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Enhanced automated quantity take-off in building information modeling

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Automation;
Industry Foundation Classes (IFC).

Abstract. Material quantity take-off is a necessary factor in estimating the cost of construction projects; accordingly, fast and precise estimations would better facilitate the overall construction process. In recent years, several Building Information Modeling (BIM) based applications (e.g., Autodesk Revit, Tekla Structure, Autodesk Navisworks Manage, and Solibri Model Checker) have emerged to facilitate performing quantity take-off. Quantity take-off measurement using these applications is accurate when the length of elements multiplies by their precise section area. Still, the process encounters errors when using element volumes or Industry Foundation Classes (IFC). In this study, the authors examined the embedded quantity take-off feature of these applications for sample steel and reinforced concrete structures and provided precautions in employing BIM properties. Consequently, an automated approach was employed to facilitate an accurate quantity take-off using an Application Program Interface (API) extracting information from a Navisworks model as well as database management systems. A case study was subsequently presented to demonstrate and validate the proposed methodology.

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1. Introduction

Cost estimation is one of the essential parts of the construction process as it is the platform for further construction tasks and duties. Following this critical stage, the dimensions of building elements are calculated. This information, which is traditionally called the "Quantity take-off list" is used for the estimation of materials' volume and cost. Cost estimation is generally carried out at various stages of the construction process, such as bidding, design, and construction stages [1]. It is usually employed competitively to evaluate the most affordable method for carrying out the project, participate in bids, maximize its profit, and perform a project successfully and economically [2].

Precise material Quantity Take-Off (QTO) is essential to estimating the procurement's materials, the required number of crews, project's duration, and cost of materials. Over-estimation or under-estimation of required materials poses a financial risk to contractors or owners. Thus, accurate QTO is vital to the success of a project from the view of various stakeholders. QTO is a tool for estimating costs to plan for bidding before construction with enough accuracy. Tradition-

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ally, the QTO process is performed in a manual process based on paper-based drawings or Computer-Aided Design (CAD) tools [3]. Researchers indicate that some of the QTO values are always required to be measured manually, even by utilizing QTO software solutions, where construction details exist in 2D formats (e.g., in CAD or on paper) [4]. In short, some of the main issues of manual QTO may be listed as follows [2,3,5–9]:

a) Examining sophisticated situations such as connections among multiple elements;
b) Wrong interoperation and distinction while studying and controlling maps;
c) Deficits of wrong input via manual designing;
d) Propagated errors.

Building Information Modeling (BIM) is becoming significantly prevalent in the construction industry in various stages of a project's lifecycle including design, construction, and operation phases. BIM is a novel concept used to define objects by properties (e.g., geometric properties) for the design and management of information based on virtual modeling. In other words, BIM is an integrated parametric model that contains different involved disciplines such as architectural, structural, mechanical, electrical, and piping. Some of the advantages of automation in BIM for the project and building managers include organizing schedules, project cost reports, and streamlining relationships with the designing team [10–12]. BIM-based QTO facilitates lifecycle cost engineering. Such an approach has evolved the role of cost estimating with early involvement of designers, contractors, and operators in cost estimating and scheduling functions by employing skills and knowledge required to deal with lifecycle costs [12]. In a study conducted using surveys, it was found that BIM would have a significant impact on future design and construction processes [10,13]. Besides, another related study showed that formation of BIM models inside the company provided more advantages than assigning this task to third-party companies [14].

BIM-based applications (e.g., Autodesk Revit, Autodesk Navisworks, and Tekla Structures) can extract rich information from the model to perform automatic QTO for the sake of cost estimation [1,12]. Most BIM tools encompass methods for performing calculations via elements' geometric properties (e.g., volume and area), which are then exported as a textual report. Automatic BIM-based QTO makes cost estimation much simpler and more accurate, which reduces personnel time and associated costs [10]. However, QTO reports generated by common BIM software applications cannot be directly manipulated.

Exchanging information between BIM software and cost estimation software is usually carried out by either converting data to a standard format such as Industry Foundation Classes (IFC) or employing Application Program Interface (API) via a shared database [3]. The IFC format is a temporary data house used to define, categorize, and organize Architecture, Engineering, and Construction (AEC) industry data, but it can also constitute deliverables within legal frameworks. A study investigated the IFC files and their application to the Heating, Ventilation, and Air Conditioning (HVAC) systems, pointing to the significance of these files in BIM [15]. Moreover, Marmo et al. [16] integrated Facility Management (FM) systems with BIM to deal with IFC viewer application limitations and better manage maintenance operations in buildings.

Despite the full range of relevant software products in the context of BIM, IFC format is not applicable in all countries [2,3]. Moreover, there are some reading issues when different BIM applications deal with IFC files. First, some properties may not transfer adequately due to interoperability issues between the initial and target BIM applications. More importantly, some auto-calculated properties (item volumes calculated by Revit software) might be inaccurate, with significant errors being as high as 25% sometimes, while acceptable errors in the detailed QTO should not exceed 5%.

Due to errors in the exchange of information with IFC files, some researchers have attempted to increase the accuracy of QTO and enhance the efficiency of the BIM tools against errors using API-based solutions. For example, Eastman et al. [6] built a software solution extracting information from BIM-based models that allow operators to use tools designed for their requirements without the need for learning all traits of a specific BIM tool. In a study, the development of human knowledge on BIM applications, capabilities, and customizations has been investigated [17,18].

Automation in construction is widely used in different application areas such as detecting concrete rebar [19], construction equipment path planning [20], and construction performance monitoring [21,22]. Similarly, BIM has been found to be a beneficial tool that can be used for several purposes in the construction domain [23,24]. The automated BIM-based QTO approach is becoming popular in the construction industry employing various software solutions of the BIM industry [1,8,13,25–29]. However, BIM-based QTO is also prone to errors. For instance, one may encounter some errors in calculating the area section or volumes of building elements employing BIM-based QTO solutions, while counts of building elements extracted from the model are usually more reliable [30]. Thus, automated QTO requires an experienced BIM expert who has enough information about manual and automatic QTO. The expert must also be knowledgeable about parametric modeling, navigation, and filtering in the integrated model (e.g., architectural, structural, and MEP disciplines in BIM) as well as interpolating and validating QTO results extracted by the BIM-based solution [3,28,29]. Some other research studies have focused on discrepancies in QTO between design and construction phases of projects using various applications such as Revit and Tekla Structure [25,31]. Whang and Park [32] made a comparison in a case study and concluded that BIM-based methods exhibited higher QTO precision (95%) than manual-based approaches (89%). However, the accuracy of the QTO is dependent on the details of the model [26,27].

In recent years, API has been extensively applied for various research objectives in the context of automation. Liu et al. [25] employed API in their study to achieve automatic scheduling while facing resource limitations. Their methodology consists of three stages:

a) Microsoft access database, which includes all information about the project containing Work Breakdown Structure (WBS) and resources;
b) Microsoft Project (MSP) software to generate the automatic schedule;
c) Autodesk Revit software to design 3D models.

Liu et al. [33] proposed an ontology-based semantic approach for QTO by developing an add-on in Autodesk Revit. However, this method is only tested on a wood-framed residential building. Furthermore, Akanbi and Zhang [34] proposed an automated method using Natural Language Processing (NLP) to extract design information from construction specifications. This method is used to estimate the cost of wood construction. Taghaddos et al. [9] employed API to filter all elements about a particular discipline in a given working area and to automate cost estimation and QTO using boundary boxes (i.e., surrounding rectangular box defined for each model item in BIM). This approach works well where the model item has a rectangular or cylindrical shape. However, it may suffer a lack of accuracy if a model item has an irregular geometry or if is not aligned horizontally or vertically.

In summary, some of the limitations of BIM-based QTO are as follows:

1. Most of the BIM applications rely on the IFC format, which is not common in many countries;
2. IFC still suffers interoperability and reading issues when different BIM applications are involved;
3. Some auto-calculated properties may be inaccurate due to the simplifying approach in the BIM-based modeling plugins (e.g., algorithm to calculate rebar section in Autodesk Revit).

Limited research has been performed to identify the errors or enhance the accuracy of the automated QTO approach. Thus, there is a need for a robust automated method for QTO to resolve the above limitations. This study has proposed solutions for resolving the issues mentioned above. First, it provides an awareness of sources of error in QTO in commonly used BIM-based applications by investigating the sources of these issues. Second, this paper empowers the capabilities of BIM applications and enhances the accuracy of BIM-based QTO by employing a data-driven API-based approach and linking to a database to modify/add proper properties. A more detailed methodology is elaborated in the next section.

2. Material and methods

In this study, errors in estimating the parameters associated with materials were investigated in various BIM applications. For this purpose, three applications (i.e., Autodesk Revit, Tekla, and Autodesk Navisworks) were examined. Then, the errors in the QTO of metal, concrete, and reinforcement elements in these three software solutions were studied. A attempt to take a closer look at a metal structure and a concrete structure was then made. Finally, an API was used in a framework to increase the accuracy of estimating materials in these applications.

As shown in Figure 1, in the first step, the volume and weight of different rebar and steel sections, modeled in Tekla, were examined. Then, this investigation was carried out in Autodesk Revit. In Revit, two scenarios were checked. The first scenario is when the item is modeled manually without using the modeling extension of Revit. The second scenario is when it is modeled using the predefined modeling tool extension in Revit. At the next step, metal and concrete structures provided in the Revit software were investigated.

Moreover, metal and concrete structures were modeled using Tekla software. Then, they were exported into Navisworks software and compared in terms of QTO, with their actual weights calculated using the formula of length times weight per meter. In the current study, writing formulae in Revit Interface were not utilized to resolve QTO error. Although equations in Revit Interface can address such a mistake, errors in volume estimation still appear in the Navisworks report due to the lack of software interoperability. At the last stage of the proposed methodology, a Database Management System (DBMS) containing elements' information (e.g., lengths) is populated by API code. The DBMS queries data (e.g., multiplies the area by the weight per meter) were employed to facilitate the automated QTO process.

The main finding of the current study is to provide

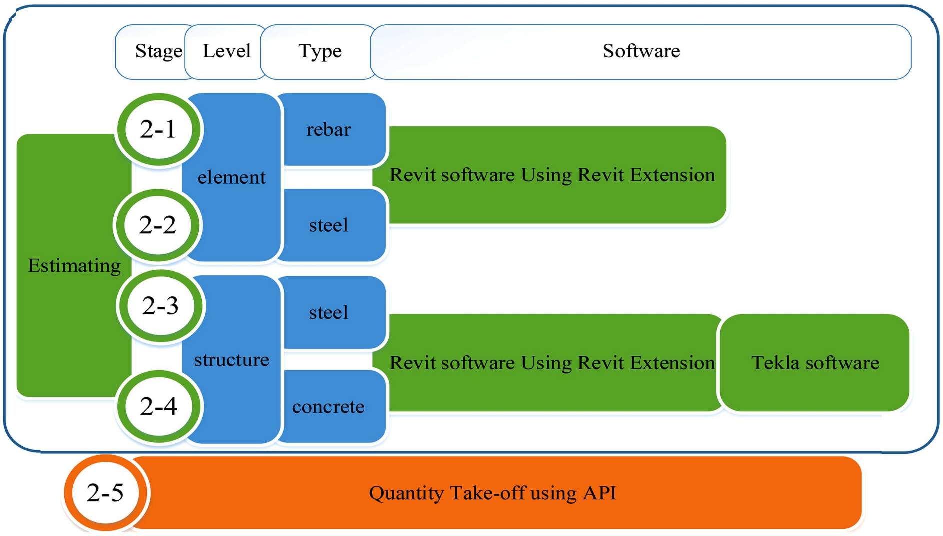


Figure 1. Proposed steps for investigating the quantity take-off accuracy in Autodesk Revit and Tekla.

an awareness about sources and number of errors in automated QTO provided by BIM applications. This study also offers a data-driven solution to eliminate the mistakes in materials QTO in any BIM software such as Autodesk Navisworks or Intergraph SmartPlant Enterprise solution.

2.1. Estimating rebar in a concrete element using Revit extension

Modeling concrete columns and beams rebar by Revit software is time consuming. However, it can be performed more quickly with a software extension. In this study, rebars with the sizes of 10, 16, 22, 25, and 32 were examined. These were further checked by the lengths 3 m, 6 m, and 10 m to compare the error rates in terms of volume or weight to their real value. The real value is the value calculated using the existing specific section area of rebar or steel profiles (e.g., wide flange beams) multiplied by the length of the element.

As shown in Figure 2, axis y is the error percentage and axis x is rebar size in the lengths mentioned above. Columns above the axis x indicate that the rate estimated by the software is less than the real value and columns under axis x show that software estimation is higher than the actual value. Furthermore, the smaller the size of rebar, the higher the error; conversely, the greater the size of rebar, the lower the error. The percentage of error varies between –2.8 and 10.98. Thus, independently, examining the accuracy of a single rebar measurement is vital, making it possible to check it in the form of a concrete structure.

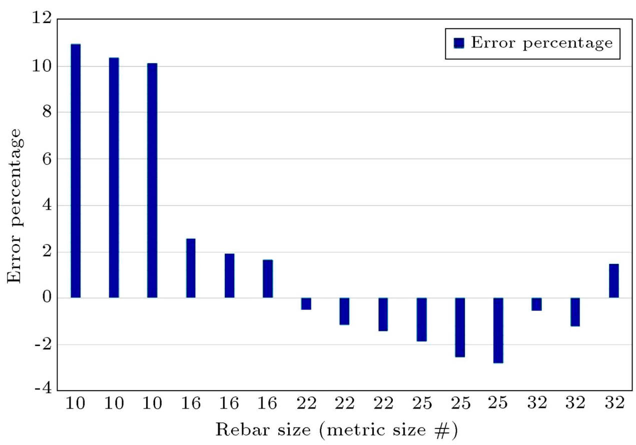


Figure 2. The error rate of compared rebar.

This error results from the miscalculation of section area because Revit approximates the section with a polygon instead of considering the exact area of the section. As an example, this polygon is inscribed in the section circle area for rebars 22 and 25 (Figure 3(a)) and circumscribes the circle for rebars 10 and 16 (Figure 3(b)).

Eqs. (1) and (2) are the formulas for approximating the area of the unit circle using inscribed and circumscribed polygons, known as the classical method of exhaustion:

Inscribed polygon with n sides:

$$A\ (\text{polygon}) = \frac{1}{2} n \sin \frac{2\pi}{n}. \qquad (1)$$

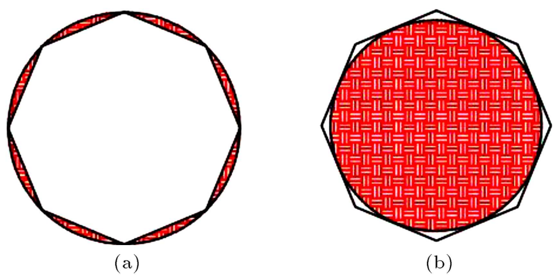


Figure 3. Rebar element: (a) Inscribed polygon inside the area and (b) circumscribed polygon outside the area.

Circumscribed polygon with n sides:

$$A\ (\text{polygon}) = \frac{n}{2}\left(\frac{1}{\cos\frac{\pi}{n}}\right)^2 \sin\frac{2\pi}{n}. \qquad (2)$$

These formulas show that as the number of sides (n) tends to infinity, the area of polygon approaches that of the unit circle.

2.2. Estimating a steel element using Revit extension

Modeling steel elements with Revit Extension is much faster than modeling with the Revit software. However, this study shows that the amount of QTO error is higher, overall. To investigate this claim, metal elements are individually modeled and then, modeled in the form of a metal structure. For this study, the authors investigated eight sections with different sizes. Table 1 shows some steel sections in the Extension of Autodesk Revit software.

After conducting a review, authors found that Revit software automatically incorporated length, volume, and count and inserted the area and weight of each square meter into the table of QTO from properties in which data were manually added. In the process of calculating volume, authors found that by multiplying the area into length, the information contained in the table report was not used. Thus, various profiles in beam and column and bracing modes and different sizes and lengths were modeled in Revit software to accurately study errors related to volume and weight (Figure 4).

The profiles mentioned in Table 1 in column mode were studied with the lengths 3, 10, 20, 30, 40, 60, 80, and 100 feet. As shown in Figure 5, some profiles have less volume, while some have more volume than the actual value. Note that axis x gives the type and size of the profile, and axis y displays the percentage of this error. For example, the detail in Table 1 shows different lengths of IPE 100 profiles, studied in the lengths mentioned above.

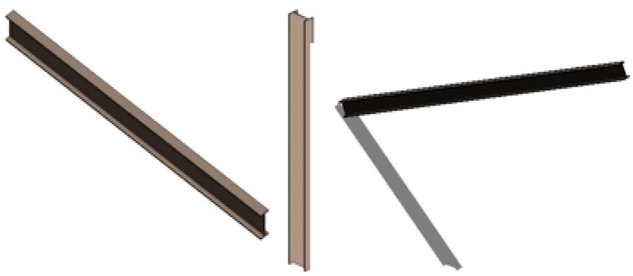


Figure 4. Different profiles' models.

According to Figure 5, by changing the length of each section, the error rate remains constant. However, by changing just the profile size, the error rate will be different. Moreover, the error rate in profiles CAE, IPE, HEB, HEA, when used as a column, ranges between 0.53% and 5.82%, less than the real value. In TRON, UPN, TCAR, and IPN profiles, the error rate is between –9.1% and 0% more than the actual value. These errors were eliminated in the research done by Taghaddos et al. [9]. Additionally, similar investigations into beams and braces were also undertaken in the study, as mentioned earlier.

The sections mentioned in Table 1 have been explored and utilized as bracing, with the lengths of 5.39, 6.40, 7.81, 9.43, 11.18, 13, 14.87, 16.76, 18.68, and 20.62 meters and angles of 22, 39, 50, 58, 63, 67, 70, 73, 74, and 76 degrees. In Figure 6(a), the actual section of a steel beam or column is shown. However, the software uses the approximate section, as shown in Figure 6(b). Thus, when it calculates the volume or weight of the element using the multiplication of length section area, it has errors.

2.3. Studying metal structure in Revit software using the tool extension and Tekla software

As shown in Figure 7, a metal structure was modeled to investigate QTO in a general form. In Figure 7, the rate of error in weight estimation is shown by individual element. The weight proposed by the Revit software and the real weight equal 3181 and 3285 kg, respectively. A difference of 104 kg equals the error rate of 3% for a simple structure. By increasing the building area and the number of floors, it can be perceived that this rate of error expands. Moreover, the IPE profile has been employed in this structure. When profiles such as INP are used, a significant difference in weight concerning the real value is produced.

According to Table 2, the sum of the weights of elements in steel structures modeled in Tekla differs from the real weight of the structure by only 8 kg, which shows that it is more accurate when compared to Revit in QTO. The value of brace weight is higher than its

Table 1. Sections studied in Revit.

HEA	HEB	IPE	IPN	CAE	TRON	TCAR	UPN

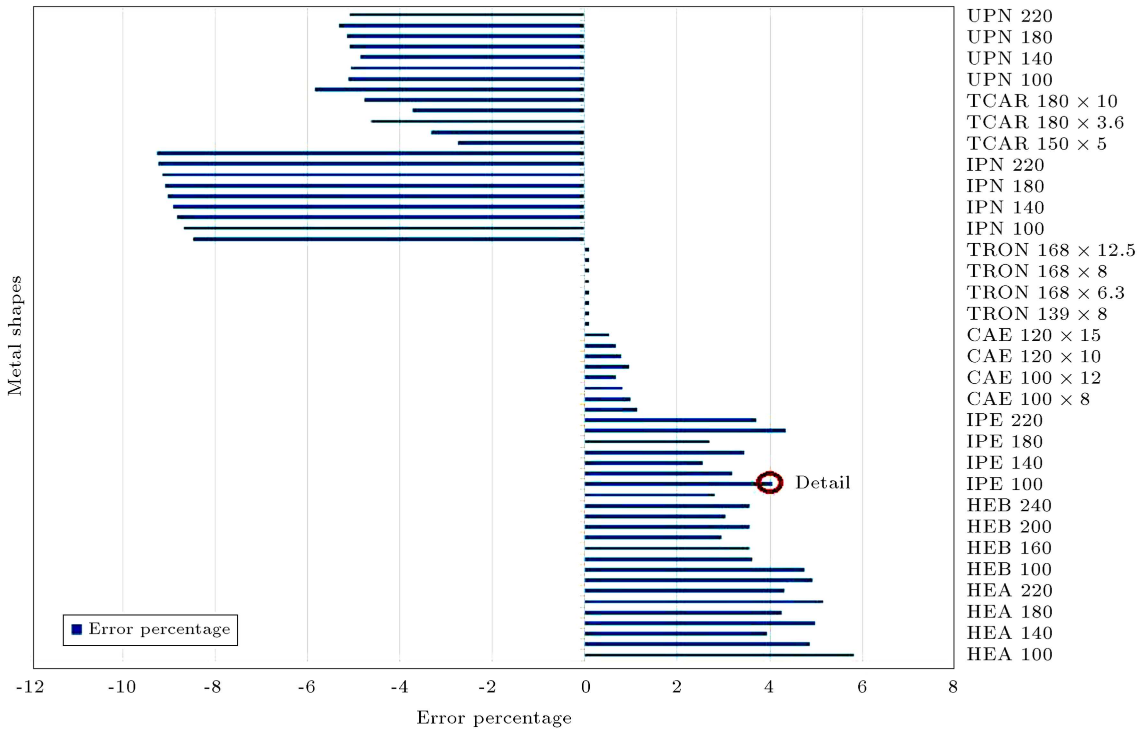
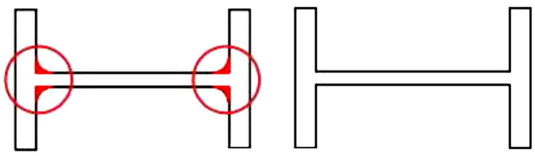


Figure 5. Different sections' area calculation errors in the software.

actual value in Tekla because it is an oblique item, and Tekla calculates the brace length from one joint to another, making it much higher than the actual value as constructed.



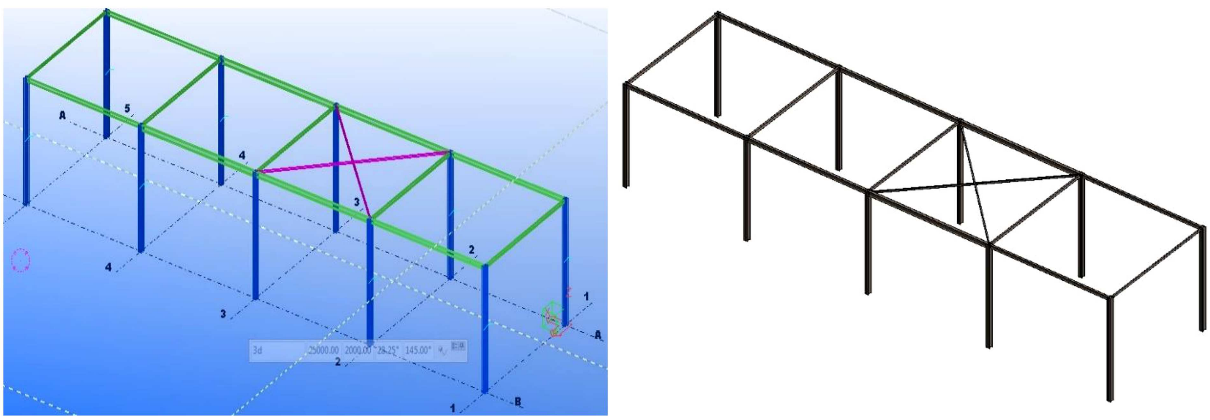
(a) (b)

Figure 6. Steel element: (a) Areas not calculated and (b) approximate area calculated.

2.4. Studying concrete structure in Revit software with the tool extension and Tekla software

According to Figure 8, a concrete structure sample was modeled in Revit software for QTO.

Table 3 reports concrete and rebar QTO. These have been investigated regarding weight and volume, but the dimensions of beam volume are entirely accurate and equal to the real values. Notably, in the Revit software, bar diameter, length, and rebar volume are calculated by the software. Rebar volume equals 2533.54 cm^3 compared to the real volume, which is 2454.36 cm^3. This is a slight discrepancy; however,



(a) (b)

Figure 7. Metal models: (a) Metal model in Tekla and (b) metal model in Revit.

Table 2. Quantity take-off by Tekla and Revit software.

Type	Element	Weight (kg)			Error (Percentage)	
		Sotware				
		Revit extension	Tekla	Actual	Revit extension	Tekla
IPE180	Column	1830	1876	1880	2.65	0.21
IPE80	Brace	98	101.8	99.96	1.96	–1.84
IPE100	Beam	45	47.1	47.14	4.54	0.089
IPE120	Beam	116	120.6	121	4.17	0.37
IPE140	Beam	146	149.8	150.2	2.76	0.23
IPE160	Beam	180	186.2	187.3	3.94	0.63
IPE180	Beam	216	221.6	223	3.12	0.61
IPE200	Beam	252	264.2	265.7	5.14	0.55
IPE220	Beam	298	309.6	310.7	4	0.35
Total		3181	3276.9	3285	3.17	0.25

Table 3. Quantity take-off of a concrete beam in Revit and Tekla.

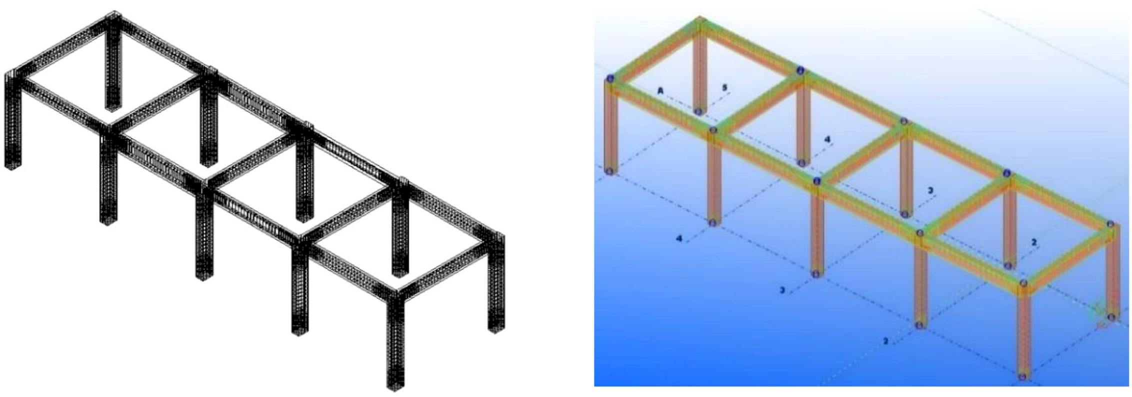
Count	Type	Column volume (m^3)	Length (cm)	Bar diameter (cm)	Rebar volume (cm^3)	Weight per meter (kg)	Total weight (kg)
10	450*600	1.35	500	2.5	2533.54	3.92	1958.33

since rebar weights are obtained by multiplying the weight of each meter by its length, this discrepancy in volume does not cause additional problems.

2.5. Quantity take-off using API

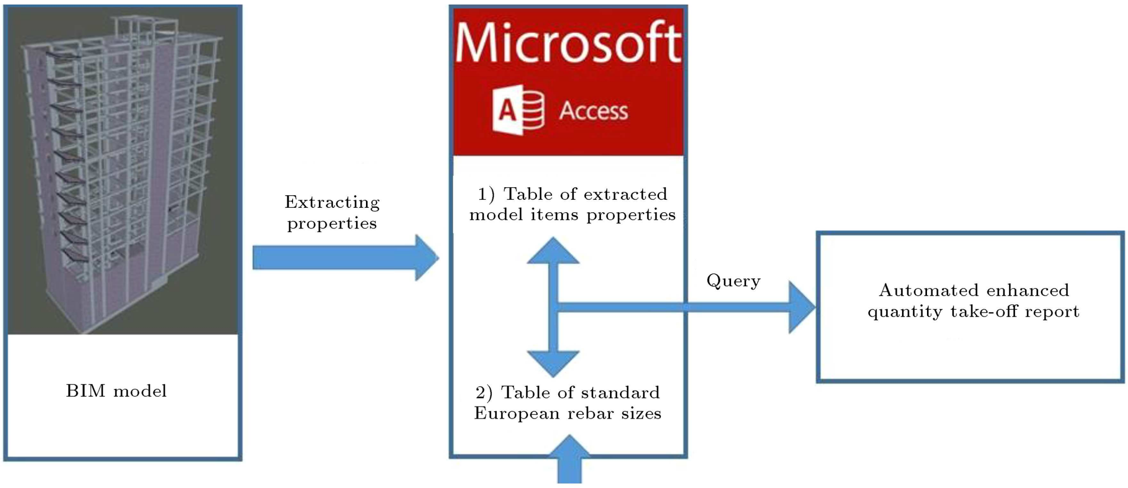
In consideration of the need for precise and quick estimation of materials in construction projects, some novel methods have been proposed in recent years [9,35]. An appropriate API was employed to overcome the above problems in estimation through the interface of the applications in this paper. This approach consists of a series of steps to obtain an accurate QTO from the model (Figure 9):

1. Create a model in each of the BIM applications (e.g., Revit and Tekla) with complete information



(a) (b)

Figure 8. Concrete models: (a) Concrete model in Revit and (b) concrete model in Tekla.



Rebar type	Nominal diameter (mm)	Nominal area (mm^2)	Density (kg/m^3)	Unit weight (kg/m)
10M	10	78.5	7859.87	0.617
12M	12	113	7858.4	0.888
14M	14	154	7857.14	1.21
16M	16	201	7860.7	1.58
25M	25	491	7841.14	3.85

Figure 9. Methodology work flow.

```
Dim Counter1 As Integer = 0

Dim MySearchResult1 As ModelItemCollection
MySearchResult1 = ActiveDocument.CurrentSelection.SelectedItems
If MySearchResult1.Count > 0 Then
    For Each oItem As ModelItem In MySearchResult1.DescendantsAndSelf
        Counter1 = Counter1 + 1
        ' each PropertyCategory
        Try
            Dim oPC As PropertyCategory = oItem.PropertyCategories.FindCategoryByDisplayName("Element")
            'For Each oPC As PropertyCategory In oItem.PropertyCategories

            ' each property
            For Each oDP As DataProperty In oPC.Properties

                tbModelComponentsDataRow = ModelItemsProps.NewRow
                tbModelComponentsDataRow("ItemID") = Counter1
                tbModelComponentsDataRow("Category Name") = (oPC.DisplayName)
                tbModelComponentsDataRow("Property Name") = (oDP.DisplayName)

                ' is a display string

                If oDP.Value.IsDisplayString Then
                    tbModelComponentsDataRow("Property Value") = (oDP.Value.ToString)
                End If
```

Figure 10. Sample Application Program Interface (API) used for extracting data from model to database.

for each element. The model should consist of families with comprehensive data such as length, area, volume, name, and type. This information is indeed the same information obtained from the Revit and Tekla software products and was saved while making families in the properties of the elements;

2. Transfer the model provided in Revit to the Navisworks software. All of the information embedded in Revit is also accessible by Navisworks software. The same area error calculation exists here and it further generates an error in calculating volume and weight. Furthermore, after transferring the concrete model built in Revit software to Navisworks, it was shown that Navisworks did not offer any information on rebar, except quantity. However, for concrete elements such as beam and column, Navisworksgives the same volume and length as Revit does;

3. The code, which is used in this paper, reads all of the properties of the model items from the model and exports them to a table in Microsoft Access as a database (Figure 10). This code searches

through the properties section of the model, and by accessing each category, it reads the property value of each model item;

4. Standard European rebar sizes are stored in a table;
5. Finally, by querying these two tables and multiplying the length by the area corresponding to each section, the volume and weight of each item are derived automatically.

3. Results and discussions

For a better assessment of the proposed approach, a real residential building in Tehran was selected. The building is a reinforced concrete structure of an eight-story building, each floor with two apartment units. It is being constructed on a strip foundation with six shear walls. The structure model of the building, when extracted to Navisworks, is shown in Figure 11. Figure 11(a) shows the entire building model in Autodesk Navisworks and Figure 11(b) shows the reinforcement model filtered out of the entire model.

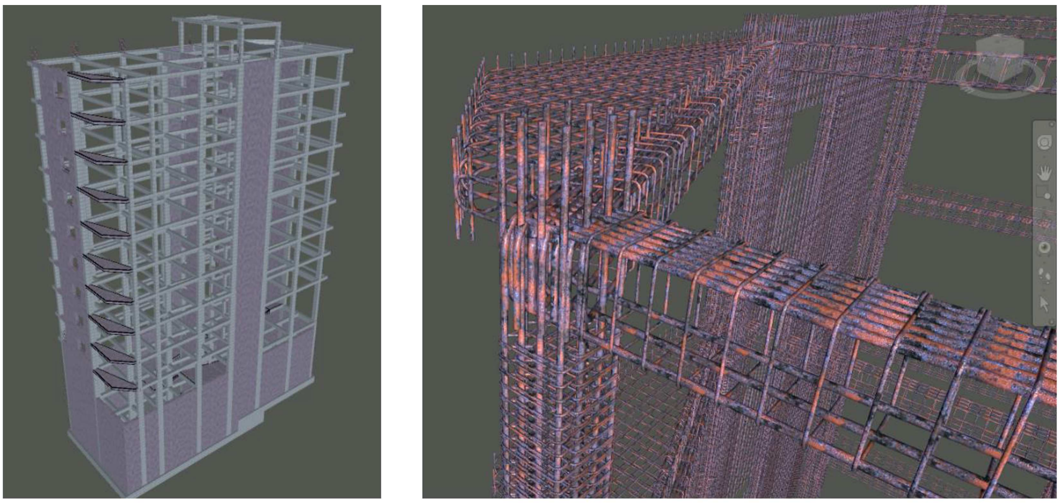
In this paper, the proposed approach was employed on the rebars of the structure and European rebar sizes were utilized (Table 4). The rebar information was stored in a database consisting of three tables: one is the output of the QTO derived by querying from the other two following tables:

1. *Tbl_ModelItemsProps* (Table 4): This table consists of extracted properties of the model items (e.g., item ID, global ID, category, type, bar diameter, quantity, bar length, and total bar length);
2. *Tbl_RebarTypes* (Table 5): This table consists of standard European rebar sizes and their specific properties (e.g., nominal area, density, and unit weight).

As mentioned, Revit erroneously estimates the volume of the rebar because of the simplifications made in the circular cross-section of the rebar. It is assumed that the cross-section is a polygon, causing the estimation of the volume to be inaccurate. For this reason, three types of QTO have been calculated in this paper and compared with each other. QTO has been calculated for rebar sizes of 10, 12, 14, 16, and 25 (Table 4).

3.1. Estimation using the weight per meter of the rebar

This type of measurement is accurate as it uses the length of specific rebar and multiplies it by its related weight per meter in rebar types table (Eqs. (3) and



(a) (b)

Figure 11. Structural model in Autodesk Navisworks: (a) Entire model and (b) reinforcement model.

Table 4. European rebar types.

Rebar type	Nominal diameter (mm)	Nominal area (mm^2)	Density (kg/m^3)	Unit weight (kg/m)
10M	10	78.5	7859.87	0.617
12M	12	113	7858.4	0.888
14M	14	154	7857.14	1.21
16M	16	201	7860.7	1.58
25M	25	491	7841.14	3.85

Table 5. Properties of extracted model items.

Item ID	Property name	Filtered property value	Item ID	Property name	Filtered property value
20084	Bar diameter	13	20087	Bar diameter	16
20084	Bar length	6500	20087	Bar length	3050
20084	Category	Structural rebar	20087	Category	Structural rebar
20084	ID	884690	20087	ID	638795
20084	Quantity	14	20087	Quantity	1
20084	Total bar length	91000	20087	Total bar length	3050
20084	Type	14M	20087	Type	16M
20086	Bar diameter	16	20088	Bar diameter	16
20086	Bar length	3050	20088	Bar length	3050
20086	Category	Structural rebar	20088	Category	Structural rebar
20086	ID	638794	20088	ID	638796
20086	Quantity	1	20088	Quantity	1
20086	Total bar length	3050	20088	Total bar length	3050
20086	Type	16M	20088	Type	16M

(4)). This value is shown in Table 6 as Weight 1.

$$\text{Rebar total length (mm)} = \text{Rebar quantity} \times \text{Rebar length (mm)}, \quad (3)$$

$$\text{Rebar total weight (kg)} = \frac{\text{Rebar total length (mm)}}{1000} \times \text{Unit weight} \left(\frac{\text{kg}}{\text{m}}\right). \quad (4)$$

3.2. Estimation using the proposed method

Through this estimation, the actual errors in calculating the cross-section area of the rebar and its volume are corrected. In this type of calculation, the query reads the total length of the specific rebar and multiplies it by its related nominal area and density in another table (Eq. (5)). This value is shown in Table 6 as Weight 2.

$$\text{Rebar total weight (kg)} = \frac{\text{Rebar total length (mm)} \times \text{Nominal area (mm}^2)}{10^9} \times \text{Rebar density} \left(\frac{\text{kg}}{\text{m}^3}\right). \quad (5)$$

3.3. Estimating using existing volume calculation of Revit

As mentioned before, Autodesk Revit estimates the volume of the materials using its internal calculations; it is not accurate because it simplifies the cross-section of the rebar or other steel profiles. Instead, using API, this is extracted and shown in Table 6 as Weight 3. As shown in Table 6, the value of volume, which is calculated by the software, has an error rate of 6%. However, this error has decreased to 0.00001% using the proposed method, which substantially equals the actual value.

4. Conclusion

Although Industry Foundation Classes (IFC) formats have been highly utilized to describe the construction industry data and facilitate interoperability in the Architecture, Engineering, and Construction (AEC) industry, they still face significant readability issues. Moreover, some auto-calculated properties such as volumes of model items may run into as much as 25% QTO errors, while the acceptable errors in detailed Quantity Take-Off (QTO) should not exceed 5%.

In this study, material QTO of basic building materials was analyzed in depth. This paper proposed an innovative solution to evaluate and address these errors. First of all, this study informs Building Information Modeling (BIM) experts about various sources and the amount of errors in an automated QTO provided by BIM applications when properties are used for QTO. Then, it empowers the capabilities of BIM applications by employing Application Program Interface (API) and linking the model to a database to modify/add proper properties. Based on the study performed on three common BIM applications (Tekla, Revit, and Navisworks Manage), it is concluded that:

1. The percentage of error in volume and weight of steel profiles (e.g., CAE, IPE, HEB, HEA, UPN, TCAR, IPN) in Revit extension ranges from 6% to –9%. It is notable that such an error does not differ significantly among beam, column, and bracing elements;
2. The percentage of error in the volume or weight of rebars (in beams or columns) used in Revit

Table 6. Different quantity take-off reports and comparison.

Item ID	Global ID	Category	Type	Quantity	Length (mm)	Total length (mm)	Weight 1 (kg)	Weight 2 (kg)	Weight 3 (kg)
20076	854018	Structural rebar	14M	24	4261	102240	123.7104	123.710355	106.664523
20077	881218	Structural rebar	14M	14	6850	95900	116.039	116.0389578	100.0501758
20078	881219	Structural rebar	14M	14	6850	95900	116.039	116.0389578	100.0501758
20079	884654	Structural rebar	14M	14	6300	88200	106.722	106.7219612	92.0169414
20080	884655	Structural rebar	14M	14	6300	88200	106.722	106.7219612	92.0169414
20084	884690	Structural rebar	14M	14	6500	91000	110.11	110.10996	94.9381104
20086	638794	Structural rebar	16M	1	3050	3050	4.819	4.819002135	4.760016
20087	638795	Structural rebar	16M	1	3050	3050	4.819	4.819002135	4.760016
20088	638796	Structural rebar	16M	1	3050	3050	4.819	4.819002135	4.760016
20089	638797	Structural rebar	16M	1	3050	3050	4.819	4.819002135	4.760016
20090	652559	Structural rebar	16M	39	6000	234000	369.72	369.7201638	365.1930492
20091	652560	Structural rebar	16M	39	6035	235560	372.1848	372.1849649	367.6276842
15515	800526	Structural rebar	10M	22	490	10780	6.65126	6.65125779	6.0059046
15516	800527	Structural rebar	10M	6	490	2940	1.81398	1.813979397	1.6379454
15517	800528	Structural rebar	10M	22	490	10780	6.65126	6.65125779	6.0059046
15518	800529	Structural rebar	10M	22	490	10780	6.65126	6.65125779	6.0059046
15519	800530	Structural rebar	10M	6	490	2940	1.81398	1.813979397	1.6379454
15520	800531	Structural rebar	10M	22	490	10780	6.65126	6.65125779	6.0059046
12022	822822	Structural rebar	25M	2	5050	10100	38.885	38.88499737	40.225515
12023	822823	Structural rebar	25M	2	5050	10100	38.885	38.88499737	40.225515
12024	822824	Structural rebar	25M	13	800	10400	40.04	40.0399973	41.4203136
12025	822825	Structural rebar	25M	13	800	10400	40.04	40.0399973	41.4203136
12026	822826	Structural rebar	25M	13	2550	33150	127.6275	127.6274914	132.027171
12027	822827	Structural rebar	25M	13	2550	33150	127.6275	127.6274914	132.027171
21641	771226	Structural rebar	12M	22	508	11220	9.96336	9.963351024	8.3808822
21642	771227	Structural rebar	12M	8	508	4080	3.62304	3.623036736	3.0476364
21643	771228	Structural rebar	12M	22	508	11220	9.96336	9.963351024	8.3808822
21644	786182	Structural rebar	12M	99	2248	222750	197.802	197.8018218	166.3855104
21645	786333	Structural rebar	12M	109	2248	245250	217.782	217.7818038	183.1921554
20105	659785	Structural rebar	16M	29	4580	132820	209.8556	209.855693	207.2861208
20106	659810	Structural rebar	16M	33	4550	150150	237.237	237.2371051	234.3322236
						Sum of weights (kg) = 2770.088		2770.087	2603.249
						Error (%) = N/A		–0.00001	–6.02287

Extension varies from –3% to 11%. These errors are somehow similar in beams and columns and range from –10.98% to +2.8%;

3. Navisworks software is not capable of generating QTO from the model built in Tekla software and it only shows the information of elements in the properties tab;

4. The aforementioned errors in QTO can be eliminated when the model is exported from Revit to Navisworks using API.

Figure 12 compares two typical BIM-based applications (i.e. Revit and Tekla) in terms of the simplicity of modeling and QTO accuracy. QTO in Autodesk Revit is fast using QTO extension. However, customized fam-

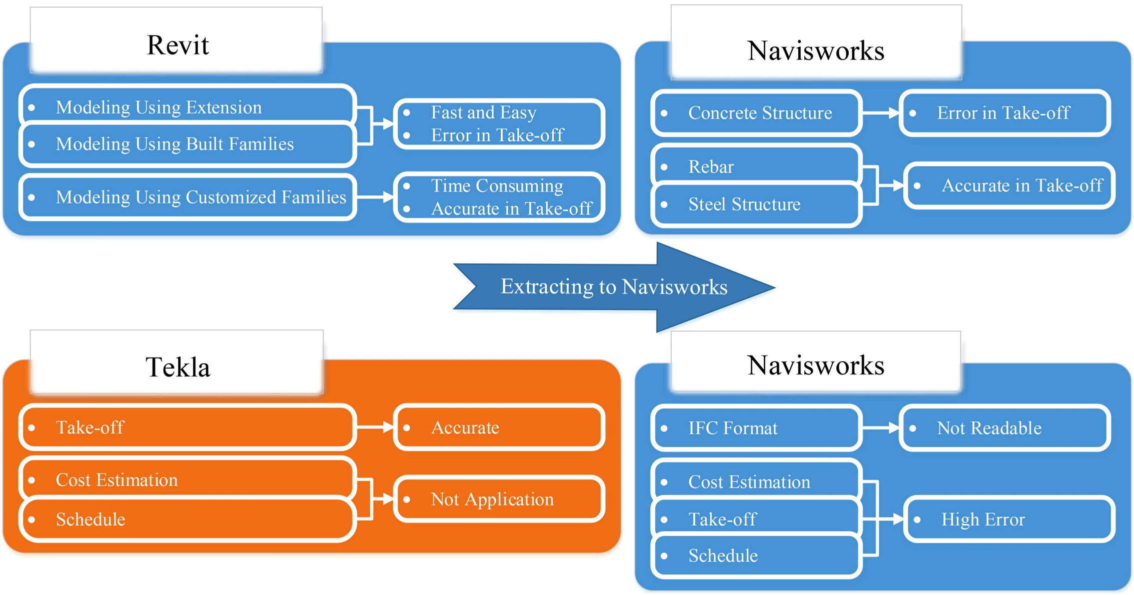


Figure 12. Revit and Tekla comparison in automated quantity take-off.

ilies should be used to increase the accuracy. Autodesk Navisworks application often faces incomplete take-off when working with concrete structures. It also has interoperability issues when the IFC format is involved. Although Tekla software provides an accurate QTO, it does not provide enough support for cost estimation and scheduling.

This paper proposed a data-driven approach to enhance the accuracy of automated QTO. Employing API in this study facilitated extracting the information from Autodesk Navisworks and calculating the weight and volume of elements accurately. Furthermore, every element position (x, y, and z) can be accessed in this API code and QTO for every floor or space is provided separately. This paper proposed a shortcut to prevent all the issues regarding the QTO in BIM applications. It used the properties of the elements extracted from BIM applications, stored them in a database, and finally utilized the pre-added property tables to determine their corresponding element to determine the quantity of each element.

In summary, once a project is confronted with errors in material estimation, it not only influences the procurement and material waste, but also affects workforce estimation and crew productivity on construction site. Further research is focused on the impact of QTO on cost estimation, schedule, and the required workforce for construction.

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