 4.79 RES-5 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	97,90	98,64	114,24	114,24	114,24	111,64	650,90
BIM- Based Method		91,66	109,83	109,83	109,83	109,83	109,83	640,81
APE	%	6,81	10,19	4,02	4,02	4,02	1,65	1,57
Computational Method	Gross Area m2	305,96	324,49	366,08	366,08	366,08	371,87	2100,56
BIM- Based Method		305,53	366,09	366,09	366,09	366,09	366,09	2135,98
APE	%	0,14	11,36	0,00	0,00	0,00	1,58	1,66
Computational Method	Net Area m2	305,96	308,25	357,00	357,02	357,00	348,89	2034,12
BIM- Based Method		305,53	357,01	357,01	357,01	357,01	357,01	2090,58
APE	%	0,14	13,66	0,00	0,00	0,00	2,27	2,70

The slab is examined three sub-titles. These are volume, gross area and net area of the slab.

The first stage is the volume of the slab. The maximum difference is 10,19% on the first floor. The least difference is 1,65% on the roof floor. The overall result of the difference is 1,57%.

The second stage is the gross area. The maximum difference is 11,36% on the first floor. The least difference is 0,05% on the second, third and fourth floors. The overall result of the difference is 1,66%

The third stage is the net area of the slab comparison. The maximum difference is 13,66% on the first floor. The least difference is 0,00% on the second, third and fourth floors. The overall result of the difference is 2,70%.

The table below also shows the overall slab result of the comparison between traditional and computational method (**Table 4.80**).

Table 4.80 RES-5 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Roof Floor	Total Result
Computational Method	Volume m3	97,90	98,64	114,24	114,24	114,24	111,64	650,90
Traditional Method		97,90	112,78	113,92	113,92	113,92	114,08	666,52
APE	%	0,00	12,54	0,28	0,28	0,28	2,14	2,34
Computational Method	Gross Area m2	305,96	324,49	366,08	366,08	366,08	371,87	2100,56
Traditional Method		305,95	366,08	366,08	366,08	366,08	371,87	2142,14
APE	%	0,00	11,36	0,00	0,00	0,00	0,00	1,94
Computational Method	Net Area m2	305,96	308,25	357,00	357,02	357,00	348,89	2034,12
Traditional Method		305,95	352,44	356,02	356,02	356,00	356,53	2082,96
APE	%	0,00	12,54	0,28	0,28	0,28	2,14	2,34

The first stage comparison is the volume of the slab. The maximum difference is 12,54% on the second floor. The minimum difference is 0,00% on the ground floor. The overall difference is 2,34%.

The second stage is the gross area of the slab. The maximum difference is 11,36% on the first floor. The least difference is 0,00% on all floors except the first floor. The overall difference is 1,94%.

The third stage is the net area. The maximum difference is 12,54% on the second floor. The least difference is 0,00% on the ground floor. The overall result of the difference is 2,34%.

4.9. PLB-1 QTO RESULTS

4.9.1. PLB-1 WALL QTO RESULT

Wall Quantity take-off result of the comparison between Computational Method and BIM-based method (**Table 4.81**).

Table 4.81 PLB-1 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	Total Result
Computational Method	Volume m3	97,17	97,17
BIM- Based Method		97,48	97,48
APE	%	0,32	0,32
Computational Method	Surface Area m2	562,08	562,08
BIM- Based Method		558,03	558,03
APE	%	0,72	0,72
Computational Method	Area m2	42,44	42,44
BIM- Based Method		43,56	43,56
APE	%	2,57	2,57

The wall comparison results are examined in three stages as the volume of the wall, surface area and the base area of the wall. The first stage has only one-floor difference value. The difference is 0,32% on the ground floor. The overall result of the difference is 0,32%.

The second stage is the surface area of the wall. The difference is 0,72% on the ground floor. The overall result of the difference is 0,72%.

The third stage is the base area of the wall. The difference is 2,571% on the ground floor. The overall result of the difference 2,57%.

The volume and the base area of the wall results are close each. However, the surface area of the wall has significant differences.

Wall Quantity take-off result of the comparison between Computational Method and the traditional method (**Table 4.82**).

The first stage of the wall result difference is volume. The difference is 9,69% on the ground floor. The overall result of the difference is 9,69%.

The second stage is the surface area. The difference is 9,47% on the ground floor and the overall result of the difference.

The final stage is the base area of the wall. The difference is 1,85% on the ground floor. The overall result of the difference is 1,85%.

Table 4.82 PLB-1 wall QTO result of the comparison between computational method and computational method

QTO_Method	Unit	Ground Floor	Total Result
Computational Method	Volume m3	97,17	97,17
Traditional Method		88,59	88,59
APE	%	9,69	9,69
Computational Method	Surface Area m2	562,08	562,08
Traditional Method		513,43	513,43
APE	%	9,47	9,47
Computational Method	Area m2	42,44	42,44
Traditional Method		43,24	43,24
APE	%	1,85	1,85

4.9.2. PLB-1 WINDOWS QTO RESULT

Window Quantity take-off result of the comparison between Computational Method and BIM-based method (**Table 4.83**).

Table 4.83 PLB-1 window QTO result of the comparison between computational method and BIM-based method

QTO METHODS	Unit	Ground Floor	Total Result
Computational Method	Surface Area m2	183,77	183,77
BIM- Based Method		181,82	181,82
APE	%	1,07	1,07
Computational Method	Area m2	11,02	11,02
BIM- Based Method		-	-
APE	%	-	-

Window QTO has been examined two under sub-titles. These are the surface area of the window and base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

The first stage of the windows comparison is the surface area. The maximum difference is 1,07% on the ground floor. The overall difference is 1,07%.

The table below also shows the window overall result of the comparison between traditional and computational method (**Table 4.84**).

Table 4.84 PLB-1 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	Total Result
Computational Method	Surface Area m2	183,77	183,77
Traditional Method		178,32	178,32
APE	%	3,06	3,06
Computational Method	Area m2	11,02	11,02
Traditional Method		10,60	10,60
APE	%	3,96	3,96

The first stage of the window comparison is the surface area of the window. The maximum difference is 3,06% on the ground floor. The overall result difference is 3,06%.

The second stage is the base area of the window. The maximum difference is 3,96% on the ground floor. The overall result of the difference is 3,96%.

4.9.3. PLB-1 DOOR QTO RESULT

The table below also shows the overall door result of the comparison between BIM-based and computational method (**Table 4.85**).

Table 4.85 PLB-1 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	Total Result
Computational Method	Surface Area m2	105,86	105,86
BIM- Based Method		107,21	107,21
APE	%	1,25	1,25
Computational Method	Area m2	4,93	4,93
BIM- Based Method		-	-
APE	%	-	-

Door QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

The first stage of the door comparison is the surface area. The floor and overall result of the difference are 1,25%.

The table below also shows the overall door result of the comparison between traditional and computational method (**Table 4.86**).

Table 4.86 PLB-1 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	Total Result
Computational Method	Surface Area m2	105,86	105,86
Traditional Method		102,44	102,44
APE	%	3,33	3,33
Computational Method	Area m2	4,93	4,93
Traditional Method		5,43	5,43
APE	%	9,21	9,21

The first stage of the door comparison is the surface area. The maximum difference is 3,33% on the ground floor. The overall difference is 3,33%.

The second stage is the base area of the door. The floor and overall result of the differences are 9,21%.

4.9.4. PLB-1 COLUMN QTO RESULT

The carrier system of this project is not reinforced concrete; there are no columns on the project.

4.9.5. PLB-1 SLAB QTO RESULT

The table below also shows the overall slab result of the comparison between BIM-based and computational method (**Table 4.87**).

The slab is examined three under sub-titles. These are volume, gross area and net area of the slab.

The first stage is the volume of the slab. The maximum difference is 39,60% on the ground floor. The overall result of the difference is 39,60%.

The second stage is the gross area. The maximum difference is 11,59% on the ground floor. The overall result of the difference is 11,59%

Table 4.87 PLB-1 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	Total Result
Computational Method	Volume m3	326,10	326,10
BIM- Based Method		233,60	233,60
APE	%	39,60	39,60
Computational Method	Gross Area m2	1019,06	1019,06
BIM- Based Method		913,24	913,24
APE	%	11,59	11,59
Computational Method	Net Area m2	1019,06	1019,06
BIM- Based Method		913,24	913,24
APE	%	11,59	11,59

Table 4.88 PLB-1 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	Total Result
Computational Method	Volume m3	326,10	326,10
Traditional Method		317,96	317,96
APE	%	2,56	2,56
Computational Method	Gross Area m2	1019,06	1019,06
Traditional Method		993,62	993,62
APE	%	2,56	2,56
Computational Method	Net Area m2	1019,06	1019,06
Traditional Method		993,62	993,62
APE	%	2,56	2,56

The third stage is the net area of the slab comparison. The maximum difference is 11,59% on the ground floor. The overall result of the difference is 11,59%.

The table below also shows the overall slab result of the comparison between traditional and computational method (**Table 4.88**).

All the comparison element results of the difference are the same value. The value is 2,56%.

4.10. COM-1 QTO RESULTS

4.10.1. COM-1 WALL QTO RESULT

Wall Quantity take-off result of the comparison between Computational Method and BIM-based method (**Table 4.89**).

Table 4.89 COM-1 wall QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	153,37	74,4	227,77
BIM- Based Method		168,06	70,67	238,73
APE	%	8,74	5,28	4,59
Computational Method	Surface Area m2	613,3	297,25	910,55
BIM- Based Method		673,39	295,41	968,80
APE	%	8,92	0,62	6,01
Computational Method	Area m2	35,37	35,2	70,57
BIM- Based Method		35,54	36,86	72,4
APE	%	0,48	4,50	2,53

The wall comparison results are examined in three stages as the volume of the wall, the surface area and the base area of the wall. The first stage is the volume of the wall. The maximum difference is 8,74% on the ground floor. The least difference is 5,28% on the first floor. The overall result of the difference is 4,59%.

The second stage is the surface area. The maximum difference is 8,92% on the ground floor. The least difference is 0,62% on the first floor. The overall result of the difference is 6,01%.

The third stage is the base area of the wall. The maximum difference is 4,50% on the first floor. The least difference is 0,48% on the ground floor. The overall result of the difference is 2,53%.

Wall Quantity take-off result of the comparison between Computational Method and the traditional method (**Table 4.90**).

Table 4.90 COM-1 wall QTO result of the comparison between computational method and the traditional method

QTO METHODS	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m2	153,37	74,4	227,77
Traditional Method		155,71	61,18	216,89
APE	%	1,50	21,61	5,02
Computational Method	Surface Area m2	613,3	297,25	910,55
Traditional Method		622,07	243,04	865,11
APE	%	1,41	22,30	5,25
Computational Method	Area m2	35,37	35,2	70,57
Traditional Method		27	21,63	48,63
APE	%	31,00	62,74	45,12

The first stage is the volume of the wall. The maximum difference is 21,61% on the first floor. The least difference is 1,50% on the ground floor. The overall result of the difference is 5,02%.

The second stage is the surface area. The maximum difference is 22,30% on the first floor. The least difference is 1,41% on the ground floor. The overall result of the difference is 5,25%.

The third stage is a base area of the wall. The maximum difference is 62,74% on the first floor. The least difference is 31,00% on the ground floor. The overall result of the difference is 45,12%.

4.10.2. COM-1 WINDOW QTO RESULT

Window Quantity take-off result of the comparison between Computational Method and BIM-based method (**Table 4.91**).

Table 4.91 COM-1 window QTO result to comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	92,77	131,44	224,21
BIM- Based Method		96,28	118,97	215,25
APE	%	3,65	10,48	4,16
Computational Method	Area m2	4,37	13,13	17,50
BIM- Based Method		-	-	-
APE	%	-	-	-

Window QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

The first stage of the windows comparison is the surface area. The maximum difference is 10,48% on the first floor. The least difference is 3,65% on the ground floor. The overall difference is 4,16%.

The table below also shows the window overall result of the comparison between traditional and computational method (**Table 4.92**).

Table 4.92 COM-1 window QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	92,77	131,44	224,21
Traditional Method		96,25	131,45	227,70
APE	%	3,62	0,01	1,53
Computational Method	Area m2	4,37	13,13	17,50
Traditional Method		4,37	13,16	17,53
APE	%	0,00	0,23	0,17

The first stage of the window comparison is the surface area of the window. The maximum difference is 3,62% on the ground floor. The least difference is 0,01% on the first floor. The overall result difference is 1,53%.

The second stage is the base area of the window. The maximum difference is 0,23% on the first floor. The least difference is 0,00% on the ground floor. The overall result of the difference is 0,17%.

4.10.3. COM-1 DOOR QTO RESULT

The table below also shows the overall door result of the comparison between BIM-based and computational method (**Table 4.93**).

Table 4.93 COM-1 door QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	72	7,5	79,5
BIM- Based Method		71,6	7,5	79,1
APE	%	0,56	0,00	0,51
Computational Method	Area m2	4	0,75	4,75
BIM- Based Method		-	-	-
APE	%	-	-	-

Door QTO has been examined under two sub-titles. These are the surface area of the window and the base area of the window. However, with the BIM-based method, it is not possible to calculate the base area of the window.

The first stage of the door comparison is the surface area. The maximum difference is 0,56% on the ground floor. The least difference is 0,00% on the first floor. The overall difference is 0,51%.

The table below also shows the overall door result of the comparison between traditional and computational method (**Table 4.94**).

The first stage of the door comparison is the surface area. The maximum difference is 22,03% on the ground floor. The least difference is 0,00% on the first floor. The overall difference is 19,55%.

The second stage is the base area of the door. The maximum difference is 0,25% on the ground floor. The least difference is 0,00% on the first floor. The overall difference is 0,21%.

Table 4.94 COM-1 door QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Surface Area m2	72,00	7,50	79,50
Traditional Method		59,00	8,21	67,21
APE	%	22,03	8,65	18,29
Computational Method	Area m2	4,00	0,75	4,75
Traditional Method		3,99	0,75	4,74
APE	%	0,25	0,00	0,21

The first stage of the door comparison is the surface area. The maximum difference is 22,03% on the ground floor. The overall difference is 18,29%.

The second stage is the base area of the door. The maximum difference is 0,25% on the ground floor. The overall difference is 0,21%.

4.10.4. COM-1 COLUMN QTO RESULT

The table below also shows the overall column result of the comparison between BIM-based and computational method (**Table 4.95**).

Table 4.95 COM-1 column QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m2	9,79	4,90	14,69
BIM- Based Method		12,69	6,35	19,04
APE	%	22,85	22,85	22,85
Computational Method	Surface Area m2	24,48	12,24	36,72
BIM- Based Method		69,85	34,93	104,78
APE	%	64,95	64,95	64,95
Computational Method	Total Area m2	1,44	0,72	2,16
BIM- Based Method		2,02	1,01	3,03
APE	%	28,71	28,71	28,71

The column QTO has been examined under three sub-titles. These are the volume of the column, the surface area of column and base area of the column.

The first stage is the volume of the column. The floor and overall result of the differences are 22,85%

The second stage is the surface area of the column. The floor and overall result of the differences are 64,95%

The third stage is the base area of the column. The floor and overall result of the differences are 28,71%

The BIM-based system makes mistakes while calculating the surface area of the columns. Therefore, some differences in the result can been seen.

The table below also shows the overall column result of the comparison between traditional and computational method (**Table 4.96**).

Table 4.96 COM-1 column QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m2	9,79	4,90	14,69
Traditional Method		9,82	4,91	14,73
APE	%	0,31	0,31	0,31
Computational Method	Surface Area m2	24,48	12,24	36,72
Traditional Method		24,62	12,31	36,93
APE	%	0,57	0,57	0,57
Computational Method	Total Area m2	1,44	0,72	2,16
Traditional Method		1,62	0,81	2,43
APE	%	11,11	11,11	11,11

The first stage is the volume of the column. The floor and overall result of the differences are 0,31%

The second stage is the surface area of the column. The floor and overall result of the differences are 0,57%

The third stage is the base area of the column. The floor and overall result of the differences are 11,11%

4.10.5. COM-1 SLAB QTO RESULT

The table below also shows the overall slab result of the comparison between BIM-based and computational method (**Table 4.97**).

Table 4.97 COM-1 slab QTO result of the comparison between computational method and BIM-based method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	202,15	195,38	397,53
BIM- Based Method		189,48	173,33	362,81
APE	%	6,69	12,72	9,57
Computational Method	Gross Area m2	631,73	631,76	1263,49
BIM- Based Method		631,61	599,39	1231,00
APE	%	0,02	5,40	2,64
Computational Method	Net Area m2	631,73	610,56	1242,29
BIM- Based Method		631,61	577,76	1209,37
APE	%	0,02	5,68	2,72

The first stage is the volume of the slab. The maximum difference is 12,72% on the first floor. The least difference is 6,69% on the ground floor. The overall result of the difference is 9,57%.

The second stage is the gross area. The maximum difference is 5,40% on the first floor. The least difference is 0,02% on the ground floor. The overall result of the difference is 2,64%

The third stage is the net area of the slab comparison. The maximum difference is 5,68% on the first floor. The least difference is 0,02% on the ground floor. The overall result of the difference is 2,72%.

The table below also shows the overall slab result of the comparison between traditional and computational method (**Table 4.98**).

The first stage comparison is the volume of the slab. All comparison results differences are the same value. It is 0,00%.

The second stage is the gross area of the slab. The maximum difference is 2,27% on the first floor. The least difference is 0,00% on the ground floor. The overall difference is 1,12%.

The third stage is the net area. The maximum difference is 0,07% on the first floor. The least difference is 0,00% on the ground floor. The overall result of the difference is 0,03%.

Table 4.98 COM-1 slab QTO result of the comparison between computational method and the traditional method

QTO_Method	Unit	Ground Floor	First Floor	Total Result
Computational Method	Volume m3	202,15	195,38	397,53
Traditional Method		202,15	195,38	397,53
APE	%	0,00	0,00	0,00
Computational Method	Gross Area m2	631,73	631,76	1263,49
Traditional Method		631,73	617,73	1249,46
APE	%	0,00	2,27	1,12
Computational Method	Net Area m2	631,73	610,56	1242,29
Traditional Method		631,73	610,96	1242,69
APE	%	0,00	0,07	0,03

CHAPTER FIVE
DISCUSSION

5.1. TEST OF HYPOTHESES

The current study assumed that results obtained from proposed parametric/computational pipeline would yield better results than the results from other methods considered in the present work, which were BIM and traditional labour-intensive approach. In this empirical research design, 10 random building case, each consists of hundreds of different building elements are selected. For each building element in each building case, the quantities are estimated using computational, BIM, and traditional methods. 3 architectural offices agreed to participate the study. The selected cases are distributed to these offices, and they estimated the building quantities for each element. The average of their estimation was recorded as the results obtained from traditional method. All results were presented in Chapter 4, exhaustively.

The obvious pitfall of such study design is the lack of reference value. All values were estimations, and one cannot argue on which estimation method provides more accurate results compared to others. To tackle with the issue, 30 random building elements were sampled out of hundreds of building elements from 10 building cases. To conduct formal test of hypothesis, the current work employed this sample of 30 building elements which were given in **Table 5.1**.

With extreme caution and effort, the quantities of these 30 randomly sampled building elements were calculated in person which were assumed to be actual measurements of sampled building quantities. Therefore, they served as the reference values through the process of hypotheses test. Reference values of randomly selected building elements along with estimations obtained from traditional, BIM, and proposed computational approaches were provided in **Table 5.2**. More, **Table 5.2** reported absolute percentage errors (APE) of estimation values obtained from each method for each sampled building element.

Table 5.1 Sampled building elements employed through test of hypotheses

ID	Validation Case	Building Element / Unit	Floor
01	RES-1	Columns Area / m2	First Floor
02	RES-3	Columns Area / m2	First Floor
03	RES-4	Columns Area / m2	Third Floor
04	MIX-1	Columns Surface Area / m2	Third Floor
05	MIX-2	Columns Surface Area / m2	Second Floor
06	MIX-4	Columns Volume / m3	Ground Floor
07	RES-5	Door / Surface Area / m2	First Floor
08	COM-1	Door Surface Area /m2	First Floor
09	MIX-3	Door Surface Area /m2	Second Floor
10	MIX-4	Door Surface Area /m2	Second Floor
11	PLB-1	Door Surface Area /m2	Ground Floor
12	RES-2	Door Surface Area /m2	Roof Floor
13	MIX-1	Slab Gross Area / m2	Roof Floor
14	RES-4	Slab Gross Area / m2	Ground Floor
15	MIX-2	Slab Net Area / m2	Roof Floor
16	MIX-3	Slab Volume / m3	First Floor
17	MIX-4	Slab Volume / m3	First Floor
18	RES-3	Slab Volume / m3	Ground Floor
19	MIX-2	Wall Area / m2	Ground Floor
20	RES-4	Wall Area / m2	Second Floor
21	COM-1	Wall Surface Area / m2	First Floor
22	PLB-1	Wall Surface Area / m2	Ground Floor
23	MIX-3	Wall Volume / m3	Ground Floor
24	RES-5	Wall Volume / m3	Ground Floor
25	MIX-1	Windows Surface Area /m2	Ground Floor
26	MIX-1	Windows Surface Area /m2	Roof Floor
27	MIX-4	Windows Surface Area /m2	Second Floor
28	RES-4	Windows Surface Area /m2	Third Floor
29	RES-4	Windows Surface Area /m2	Second Floor
30	RES-4	Windows Surface Area /m2	Ground Floor

Table 5.2 Comparative results of quantity estimation from sampled building elements using three methods

ID	Reference Value	Traditional		BIM		Computational	
		Value (m^3/m^2)	APE (%)	Value (m^3/m^2)	APE (%)	Value (m^3/m^2)	APE (%)
01	2,65	2,65	0,0	2,75	3,77	2,5	5,66
02	2,26	2,27	0,44	2,28	0,88	2,26	0,00
03	5,61	5,62	0,18	6,7	19,43	5,61	0,00
04	27,3	27,3	0,00	35	28,21	27,3	0,00
05	34,11	36,72	7,65	38	11,40	37,75	10,67
06	29,45	32,22	9,41	28,48	3,29	31,81	8,01
07	44,05	36,33	17,53	36,33	17,53	44,11	0,14
08	7,5	8,21	9,47	7,5	0,00	7,5	0,00
09	48,15	50,071	3,99	40,34	16,22	48,11	0,08
10	77,95	78,475	0,67	79,25	1,67	78,44	0,63
11	109,72	102,447	6,63	107,21	2,29	105,86	3,52
12	8,7	7,68	11,72	10,5	20,69	8,64	0,69
13	179,89	172,85	3,91	181,76	1,04	179,89	0,00
14	358,08	357,83	0,07	357,31	0,22	357,83	0,07
15	182,21	177,54	2,56	181,43	0,43	182,21	0,00
16	113,52	130,09	14,60	124,46	9,64	113,52	0,00
17	164,59	163,73	0,52	116,76	29,06	164,59	0,00
18	46,07	43,87	4,78	50,3	9,18	46,07	0,00
19	18,1	14,69	18,84	19,39	7,13	18,16	0,33
20	45,82	25,33	44,72	52,07	13,64	44,31	3,30
21	298,225	243,04	18,50	295,41	0,94	297,25	0,33
22	561,1	513,433	8,50	558,03	0,55	562,08	0,17
23	38,58	34,77	9,88	41,08	6,48	38,33	0,65
24	57,59	44,9	22,04	56,49	1,91	57,61	0,03
25	64,64	55,11	14,74	63,71	1,44	64,79	0,23
26	13,66	9,2	32,65	14,96	9,52	12,66	7,32
27	154,925	154,725	0,13	195,31	26,07	154,96	0,02
28	79,926	81,26	1,67	84,46	5,67	79,1	1,03
29	79,926	81,26	1,67	87,56	9,55	70,92	11,27
30	74,84	83,99	12,23	81,84	9,35	75,34	0,67
Mean Absolute Percentage Error (%)			9,64		9,21		1,89

Hypotheses considered in the current work and the appropriate statistical test to conduct the tests were provided in Section 3.5, exhaustively. Recall, the first hypothesis assumes no significant difference in results from proposed computational approach and reference (actual) values. **Table 5.3** provided paired *t*-test results for this hypothesis.

Table 5.3 Results of paired t-test for $H_{0,1}$ against $H_{alt,1}$

	N	Mean	StDev	SE Mean
Reference	30	97,6	122,2	22,3
Computational	30	97,3	122,2	22,3
Difference	30	0,321	2,02	0,37

Based on the values provided above the *t* statistic was computed as 0,87 whereas the probability of the test statistic p(*t*) was computed as 0,391. The result indicates that the mean of differences among two samples is not significant at 0,05 level. Therefore, the null hypothesis cannot be rejected. That is, the evidence from empirical work is conclusive to suggest that there are no significant differences between the results obtained from actual values and proposed parametric/computational approach.

Second and third hypothesis considered in the current work was related to comparison between estimation accuracy of quantity take-off methods under study. According, the current study assumed that proposed parametric/computational method would outperform the traditional and BIM-based approaches. To test these hypotheses, the current work compared absolute percentage errors. The results obtained from test of hypotheses was given in **Table 5.4** and **Table 5.5**, respectively.

Table 5.4 Result of paired t-test for $H_{0,2}$ against $H_{alt,2}$

	N	Mean (%)	StDev (%)	SE Mean (%)
APE_computational	30	1,83	3,31	0,60
APE_traditional	30	9,32	10,48	1,91
Difference	30	-7,5	10,60	1,94

Based on the values provided above the *t* statistic was computed as -3,87 whereas the probability of the test statistic p(*t*) was computed below 0,000 level. The result indicates that the mean of differences among two samples is significant at 0,01 level. Therefore, the null hypothesis can be rejected. That is, the evidence from empirical work is conclusive to suggest that the estimation error of the proposed parametric/computational approach is significantly smaller than the estimation error of traditional labour-intensive approach.

Table 5.5 Result of paired t-test for $H_{0,3}$ against $H_{alt,3}$

	N	Mean (%)	StDev (%)	SE Mean (%)
APE_computational	30	1,83	3,31	0,60
APE_BIM	30	8,91	8,80	1,61
Difference	30	-7,08	9,58	1,75

Table 5.5 presented the results of paired t-test that aims to compare estimation errors between computational and BIM-based approaches. Based on the values provided above the *t* statistic was computed as -4,05 whereas the probability of the test statistic p(*t*) was computed below 0,000 level. The result indicates that the mean of differences among two samples is significant at 0,01 level. Therefore, the null hypothesis can be rejected. That is, the evidence from empirical work is conclusive to suggest that the estimation error of the proposed parametric/computational approach is significantly smaller than the estimation error of BIM-based approach.

Based on empirical evidence, the current work noted all three prior assumptions were accepted at 5% significance level.

5.2. ON DETAIL INVESTIGATION OF RESULTS

Chapter 4 demonstrated detailed results of quantity take-off process on a project basis using 3 approaches considered in the current work. Detailed observations were performed on such results. Since the computational approach showed a significant convergence to actual results, the BIM-based system results and the traditional result system results are compared with the computational system results to find the difference values.

In the first step, the values of the BIM-based system were determined as the highest error rate according to the results of the research conducted. Dramatic differences have been identified in results of the study. For instance, in the MIX-2 project, the QTO result of the wall floor space difference was computed as 26%. Similarly, The RES-2 project showed a 27% difference in wall floor area results. On another instance, in the RES-3 project, 63% of the wall volume results and 15% of the RES-4 project were identified. In the RES-5 project, a 19% difference was found in the wall floor area results. The wall main title is divided into three subheaders. These subheadings have been reviewed for ten different projects. The BIM-based method results varied dramatically in five values in total.

The main title of the window was examined in two subheadings. The floor area of the windows was not calculated by the BIM-based system. According to the comparison value results, a 70% difference was found in the MIX-1 project. There was a difference of 17.58% in the MIX-3 project. There was a difference of 77.31% in the RES-2 project. There are differences in three projects in total.

The main title of the door was examined in two subheadings. The floor area of the door was not calculated by the BIM-based method. When comparing benchmark results, dramatic errors were identified in five projects. These are 34,48% in the MIX-2 project, 33,97% in the MIX-3 project, 73,72% in the RES-2 project, 28,26% in the RES-3 project, In the 4th project, 31.45 differences were detected.

The main title of the column was examined in three subheadings. When BIM-based method comparison results were considered, dramatic errors were detected in 9 out of 10 projects. In all projects except the RES-3 project, dramatic errors were identified in three sub-sections.

The main title of the slab was examined in three subheadings. When BIM-based method comparison results were considered, dramatic errors were detected in only two projects. These are RES-1 and PLB-1 projects. The volume of the slab errors is 79,76% in the RES-1 and 39,60% in the PLB-1. Other errors are 66,68% to gross area and 68,53% net area in the RES-1 project.

In the second step, the values of the traditional method were determined as the highest error rate according to the results of the research conducted. When traditional method comparison results were considered for wall results. 5 of the 10 projects were found to be faulty. A total of eight errors were identified in these five projects. Of these 8 erroneous outcomes, four are about the area covered in the floor of the wall. These results are 116,96% in the RES-1, 137,52% in the RES-2, 49,11% in the RES-4 and 45,11 in the COM-1. Two of the remaining faults were found to be for wall surface area and the other two for wall volume result. The error result of the surface area is 62,48% in the MIX-3 and 111,17% in the RES-2. The error result of the volume is 66,91% in the MIX-3 and 78,54% in RES-2.

The main title of the window was examined in two subheadings. When the traditional method comparison results were considered. Two of the ten projects were found to be dramatic errors. These are 25,44% in RES-2 for the base area of the window and 18,80% in RES-4 for the surface area of the window.

The main title of the door was examined in two subheadings. When the traditional method comparison results were considered. Four of the ten projects were found to be errors.

Three of the detected faults are related to the surface area results, and the other two are connected to the area covered by the door. The error result of the surface area of the door is 29,13% in the RES-2, 16,71% in the PLB-1 and 19,55% in COM-1. The error result of the base area is 18,99% in the RES-1 and 47,98% in the RES-2

According to the comparison results for the column elements of the conventional method, only one project has been found faulty. Two errors were detected in this project. These are 33,14% for surface area and 19,33% for the base area of the column.

The main title of the slab was examined in three subheadings. When the traditional method comparison results were considered. A dramatic difference in comparison results could not be determined.

Our results provide compelling evidence in the comparison of the methods. In evaluating these results, the BIM-based method gives an error for a total of six results in five projects in the wall QTO results. Within these faults, there are three subheadings; the volume, the surface area and the floor area of the wall are equally mistaken. It is difficult to detect a dramatic result in these mistakes.

The BIM-based method gives an error for a total of three faults in three projects in the windows QTO results. Because of 3 mistakes made in 10 projects, it has not been determined that there is an error for the BIM-based method for window QTO.

The BIM-based method gives an error for a total of five faults in ten projects. The BIM-based method makes a 50% error on the door QTO.

The BIM-based method gives an error for a total of nine faults in ten projects. The BIM-based method makes a 90% error on the column QTO: In particular, this ratio was found to be 100% in calculating the column surface area.

QTO result of the slab error rates in BIM-based method results was not seen as a problem dramatically.

The traditional method gives an error for a total of five faults in five projects in the wall QTO results. It was found that 50% of the detected defects were caused by the floor area of the wall, 25% by the surface area and the remaining 25% by the volume results.

The traditional methods give an error for a total of two faults in two projects in the window QTO result. It is difficult to detect a dramatic result in these mistakes.

The traditional methods give an error for a total five faults in four projects in the door QTO result. It was found that 80% of the detected faults were caused by the surface area of the door and the remaining 20% by the base area of the doors.

The traditional methods give an error for a total of two faults in one projects in the column QTO result. It was found that 50% of the detected faults were caused by the surface area of the column and the remaining 50% by the base area of the column.

There was not found any dramatic error in the slab QTO comparison by using the traditional method.

As a result, it was determined that the BIM-based method performed the most error in the column QTO result. Wall and door QTO results also show that this method does not work correctly. The traditional method is to make the most of the error in the wall QTO results. Other than that, the door metrical effects do not give the correct result either.

It has been determined that the results of the computational design method in terms of the data taken from these results made fewer errors than the other methods. The computational design method has obviously shown fewer mistakes than the different method results. In the project comparison phase, computational method data was accepted as correct data.

CHAPTER SIX
CONCLUSION

The current study aimed at reducing the error margin in quantity estimation practices, proposing a new parametric pipeline that may be useful for practitioners especially in the early design stages. Three different methods, the traditional, BIM-based and computational methods were used to examine 50 building elements from ten projects. Each building element consisted of an average of 3 subheadings and individually for each level of the projects. Hypotheses were tested using 30 randomly selected building elements as a sample to scientifically compare estimation accuracies obtained from three methods considered in the current study. According to the hypothesis results, proposed parametric/computational design method has significantly less error margin than the other methods. Such for any result obtained from an empirical study, the current work has certain limitations in interpreting the results due to the sample.

From theoretical perspective, the current work was able to make significant contribution to our existing debates in the relevant domain. To our knowledge, there is no proper comparison of these three methods in the literature that makes the calculation of QTO the selected joint project calculation targets.

The research proposed a new framework/pipeline to perform quantity calculations and obtaining these results with fewer errors. Urge of development of an automated pipeline which can be employed by architects in the early design phase arose from the absence of an effective method for investigating and evaluating the QTO of buildings. All calculation methods and comparisons for each building element are openly shared in great level of detail. In this regard, the study successfully fulfilled its practical aim and objectives. A Grasshopper plugin is currently being developed based on the pipeline presented in the current work.

Lastly, enhancing the content of the sample by including different building functions should be considered in future work. Doing so, we can test if the plausibility of the results in greater level.

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