The Accuracy Enhancement of Architectural Walls Quantity Takeoff for Schematic BIM Models

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Abstract

The emergence of Building Information Modeling (BIM) technology makes the quantity takeoff process faster and more reliable. It helps reduce the effort in cost estimation to survey the cost feedback on alternative schemes in the early stages of design. However, at these stages, the quantity could be absent or in excess because the BIM model has a low level of development (LOD). The building elements that have layered structures such as architectural walls always face such problems. This is because during the construction phase, each layer may have a different dimension. For instance, the height of the interior finish layer of the wall may be shorter than that of the core layer. On the other hand, the walls in a BIM model during the early stages usually have low LOD. Each wall layer is not created separately and some walls may overlap structural elements because the designers need a schematic BIM model that is easy to create and manipulate. This research proposes a method that will improve the accuracy of the wall quantity takeoff in the schematic BIM model by applying the concept of BIM-based clash detection. The proposed method automatically detects the overlapped areas and subtracts or adds the material quantity of each wall layer without the need for editing the BIM model. The now accurate quantities can then be used in the chosen project delivery method where a cost estimation feedback is needed during the early stages of the design process.

Keywords –

Building Information Modeling, BIM, Quantity Takeoff, 5D BIM, Quantification, Early Stages Design, Schematic BIM Model, Clash Detection

1 Introduction

Quantity takeoff is a time-consuming task in the design and construction process. Traditionally, quantity takeoff is done manually based on 2D drawings' measurements. Quantity surveyors need specialized knowledge and experience to understand the set of design drawings; which are a series of 2D projections. They have to understand the design and decide the measurement method to be used for each building element. This process is time-consuming and the results from each quantity surveyor may not be the same.

In a conventional project delivery method or Design-Bid-Build (DBB), a precise quantity takeoff for detailed cost estimation is done after the design phase for bidding. However, there are other delivery methods such as Design-Build (DB) and Integrated Project Delivery (IPD) in which design and construction teams work together as an integrated unit from the onset [1]. One of the goals of these delivery methods is to reduce the projects' cost in order to deliver the project within the owners' budget. An accurate cost estimation during the early stages of the design can help the team to make more informed design decisions [1, 2]. Therefore, precise quantity takeoff during these early stages is important.

The emergence of Building Information Modeling (BIM) technology brings with it a new method of quantity takeoff, called a BIM-based method. This method uses geometry data: such as length, area, and volume as well as the objects information: such as category, name, and level in the BIM model for quantity takeoff. The BIM-based quantity takeoff method is proven to be faster and more reliable than the traditional 2D-based method [3]. However, this is not a straightforward or automatic process [2, 4]. Some quantity can be absent from the BIM model due to the incompleteness of the model compared to the real construction [5]. This issue usually occurs in the early stages of the design; where designers make a rough BIM model in order to explore the design. Some of the data has yet to be defined and some objects may overlap each other causing inaccuracies in the quantities reflected.

Architectural elements that are layered structures always have complications when measuring quantities off of them. For example, architectural walls are non-structural elements which are used to divide or enclose spaces. These walls can be built either between structural frames as an envelope of the building or as interior partitions to separate each room. Architectural walls consist of both a core structure layer which is typically masonry units or stud framing and finish layers which are typically plaster, tiles or wall panels. Each layer has a different size and quantity. For example, the plaster layer height on the interior may only go up to ceiling height whilst on the exterior, it may cover the surface of the beam above (see Figure 1). The measurement variable for the architectural wall materials is an area. In order to measure the accurate quantity of the wall, quantity surveyors have to measure the surface area of each layer separately. They cannot use the core layer area to infer the finish layer areas - as these would differ.

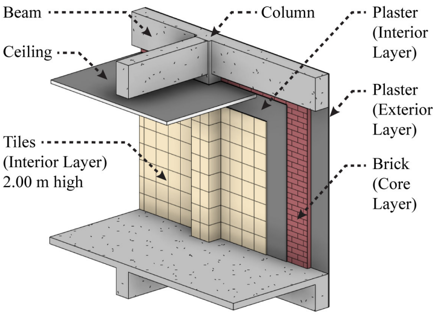

Figure 1. The example of the architectural wall that has four material layers and each layer has a different size and quantity.

In the early stages of the design, which cover the schematic design phase and design development phase, designers use a low Level of Development (LOD) [6, 7] for the wall elements in a schematic BIM model. The walls may overlap structural elements and each wall layer is not created as a separate element. This causes inaccuracies when extracting the wall and wall finishing quantities from the model.

The objective of this research is to find a new method to calculate the quantity of each wall layer in a schematic BIM model. The proposed method will improve the accuracy of the wall quantity takeoff in the early stages of the design when the BIM model is still schematic and is not as detailed. A concept of BIM-based clash detection is applied in the proposed method to enhance the BIM-based quantity takeoff. The scope focuses on architectural walls in a schematic BIM model where walls are at LOD 200 and 300 according to the Level of Development Specification 2017 by BIMForum [7]. The implementation is done by developing Dynamo [8] scripts for Autodesk Revit that can detect the overlapped area and subtract or add the material quantity for each wall layer. With this method, the chosen project delivery system such as DB or IPD will benefit from the accurate quantity takeoff for cost estimation in the early stages of the design. Furthermore, the designers or modelers can edit and adjust the BIM model easily since this method does not interfere with the original BIM model.

2 Literature Review

The strength of BIM is in its ability to share the same information among different disciplines. Hardin [1] discussed the uses of BIM in four types of project delivery methods, namely Design-Bid-Build (DBB), Construction Management at Risk (CM-at-Risk), Design-Build (DB), and Integrated Project Delivery (IPD). In the DBB method, the potential of BIM is limited because no information is shared between design teams and contractors during the design phase. Conversely, the use of BIM fits well in the CM-at-Risk, DB, and IPD methods because there are more integration and collaboration between the design and construction teams from early on. Consequently, the construction costs can be estimated during the design phase in order to verify whether or not the design is within the projects' budget.

According to Eastman et al. [2], the use of BIM for accurate quantity takeoff and cost estimation in the early stages of the project is most valuable. It is stated that "Today's use of BIM is typically limited to the late phase of design and engineering or early phases of construction. Use of BIM earlier in the design process will have greater influence on cost."

Although BIM-based quantity takeoff is reliable [2], some deviation still occurs due to practical and technical issues. With regards to the practical issues, the quality of the BIM model is a major concern [9]. Olsen and Taylor [5], interviewed general contractors and reported that up to half of the data, including architectural finishes, is absent from the BIM model because the model does not have enough detail yet. As for the technical issues, there are three causes. Firstly, some BIM software products do not have the specific modeling tools for some building elements. For example, there is no modeling tool to create formwork or rebar in ArchiCAD software [4]. Secondly, the software calculation method for some elements is incorrect [3]. And thirdly, some of the data is lost when transferring the files between BIM software products [2].

Several studies have been done on the improvement of BIM-based quantity takeoffs. Monteiro and Martins [4] explored BIM-based quantity takeoff using ArchiCAD software. This study showed that some elements could not extract the desired quantities. It was suggested to use another modeling tool in order to get the desired quantities. For example, using slab and wall tools to create stairs in order to get the volume of concrete needed. Kim et al. [10] proposed a BIM-based quantity takeoff method for building interior from a given space or room. Cho and Chun [11] proposed methods for estimating the cost of reinforced concrete structures in the design development stage by quantity takeoff and quantity prediction using data mining. Choi et al. [12] developed a quantity takeoff system that can estimate the quantity of the building frame in the early stages of the design. Rajabi et al. [13] developed a system that can estimate the quantity of mechanical, electrical, and plumbing in the early stages of the design. Lee et al. [14] studied a method to analyze the construction productivity. This study developed formulas to calculate structural formwork quantity by considering the overlapped area of concrete.

Although studies exist for quantity takeoff of many building elements, there has yet to be any research concerning the quantity takeoff for architectural walls.

3 BIM-based Quantity Takeoff Software and Its Limitation

BIM-based quantity takeoff is related to the Level of Development (LOD) of BIM elements. According to the Level of Development Specification Guide [6], LOD is divided into six levels. These are LOD 100, 200, 300, 350, 400, and 500. No standard exists to select the LOD for each BIM element in the phases of a buildings' lifecycle [6]. However, the study by Grytting et al. [15] concluded that in the early stages of the design, the LOD of BIM elements ranges from LOD 100 to LOD 300. Therefore, the proposed method used in this research is made for the wall at LOD 200 and LOD 300 since there is no definition of a wall at LOD 100 in the Level of Development Specification. The wall at LOD 200 is a generic wall with no material layers and the wall at LOD 300 is a single wall element with defined layers of core structures and finishes [7].

The early stages of the design are divided into two parts; a schematic design phase and a design development phase. In the schematic design phase, the designers may choose the walls at LOD 200 and make them penetrate columns and overlap with beams and floors of the level above. This is because schematic models need to be created and edited easily. When the design is then moved on to the design development phase, the designers may change the walls to LOD 300.

There are numerous BIM software tools on the market that can perform a quantity takeoff. However, this study makes use of Autodesk Revit software as it is currently the most popular BIM software for architectural works [5, 16, 17] and can perform a quantity takeoff efficiently.

Autodesk Revit has a schedule feature which extracts quantities in two different ways: by quantities and by material takeoffs. Quantity takeoff schedules extract data properties from the Revit elements. Material takeoff schedules extract data properties from the sub-components or materials of the Revit elements. Both quantities and materials can be extracted from architectural walls in Revit. If the wall layers are defined, the area of each material layer can be seen in a material takeoff schedule.

The investigation using Revit software reveals that when walls overlap with structural frames, the graphic shows the walls as being trimmed. When in fact, the area of the walls has not been deducted yet. Designers will then have to manually separate walls from the structural frames. One way to do this is to use the Join Geometry tool to create a cut between the walls and the structural elements. This tool will cut away the overlapped area of the walls. The quantity result is shown in Figure 2. However, editing every wall is time-consuming and the material quantities of the finish layers are still inaccurate. The areas of the interior and exterior finish layers that cover the surface of the structural elements are absent because the walls have already been cut with the structural elements (see red line in Figure 2).

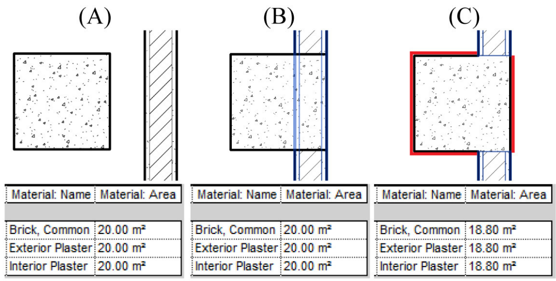

Figure 2. (A) Wall material area when the wall is outside the column. (B) Wall material area when drawing the wall through the column. (C) Wall material area decreased after using the Join Geometry tool. The red line shows the areas of the finish layers that are missing from the model.

Bečvarovská and Matějka [3] suggested that BIM models need to be made as close to the real construction as possible in order to perform an accurate quantity takeoff. Nevertheless, editing the model or creating each wall layer separately is time-consuming and impractical for the early stages of the design as the design will change many times.

4 Proposed Method

Every element in a BIM model is an object with semantic properties that represent the element in the real world. The semantic properties of each element, such as category and type can be used for multiple benefits. One benefit is that it can be used for checking the intersection between objects which is called BIM-based clash detection [2].

To improve the accuracy of the architectural walls quantity takeoff, the proposed method would apply the concept of BIM-based clash detection to assist in the BIM-based quantity takeoff. The main idea is to use the information from clash detection to subtract the exceeded quantity or add the absent quantity.

The implementation of the proposed method is done using Autodesk Revit 2018 with a Dynamo extension. Dynamo [8] is a visual programming extension in Revit that allows users to create algorithms to process data or geometry from the Revit model. Each function and variable in Dynamo is represented by nodes. Each node can be wired together to perform operations. The group of nodes can be packed into collections of nodes called packages. Packages can be published to the Dynamo website and shared with the online community.

The method for calculating the area of each layer of the architectural walls is divided into two sections: the calculation method for the core layer and the calculation method for the finish layer.

4.1 Calculation Method for the Core Layer of the Walls

The core layer of the architectural walls is the structure of the walls. The most common materials used for the core layer are masonry units such as bricks or concrete blocks and stud framing such as wood or metal studs. Generally, the core layer does not cover or intersect with other objects, thus the idea is to find the area of the wall that intersects with other objects such as columns, beams, and floors.

The workflow in Dynamo begins with the input of element categories from the Revit model. The categories are walls, structural columns, structural framing, and floors. The overall process is shown in Figure 3.

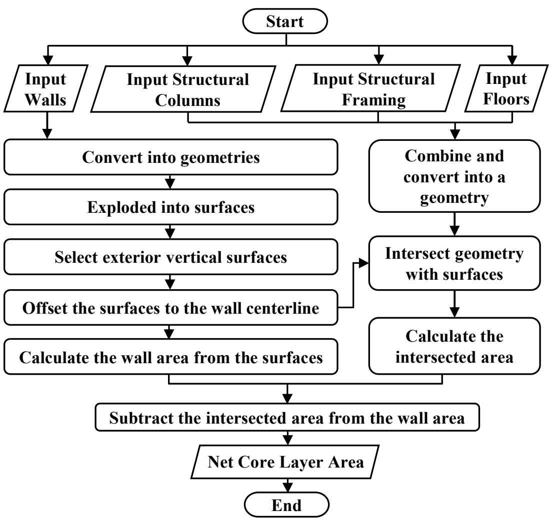

Figure 3. The flowchart diagram of the calculation method for the core layer of the walls.

The structural columns, structural framing, and floors will be combined and converted into a geometry. This geometry will be used to check the intersecting area of the walls.

The walls will then be converted into geometries and exploded into surfaces. The exterior vertical surfaces will be selected and offset to the wall centerlines. These surfaces represent the core area of the wall. They will be intersected with the structure geometry.

The intersected surface will be shown in the 3D view and the intersected area will be calculated and subtracted from the wall area. The result is the net area of the core layer (see Figure 4).

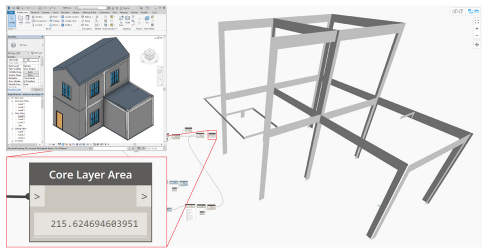

Figure 4. The surfaces of the walls that intersect with columns, beams, and floors are shown in Dynamo. The net core layer area of the wall is calculated.

4.2 Calculation Method for the Finish Layers of the Walls

Finding the area of the finish layers is more complex than the area of the core layer. This is because there are multiple scenarios for each type of finish layer depending on the materials used and the design. Usually, the materials of the finish layers are dependent on the material of the core layer.

The walls that have stud framing at their core, usually have wall panels as the finish layer. Examples of wall panels are wooden planks, gypsum board, fiber cement boards, and cladding. The area of the wall panels is usually equal to the area of the stud framing core as the panels attach to the studs. In this scenario, the same method used for calculating the core layer can be applied to this type of finish layer.

On the other hand, the walls that have the masonry at their core will usually have plaster as the finish layer. In some cases, tiles, wall paint or wallpaper will form the second finish layer on top of the plaster. The plaster, tiles, wall paint, and wallpaper usually only cover the surface of the structural elements that the walls cut through. Furthermore, on the interior, the height of the finish layers may not be as tall as the core layer. The height may only go up to the ceiling or it could have a custom height (see Figure 1). These scenarios need different methods to calculate the finish layer area.

The calculation method for the finish layers of the walls is divided into three parts: the method for the exterior finish layer, the method for the interior finish layer, and the method for the custom height interior finish layer. The concept of clash detection is still used here. Room elements in Revit will be used to check whether the surface of the wall is exterior or interior. The structural elements that intersect with the wall will be used to calculate the covered surface area of the finish layer.

4.2.1 Calculation Method for the Exterior Finish Layer of the Walls

The exterior finish layer is the wall layer that covers the outside surfaces of the building. The materials of these layers are typically plaster, tiles, cladding, or wall paint. This method is developed for the scenarios where the exterior finish layer covers the entire area of the exterior surfaces. The wall surfaces and the structural element surfaces that are exposed to the exterior are included in this method. However, it excludes the surfaces of the roof as well as the top and bottom surfaces of the floor, which typically have other materials.

The workflow in Dynamo begins with the input element categories from the Revit model. The categories are walls, structural columns, structural framing, floors, and rooms. The overall process is shown in Figure 5.

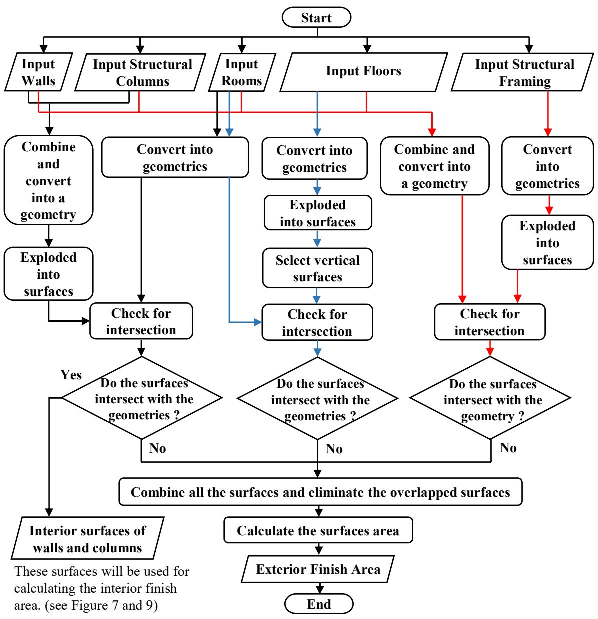

Figure 5. The flowchart diagram of the calculation method for the exterior finish layer of the walls.

In the first step, the walls and structural columns from each floor level will be combined and converted into a geometry. This geometry will be exploded into surfaces and each surface will be checked with the room geometries. The surfaces that intersect with the room will be interior surfaces which will be used for calculating the interior finish area. The surfaces that do not intersect with the room will be exterior surfaces which will be used in the final step.

The second step is to find the surface area of the structural framing (beams) that are exposed to the exterior. The walls, structural columns, floors, and rooms will be combined into a geometry. This geometry will be checked with the structural framing geometries that are exploded into surfaces. The surfaces of the structural framing that do not intersect with the geometry will be used in the final step.

The third step is to find the surface area of the floor edges that are exposed to the exterior. The floors will be converted into geometry and exploded into surfaces. The vertical surfaces will be selected. The rooms will be used to check and eliminate the interior vertical surfaces of the floors such as the interior hall and stairways. The remaining surfaces will be used in the final step.

The final step is to combine all the surfaces from the first, second, and third steps. The result is the surfaces of the wall, structural columns, structural framing, and floor edges that are exposed to the exterior. Thereafter the overlapped surfaces will be deleted. The remaining surfaces will be used to calculate the area of the exterior finish layer of the walls (see Figure 6).

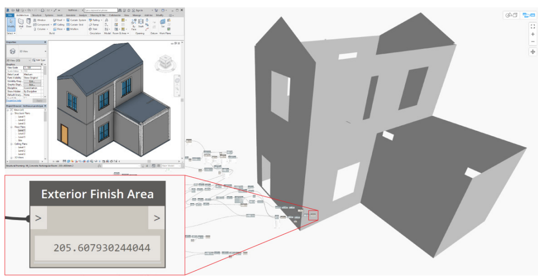

Figure 6. The surfaces of the exterior finish layer and the calculated area are shown in Dynamo.

4.2.2 Calculation Method for the Interior Finish Layer of the Walls

The interior finish layer is the wall layer that covers the inside surfaces of the building. This layer usually covers the surface of the walls and columns in the rooms. The height of this layer usually attaches to the top of the ceiling or the underside of the above levels' beams or floors if there is no ceiling in these rooms.

The interior surfaces of the walls and structural columns from the first step of the calculation method for exterior finish layer of the walls will be used. The overall process is shown in Figure 7.

In order to set the height of the interior finish layer, the Limit Offset property of each room must be set to the ceiling height or the desired height.

The rooms will be converted into geometries. These geometries will be used to subtract the height from the interior surfaces of the walls. The outcome surfaces will be used to calculate the area of the interior finish layer of the walls (see Figure 8).

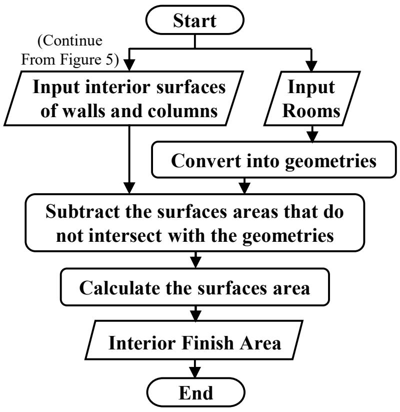

Figure 7. The flowchart diagram of the calculation method for the interior finish layer of the walls.

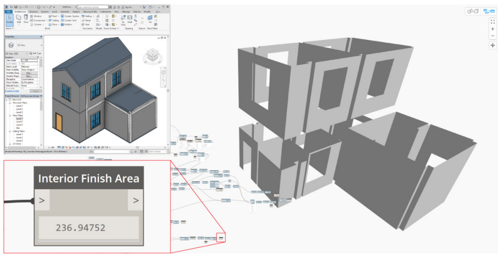

Figure 8. The surfaces of the interior finish layer and the calculated area are shown in Dynamo.

4.2.3 Calculation Method for the Custom Height Interior Finish Layer of the Walls

The interior finish layer may have a second layer. For instance, restrooms or kitchens may have a tile layer on top of the plaster layer. Sometimes the height of this layer will not go up to the ceiling height or up to the underside of the above levels' beam or floor.

The method is similar to the calculation method for the interior finish layer of the walls, but instead it will only calculate the areas for the selected rooms. The overall process is shown in Figure 9.

The desired rooms will be selected by inputting the rooms' name. The selected rooms' boundaries will be converted into surfaces. The surfaces will be extruded into 3D geometries. The height of the geometries will be controlled by the Number Slider node. These geometries will be used to subtract the height from the interior surfaces of the selected rooms. The outcome surfaces will be used to calculate the area of the custom height interior finish layer of the walls (see Figure 10).

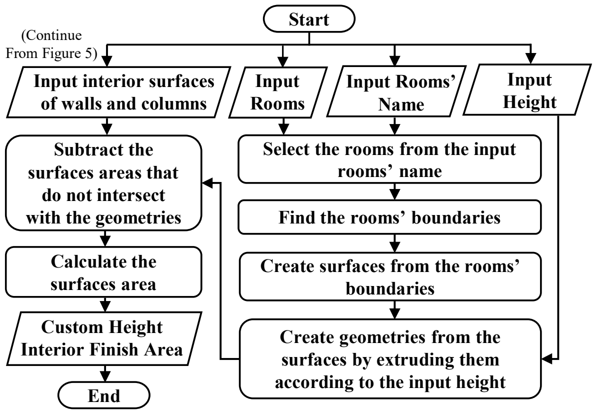

Figure 9. The flowchart diagram of the calculation method for custom height interior finish layer of the walls.

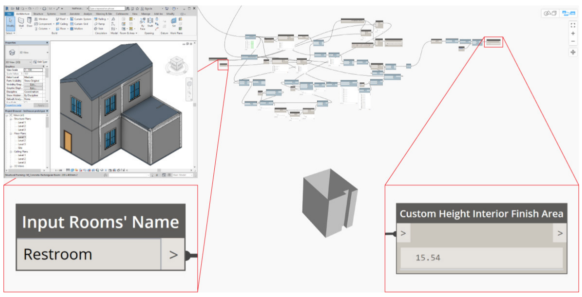

Figure 10. The interior surfaces of the restroom and the calculated area are shown in Dynamo.

5 Implementation and Validation

The implementation is done using two buildings as case studies. Two versions of BIM models were made in Autodesk Revit 2018. One is the schematic model for testing and the other is the detailed model for validating.

The two buildings are different in shape and number of floors, but wall materials, structure type, and level heights are at the same settings. The buildings have reinforced concrete columns, beams, and floors as its structure. The walls are brick masonry with plaster that covers the exterior and interior surfaces. The brick layer is 70mm thick and the plaster layer is 15mm thick. The restrooms have the tile layer on top of the plaster layer which is 10mm thick. The height of the tile layer in the restrooms is at 2.1m. The ceiling height of the restrooms is at 2.3m. The ceiling height of the other rooms is at 2.6m.

In order to compare the quantity of each wall layer, the wall at LOD 300 is used for the schematic BIM model. The walls are single elements with three layers; the core layer, the exterior finish layer, and the interior finish layer. The total wall thickness is 100mm. The walls are created by drawing through structural columns and overlapping with beams and floors. The developed Dynamo scripts are used to find the area of the core layer, exterior finish layer, interior finish layer, and a custom height interior finish layer in the restrooms (see Figure 11). The wall material takeoff from Revit will be compared with the result from the Dynamo scripts.

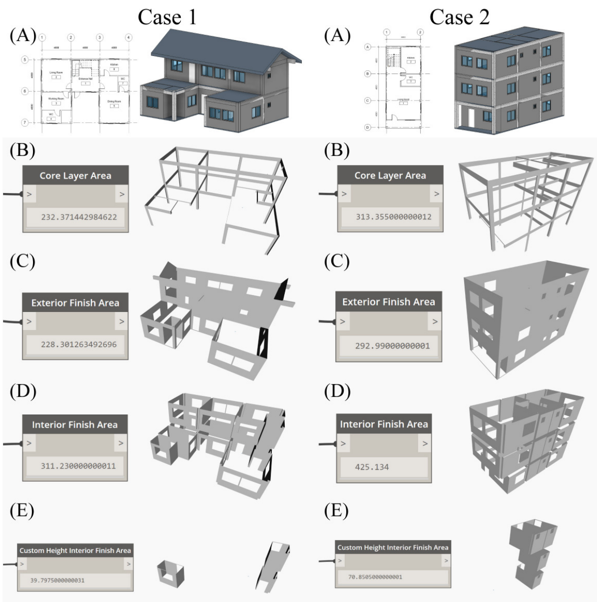

Figure 11. (A) The schematic BIM models of the two buildings. (B) The area of the core layer in Dynamo. (C) The area of the exterior finish layer in Dynamo. (D) The area of the interior layer in Dynamo. (E) The area of the restrooms' interior layer in Dynamo.

In the detailed BIM models, each wall layer is created separately. The height and the thickness of each layer are defined (see Figure 12). The material takeoff is done in Revit and the result will be compared to the result from the schematic BIM models.

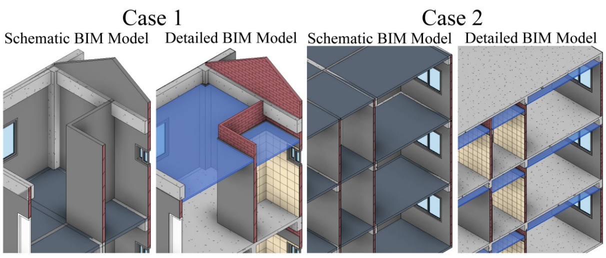

Figure 12. The comparison between schematic BIM models and detailed BIM models.

Table 1 and Table 2 show the comparison of the material area from the detailed BIM models, the schematic BIM models as well as the Dynamo scripts. The case number is written in the parentheses after the name of the wall layers. The results from the detailed BIM models form the baseline of this comparison. The results from the Dynamo scripts when compared to the baseline have about a ±1% deviation, which is acceptable. The deviation is caused by the thickness of the material layers in the detailed BIM models. On the other hand, the results from the schematic BIM models have a significant deviation.

Table 1. Comparison result between detailed BIM model and schematic BIM model

Wall Layers	Detailed BIM Model	Schematic BIM model	% Deviation
Core (1)	234.60 m^2	299.31 m^2	-27.58%
Core (2)	315.95 m^2	391.08 m^2	-23.78%
Ext. (1)	226.08 m^2	299.31 m^2	-32.39%
Ext. (2)	291.00 m^2	391.08 m^2	-34.39%
Int. (1)	314.65 m^2	299.31 m^2	4.88%
Int. (2)	426.83 m^2	391.08 m^2	8.38%
Tile (1)	39.55 m^2	N/A	N/A
Tile (2)	70.50 m^2	N/A	N/A

Table 2. Comparison result between detailed BIM model and Dynamo scripts

Wall Layers	Detailed BIM Model	Dynamo Scripts	% Deviation
Core (1)	234.60 m^2	232.37 m^2	0.95%
Core (2)	315.95 m^2	313.36 m^2	0.82%
Ext. (1)	226.08 m^2	228.30 m^2	-0.98%
Ext. (2)	291.00 m^2	292.99 m^2	-0.68%
Int. (1)	314.65 m^2	311.23 m^2	1.09%
Int. (2)	426.83 m^2	425.13 m^2	0.40%
Tile (1)	39.55 m^2	39.80 m^2	-0.63%
Tile (2)	70.50 m^2	70.85 m^2	-0.50%

6 Conclusion

The proposed method for calculating the area of each layer of the architectural walls is executed in Dynamo - a visual programming extension in Revit. Each Dynamo script is designed to calculate the surface area in a specific scenario. For example, if designers want to find the area of the exterior paint, they will use the script that calculates the exterior finish layer. If designers want to find the area of the interior plaster, they will use the script that calculates the interior finish layer. If designers want to find the area of the interior wall panels that only attach to the stud framing layer, they will use the script that calculates the core layer.

The results from the Dynamo scripts are accurate when compared to the results from the detailed BIM model. With this method, the designers who work in the early stages of the design can know the accurate quantity of the architectural walls and finish layers without having to make a detailed BIM model. The model can easily be edited while the designers get instant feedback. The accurate quantity of the walls and finishes can be used to estimate the building cost in the early stages of the design process for the project delivery methods which have higher collaboration between design and construction teams, namely DB and IPD.

However, these Dynamo scripts still have their limitations. The scripts cannot find the area of the surface if there are multiple materials used. For example, if the tile layer has two types of tiles, the scripts cannot separate the areas of each type. In this case, a detailed BIM model is needed for the accurate quantity takeoff.

In future research, the implementation will need more case studies for validation and the Dynamo scripts will need to be improved. There are three possible features to improve on in the future Dynamo scripts. Firstly, the Limit Offset property in each room should be adjusted automatically. As of now the user still has to edit the Limit Offset property to match the ceiling height manually, - which is error-prone. Secondly, the adjustable height of the custom interior finish layer should be limited to the ceiling height or floor-to-floor height. Lastly, in the case that there are many wall types in the building, the user should be able to select the wall type that will be used in the calculation.

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