www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

COMPARATIVE ANALYSIS OF QUANTITY TAKE-OFF IN CONCRETE, STEEL BARS AND FORMWORK IN APARTMENT BUILDINGS BASED ON CAD AND BIM METHODOLOGIES

SUBMITTED: October 2023
REVISED: February 2025
PUBLISHED: March 2025
EDITOR: Robert Amor
DOI: 10.36680/j.itcon.2025.008

Rodrigo Saavedra
Faculty of Engineering, Department of Civil Engineering, Universidad Andrés Bello, Chile
r.saavedraortega@uandresbello.edu

Walter Meléndez
Faculty of Engineering, Department of Civil Engineering, Universidad Andrés Bello, Chile
w.melndezbernardo@uandresbello.edu

Gonzalo Garcés
Faculty of Engineering, Universidad del Bío-Bío, ChileUniversitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
gegarces@ubiobio.cl

SUMMARY: *Building Information Modeling (BIM) prepares the quantity take-off (QTO) of the construction elements, helping in the management of the design and construction process and preparing the 3D visualization of the construction phases. BIM increases efficiency and gives users more control over construction-related tasks. Construction industry professionals are aware of the advantages of BIM, but because the software BIM is expensive and requires staff training, BIM is not yet widely used. The present investigation identifies the New Cycle building as a Case Study, in which inconsistencies were detected in the QTO, compared to the real quantities of budgeted materials, so the interested parties decided to implement BIM in the use of QTO as a mechanism of control. The central question addressed was: If BIM had been implemented at the tender stage, could it have provided benefits to the project? To do this, various parameters were evaluated that allowed a comparative analysis to be carried out between the results obtained through the use of the CAD and BIM methodology in the same project. In addition, the work processes associated with both methodologies were studied and the perception of CAD and BIM users in the Architecture, Engineering & Construction (AEC) industry was analyzed through the Delphi method. Using the Analytical Hierarchy Process (AHP) method, it was possible to evaluate and compare the two alternatives, CAD and BIM, in order to determine which of them would have been more effective in satisfying the objectives set in the project, considering various variables, both technical and economical. The study highlights the advantages of BIM over CAD for QTO in construction projects, providing valuable information for informed decision making in future projects. However, BIM adoption faces challenges such as the need for specialized training, industry resistance to change, complex workflows, and investments in software and hardware. To overcome these barriers, it is recommended to implement comprehensive training programs, foster a culture of innovation and collaboration, simplify BIM-QTO workflows, and explore scalable and accessible technological solutions.*

KEYWORDS: *Building Information Modeling; Quantity take-off; case study; Construction Projects.*

REFERENCE: *Rodrigo Saavedra, Walter Meléndez & Gonzalo Garcés (2025). Comparative analysis of quantity take-off in concrete, steel bars and formwork in apartment buildings based on CAD and BIM methodologies. Journal of Information Technology in Construction (ITcon), Vol. 30, pg. 159-184, DOI: 10.36680/j.itcon.2025.008*

1. INTRODUCTION

In the construction industry, as in any industry, effective cost and time management are crucial to achieving project success. Timely completion, cost control, and meeting quality and performance requirements define achievement (Parsamehr *et al.*, 2023). Improving work and production processes is essential for this success. Construction project stakeholders, including owners, architects and general contractors, are increasingly aware of ways to reduce time and costs, including cost estimating using BIM, as the architecture, engineering and construction (AEC) industry adopts Building Information Modeling (BIM) in its construction projects (Jin *et al.*, 2017; Gholizadeh, Esmaeili and Goodrum, 2018). Compared to conventional estimating methods, research studies have shown that using BIM for estimating reduces work time and errors and improves estimator performance (Peterson *et al.*, 2011; Kim, Chin and Kwon, 2019). However, the use of BIM estimation comes with several challenges, including: (1) a lack of knowledge and understanding of BIM on the part of the estimator; (2) implementing data sharing between various applications such as estimating software and BIM creation tools; and (3) limitations in maintaining relationships between cost information and construction elements modeled in three-dimensional (3D) objects (Aibinu and Venkatesh, 2014; Kim, Chin and Kwon, 2019).

BIM is characterized by being a methodology that optimizes performance and productivity in construction projects, achieving greater efficiency and collaboration in the processes. The highly detailed information available makes it possible to detect and eliminate conflicts and errors in modeling, as well as improve communication and planning (Garcés *et al*., 2025). These aspects ultimately bring about a reduction in costs and time in the project. This methodology allows architects, engineers and builders to develop projects effectively throughout their life cycle, which, in turn, it provides an important opportunity to optimize and streamline resource management at every stage of a construction project. In construction, costs are closely related to quantity take-off (QTO), through these, the quantities of materials necessary to develop a project are determined, resulting in the basis for calculating the costs associated with each element and, with this, preparing a detailed budget.

An inconsistency in the quantity extracted from building components can make the quantities calculated difficult. This is because the quantities used to prepare a budget during the design phase serve as a basis for calculating the tender price, and evaluating the suitability of construction cost when deciding on a general contract (Kim, Chin and Kwon, 2019), therefore, accurate measurements must be made to reduce the possibility of the total construction cost increasing or decreasing during construction (Ashworth and Perera, 2015; Hyari, 2016). Additionally, quantities that have been measured may be reflected in subcontracts with other companies. It is crucial to consistently estimate quantities at the bidding stage. For this reason, in construction projects that use BIM methodology, a BIM model divided into architecture, structure and mechanics, electricity and plumbing (MEP) is generated at different levels of development (LOD) for each element through consultation between participants (Wang *et al.*, 2016). As a result, there are numerous ways of expressing the models and components that make up BIM that can cause discrepancies in the resulting quantities.

This research compares the results of the quantity take-off based on traditional methodology, such as CAD, and on BIM methodology through a case study, which is a 16-story building plus two basements. The work processes associated with both methodologies were studied and the perception of CAD (Computer-Aided Design) and BIM (Building Information Modeling) users in the AEC industry was analyzed. The QTO of Concrete, reinforcing steel bars and formwork, prepared through CAD with which the budget of the New Cycle project was prepared, delivered in the bidding stage of the construction project, this is "QTO CAD"; and the QTO using the BIM methodology for this research is called "QTO BIM". The combination of these studies and analyses provided substantial information to determine whether the implementation of BIM would have provided better results than CAD in the case study. This study also presents what is the best alternative to have a more precise and effective QTO and budget, using the Delphi method, which is a prospective structured communication technique, developed as a systematic and interactive prediction method, which is based on a group of experts, to obtain essentially qualitative (Sackman, 1974; Ameyaw *et al.*, 2016), but relatively precise, information about the future, and using the Analytic Hierarchy Process (AHP) method, which is a structured technique for dealing with complex decisions (Darko *et al.*, 2019).

2. LITERATURE REVIEW

Each construction effort has unique calculations, such as preparing plans, quantity take-off, performing structural analysis, preparing the construction schedule, and constructing the project. The aforementioned tasks require the cooperation of multidisciplinary professionals and data flow management. On the other hand, the construction sector is very competitive, so construction companies must execute tasks quickly and economically. These objectives create significant stress on project stakeholders, making task execution vulnerable to errors (Ergen and Bettemir, 2022).

BIM is a convenient methodology for construction companies to manage the flow of data between project participants (Haider *et al.*, 2020; Garcés and Peña, 2022, 2023; Kwon *et al.*, 2023). Preparation of technical drawings, QTO and scheduling of construction tasks can be given as examples that are done with different software. Running construction management tasks in software has several benefits for contractors and engineers, as it reduces the risk of data extraction malfunctions, incompatibilities caused by version differences and the reworking of the documents prepared (Bradley *et al.*, 2016; Darko *et al.*, 2020).

QTO of building elements involves laborious manual calculations and is prone to errors. Bettemir (2018) proposed a methodology for computational workload and demand calculations of excavation, concreting and formwork quantities. Khosakitchalert, Yabuki and Fukuda (2019) used visual programming to prepare QTO of construction elements, such as floor and wall coverings. Kwon *et al.* (2023), to quantitatively validate the variation in the amount of reinforcement, various simplification tests were carried out based on BIM software and Length types of Processed Rebar Simplification (LPRS), thus quantitatively evaluating the degree of impact of the simplification on the amount of reinforcing materials, it can help prevent excessive increases in the material costs.

Choi, Kim and Kim (2015) prepared a schematic QTO estimation process for the preliminary design phase of the buildings. Data is extracted from the IFC model to Open BIM software. The method includes verification of data and data quality, a schematic estimation, and calculation of QTO. Liu, Lu and Al-Hussein (2016) developed an ontology-based semantic approach for QTO. For the system to work, entity relationships must be established between building components and the associated labour and materials that make up the ontology. The proposed system allowed for faster and more accurate QTO.

Olsen and Taylor (2017) used a survey to analyze the advantages of BIM software. Respondents cited the advantages of BIM, including faster QTO preparation and more accurate QTO than manually created QTO. In addition to this, if implemented early enough, BIM helps in risk identification. The complexity of BIM software and the possibility of entering obsolete data are disadvantages of BIM implementation. Kim, Chin and Kwon, (2019) examined differences in QTO calculations caused by the definition of object models. Definitions of compositely modeled objects and individually modeled objects are investigated, and the study concludes that up to 6% of the exact QTO value can be biased by definitions of compositely modeled objects. Individually modeled object definitions contain more information and consequently produce better results. Liu *et al.* (2022), in order to overcome the limitations of state-of-the-art BIM software that lacks all the data necessary for automatic and accurate QTO, proposed a new QTO model based on a knowledge model. The study suggests defining different types of slab-walls; slab beam; slab-column and slab-wall joint joints. Consequently, better QTO estimates are obtained.

Compared to manual calculations, quantity calculations performed in BIM take less time and can be more accurate (Ergen and Bettemir, 2022). Preparing the QTO BIM can help compare different construction methods. However, the use of BIM has some obstacles, for example, the development of a universal BIM is seriously hampered by discrepancies in codes, documentation and language (Migilinskas *et al.*, 2013).

Since the traditional QTO CAD approach requires between 50% and 80% of the total work time on estimates, extracting data from the model means that a QTO estimated with BIM can improve the productivity and accuracy of an estimator's work (Peterson *et al.*, 2011; Lawrence *et al.*, 2014). BIM allows estimators to check for errors and omissions in a design beforehand, which has improved estimating performance (Shen and Issa, 2010). Some previous studies identified activities such as connections between 3D objects and cost data, proposing an integration of data concerning cost and time to increase the use of BIM (Staub-French *et al.*, 2003; Lu, Won and Cheng, 2016; Meléndez, Saavedra and Garcés, 2024). Some studies focused on rough estimating, an approach that links quantities extracted from a spatial model with cost information from a parametric estimating model. Therefore, it is possible to estimate the construction cost either during the initial planning phase of the project or during its design phase (Jrade and Alkass, 2007; Choi, Kim and Kim, 2015). Despite these studies and the numerous uses and advantages of BIM, QTO with BIM has not yet been successfully implemented due to a lack of BIM experience and well-established conventional estimating practices (Boktor, Hanna and Menassa, 2014; Gholizadeh, Esmaeili and Goodrum, 2018). A review is necessary to ensure that BIM QTO complies with a measurement rule, and QTO with BIM still needs a manual process to integrate 3D object data and cost data (McCuen, 2015).

The use of the BIM methodology for QTO is explained in the methodology section, where a case study is carried out to compare the results of the QTO based on traditional methodology, such as CAD, and BIM, finally, it is identified which is the best alternative to have a more precise and effective QTO and budget. Then the results obtained are discussed and concluded, which offer a valuable and informed vision for making informed decisions for future construction projects in which the advantages of the implementation of BIM over CAD are considered, contributing to a change in perception about the adoption of new work methodologies.

3. QUANTITY TAKE-OFF (QTO) USING CAD AND BIM SOFTWARE

Traditionally, cost estimation in a construction project is mainly divided into two processes: (1) QTO for materials; and (2) calculation of costs and generation of an account of quantities, which are carried out using measurement rules or estimating manuals offered by owners and the government as a standard for calculating the required quantities of construction resources (Abanda, Kamsu-Foguem and Tah, 2017; Kim, Chin and Kwon, 2019). Since the 1990s, QTO has been calculated by importing from computer-aided design (CAD) drawings the dimensions required for measurement formulas (Saleh, 1999; Seeley and Winfield, 1999). More recently, the QTO has been determined by directly extracting quantities that comply with existing measurement rules from 3D objects in BIM (Staub-French *et al.*, 2003; Jrade and Alkass, 2007). QTOs can be extrapolated from the property values of BIM objects as component and material property values are assigned during the object modeling process. This differs from conventional estimating methods where dimensions are calculated from measurement formulas and imported into CAD drawings (Shen and Issa, 2010; McCuen, 2015).

When referring to Computer-Aided Design (CAD) software that is used to represent structural elements in 2D plans or 3D models, its application to develop QTO is a part of the calculation process. For QTO with this type of software, clear and detailed information must be available, expressed geometrically in plans, through sets of lines, symbols, labels and notes that represent all types of elements. These elements must be sized by the applicable requirements and criteria and follow a precise interpretation of the plans. The information collected from the plans must be transferred to spreadsheets external to the CAD software, in which ideally the calculations of total lengths, perimeters, areas, volumes and weights are automated, allowing to obtain the quantities of materials based on what is represented on the plans. In this way, Computer Aided Design (CAD) allows, through the use of software, to analyze designs in 2D. On the other hand, QTO BIM involves using a 3D digital model of a construction project to calculate the quantities of materials required (Monteiro and Poças Martins, 2013). BIM models provide an accurate and detailed representation of the project components. For Ergen and Bettemir (2022), the main benefit provided by the application of BIM software for QTO is that the risk of failures in data extraction is reduced, incompatibilities due to different versions are avoided and the need to redo previously prepared documents is eliminated.

By having a BIM model that contains detailed information on structural elements such as walls, slabs, columns, beams and others, the functions of the corresponding BIM software are used to select the specific elements that are desired QTO (Choi, Kim and Kim, 2015). The software allows you to automatically dimension the elements selected in the model, as well as generate reports on the quantities of materials according to the information added to the model. These QTO results are automatically updated if the model has been modified in any aspect, delivering accurate material quantities at all stages of the project (Olsen and Taylor, 2017).

Liu *et al.* (2022) point out that BIM has had revolutionary impacts on the conventional QTO process (QTO BIM), because quantities can be automatically taken from 3D models, making the QTO process more automated and reliable than conventional 2D methods (QTO CAD). This reliability is due to the precision that BIM presents as it is a parametric methodology, that is, it can automatically update the properties of the structural elements after modifications in the model design.

BIM is a methodology that allows you to optimize the processes linked to construction projects, increasing efficiency in information management. This methodology shows evident improvements in project management when contrasted with CAD, which is the traditional method of use (Denzer and Hedges, 2008; Yang *et al.*, 2020). However, given the knowledge of the benefits that its implementation brings, there are also reasons why its use is not yet widespread.

CAD and BIM workflows differ in how design, collaboration, and documentation are addressed in construction projects (Nugraha Bahar *et al.*, 2014; Brückner *et al.*, 2019). In CAD, a 2D or 3D drawing is created and detailed plans are generated, while in BIM a 3D digital model loaded with technical information is created and allows for simultaneous collaboration (Berwald, 2008). BIM also allows analysis and simulations to be carried out, automatically generating the necessary documentation. In addition, it facilitates project management, from design to operation and maintenance of the building.

3.1 Quantity take-off process flow in CAD

The QTO process flow in CAD consists of entering plans into CAD software and carrying out the study based on them, using spreadsheets to process the data (see Figure 1). QTOs depend on the understanding of plans, so early detection of inconsistencies is key to not obtaining results with errors associated with a bad study.

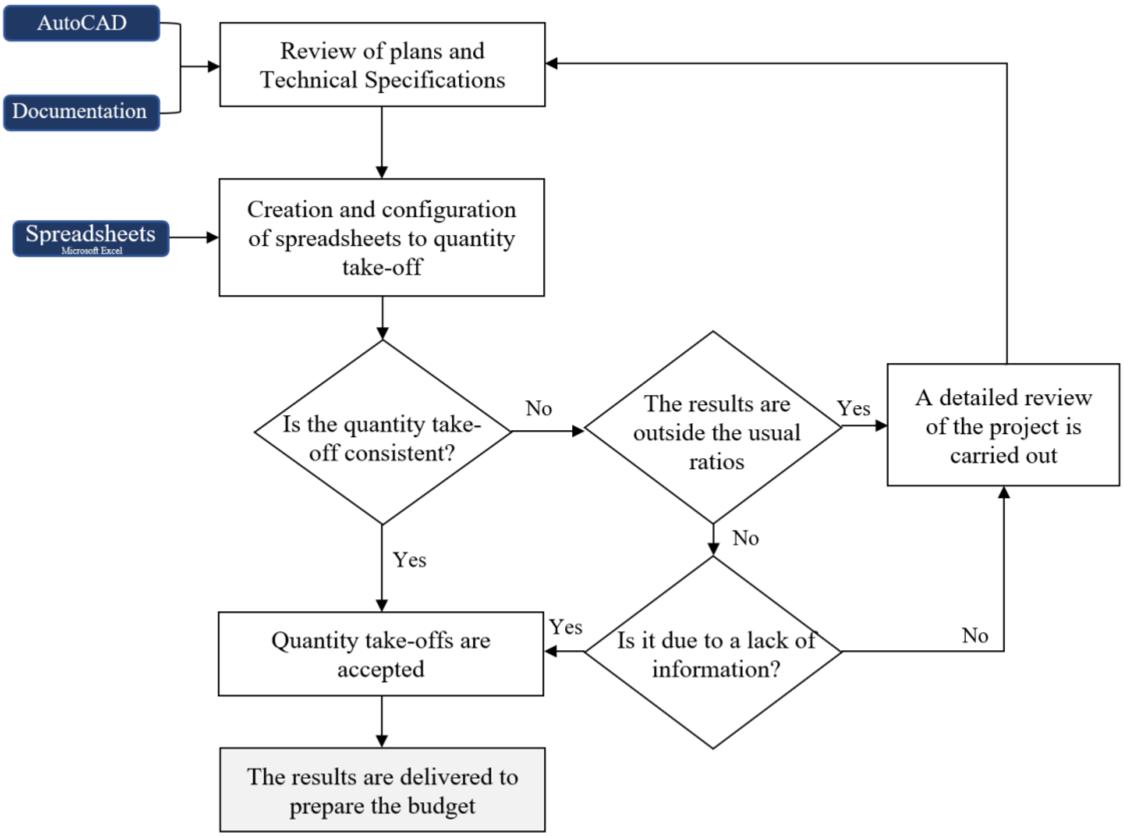


Figure 1: QTO CAD process flow.

3.2 Quantity take-off process flow in BIM

QTOs in BIM begin with planimetry in CAD software, therefore, the 3D model must be created according to the 2D indications. The great advantage that BIM models have is that the results of the developed QTOs are automatically updated in conjunction with model updates and changes (see Figure 2). BIM models integrate all project information. For this, there are iterative processes of data collection and model updating, updating the results without affecting the QTO calculation process.

The QTO processes in CAD and BIM differ in the review instances and their depth. Given the parameterization of the BIM models, revisions can be made considering that any modification will be updated automatically. Furthermore, the same reviews, as well as the calculations, are carried out in greater detail since, unlike CAD, the information processing is mostly done internally in the design software, without the need for external programs, avoiding possible transfer errors. Therefore, BIM work processes are denser and more iterative than CAD, however, this contributes to more detailed and efficient calculations, as well as more fluid processing of information (Sampaio, 2017).

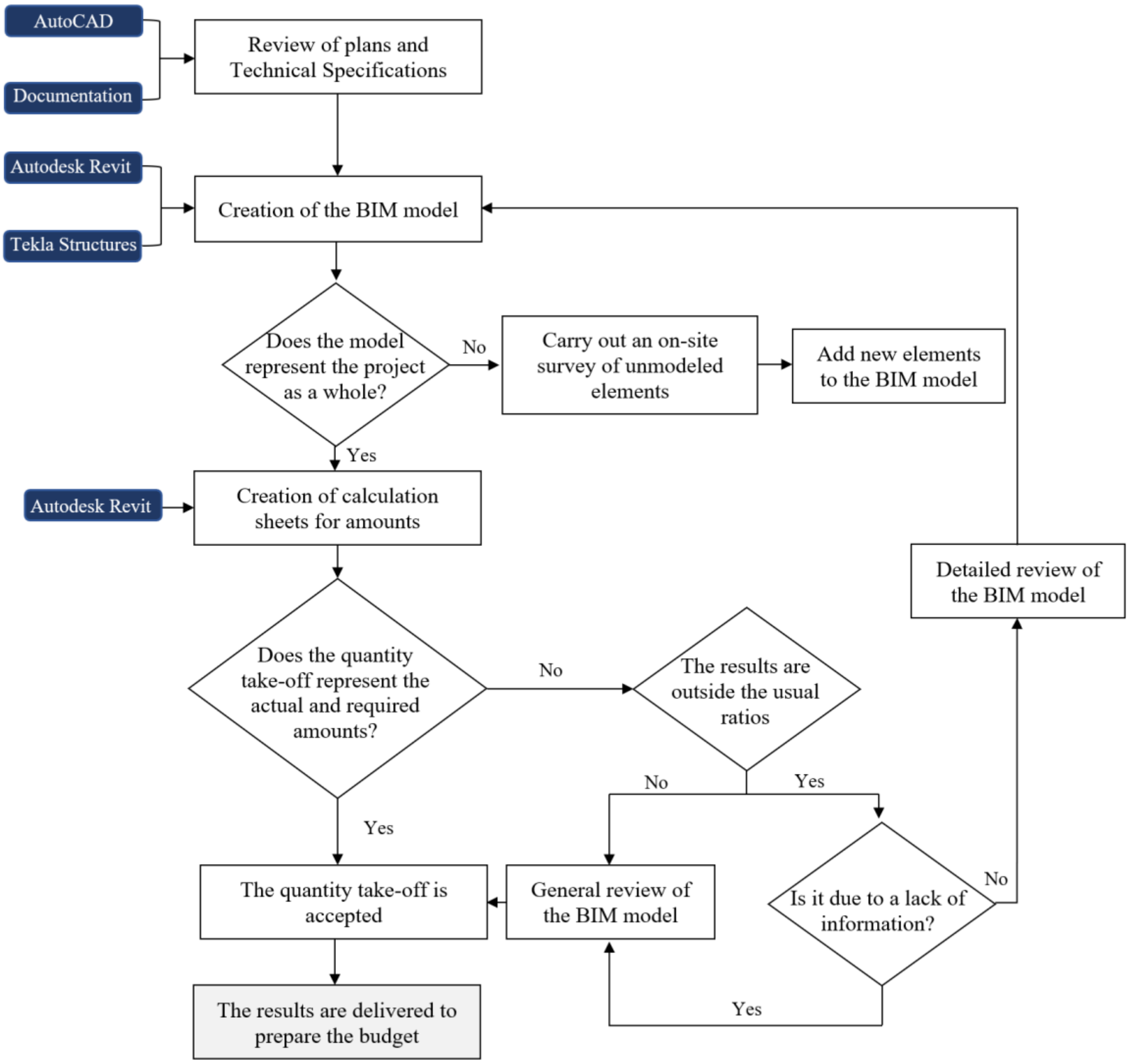


Figure 2: QTO BIM process flow.

4. METHODOLOGY

This research carries out a comparative analysis of quantities of concrete, reinforcing steel bars and formwork in high-rise buildings based on CAD and BIM methodologies. Figure 3 details the activities necessary to carry out this research, along with the tools and methodologies used in its development. To practically represent the research process, the research methodology in Design Sciences has been used (Design Science Research Methodology—DSRM) (Schimanski *et al.*, 2019; Ramanayaka, Olatunji and Weerasuriya, 2022), organized in 5 stages: (1 Identification of problems observed; (2) definition of objectives for a potential solution; (3) design and development; (4) demonstration; (5) evaluation.

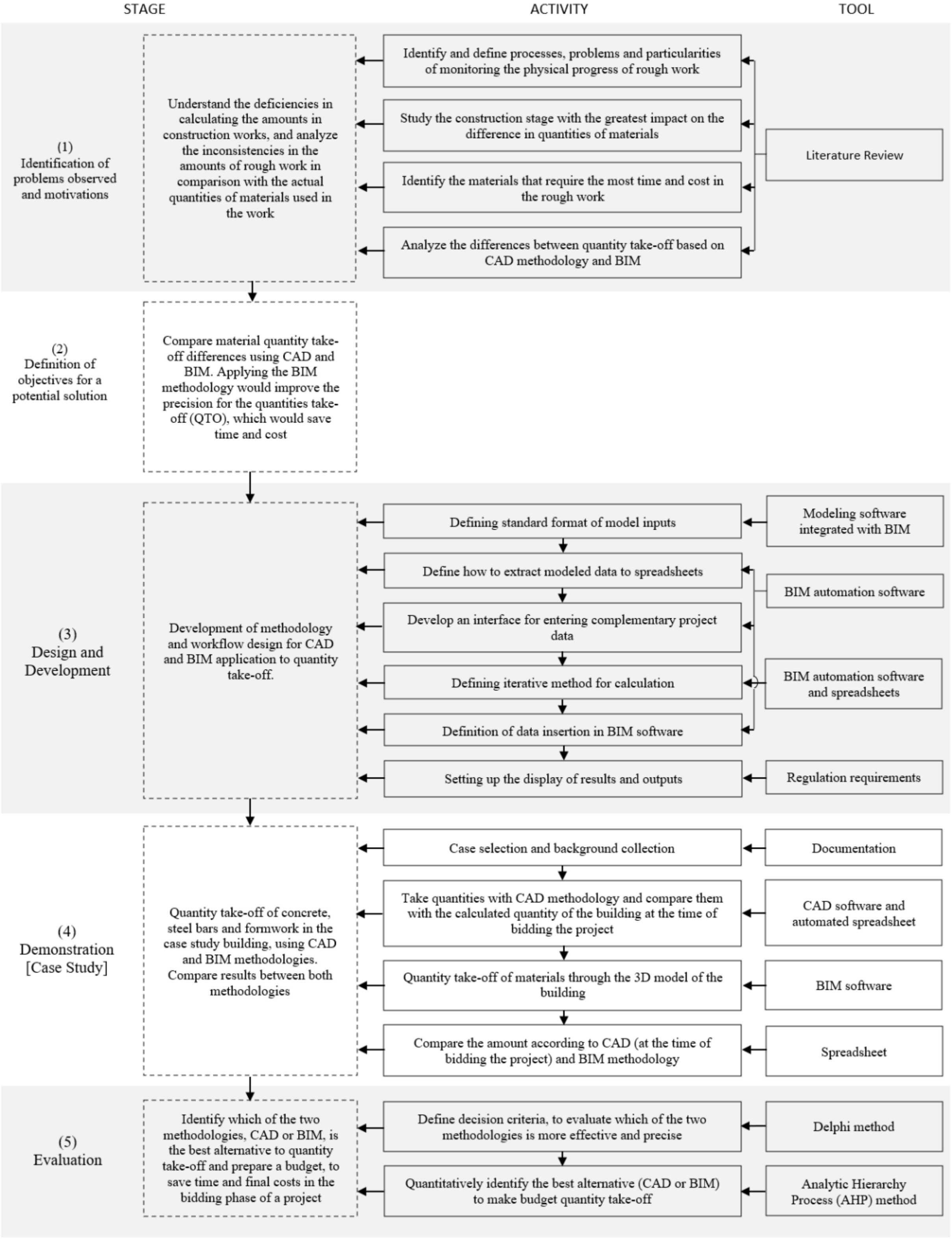


Figure 3: Research methodology.

In the first stage, a literature review was carried out based on the Web of Science and Scopus repositories, along with the review of manuals, guides and technical reports, to identify deficiencies and particularities of traditional methods for QTO and methods using BIM software. In parallel with this literature review, the potential of the BIM methodology that has been incorporated into the AEC industry for QTO in a more effective and precise way was studied. Based on the background information collected, in the second stage, the objective of a possible solution to the identified problems has been defined: the use of the BIM methodology as a possible solution to calculate QTO that could save time and cost.

In the third stage, the methodology and workflow design for the CAD and BIM application to calculate material quantities are developed. At this stage, the processes for QTO were analyzed using CAD and BIM. For this, the analysis of the process of a construction project was carried out, defining its stages. Then, a more specific study of the bidding stage defines their respective activities. Once the conventional bidding process is established, its process can be studied in depth, highlighting the stages in which the QTO appears as the tool to initiate the budget. Finally, the QTO development workflow using CAD for the New Cycle Building and the QTO development workflow in BIM used in the case study are analyzed.

In the fourth stage, the workflow described for the building case study was implemented. To carry out the QTO using CAD, it is necessary to have architectural plans, structure, specialties and details in CAD software, with which all the elements that make up the structure to be built can be dimensioned and these data transferred to calculation sheets that present the totals associated with each element. On the other hand, QTOs can be carried out using BIM software, which contains a three-dimensional model of the project and integrates information on both structure and specialties in order to obtain the quantities of materials with a high level of detail. By the above, in this research a comparative analysis was developed between the QTO processes of gross work carried out using CAD and BIM methodologies. For this, the quantities of materials in a case study are taken as a basis, specifically the New Cycle Building, in Chile. This building is characterized by using BIM models during its development. In the first instance, a structure model was developed that contains all the steel bars to reinforce the building, which made it possible to optimize the installation, as well as to know the precise amount of steel required. Along with this, in the design stage, an Integrated BIM Model was developed in order to control the development of activities. As the project was ongoing, it was realized that the QTOs of the materials budgeted in the bidding stage at the bidding stage, using CAD, presented significant differences concerning the quantities of materials used in reality. Given this difference, the 3D model of the building was used to determine the actual quantities of materials used. In this stage, the QTO processes that were carried out to prepare the project budget will be studied and their differences will be compared using the CAD methodology. Likewise, these QTO differences will be compared with the quantities obtained using the BIM methodology. The purpose is to determine how significant the application of one methodology or another is in the QTOs of the same project.

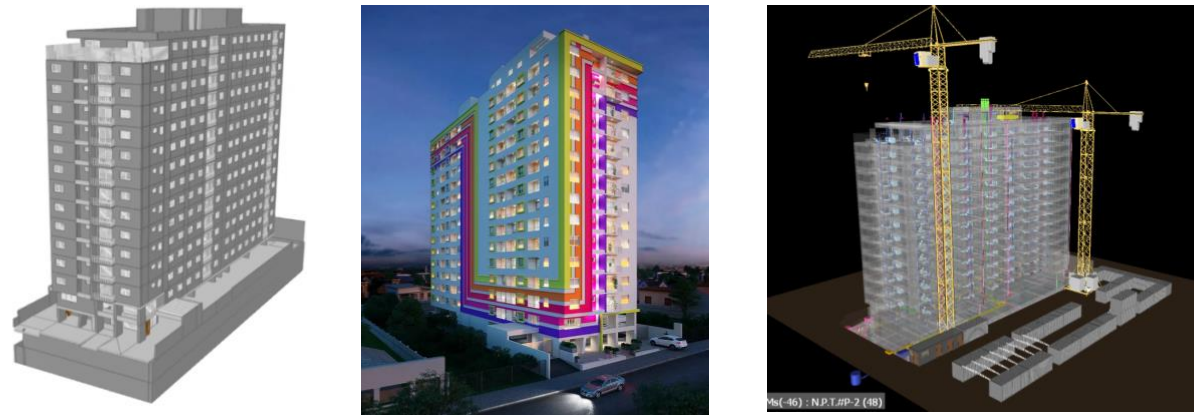
Finally, in the fifth stage, the Delphi method is applied, to carry out prospecting, and identifying variables and possibilities that impact the future performance of construction projects. For this, a series of meetings were held with experts in the area to learn their perspectives about the applications of CAD and BIM on QTO and how their use will be in the future, knowing firsthand the current market, and detecting its shortcomings and its possibilities for improvement. With the comparative studies of results and processes, in addition to the opinions of experts, through the AHP method, it was possible to value CAD and BIM to define which methodology best meets, under certain criteria, the requirements to prepare optimal QTOs for the budget.

5. CASE STUDY

The present research focuses on the comparative analysis of the uses of CAD and BIM in QTO of the core work of the New Cycle building, located in the city of Concepción, Chile. During the developing of this research, New Cycle has been in the construction and completion stages. This case study consists of a residential building for apartments. In addition, its design includes 16 floors, 2 basements and various spaces for uses and services (see Figure 4).

The Real Estate Company that manages New Cycle made a 3D model of the building, in the early stages of the project, which was more linked to the architecture, so it was used only as a rendering of the building. Given this, the project's Construction Company decided to remake the model, integrating all the specialties, where only the concrete modeling was considered. For the structural part, a new 3D model was developed, given that its design characteristics required different skills. They were developed in collaboration with modeling contractor companies specializing in the design and installation of steel bars. Finally, a "plugin" that allowed obtaining the m^2 based on the concrete model. The objectives set with this structural model were: 1) optimize the purchasing process, 2) identify incompatibilities of the reinforcing steel bars project, and 3) increase efficiency in execution, since, if the bars are designed to be easily sized and installed, the purchasing process would be faster, thus avoiding delays in the execution of the heavy work process due to the high latency in the response of the estimator, and on the other hand, the amount of steel on the ground would be reduced, avoiding the performance of repetitive work, thus increasing the work efficiency of workers.

With this, at New Cycle BIM was implemented with 2 models: one to manage the control and execution of the installation of steel bars and another model that integrates and coordinates the specialties, in order to keep track of both modifications and real-time progress of the project.



BIM Model of the New Cycle Building | Render of the New Cycle Building | Simulation of the construction process

Figure 4: BIM model and render of the case study building.

5.1 Problematic

Due to differences in the budgeted QTO of materials versus the actual ones used, the need arises to create a quantity control mechanism, including the modifications that may bring about changes in requirements and design. Given this, the use of CAD methodologies in the case study for the QTO is evaluated to contrast it with the real QTO obtained through BIM models (QTO CAD vs QTO BIM), in order to study the impact on the project if BIM had been implemented at the beginning, over the traditional applied work methodology, this is CAD. To study the greatest impact on the difference in quantities of materials, the bulk construction stage is analyzed exclusively, which is the stage with the greatest impact on costs. The main items within the gross construction work are concrete (m^3), reinforcing steel bars (tons) and formwork (m^2) (Choi, Kim and Kim, 2015; Whang and Park, 2016; Olsen and Taylor, 2017; Liu *et al.*, 2022; Garcés and Molina, 2023), and correspond to the instances that require more time and costs, therefore, the QTOs carried out and studied correspond to these three items.

Not all quantities of materials required for construction cost estimation can necessarily be extracted from the BIM model, because some construction elements cannot be modeled as a 3D object, for example, some elements of irregular or complex shape (curved ducts, pipes with elbows or special pieces), prefabricated or modular elements, temporary or auxiliary elements (scaffolding for example), elements external to the building (fences, landscaping), small or detailed elements (screws, bolts, nails), among others (Kim, Chin and Kwon, 2019). This situation arises in the present thesis research, where the BIM information of formwork was not provided. This is because the formwork was not included as part of the BIM model due to the nature of its representation as volumes, making it not possible, through the standard parameterization of the elements in a BIM model, to obtain said quantities. However, in this research, the "Proisac Formwork" plugin was added to Revit to carry out the corresponding QTO.

5.2 Software used

The QTOs were made with CAD files (drawing in "DWG" format) using the Autodesk AutoCAD software with which the construction project is budgeted. The information collected from the plans was transferred to Excel spreadsheets for processing. The complete model of the residential building was made in Autodesk Revit, which took around two and a half months (architecture model, structure and specialties), modeled at the tender stage by architects and engineers who are experts in BIM modeling (more than 10 years of experience); only the reinforcing steel bars and metal profiles were modeled in Tekla Structures and then transferred to the Trimble Connect viewer via an IFC format ("Industry Foundation Classes" file format, an interoperability standard for the construction industry). For the QTO in BIM of formwork, Autodesk Revit was used through the "Proisac Formwork" application. Finally, for the application of the AHP method as a decision maker to determine the best alternative for QTO, the "Total Decision" software was used, a program specialized in the matrix development of this method.

Certain ranges of percentage differences were established to define how acceptable the results obtained are when comparing the QTO in CAD and BIM of the New Cycle building with the QTO carried out in this research, these are: (1) <2% acceptable; (2); 2-5% moderately acceptable; and (3) >5% not acceptable.

6. ANALYSIS OF RESULTS

To carry out the QTO comparison, three parameters were considered: (1) the QTO of Concrete, reinforcing steel bars and formwork, made using CAD with which the New Cycle project budget was developed (hereinafter "CAD NC"), delivered at the bidding stage of the construction project; (2) QTO through CAD of the building in said items made for the development of this investigation (hereinafter "CAD Research"), considering the same plans of the original QTO; (3) and the QTO of Concrete, steel bars and formwork, using New Cycle BIM models (hereinafter "BIM Research"). With these QTO parameters, comparative analysis can be performed "CAD NC vs CAD Research" to detect and interpret the causes of the differences in the results, understanding that the application of CAD in QTO of the same project, and carried out by different criteria, can bring results, in some cases, with significant differences. See Figure 5.

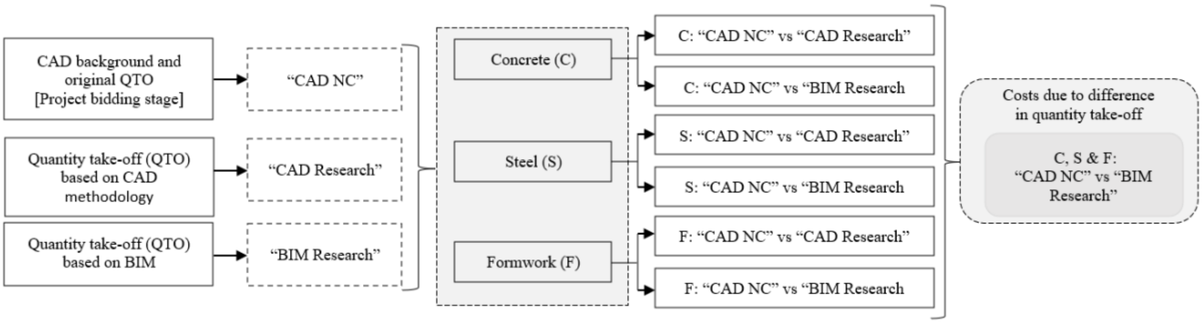


Figure 5: Quantity take-off of the New Cycle (NC) building.

Another comparative instance is to contrast the QTOs between the original CAD methodology of the project versus the QTOs based on the BIM methodology. Thus, through the comparison "CAD NC vs BIM Research" you can know the differences between what was budgeted and what was required in the execution of the project.

QTO comparisons are presented using results by level, from the foundation slab, basement -2 and -1 and floors 1 to 16. It is worth mentioning that the project indicates that between floors 3 to 14 the architecture is the same. In the original QTO, "CAD NC", the criterion was to obtain the QTO of the entire building from the information on the elevations of the plans, considering effective lengths, as indicated on the plans. In "CAD Research" the QTO criterion was applied by levels and not by the effective lengths of the elevations, thus considering specific thicknesses and lengths and, in the case of steel bars, the corresponding splices for irons of certain diameters, as presented in information tables and details of plans.

Another aspect that differentiates the CAD works in this study is the way of processing data. In "CAD NC" QTO sheets were used for concrete, steel bars for reinforcement and formwork, independent of each other. On the other hand, "CAD Research" works with automated spreadsheets in which the information from one element contributes to the calculation of the others, linking the spreadsheets. All of these QTOs, for both cases, were developed using AutoCAD and Excel.

6.1 Concrete: "CAD NC" vs "CAD Research"

In Table 1, "CAD NC" there is a total of 5856 m^3 of concrete, while "CAD Research" records 5663.73 m^3. The difference between both quantities is 192.27 m^3, equivalent to a percentage difference of 3.28%. Analyzing each level in detail, both positive and negative differences are observed, which ends up compensating for the total value of the differences. In the foundation slab, basement -2 and Floor 16, the amount of concrete calculated in “CAD Research” is greater than in “CAD NC”, while in Floor 1, Floors 3 to 14 and Floor 16 greater differences are recorded at 5%, considered unacceptable.

Table 1: Concrete CAD Results.

	CAD NC	CAD Research	Difference	% Difference
TOTAL	5856.00 m³	5663.73 m³	192.27 m³	3.28%
Foundation slab	1394.84 m³	1410.73 m³	-15.89 m³	-1.14%
Basement -2	445.81 m³	458.03 m³	-12.22 m³	-2.74%
Basement -1	470.40 m³	456.44 m³	13.95 m³	2.97%
1st Floor	244.05 m³	223.05 m³	21.00 m³	8.60%
2nd Floor	227.90 m³	221.39 m³	6.51 m³	2.86%
3rd Floor — 14th Floor	234.85 m³	220.23 m³	14.63 m³	6.23%
15th Floor	211.24 m³	204.70 m³	6.54 m³	3.10%
16th Floor	43.53 m³	46.67 m³	-3.14 m³	-7.22%

The total difference of 3.28% (192.27 m³) in the concrete QTO should not be underestimated, since it represents a significant amount. These variations are mainly due to the way the structural elements are dimensioned and the data processing when transferring the information from AutoCAD to Excel. In “CAD NC”, the dimensions were taken directly from the axis elevations, while in “CAD Research” the dimensions between floors were considered, distinguishing each structural element with their respective volumes. Furthermore, in “CAD Research” spreadsheets were used that work in parallel with the formwork dimensions, which provides support in case of errors in any dimensioning.

6.2 Steel bars: “CAD NC” vs “CAD Research”

CAD NC” presents a total of 617.88 tons of steel, while “CAD Research” shows a total QTO of 643.98 tons (see Table 2). The difference between the QTO is -26.10 tons, which represents a percentage difference of -4.22%. At foundation slab levels, basement -2 and -1, and Floors 9 to 14, the difference in quantities is negative, which indicates that more steel was calculated in the “CAD Research” QTOs than in “CAD NC”. It is important to mention that, at the foundation slab levels, basement -2 and -1, and Floors 1, 2, 15 and 16, the QTO differences are greater than 5%, which classifies them as unacceptable. On the other hand, the other levels are distributed between acceptable and moderately acceptable.

The total difference of -4.22% (-26.10 tons) represents a numerically smaller percentage difference, but in terms of quantity it is significant. The variations in the results are mainly due to the criteria used for QTO, where “CAD NC” considered sizing the steel bars according to their effective lengths, thus omitting splices and hooks. Furthermore, the difference in interpreting the detailed information in plans marks another point of discrepancy, calculating more or less tons for the same elements. These factors led “CAD NC” to make errors that resulted in a calculation with inaccuracies in the steel QTOs required for the project.

6.3 Formwork: “CAD NC” vs “CAD Research”

In Table 3, a total difference of 185.13 m² is observed between “CAD NC” and “CAD Research”, equivalent to a variation of 0.65% between both calculations. Differences are detected between all levels, both positive and negative, which end up balancing in a slight total value.

At the foundation slab, basement -2 and -1, Floors 1 and 16 levels, negative differences in QTO are identified, indicating that in “CAD Research” more square meters of formwork were calculated than in “CAD NC”. These differences exceed the established 5% acceptability criterion, which implies that at these levels the discrepancies between the two calculations are not acceptable. However, on the other levels of the building, “CAD NC” presents higher results than “CAD Research”, finally deciding that the official QTO of the New Cycle of formwork is greater than the QTO carried out in this research.

The total difference of 185.13 m^2 (0.65%) is minimal. This is given that the formwork QTOs do not require a more demanding analysis. Consequently, the calculations in both methods are very similar, reflected in tight and consistent results between “CAD NC” and “CAD Research”.

Table 2: CAD results of reinforcing steel bars.

	CAD NC	CAD Research	Difference	% Difference
TOTAL	617.88 Ton	643.98 Ton	-26.10 Ton	-4.22%
Foundation slab	64.14 Ton	73.33 Ton	-9.18 Ton	-14.31%
Basement -2	44.05 Ton	61.24 Ton	-17.19 Ton	-39.02%
Basement -1	43.19 Ton	56.21 Ton	-13.01 Ton	-30.13%
1st Floor	39.85 Ton	36.94 Ton	2.91 Ton	7.29%
2nd Floor	44.68 Ton	41.79 Ton	2.89 Ton	6.47%
3rd Floor	36.09 Ton	34.60 Ton	1.49 Ton	4.12%
4th Floor	32.42 Ton	31.80 Ton	0.63 Ton	1.93%
5th Floor	30.85 Ton	30.49 Ton	0.35 Ton	1.15%
6th Floor	29.58 Ton	29.02 Ton	0.55 Ton	1.87%
7th Floor	28.33 Ton	28.09 Ton	0.24 Ton	0.83%
8th Floor	27.96 Ton	27.74 Ton	0.22 Ton	0.77%
9th Floor	26.68 Ton	27.35 Ton	-0.67 Ton	-2.53%
10th Floor	26.43 Ton	26.63 Ton	-0.20 Ton	-0.75%
11th Floor	26.02 Ton	26.36 Ton	-0.34 Ton	-1.30%
12th Floor	26.00 Ton	26.13 Ton	-0.13 Ton	-0.51%
13th Floor	25.37 Ton	25.99 Ton	-0.62 Ton	-2.45%
14th Floor	24.56 Ton	25.42 Ton	-0.87 Ton	-3.53%
15th Floor	24.38 Ton	21.27 Ton	3.11 Ton	12.75%
16th Floor	17.31 Ton	13.57 Ton	3.74 Ton	21.60%

Table 3: Formwork CAD results.

	CAD NC	CAD Research	Difference	% Difference
TOTAL	28421.00 m^2	28235.87 m^2	185.13 m^2	0.65%
Foundation slab	112.80 m^2	126.65 m^2	-13.85 m^2	-12.28%
Basement -2	2154.24 m^2	2650.24 m^2	-496.01 m^2	-23.02%
Basement -1	2294.80 m^2	2651.29 m^2	-356.49 m^2	-15.53%
1st Floor	1490.60 m^2	1326.94 m^2	163.66 m^2	10.98%
2nd Floor	1551.16 m^2	1503.36 m^2	47.80 m^2	3.08%
3rd Floor — 14th Floor	1582.69 m^2	1515.93 m^2	66.75 m^2	4.22%
15th Floor	1462.26 m^2	1419.29 m^2	42.97 m^2	2.94%
16th Floor	362.90 m^2	366.88 m^2	-3.98 m^2	-1.10%

6.4 Concrete: “CAD NC” vs “BIM Research”

Table 4 shows that “CAD NC” calculated 5856 m^3 of concrete, while “BIM Research” recorded 5719.87 m^3. The totals differ by 136.13 m^3, representing a 2.32% percentage difference. The high level of detail in the “BIM Research” models provides a more precise and realistic estimate of the volume of concrete required for the New Cycle project. In the foundation slab and basement -2 and -1 the differences are negative, indicating that “CAD NC” quantities of concrete were underestimated. Under the acceptability criteria, Foundation Slab presents an unacceptable difference, while both subways have moderately acceptable differences between CAD and BIM applications. On the other hand, for Floors 1 to 16, the differences are considered unacceptable, which implies that "CAD NC" calculated a volume of concrete above the real needs of the project.

The discrepancies in results are mainly due to the differences in the way of sizing the structural elements in each methodology. "BIM Research" carries out a detailed calculation of each element separately, grouping them by parameters, according to the type of concrete, type of element and corresponding level. On the other hand, "CAD NC" carried out the calculation by elevations, considering the total lengths of each level. In addition, "BIM Research" takes into account empty spaces where concrete is not required, such as shafts, which contributes to a calculation adjusted to reality.

Table 4: Concrete CAD and BIM Results.

	CAD NC	BIM Research	Difference	% Difference
TOTAL	5856.00 m³	5719.87 m³	136.13 m³	2.32%
Foundation slab	1394.84 m³	1665.94 m³	-271.10 m³	-19.44%
Basement -2	445.81 m³	455.81 m³	-10.00 m³	-2.24%
Basement -1	470.40 m³	487.53 m³	-17.13 m³	-3.64%
1st Floor	244.05 m³	219.12 m³	24.93 m³	10.21%
2nd Floor	227.90 m³	186.99 m³	40.91 m³	17.95%
3rd Floor	234.85 m³	214.91 m³	19.94 m³	8.49%
4th Floor	234.85 m³	214.89 m³	19.96 m³	8.50%
5th Floor	234.85 m³	215.40 m³	19.45 m³	8.28%
6th Floor	234.85 m³	215.63 m³	19.22 m³	8.19%
7th Floor	234.85 m³	215.69 m³	19.16 m³	8.16%
8th Floor	234.85 m³	215.79 m³	19.06 m³	8.12%
9th Floor	234.85 m³	214.78 m³	20.07 m³	8.55%
10th Floor	234.85 m³	214.50 m³	20.35 m³	8.67%
11th Floor	234.85 m³	214.68 m³	20.17 m³	8.59%
12th Floor	234.85 m³	210.51 m³	24.34 m³	10.37%
13th Floor	234.85 m³	215.25 m³	19.60 m³	8.35%
14th Floor	234.85 m³	187.35 m³	47.50 m³	20.23%
15th Floor	211.24 m³	131.97 m³	79.27 m³	37.52%
16th Floor	43.53 m³	23.13 m³	20.40 m³	46.87%

It is important to mention that the difference that occurs on the 16th Floor is due to a redesign on said floor, reducing its area, and therefore, its amount of concrete. This modification was not considered by "CAD NC".

6.5 Steel bars: "CAD NC" vs "BIM Research"

The observed differences caused problems in terms of project processes and costs. There is a difference of -61.93 tons of iron, which represents a discrepancy of 10.02% compared to the amount budgeted by "CAD NC" (see Table 5). Both positive and negative differences are identified in Floors 3 to 14, but all of them are within the acceptable and moderately acceptable range. However, the foundation slab, basement -2 and -1, and Floors 1, 2, 15 and 16 present differences that are not acceptable according to the established criteria. It is important to highlight that the greatest differences are evident in basements -2 and -1, where "CAD NC" considerably underestimated the amount of steel bars required compared to the actual amount.

"BIM Research" considers all the elements of the steel bars, even those that do not have a structural function, but are necessary from a construction point of view, such as extra locks, splices and hooks, to support slabs, and master bars, among others. These additional elements are not detailed in the plans, but are required during the installation of the steel bars. This difference in the consideration of non-structural elements explains why “BIM Research” shows superior steel QTO results than “CAD NC”. It is important to note that the redesign of the 16th floor was not considered by “CAD NC”, so the amount of steel was greater than that required for that level.

Table 5: CAD and BIM results of reinforcing steel bars.

	CAD NC	BIM Research	Difference	% Difference
TOTAL	617.88 Ton	679.81 Ton	-61.93 Ton	-10.02%
Foundation slab	64.14 Ton	70.82 Ton	-6.68 Ton	-10.41%
Basement -2	44.05 Ton	81.45 Ton	-37.40 Ton	-84.89%
Basement -1	43.19 Ton	67.45 Ton	-24.26 Ton	-56.17%
1st Floor	39.85 Ton	52.06 Ton	-12.21 Ton	-30.65%
2nd Floor	44.68 Ton	40.76 Ton	3.92 Ton	8.78%
3rd Floor	36.09 Ton	34.53 Ton	1.56 Ton	4.33%
4th Floor	32.42 Ton	33.45 Ton	-1.03 Ton	-3.17%
5th Floor	30.85 Ton	30.14 Ton	0.71 Ton	2.31%
6th Floor	29.58 Ton	30.31 Ton	-0.73 Ton	-2.47%
7th Floor	28.33 Ton	27.86 Ton	0.47 Ton	1.65%
8th Floor	27.96 Ton	28.53 Ton	-0.57 Ton	-2.03%
9th Floor	26.68 Ton	26.66 Ton	0.02 Ton	0.07%
10th Floor	26.43 Ton	27.15 Ton	-0.72 Ton	-2.71%
11th Floor	26.02 Ton	25.77 Ton	0.25 Ton	0.97%
12th Floor	26.00 Ton	26.66 Ton	-0.66 Ton	-2.56%
13th Floor	25.37 Ton	25.32 Ton	0.05 Ton	0.19%
14th Floor	24.56 Ton	25.62 Ton	-1.06 Ton	-4.31%
15th Floor	24.38 Ton	20.90 Ton	3.48 Ton	14.28%
16th Floor	17.31 Ton	4.39 Ton	12.92 Ton	74.64%

6.6 Formwork: “CAD NC” vs “BIM NC”

Between the results of “CAD NC” and “BIM Research” there is a difference of 229.36 m² of formwork, which translates into a differential of 0.81% between what was budgeted and what was used (see Table 6). The total difference turns out to be very slight, with various differences, positive and negative, existing in the calculations for each level of the building. in foundation slab, basement -2 and -1, floors 1, 2 and 16 the differences are negative, that is, what was budgeted was less than what was required. Existe una gran variación en el criterio de aceptabilidad entre cada nivel. The “not acceptable” results are offset by the results that are “moderately acceptable”, finally having a total difference categorized as “acceptable” between the CAD and BIM methodologies in formwork QTO.

Like the “CAD NC” vs “CAD Research” comparison, the difference with “BIM Research” of 0.81% (229.36 m²) is minimal. This reinforces what was previously stated, that the formwork QTOs do not require a major analysis for the calculation of areas. The use of CAD or BIM for this purpose applies the same calculation considerations, with differences in the precision of results, but maintaining a similar range in the totals obtained.

6.7 Detection of errors in quantity take-off

When studying the “CAD NC” QTO process of concrete and formwork, differences were identified in criteria to perform the calculations, concerning “CAD Research”. These criteria represent results that, under the established ranges, are “acceptable” and “moderately acceptable.” In the case of the calculation of steel bars the situation is different. When studying the work processes, errors were detected in the calculations by “CAD NC”, which are, in part, the cause of the difference concerning the real quantities of steel for the New Cycle project. These errors correspond to failures in the interpretation of plans and the late detection of incompatibilities between Architecture and Engineering.

Some errors detected correspond to imprecise calculations, given a misinterpretation of the information explained in the plans, specifically calculating fewer horizontal and vertical reinforcements in walls (11.7 Ton). Another error corresponds to indications of the building design, which indicates the location of locks and abutments of certain walls in reduced sections, requiring reinforcement of the complete sections. In “CAD NC” the QTO for steel was made according to the drawings, not considering the missing sections (7.55 Ton). The last error detected corresponds to an incompatibility between architectural and steel plans, where the same structural elements are indicated, but with different dimensions (0.57 Ton). These errors total approximately 20 tons of the 61.93 tons of difference between what was budgeted by “CAD NC” and what was actually calculated by “BIM Research”.

Table 6: CAD and BIM results of formwork.

	CAD NC	BIM Research	Difference	% Difference
TOTAL	28421.00 m²	28191.64 m²	229.36 m²	0.81%
Foundation slab	112.80 m²	126.47 m²	-13.67 m²	-12.12%
Basement -2	2154.24 m²	2482.91 m²	-328.67 m²	-15.26%
Basement -1	2294.80 m²	2583.88 m²	-289.08 m²	-12.60%
1st Floor	1490.60 m²	1577.68 m²	-87.08 m²	-5.84%
2nd Floor	1551.16 m²	1813.38 m²	-262.22 m²	-16.90%
3rd Floor	1582.69 m²	1502.75 m²	79.94 m²	5.05%
4th Floor	1582.69 m²	1508.76 m²	73.93 m²	4.67%
5th Floor	1582.69 m²	1507.23 m²	75.46 m²	4.77%
6th Floor	1582.69 m²	1503.03 m²	79.65 m²	5.03%
7th Floor	1582.69 m²	1505.59 m²	77.10 m²	4.87%
8th Floor	1582.69 m²	1506.66 m²	76.03 m²	4.80%
9th Floor	1582.69 m²	1506.18 m²	76.51 m²	4.83%
10th Floor	1582.69 m²	1499.78 m²	82.91 m²	5.24%
11th Floor	1582.69 m²	1506.78 m²	75.91 m²	4.80%
12th Floor	1582.69 m²	1507.38 m²	75.31 m²	4.76%
13th Floor	1582.69 m²	1472.15 m²	110.54 m²	6.98%
14th Floor	1582.69 m²	1507.26 m²	75.43 m²	4.77%
15th Floor	1462.26 m²	1204.45 m²	257.81 m²	17.63%
16th Floor	362.90 m²	369.34 m²	-6.44 m²	-1.78%

6.8 Differences in costs

In general, the differences detected in the QTOs carried out by “CAD NC” and “CAD Research” show that, if there is no standard criterion in the studies of a project, the ways of carrying out the calculations will result in important variations that. Although they are minor in total, during the project it can cause significant problems in controlling the development of the works. On the other hand, the difference observed between the applications of “CAD NC” and “BIM Research” in the case study reveals the differences in the methodologies applied in the use of quantity estimation, where CAD presents approximate quantities, in which, adding irregularities in the process, make the results far from the real ones, considered and calculated by BIM. This difference, between what is budgeted and what is actual, is accentuated when taken to the cost field. See Table 7.

The unit costs of concrete were \$108.54USD/m^3, for steel bars, it was \$1.16USD/kg, and for formwork, it was \$11.43USD/m^2. Table 7 shows the cost differences between “CAD NC” and “BIM Research” associated with each material.

Table 7: Costs due to differences in quantities (CAD NC vs BIM Research).

	Concrete Cost Differences	Steel bars Cost Differences	Formwork Cost Differences	Total Cost Differences
TOTAL	$14,776	-$71,963	$2,633	-$54,554
Foundation slab	-$29,426	-$7,761	-$157	-$37,344
Basement -2	-$1,086	-$43,454	-$3,773	-$48,312
Basement -1	-$1,860	-$28,190	-$3,318	-$33,367
1st Floor	$2,706	-$14,192	-$999	-$12,486
2nd Floor	$4,441	$4,558	-$3,010	$5,990
3rd Floor	$2,165	$1,818	$918	$4,900
4th Floor	$2,167	-$1,194	$849	$1,821
5th Floor	$2,112	$827	$866	$3,804
6th Floor	$2,087	-$850	$914	$2,151
7th Floor	$2,080	$542	$885	$3,507
8th Floor	$2,069	-$661	$873	$2,281
9th Floor	$2,179	$23	$878	$3,080
10th Floor	$2,209	-$833	$952	$2,328
11th Floor	$2,190	$292	$871	$3,353
12th Floor	$2,642	-$772	$864	$2,734
13th Floor	$2,128	$55	$1,269	$3,452
14th Floor	$5,156	-$1,230	$866	$4,792
15th Floor	$8,604	$4,046	$2,959	$15,609
16th Floor	$2,215	$15,013	-$74	$17,153

Since the total formwork turned out to be greater than the actual demand of the project, the difference was $2,633 USD. For concrete, “CAD NC” budgeted $14,776 more than was used. Finally, the steel required was greater than budgeted, with a negative difference of $71,963. Therefore, the budget differed by $54,554 between concrete, reinforcing steel bars and formwork from the total cost of the project, taking into account materials exclusively, without considering the associated costs of the items.

7. RESULTS OF THE APPLICATION OF THE DELPHI METHOD AND THE AHP METHOD

To enhance the analysis and provide a robust framework for comparison, this study leverages two established decision-making methodologies: the Delphi method and the Analytic Hierarchy Process (AHP). On the one hand, the Delphi method facilitates expert consensus on key parameters and criteria influencing QTO, addressing the subjectivity inherent in evaluating different approaches, and on the other hand, the AHP method provides a structured framework for weighing defined criteria between CAD and BIM in terms of accuracy, time efficiency, and other relevant factors. By integrating these methodologies, this research aims to provide a comprehensive and objective evaluation between CAD and BIM for quantity take-off (QTO) in apartment building projects.

7.1 Delphi Method Application

The Delphi method is a technique for developing surveys of a given area, based on the perspectives and opinions generated by a group of experts related to the area, within the framework of interview instances (Ameyaw *et al.*, 2016; Yusof, Ishak and Doheim, 2018). To apply this method in this research, a group of professionals with experience in construction projects applying CAD and BIM methodologies was chosen. For this, through meetings the various opinions about the AEC industry and its methodological changes and the impact that this brings on the market were known.

The experts contacted have vast knowledge and experience in real estate projects and the application of technologies in the area of engineering and construction. In addition, some of them have direct participation in the New Cycle project. Along these lines, the meetings were held with the Project Administrator, the QTO professional of the project, the Engineers in charge of the New Cycle design and the engineer in charge of the optimized installation of steel reinforcement. In addition, meetings were held with professionals who were experts in BIM methodologies and bidding processes, without direct links to the New Cycle building.

Through interviews, opinions on the implementation of BIM in construction projects and the current perception of the industry regarding the work system based on CAD software were investigated. In addition, the workflows and changes observed when adopting BIM instead of CAD were consulted. A crucial aspect was to analyze the level of knowledge about BIM applications in the sector and the reasons why its adoption has not been massive, despite there being entities that promote its implementation. Finally, the opinion was requested on the application of BIM in a specific case, such as the estimation of quantities and costs for the preparation of QTO in the early stages of a project.

15 questions were asked per round of the Delphi survey. This range allows you to collect a sufficient amount of information while maintaining a manageable survey duration and respondent participation (Al-Izzy and Al-Btoush, 2022; Tan and Gümüşburun, 2022). For the first Round (Initial Evaluation) questions were asked such as: 1) What is your level of experience with BIM and CAD methodologies in construction projects?; 2) In your opinion, what are the main strengths and weaknesses of BIM for QTO compared to CAD?; 3) What are the key challenges and opportunities associated with implementing BIM for QTO in construction projects?; 4) How would you rate the overall effectiveness of BIM for QTO compared to CAD?; 5) What specific aspects of BIM or CAD do you see as most beneficial to QTO in terms of accuracy, efficiency and cost savings? For the second Round (In-Depth Evaluation) questions were asked such as: 1) In your experience, what are the typical error rates or discrepancies found when using BIM or CAD for QTO?; 2) How do you perceive the impact of BIM and CAD on the overall quality and reliability of QTO in construction projects?; 3) What role do you think BIM and CAD will play in the future of QTO practices in the construction industry?; 4) Taking into account factors such as project complexity, budget constraints and team experience, when would you recommend using BIM instead of CAD for QTO and vice versa? 5) What are the possible barriers or challenges that may hinder wider adoption of BIM for QTO in the construction industry?; 6) What strategies or actions can be taken to promote the effective implementation and utilization of BIM for QTO in construction projects?; 7) How can we ensure that the benefits of BIM for QTO are realized and shared across the construction industry?

The interviews revealed a widespread and notable appreciation of the advantages that BIM offers compared to traditional CAD methods in construction projects. However, the response regarding the option of assuming the change in work methodologies by implementing BIM is varied. Two factors cause resistance to change: (1) comfort with current work methods and costs associated with BIM implementation. In some cases, it is considered that the traditional work system has brought profits for a long time, so change is not necessary. (2) Furthermore, the cost of implementing BIM is a barrier that not any company can overcome, so, although BIM is highly valued, the option of moving from CAD to BIM is difficult. On the other hand, there is a group of interviewees who believe that BIM implementation in Chile is not advancing rapidly due to conformity with traditional methods. However, the opinion on the use of BIM in construction projects is positive and it seeks to apply more and more BIM uses to generate a standardized, interconnected and fluid work methodology.

The ability to explore diverse perspectives and opinions on the same issue is a fundamental value of the Delphi method. Although the benefits of BIM in terms of precision and efficiency in project development are widely recognized, its implementation remains limited to certain sectors, since not all companies have the resources or capacity to adopt it.

In the context of this research to determine the most effective and convenient methodology for the QTO of heavy work in high-rise residential buildings (apartments), the Delphi method can be a valuable tool to: 1) Compile information from experts: allows consulting a panel of BIM and CAD experts about their experiences, knowledge and preferences regarding both methodologies. This qualitative information can be crucial to understanding the advantages and disadvantages of each approach from the perspective of those who have used them in real projects; 2) Identify evaluation criteria: Relevant criteria can be identified and refined to evaluate the effectiveness of BIM and CAD methodologies. These criteria may include aspects such as cost, accuracy, ease of use, interoperability and other factors relevant to the specific context of building construction; 3) Prioritize criteria: The Delphi method can be used to weigh the relative importance of the identified criteria, obtaining a consensus perspective on which are the most relevant aspects to consider when choosing between BIM and CAD; 4) Evaluate the methodologies: once the criteria and their weighting are defined, the Delphi method allows the BIM and CAD methodologies to be evaluated based on each criterion. Feedback between experts helps refine assessments and reach stronger conclusions; and 5) Facilitate consensus: The anonymity and iterative structure of the Delphi method encourage individual reflection and free expression of opinions, which can lead to greater consensus among experts on the most appropriate methodology for QTO in residential buildings. Therefore, the Delphi method can be a valuable tool to complement other research methods in selecting the most effective methodology for calculating quantities of gross work in tall buildings. Its prospective, expert consensus-based approach can provide crucial information for informed decision-making in the construction industry.

The perceptions that the experts consulted have about the uses of CAD and BIM in construction and the behavior of the industry in the face of advances, within 5 to 10 years is that BIM implementation will increase due to the need for companies to remain competitive in the market. With this, it is thought that the engineering and construction industry in Chile will have considerable progress and improvement. On the other hand, it is estimated that there will be a break between companies that exclusively use CAD or BIM in bidding processes, since the budgets prepared will be noticeably different, so the option of competing for the same project using different methodologies will bring about segmentation in the industry. Along these lines, it is said that the massification of BIM implementation will cause many small and medium-sized construction companies to be relegated to minor projects or, outright, to go bankrupt, due to not being able to assume the costs of BIM or not being able to participate in projects that maintain the economic solvency of the companies.

Finally, from the opinions of the experts, a series of criteria emerge to choose to implement BIM in the use of quantity estimation (QTO) and costs, the main ones being precision and efficiency in its process, as well as compatibility with other systems and the availability of resources. In addition, there are two fundamental aspects of decision-making: the costs associated with implementation and the ease of using the software.

7.2 AHP Method

Analytic Hierarchy Process (AHP) is a decision-making method in which alternatives are evaluated using a mathematical model, based on a series of criteria, to define which best meets the objective of a process (Darko *et al.*, 2019). In this research, AHP is applied to define which alternative, CAD or BIM, best satisfies the requirements to develop QTO in the bidding stage.

The AHP is a systematic and rigorous approach making it a useful tool for decision making in various contexts, including the selection of methodologies for QTO in high-rise residential buildings. Within the framework of this research, the AHP can be used to: 1) Establish a hierarchy of criteria: first, a hierarchy is defined that decomposes the problem into a structure of levels, starting with the general objective (choosing the most effective methodology for the QTO) and disaggregating it into increasingly specific criteria and sub-criteria; 2) Compare the methodologies: Once the hierarchy is defined, the BIM and CAD methodologies are compared in pairs based on each criterion and sub-criterion. This is done using comparative judgments between the methodologies, expressed on numerical scales that represent the intensity of the preference. For example, the accuracy of BIM and CAD could be compared by assigning a score of 1 to the methodology considered least accurate and 9 to the most accurate, with scores in between to represent gradual differences in preference; 3) Synthesize the comparisons: pairwise comparisons are synthesized into relative weights for each criterion and subcriterion, which represent the relative importance of each factor in the final decision. These weights are calculated using an iterative process that ensures the internal consistency of the comparisons; 4) Evaluate the methodologies globally: Using the weights of the criteria and subcriteria, the global performance of the BIM and CAD methodologies is evaluated. This is done by calculating a weighted score for each methodology, which reflects its relative performance based on the importance of each criterion considered in the hierarchy; 5) Select the most appropriate methodology: The methodology with the highest weighted score is considered the most appropriate for QTO in residential buildings, considering the criteria and sub-criteria established in the hierarchy. In conclusion, the AHP can be a valuable tool for selecting the most effective methodology for QTO, considering criteria such as cost, efficiency, precision, ease of use, interoperability and investment cost, where the selection of criteria and sub-criteria is crucial for the representativeness of the analysis and the validity of the results. Furthermore, the effectiveness of the AHP depends largely on the quality of the pairwise comparisons, which should be based on expert judgment and available information. Finally, its systematic approach, based on pairwise comparisons and weighting of criteria, allows methodologies to be evaluated in a structured and rigorous manner, facilitating informed decision-making.

To develop the AHP, the objective must be defined ("Define whether the CAD or BIM methodology is the best alternative to perform QTO and budget calculations in the bidding stage of a construction project"), and the criteria and alternatives (CAD and BIM) to make the best decision. It is worth mentioning that the criteria were defined according to the perceptions of the experts consulted in the Delphi method stage. Six criteria are presented in Table 8 along with their corresponding sub-criteria. The first 4 criteria consider technical aspects that have direct implications in the use of CAD and BIM methodologies. Criteria 5 and 6 respond to qualitative aspects, which consider perceptions of barriers to overcome for the adoption and use of software related to work methodologies.

Table 8: AHP criteria and sub-criteria.

N°	Criteria	Sub-criteria
1	Precision in quantity take-off	• Ability to identify elements in plans/models • Accuracy in the quantity of the elements identified
2	Efficiency in the quantity take-off process	• Speed of the QTO process • Degree of automation of the QTO process
3	Compatibility with other systems	• Ability to import and export data to other systems • Interoperability with other systems
4	Resource availability	• Availability of personnel trained in the use of the software • Availability of technical support and updates
5	Investment cost	• The initial cost of licenses • Cost of maintenance and updates
6	Easy to use	• Level of technical knowledge required to use software • The friendliness of the software interface

Once the objectives, criteria and alternatives are established, the hierarchical analytical process is carried out. For this, the "Total Decision" software specialized in AHP was used, in which the evaluation inputs between criteria and alternatives must be entered in order to know the hierarchical order between criteria and then, define the best alternative to satisfy the established objective.

The first step to develop the AHP method in Total Decision is to enter the already established objective, criteria and alternatives. The criteria are then compared to each other, one by one, using ratings that indicate their degree of importance. With this process, the weights of each criterion are obtained in order to define the hierarchy between them, knowing which criteria are the most relevant within the analysis. The evaluations to compare criteria and alternatives based on the objective obey scores from 1 to 9 as presented in Table 9.

Table 9: AHP rating scale.

Equal Importance	Moderate importance	Great importance	Very great importance	Extreme importance
1	3	5	7	9

The ratings entered into the software are based on information collected from interviews with experts. From this, each criterion was scored, understanding the degree of importance that each one has when carrying out the QTO, both by CAD and BIM. In this stage, the hierarchy of criteria is established, obtaining that the "Investment cost" criterion is the one with the greatest weight, followed by the "Precision in QTO" criterion as the second most relevant. This indicates that the "Investment cost", although not a technical aspect, is the most important criterion when making decisions about which work methodology to adopt to carry out QTO. Furthermore, the two main criteria are followed in the ranking by: "Efficiency in the QTO process", "Compatibility with other systems", "Resource availability" and, finally, "Easy to use".

The next step is to evaluate each criterion concerning each of the alternatives. The same assessment scale used previously is used to rate the performance of each alternative based on the objective, as shown in Figure 6.

These evaluations provide a measure of the performance of each alternative in relation to the objective. The evaluations are developed by matrixly ordering the results for each comparative instance. From each matrix, the eigenvectors are obtained that indicate the relative weights of each comparative pair. By obtaining all the eigenvectors, a global decision matrix is constructed with which, finally, the alternative with the greatest weight for decision-making can be obtained. This entire mathematical process was carried out using the Total Decision software.

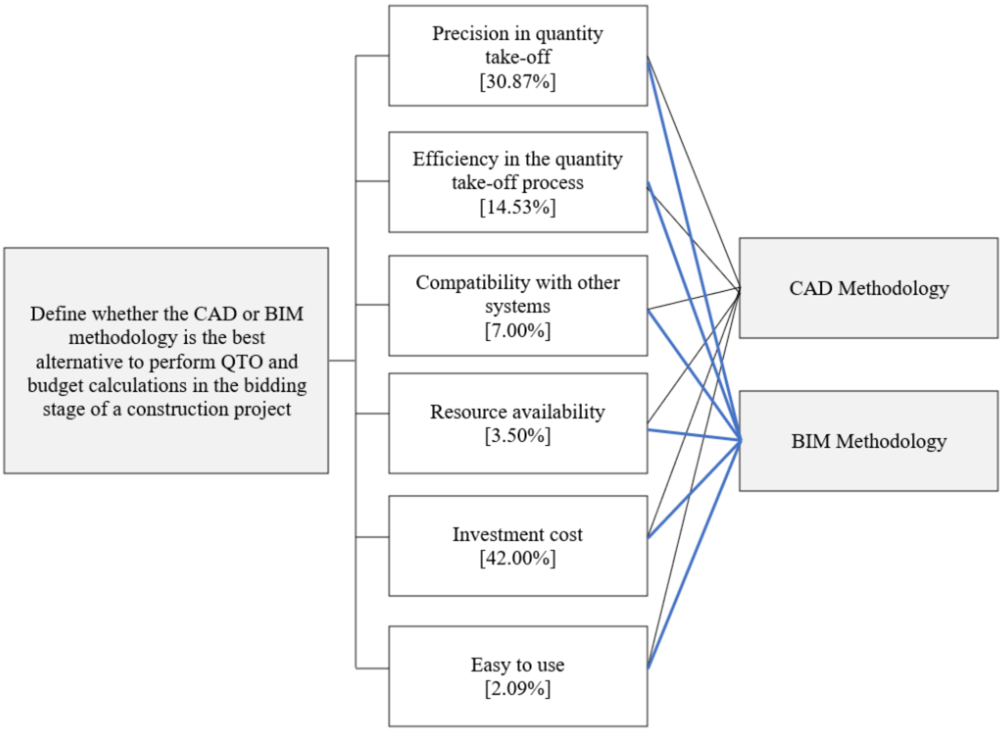


Figure 6: AHP structure of hierarchies.

Finally, with the AHP Method, through the calculation software, it is concluded that the best alternative to perform QTO and budget calculation in the bidding stage of a project is the BIM methodology over CAD (see Figure 7).

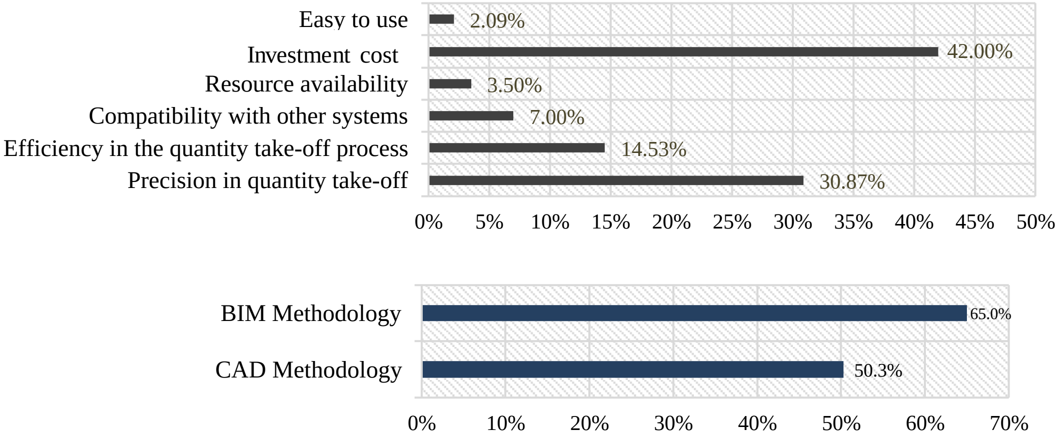


Figure 7: AHP Sensitivity Analysis - Final Results.

Given that the “investment cost” criterion has high relevance in the study, considering that the costs associated with BIM are higher compared to CAD, the gap between alternatives may not turn out to be completely representative. On the other hand, when carrying out the same study without considering the “investment cost” criterion, the decision-making is decisively more conclusive, defining BIM as the alternative with almost ideal performance to satisfy the objective, as shown in Figure 8.

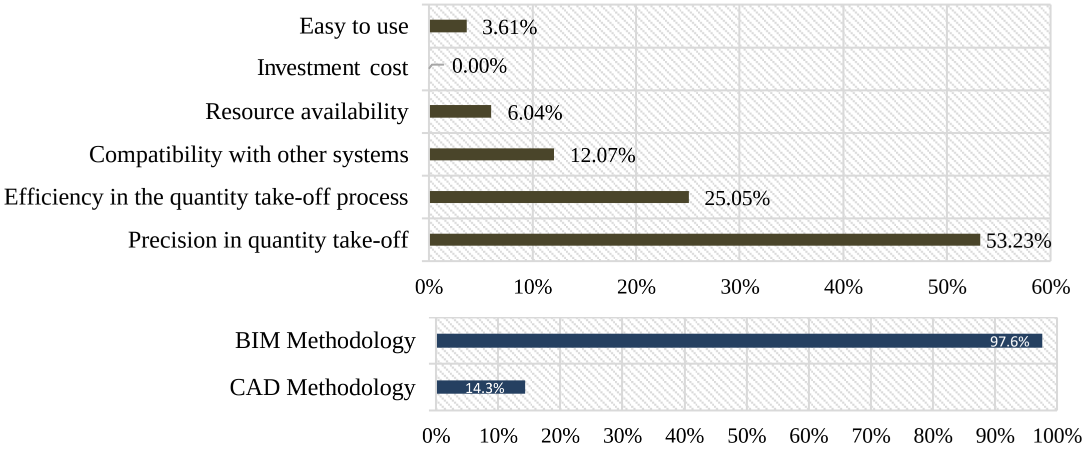


Figure 8: AHP sensitivity analysis - Simulation of results without Cost criteria.

This supports that the “investment cost” variable has a fundamental role in quantifying the best decision. However, in both cases, the BIM alternative presents the best performance, based on the criteria and its hierarchical analysis, to satisfy the objective of defining CAD or BIM as the best alternative to carry out QTO and budget in the bidding stage of a project.

8. CONCLUSIONS

The comparative analysis between the QTOs carried out with “CAD NC” and “BIM Research” has revealed important information regarding the precision and accuracy of the results. In the case of concrete, it is observed that “BIM Research” provides a real and precise quantity, avoiding overestimation of quantities, while “CAD NC” shows a tendency to overestimate volumes. This demonstrates the superiority of BIM in terms of obtaining accurate information and avoiding deviations in project processes and costs, and it could make projects more competitive by using them in earlier stages. Similarly, when comparing the QTO of steel bars, it is again evident that “BIM Research” offers a more detailed and complete analysis for the required elements, considering even those that do not have structural purposes but are necessary for construction. On the other hand, “CAD NC” presented discrepancies and errors in the study of plans, which generated imbalances in the processes and associated costs. It is important to highlight that the errors detected in the QTO are related to CAD, which supports the need to adopt more advanced methodologies such as BIM to avoid carryover of errors and detect incompatibilities early; This generates claims for defects in the design, which then end up being awarded to the client or assumed as a loss.

Regarding what was obtained through the AHP method, the normalized results taken as a percentage represent the best result obtained among the alternatives to achieve the defined objective. The result of the mathematical method for AHP of 65.01% indicates that the BIM alternative satisfies the objective through the six established criteria, above the 50.30% of CAD. It is important to understand that these percentages represent the relative performance of the alternatives based on the evaluated criteria, indicating how much each alternative contributes to satisfying the objective compared to the other alternatives. This is given that the AHP carries out an independent analysis between alternatives, so the percentages represent a relative comparison, not an absolute evaluation. With the established criteria and the evaluations according to the conclusions after consulting experts, it is determined, through the AHP method, that the BIM methodology best responds to the requirements to carry out QTO in the bidding stage. However, it is important to highlight that, despite the result in favor of BIM, the most predominant criterion is Cost, an aspect that is a great barrier to overcome to adopt this methodology and what makes many users consider the implementation risk in the face of benefits brought by the structuring, parameterization and optimization of construction processes associated with BIM.

Some reasons why BIM is not fully adopted in the industry include the time required to train employees, the cost of upgrading hardware, the cost of software, and the fundamental change in work processes if BIM is adopted in projects (Sriyolja, Harwin and Yahya, 2021; Olanrewaju *et al.*, 2022). It is essential to demystify the idea that simply adopting a BIM model will automatically improve a project. Although the BIM model contributes greatly, it is crucial to have efficient and fluid work processes to achieve optimal results. Resistance to change and lack of updating in technologies and work methodologies are obstacles that must be overcome to fully take advantage of the benefits of BIM in the construction industry (Shin and Kim, 2021). It is important to generate a change in the perception of BIM implementation, considering it as expensive and risky. While there is an associated cost, it should be understood as an investment rather than a risk, considering the significant benefits that BIM brings to engineering and construction work processes.

The application of the Delphi method in the research allowed us to analyze the opinions and perceptions of experts in the field. Despite the diversity of opinions, there is a general consensus that BIM considerably improves work processes in the AEC industry, thus supporting the relevance and effectiveness of this methodology. With this, the evaluation carried out using the AHP method has shown that BIM satisfies the objectives set to a greater degree than CAD, with a score of 65.01% compared to 50.30%, having the criteria “investment cost” and “accuracy in QTO”. as the most relevant aspects when deciding which methodology has the best performance in budget QTO processes at the bidding stage. This confirms the fulfillment of the research objective by analyzing the impact of the use of the BIM methodology in the development of QTO in the budget stage of the case study of the New Cycle building.

This article enriches current knowledge by presenting empirical evidence supporting the advantages of BIM over CAD. This contribution is especially relevant to demonstrate the practical benefits of adopting BIM in the construction field. However, it is essential to highlight the potential challenges that QTO extraction using the BIM methodology could present, as this topic is still the subject of debate today. Some of the challenges and limitations of BIM-based QTO are: 1) Lack of implementation of standards and interoperability: The lack of implementation or improvement of universal standards for the creation and management of BIM models (for example: ISO 19650, BuildingSMART International, National BIM Standard-United States®, IFC standard, among others) can generate inconsistencies in the information and hinder interoperability between different BIM software. In addition, the incompatibility of file formats between different BIM software can hinder the sharing of models and collaboration between teams, which can generate delays and additional costs.; 2) Lack of experience and training: many professionals do not have the necessary experience and training to use technology effectively. This can lead to errors in modeling, quantity extraction and BIM information management. Lack of adequate training in extracting quantities from BIM models can lead to inaccurate or incomplete results, which can have a significant impact on project budget and execution; 3) Complexity of BIM models: BIM models of high-rise residential buildings can be extremely complex, with a large amount of detailed information. This can make it difficult to extract accurate and efficient quantities, especially for professionals with little experience in BIM, and new specialized tools and software may be required for QTO extraction, which can increase project costs; 4) Errors in modeling: errors in geometry, element classification or attribute assignment can generate incorrect results and affect the accuracy of the project budget; 5) Lack of integration with cost estimating systems: the integration between BIM models and cost estimating systems is not always smooth, which can make it difficult to transfer information and automate the quantity extraction process; 6) Impact on cost and time: Implementing BIM for quantity extraction may require an initial investment in software, training and human resources. Additionally, the learning curve to use BIM effectively can be significant, which can lead to delays in project execution in the early stages; and 7) Resistance to change: Lack of management or client support for the use of BIM can be a significant obstacle to the adoption of the technology. In conclusion, addressing critical challenges through the implementation of standards, adequate training, efficient management of BIM information and integration with cost estimating systems will allow the benefits of this technology to be fully realized in the construction industry.

RECOMMENDATIONS AND FUTURE RESEARCH

Because the analysis carried out was restricted to the quantities of materials, associated costs such as equipment, labor, general expenses, etc. were not considered. It is recommended to carry out an analysis focused on costs in its entirety, to understand the behavior of a project from the moment the risk of implementing BIM is assumed until its completion and to broadly understand the contrast in work processes compared to CAD.

Another aspect to recommend is to encourage a change in the conception of updating work methodologies. It is considered that changing processes brings complications that can affect the result of the project, so it is necessary to raise awareness that the benefits of BIM outweigh the initial difficulties inherent in the adoption of any new methodology and thus overcome resistance to change. It is important to know that BIM presents differences in work processes with respect to CAD, but these differences are based on increasing detail, efficiency and optimization in construction projects.

Finally, as this research focuses on QTO in apartment buildings, it would be of great interest to carry out analyses, similar to that of this research, on different types of projects within the industry, such as real estate, structural, road, hydraulic, among others, in order to obtain a general criterion on the application of BIM as a base work methodology. Future studies will aim to identify discrepancies in determining QTO in other building types or interior designs using more case studies and more data. Based on the findings of this research, future work can predict a variety of QTO discrepancies by level of detail by analyzing more cases involving different building types and estimating the completeness and reliability of the QTO results. The integrity of a BIM model for cost estimation can also be measured in the future by evaluating the reliability of the QTO, according to new criteria that may be developed.

REFERENCES

Abanda, F. H., Kamsu-Foguem, B. and Tah, J. H. M. (2017) ‘BIM – New rules of measurement ontology for construction cost estimation’, Engineering Science and Technology, an International Journal, 20(2), pp. 443–459. doi: 10.1016/j.jestch.2017.01.007.

Aibinu, A. and Venkatesh, S. (2014) ‘Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia’, Journal of Professional Issues in Engineering Education and Practice, 140(3). doi: 10.1061/(ASCE)EI.1943-5541.0000193.

Al-Izzy, A. and Al-Btoush, M. (2022) ‘Benefits of Using BIM Tools to Resolve Clashes in Iraqi Construction Projects: A Case Study’, Journal of Advanced Sciences and Engineering Technologies, 5(1), pp. 41–56. doi: 10.32441/jaset.05.01.05.

Ameyaw, E. E. et al. (2016) ‘Application of Delphi method in construction engineering and management research: a quantitative perspective’, Journal of Civil Engineering and Management, 22(8), pp. 991–1000. doi: 10.3846/13923730.2014.945953.

Ashworth, A. and Perera, S. (2015) Cost studies of buildings. New York: Pearson, Prentice Hall.

Berwald, S. (2008) ‘From CAD to BIM: The Experience of Architectural Education with Building Information Modeling’, in AEI 2008. Reston, VA: American Society of Civil Engineers, pp. 1–5. doi: 10.1061/41002(328)8.

Bettemir, Ö. H. (2018) ‘Development of spreadsheet based quantity take-off and cost estimation application’, Journal of Construction Engineering, Management & Innovation, 1(3), pp. 108–117. doi: 10.31462/jcemi.2018.03108117.

Boktor, J., Hanna, A. and Menassa, C. C. (2014) ‘State of Practice of Building Information Modeling in the Mechanical Construction Industry’, Journal of Management in Engineering, 30(1), pp. 78–85. doi: 10.1061/(ASCE)ME.1943-5479.0000176.

Bradley, A. et al. (2016) ‘BIM for infrastructure: An overall review and constructor perspective’, Automation in Construction, 71, pp. 139–152. doi: 10.1016/j.autcon.2016.08.019.

Brückner, I. et al. (2019) ‘How to develop a BIM-workflow for landscape architecture: A practical approach’, Journal of Digital Landscape Architecture, 4, pp. 112–130. doi: 10.14627/537663013.

Choi, J., Kim, H. and Kim, I. (2015) ‘Open BIM-based quantity take-off system for schematic estimation of building frame in early design stage’, Journal of Computational Design and Engineering, 2(1), pp. 16–25. doi: 10.1016/j.jcde.2014.11.002.

Darko, A. et al. (2019) ‘Review of application of analytic hierarchy process (AHP) in construction’, International Journal of Construction Management, 19(5), pp. 436–452. doi: 10.1080/15623599.2018.1452098.

Darko, A. et al. (2020) ‘Building information modeling (BIM)-based modular integrated construction risk management – Critical survey and future needs’, Computers in Industry, 123, p. 103327. doi:

10.1016/j.compind.2020.103327.

Denzer, A. S. and Hedges, K. E. (2008) ‘From CAD to BIM: Educational Strategies for the Coming Paradigm Shift’, in AEI 2008. Reston, VA: American Society of Civil Engineers, pp. 1–11. doi: 10.1061/41002(328)6.

Ergen, F. and Bettemir, Ö. H. (2022) ‘Development of BIM software with quantity take-off and visualization capabilities’, Journal of Construction Engineering Management & Innovation, 5(1), pp. 01–14. Available at: https://www.goldenlightpublish.com/dosyalar/baski/JCEMI_2021_300.pdf.

Garcés, G. and Molina, A. (2023) ‘Proposal of a model for the quantification of construction waste costs in the planning stage of construction projects’, Informes de la Construcción, 75(571), p. e515. doi: https://doi.org/10.3989/ic.6425.

Garcés, G. and Peña, C. (2022) ‘Adapting engineering education to BIM and industry 4.0: A view from Kolb’s experiential theory in the laboratory’, Ingeniare. Revista chilena de ingeniería, 30(3), pp. 497–512. doi: 10.4067/S0718-33052022000300497.

Garcés, G. and Peña, C. (2023) ‘A Review on Lean Construction for Construction Project Management’, Revista Ingeniería de Construcción, 38(1), pp. 43–60. doi: http://dx.doi.org/10.7764/RIC.00051.21.

Garcés, G., Forcael, E., Osorio, C., Castañeda, K., and Sánchez, O. (2025). ‘Systematic review of Lean Construction: an approach to sustainability and efficiency in construction management’, Journal of Infrastructure Preservation and Resilience, 6(1), pp. 1–28. doi: 10.1186/s43065-025-00119-1

Gholizadeh, P., Esmaeili, B. and Goodrum, P. (2018) ‘Diffusion of Building Information Modeling Functions in the Construction Industry’, Journal of Management in Engineering, 34(2). doi: 10.1061/(ASCE)ME.1943-5479.0000589.

Haider, U. et al. (2020) ‘Cost Comparison of a Building Project by Manual and BIM’, Civil Engineering Journal, 6(1), pp. 34–49. doi: 10.28991/cej-2020-03091451.

Hyari, K. H. (2016) ‘Handling Unbalanced Bidding in Construction Projects: Prevention Rather Than Detection’, Journal of Construction Engineering and Management, 142(2). doi: 10.1061/(ASCE)CO.1943-7862.0001045.

Jin, R. et al. (2017) ‘BIM Investment, Returns, and Risks in China’s AEC Industries’, Journal of Construction Engineering and Management, 143(12). doi: 10.1061/(ASCE)CO.1943-7862.0001408.

Jrade, A. and Alkass, S. (2007) ‘Computer-Integrated System for Estimating the Costs of Building Projects’, Journal of Architectural Engineering, 13(4), pp. 205–223. doi: 10.1061/(ASCE)1076-0431(2007)13:4(205).

Khosakitchalert, C., Yabuki, N. and Fukuda, T. (2019) ‘Automatic concrete formwork quantity takeoff using building information modeling’, in Proceedings of the 19th International Conference on Construction Applications of Virtual Reality (CONVR), pp. 21–28.

Kim, S., Chin, S. and Kwon, S. (2019) ‘A Discrepancy Analysis of BIM-Based Quantity Take-Off for Building Interior Components’, Journal of Management in Engineering, 35(3). doi: 10.1061/(ASCE)ME.1943-5479.0000684.

Kwon, W. et al. (2023) ‘Analysis of BIM-Based Quantity Take-Off in Simplification of the Length of Processed Rebar’, Applied Sciences, 13(4), p. 2468. doi: 10.3390/app13042468.

Lawrence, M. et al. (2014) ‘Creating flexible mappings between Building Information Models and cost information’, Automation in Construction, 45, pp. 107–118. doi: 10.1016/j.autcon.2014.05.006.

Liu, H. et al. (2022) ‘A knowledge model-based BIM framework for automatic code-compliant quantity take-off’, Automation in Construction, 133, p. 104024. doi: 10.1016/j.autcon.2021.104024.

Liu, H., Lu, M. and Al-Hussein, M. (2016) ‘Ontology-based semantic approach for construction-oriented quantity take-off from BIM models in the light-frame building industry’, Advanced Engineering Informatics, 30(2), pp. 190–207. doi: 10.1016/j.aei.2016.03.001.

Lu, Q., Won, J. and Cheng, J. C. P. (2016) 'A financial decision making framework for construction projects based on 5D Building Information Modeling (BIM)', International Journal of Project Management, 34(1), pp. 3–21. doi: 10.1016/j.ijproman.2015.09.004.

McCuen, T. L. (2015) 'BIM and Cost Estimating: A Change in the Process for Determining Project Costs', in Building Information Modeling. Reston, VA: American Society of Civil Engineers, pp. 63–81. doi: 10.1061/9780784413982.ch03.

Meléndez, W., Saavedra, R. and Garcés, G. (2024) 'Quantity Take-Off in Rough Construction of High-Rise Buildings Based on CAD and BIM Methodologies: A Case Study', in Proceedings of the 32nd Annual Conference of the International Group for Lean Construction (IGLC 32). Auckland, New Zealand, pp. 793–806. doi: 10.24928/2024/0236.

Migilinskas, D. et al. (2013) 'The Benefits, Obstacles and Problems of Practical Bim Implementation', Procedia Engineering, 57, pp. 767–774. doi: 10.1016/j.proeng.2013.04.097.

Monteiro, A. and Poças Martins, J. (2013) 'A survey on modeling guidelines for quantity takeoff-oriented BIM-based design', Automation in Construction, 35, pp. 238–253. doi: 10.1016/j.autcon.2013.05.005.

Nugraha Bahar, Y. et al. (2014) 'CAD data workflow toward the thermal simulation and visualization in virtual reality', International Journal on Interactive Design and Manufacturing (IJIDeM), 8(4), pp. 283–292. doi: 10.1007/s12008-013-0200-5.

Olanrewaju, O. I. et al. (2022) 'Modelling the relationship between Building Information Modelling (BIM) implementation barriers, usage and awareness on building project lifecycle', Building and Environment, 207, p. 108556. doi: 10.1016/j.buildenv.2021.108556.

Olsen, D. and Taylor, J. M. (2017) 'Quantity Take-Off Using Building Information Modeling (BIM), and Its Limiting Factors', Procedia Engineering, 196, pp. 1098–1105. doi: 10.1016/j.proeng.2017.08.067.

Parsamehr, M. et al. (2023) 'A review of construction management challenges and BIM-based solutions: perspectives from the schedule, cost, quality, and safety management', Asian Journal of Civil Engineering, 24(1), pp. 353–389. doi: 10.1007/s42107-022-00501-4.

Peterson, F. et al. (2011) 'Teaching construction project management with BIM support: Experience and lessons learned', Automation in Construction, 20(2), pp. 115–125. doi: 10.1016/j.autcon.2010.09.009.

Ramanayaka, C. D. E., Olatunji, O. A. and Weerasuriya, A. U. (2022) 'Motivating immersive BIM uptake through user attitude: analysis of initial solution using design science approach', Built Environment Project and Asset Management, 12(4), pp. 630–648. doi: 10.1108/BEPAM-10-2021-0126.

Sackman, H. (1974) Delphi critique: Expert opinion, forecasting, and group process. First Edit. Lexington Books.

Saleh, M. A. E. (1999) 'Automation of Quantity Surveying in Construction Projects', Journal of Architectural Engineering, 5(4), pp. 141–148. doi: 10.1061/(ASCE)1076-0431(1999)5:4(141).

Sampaio, A. Z. (2017) 'BIM as a Computer-Aided Design Methodology in Civil Engineering', Journal of Software Engineering and Applications, 10(02), pp. 194–210. doi: 10.4236/jsea.2017.102012.

Schimanski et al. (2019) 'Pushing Digital Automation of Configure-to-Order Services in Small and Medium Enterprises of the Construction Equipment Industry: A Design Science Research Approach', Applied Sciences, 9(18), p. 3780. doi: 10.3390/app9183780.

Seeley, I. H. and Winfield, R. (1999) Building quantities explained. London: Macmillan.

Shen, Z. and Issa, R. (2010) 'Quantitative evaluation of the BIMassisted construction detailed cost estimates', Journal of Information Technology in Construction, 15, pp. 234–257. Available at: https://www.itcon.org/papers/2010_18.content.07578.pdf.

Shin, M.-H. and Kim, H.-Y. (2021) 'Facilitators and Barriers in Applying Building Information Modeling (BIM) for Construction Industry', Applied Sciences, 11(19), p. 8983. doi: 10.3390/app11198983.

Sriyolja, Z., Harwin, N. and Yahya, K. (2021) 'Barriers to Implement Building Information Modeling (BIM) in

Construction Industry: A Critical Review', IOP Conference Series: Earth and Environmental Science, 738(1), p. 012021. doi: 10.1088/1755-1315/738/1/012021.

Staub-French, S. et al. (2003) 'An Ontology for Relating Features with Activities to Calculate Costs', Journal of Computing in Civil Engineering, 17(4), pp. 243–254. doi: 10.1061/(ASCE)0887-3801(2003)17:4(243).

Tan, S. and Gümüşburun, G. (2022) 'Identifying Factors Limiting the Prevalent Use of BIM Technology in the Turkish Construction Industry', in, pp. 3–18. doi: 10.1007/978-3-031-16895-6_1.

Wang, J. et al. (2016) 'Building information modeling-based integration of MEP layout designs and constructability', Automation in Construction, 61, pp. 134–146. doi: 10.1016/j.autcon.2015.10.003.

Whang, S. W. and Park, S. M. (2016) 'Building information modeling (BIM) for project value: Quantity take-off of building frame approach', International Journal of Applied Engineering Research, 11(12), pp. 7749–7757. Available at: https://repository.uel.ac.uk/item/87v7q.

Yang, B. et al. (2020) 'Semiautomatic Structural BIM-Model Generation Methodology Using CAD Construction Drawings', Journal of Computing in Civil Engineering, 34(3). doi: 10.1061/(ASCE)CP.1943-5487.0000885.

Yusof, N. A., Ishak, S. S. and Doheim, R. (2018) 'Identifying factors for incorporating spatial data into BIM using the delphi method', Construction Economics and Building, 18(3), pp. 1–17.