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Chapter

5D BIM Applications in Quantity Surveying: Dynamo and 3D Printing Technologies

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Abstract

Digital construction is increasingly introduced to the architecture, engineering, and construction (AEC) industry. The fifth dimension of Building Information Modeling (5D BIM) has a significant contribution to the AEC industry, such as managing time and costs and resources management. However, 5D BIM has not fulfilled its promise completely. The major challenge of implementing the 5D BIM technology and applications is the interoperability between technologies and the low accuracy of measurement estimations. Dynamo is adopted in this chapter for detailed quantity measurement. Three-dimensional printing (3DP) is one of the additive manufacturing technologies which is recommended to be used in construction. 3DP is aiming to create complex and customized geometries. This chapter demonstrates how to apply the Dynamo scripts of detailed quantity take-off for estimating the volume of elements created by 3DP. Dynamo as a quantity take-off Add-in in Revit is always used for detailed quantity take-off or precise model created. After the detailed quantity take-off from Revit, the data can be exported into Excel extension, which allows the quantity surveyors to insert the price per unit to the file and to generate a Bill of Quantity (BOQ). This chapter will offer a procedure for applying Dynamo through two selected case studies.

Keywords: 5D BIM, quantity surveyor, dynamo, Revit, decision-making, quantity extraction, 3DP, data-driven procedure

1. Introduction

Building Information Modeling (BIM) has been adopted in the AEC industry for a long time, especially in the offsite (prefabrication) construction [1, 2]. 5D BIM is Building Information Modeling that includes a 3D model plus scheduling (4D) and cost management (5D) [3]. 5D BIM is an advanced technology in the AEC industry, which can be used for managing time, cost, and resources; it can even handle the logistical site plan. 5D BIM can help quantity surveyors review alternative designs during the early stage of the project as a decision-making tool [4], since the 5D BIM can quickly extract approximated quantity from different 3D BIM models and then add the 4D schedule to finalise the 5D cost budget. However, the development of 5D BIM is hampered [3], by many reasons, such as the high initial implementation costs [5] but low accuracy [3]. Moreover, the current 5D BIM software and

applications cannot fulfil the subcontractors' requirements which are focused on detailed works, such as external cladding. They are appropriate for the rough cost estimation of a large scope, which is satisfied with the requirements from project planners and head contractors. The quantity take-off of current major 5D BIM applications or software is approximate quantity instead of exact quantity due to the Level of Development (LOD) limitation. Dynamo is more appropriate for the detailed quantity take-off, such as three-dimensional printing (3DP) elements. 3DP is used to print precise and complex elements [6].

Hall and Tewdwr-Jones [7] demonstrated that the lack of cooperation and difficulty of information sharing are the major reasons for the communication issue during the entire project life cycle. However, the BIM cannot always guarantee the communication to be effective [5]. The chapter will investigate how Dynamo Revit can be used for detailed quantity take-off and how to analyse the combination of 5D BIM quantity take-off appliances (Dynamo) with 3DP. A face-to-face semi-structured interview with regard to the case study will be conducted. Scopus database was the main source used for literature review in this chapter, since it has a relatively wide range of data [8], especially for BIM and the 3DP.

Figure 1 visualizes the geographical locations of the 5D BIM papers published in different countries or territories. The nodes present the number of papers that contributed to each country or territory. These nodes are grouped into two groups with different colors by running the Modularity program. The Modularity program implements a community detection algorithm, called the Louvain method [9].

2. Aims and objectives

The aim of this chapter is to present the current status of 5D BIM and the prospect of the integration of 3DP with 5D BIM in the AEC industry. The key objectives of these investigations are as follows:

Objective 1: To identify the advantages and challenges of the 5D BIM implementation in the AEC industry.
Objective 2: To evaluate the implementation of 3DP in the AEC industry.
Objective 3: To develop a 5D BIM-3DP integrated workflow for the project's cost analysis.



Figure 1.
Geographical locations of articles contribution.

3. Literature review

3.1 BIM

'A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition' [10]. Regarding BIM, 4D BIM is about scheduling, 5D BIM is used for the cost analysis, 6D BIM is for sustainability analysis, and 7D is about the facility management [11]. BIM generates a comprehensive environment for a project and also assigns personnel responsibilities [12]. The AEC industry is always low in productivity and lacks cooperation and innovation. BIM has the potential to solve these challenges [13, 14].

3.2 5D BIM implementation advantages

As a useful information platform, 5D BIM is not only utilized during the project construction process but also during the entire life cycle. For example, BIM can share and update the drawings and specifications easily in the cloud database, and then 5D BIM can generate more consistent and accurate cost estimation. BIM platform provides a smooth flow of information sharing among stakeholders to transfer the information quicker and easier among multidisciplines [15] to reduce errors or unnecessary works. Additionally, 5D BIM can show a clear budget and construction progresses to participants [3]. Moreover, 5D BIM is time efficient for alternative design analysis and decisions at the early stage. 5D BIM often conducted the cost management and cost analysis in other software or application. 5D BIM can better monitor the project costs not only in the short term but also in the long term by including related information and resources during [16].

3.3 5D BIM implementation challenges

The challenges of 5D BIM adoption are, for instance, software securing, training investment, and low time efficiency, lacking standards of software compatibility [16]. Sattineni and Macdonald [3] reported that 5D BIM always has high initial installation costs and requires new expertise, such as computer experts, compared to traditional construction. Thus, the company is unwilling to change [3]. The other limitation of 5D BIM is the low LOD, which cannot extract the detailed data from the 3D model for cost estimation. Aibinu and Venkatesh [5] stated there are several difficulties of 5D BIM used by the quantity surveying organization, such as the low LOD of a model. This statement is based on 40 responses received from their 180 QS web survey, and two in-depth interviews are conducted. Therefore, due to the lack of detailed information, the team always spent longer time to make sure the quantity take-off is accurate [3, 5].

BIM-based clash detection is a quantity take-off method, which was introduced by Khosakitchalert et al. [4] to enhance the level of the quantity take-off accuracy of the layered structure. BIM-based clash detection approach extracts quantity information by geometry data of the model, such as the area and the name of the target objects [4]. Dynamo-extension is one Add-in of the Revit, and it calculates the quantity for the components by script [4]. Khosakitchalert et al. [4] stated that the LOD of the layered structures is low, such as walls, which causes low accuracy of the quantity take-off [4]. Different layers of the components have different dimensions due to the overlapped connection requirements [4]. Revit supports two different quantity take-offs, one is the material take-off and the other one is the

quantity take-off [4]. The quantity take-off is based on elements, and the material take-off is based on material information [4]. The data or 3D model can be processed by creating an algorithm in Dynamo [4]. Dynamo cannot conduct quantity take-off for one element when various materials are used in this element [4]. Besides, there is rare software available for higher-level BIM functions at the same time [4]. The common 5D BIM or BIM software is not suitable for the detailed quantity take-off, for instance, cladding tasks. Since architectures and designers always add many details into the drawings instead of models, most of the subcontractor companies used BIM only for the 3D model visualization. Some subcontractors do not share the information with the crew members timely, and the designers might not be willing to share the models with the construction team. It is easy to case unneeded work due to inefficient communication and inconsistent drawings. In addition, the design drawings and specifications may conflict, which is caused by the errors or data missing and ultimately leads to inaccurate cost estimation [17, 18]. Furthermore, the model's errors may be not revised timely, which will affect the accuracy of the quantity take-off [3]. Mayouf et al. [17] also stated that the 5D BIM implementation requires a comprehensive workflow and information. One of the difficulties of quantity surveyors' work is the poor quality of design documentation. Multidisciplinary and collaborative approaches play an essential role in improving the efficiency of communication and the quality of the documentations [17].

The BIM models are not designed for the quantity take-off or the cost estimation, so some details will not be shown in the models. It is a significant issue for the quantity surveying companies [5]. Thus, it is tough to extract the detailed quantity from elements for quantity estimation. 5D BIM provides timely communication but cannot guarantee the quality of the communication. At the end of 2016, Software Advice (UK) analysed and reported that 50% of the investigated small and medium enterprises still conduct the cost estimation manually [16]. There are many limitations of CUBIT adoption in New Zealand and Australia, such as low accuracy of quantity take-off or detailed quantity missing [16, 19]. CUBIT Buildsoft is developed by MiTek (an Australian company) and used in Australia, New Zealand, the United Kingdom, and Ireland [16].

There are other challenges of 5D BIM applied in a project, such as the standardization [20] and high training costs that some organizations may not able to afford [20].

Different from academia, the industry believes BIM needs a process change approach than information—drive approach [17]. **Table 1** shows the academic paper reviewing the possibility of integrating Dynamo with other tools. These papers were selected from the Scopus database since they focus on the Dynamo Revit. The Dynamo is the essential step for the 5D BIM-3DP integrated workflow. **Table 2** presents those papers which focused on sustainability applications. In both tables, green color means the article is related to Dynamo and Revit for the quantity take-off; blue color means partially related.

3.4 3D printing

Contour crafting (CC) was developed by researchers at Loughborough University, UK [38, 39]. The conventional construction methods damage the environment [40] with lower efficiency, and it is hard to achieve a project on time and within budget without compromising the quality [41, 42]. 3DP can reduce the cost, shorten construction duration, and minimize waste. At the same time, 3DP is efficient and sustainable and can achieve customization [43]. Additionally, Tay et al. [44] reviewed 115 relevant articles in the Web of Science and Science Direct and stated

Aims and objectives	Method and case studies	Limitations or suggestions for future	Findings or contribution
To develop a BIM-based impact of change order evaluation systems [21]	System (Autodesk Revit, Dynamo, Microsoft Excel, and VBA) quantifies three impacts of change in projects, which are physical conditions, schedule, and budget	Limited to an overview of system architecture and each component of the system	Dynamo can import the data to Revit and then export it to other parts of the system. Besides, use Dynamo to store the cost and schedule of the 3D model
To utilize the development of BIM technology in bridge engineering [22]	Case study: Shenyang Wuai Overpass is selected	Not mentioned	Through Dynamo, design heteromorphic ramp parameters with high accuracy
To analyze and evaluate the BIM statement in a heritage building and further development [23]	Case study: Jewel Tower, UK, is selected	Potential of reporting and forecasting complex models should be examined	Dynamo (Python - algorithm) used to portray the spatial distribution of moisture with RGB parametrization
To utilize more tools for integrated digital simulation [24]	Case studies from two companies: Danish architecture firm BIG and international engineers BuroHappold	Not mentioned	Using the "Dynamo Masterplanning Tool" for different mechanical, electrical, and public health based on building form parameters. Also, it can be used to update the floor area and the external wall area
Capture facility information to deliver integrated handover deliverables [25]	Case study: Two-storey educational building in Rocky Mountain Region, USA	The framework needs customization for each project based on the owner and end-user needs	Dynamo workflow used to fulfill the parameters of the 'Master Format Division' with the appropriate value in the Building Handover Information Model (BHIM) framework
To utilize interdisciplinary and overall digital design methods [26]	Case studies such as structural BIM models for the 'HENN Architekten', a competition, Shenzhen, China, 2013	Not mentioned	Grasshopper for Rhino or Dynamo for Revit can visualize and assess the designs and generate many alternative designs in a short time
Through Dynamo, visual programming language, based on the parameters, combined the bird threat assessment of facade material, analysis building geometry relative to the materials, and evaluate the users' input to the building operation [27]	The resulted workflow allows designers to start building a model in Revit using custom families, which contain the factors and then run the Dynamo	The problem of walls and windows as they cross over the two zones in Dynamo can be solved by Dynamo, but difficult	Bird collisions on building facades are important and should through Dynamo/Revit (VPL/BIM) be revised and released, to present a standard way to assess compliance with LEED Pilot Credit 55

Aims and objectives	Method and case studies	Limitations or suggestions for future	Findings or contribution
To develop a new mesh-to-HBIM modeling workflow and connect the elements of HBIM and historical knowledge through integrating BIM management system [28]	Case study: St-Pierre-le-Jeune Church, Strasbourg, France	Not mentioned	Dynamo can provide the interactive interface in the study, and users can browse the semantic information reserved in the ontology database and the 3D model in BIM at the same time
To present a workflow that incorporates with Revit of an architectural precast concrete manufacturer [29]	Case study: A hospital designed by Flad Architects which expands the University of Florida Health Shands complex, Gainesville, Florida	In the future, the workflow could involve the subcontractors early for the advice and decision-makings. It could be called as 'Design-Assist'	Dynamo can create any of the panels of the case study of an architectural precast concrete manufacturer that the Revit model could
To reduce labour involvement during the modeling process by shaping the mesh geometry [30]	An antique monument, Petit château du Meisenbach, and a church of the Abbey of Niedermunster	Dynamo can be used to create a building modeling based on the 'family' of objects	Dynamo can develop a semiautomated function to reduce the human process. Dynamo can adjust the element parameters by parameter name and value
To have the BIM model as a control system of building energy performance service [31]	Case study: Building facade design	Not mentioned	Dynamo is used for parametric Adaptive Skin System (PASS), which consists of kinetic facade components
To extract and process the BIM data through Revit, the Dynamo can help for data processing and analyzing [32]		There are no ready modes for all functions of the Revit API	Dynamo can develop external applications that provide extensive opportunities for expansion of applications, convenience, speed, and, as a consequence, productivity in Revit

Table 1.
Summary of papers examines in dynamo and Revit applications.

3DP could achieve higher productivity with lower investment cost and waste. Tay et al. [44] also indicated that the 3DP is appropriate for flexible component customization. Sakin and Kiroglu [45] stated the 3DP might be developed along with the traditional construction method.

However, the 3DP is also not fulfilled its promise completely [46]. Although the 3DP can reduce the labour to save the costs, the more equipment is required in the construction site, and the depreciation costs also need to be considered. Therefore, it is hard to state if the 3DP is saving money or not. The material technology is a significant challenge for 3DP development. Gosselin et al. [47] are against to the idea that the 3DP can achieve the feasibility 'free-form' structures. For instance, if 3DP material is clay, then the suspended parts cannot stand immediately after the printing without any support (see **Figure 2**). **Figure 2** shows the sagging section

Aims and objectives	Method and case studies	Limitations or suggestions for future	Findings or contribution
Develop an integration interface of manufacturer-based LCA data in BIM by combining Revit, Dynamo, and Excel [33]	Case study: The scientific approach for decision-making, with models. Single-family social housing unit model, municipality of Acailandia, state of Maranhao, Brazil	The complexity of the programming; it is difficult to import and extract the data from different construction subsystems	Obtain environmental performance for decision-making in the initial design stages in an automated way of information insertion/extraction to or from the model
To encourage the BIM for the design uncertainties affecting building energy performance [34]	Case study: Residential unit in College Station, Texas, USA	Not mentioned	Dynamo exports input variables to a spreadsheet-based energy analysis tool for uncertainty and sensitivity analyses
To investigate the feasibility of connecting environmental sensors such as light, humidity, or CO_2 receptors to a BIM [35]	Case study	The slower interaction time in Dynamo Revit than Grasshopper Rhino	Dynamo and Revit API are interfaces of case studies, the software linking the environment sensor with BIM, such as linking the Revit and the Arduino board. Dynamo also can help to adjust the object's parameters
To create a smarter and more flexible BIM by programming and scripting [36]	Case study: Facade component	Verify the level of customization and flexibility with basic programming knowledge	Dynamo is the major concept in the case of a solar-activated kinetic façade component through creating programming
To extend Dynamo by using a building energy simulation package, controlled by a virtual model's response through light level sensors [37]	Case studies used for Energy Analysis of Dynamo linking photoresistor value to 3D model and produce dynamic solar shades	Lack of consistent nomenclature between Revit and Dynamo about families and parameters; less stability and missing nodes and features	Dynamo can use with other software programs, although currently it is not widely implemented in practice. Test interactively updating shading components for a building facade based on solar angles

Table 2.
Summary of papers focusing on sustainability issues by implementing dynamo and Revit applications.

(red square) of a clay 3DP model. The 3DP challenges are summarized into (1) material development, (2) reinforcement implementation, and (3) process parameter optimization, such as the flow rate of material and print speed [44]. Since the materials are the major challenge of 3DP development, the 5D BIM-3DP integrated workflow in this chapter focuses on the material quantity take-off.

3.5 BIM-3DP integration

There are many projects adopted by BIM technologies to combinate with offsite construction. Offsite construction is also named prefabrication construction, which is a method to produce the standardized components under the controlled

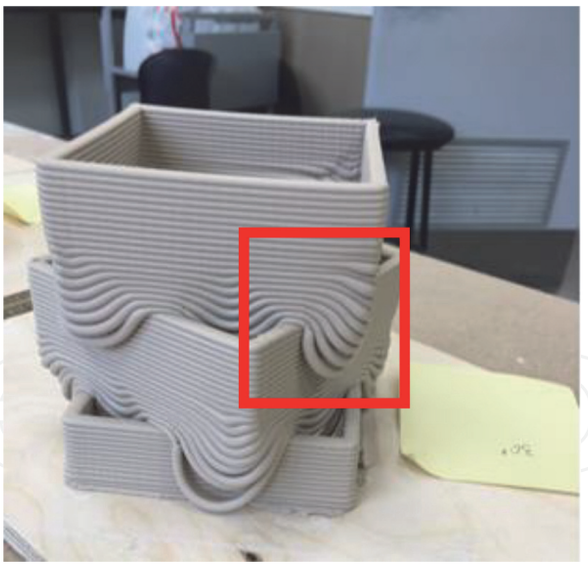


Figure 2.
Column models in laboratory scale with 30 degrees.

environment to ensure the project's quality and efficiency [48]. 3DP is very similar to offsite construction. Although 3DP lacks the corresponding regulations and standards, and the data exchange efficiency might be improved after combinating with the BIM, 3DP is time efficient and sustainable and can achieve customization [43] than the offsite construction. Thus, BIM and also 5D BIM can integrate with 3DP instead of offsite construction. BIM can automate the 3DP since it can store the equipment and manufacturing information, such as printer control data [44]. The integration of the multi-nozzle with a hybrid 3DP system is useful for concrete structures with various materials and elements, such as rebar. The combination of 3DP with BIM can monitor the variables in the construction site [49, 50]. Also, this 5D BIM-3DP integrated workflow can achieve a simple customized building structure [44] in a laboratory scale and be brought to the construction site or meeting for communication quality improvement.

4. Methodology

The methods in this section are two case studies. Case study 1 is aiming to apply the 5D BIM quantity take-off to the multilayer wall to get all the layers' quantity information at the same time. The second case study is to apply 5D BIM to the 3DP elements. The builder and stakeholders cannot get all the layers' quantity information at the same time by using the conventional 5D BIM applications or software. This chapter adopts the Dynamo script principle that is mentioned in Khosakitchalert et al. [4], to design a script for all the layers' quantity take-off from one multilayer wall at the same time, to detect the meticulous differences among the layers. Furthermore, this script can be used to extract the detailed quantities from the 3DP elements.

Figure 3 is only a simple script to show the area quantity extracted from the existing models. Also, Dynamo can be used to create a precise 3D model by node (units in Dynamo script) (see **Figure 4**). Later, the 3D model's dimensions can be revised or changed precisely through the nodes in the core category of the Dynamo library. Each node is a function or order of the executed commands [4].

The floor is just an example to show the basic concept for the entire programming.

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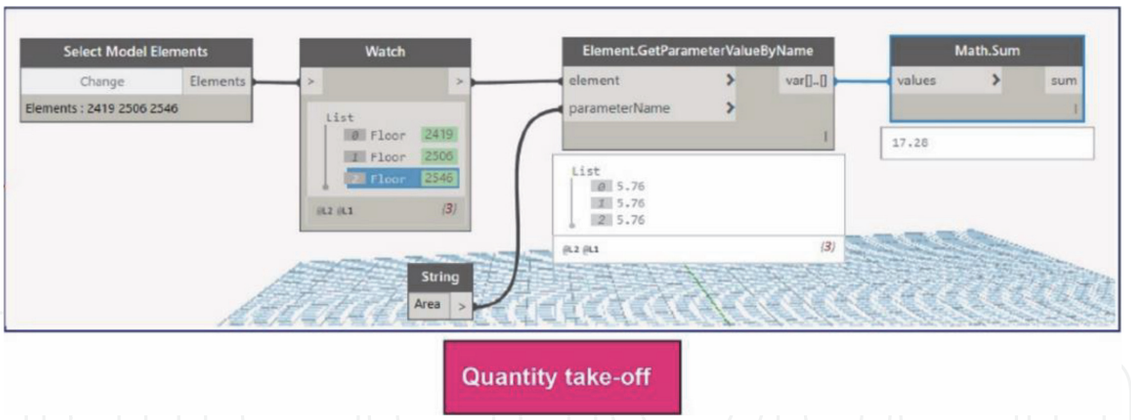


Figure 3.
Dynamo-extension in the Revit for detailed quantity take-off.

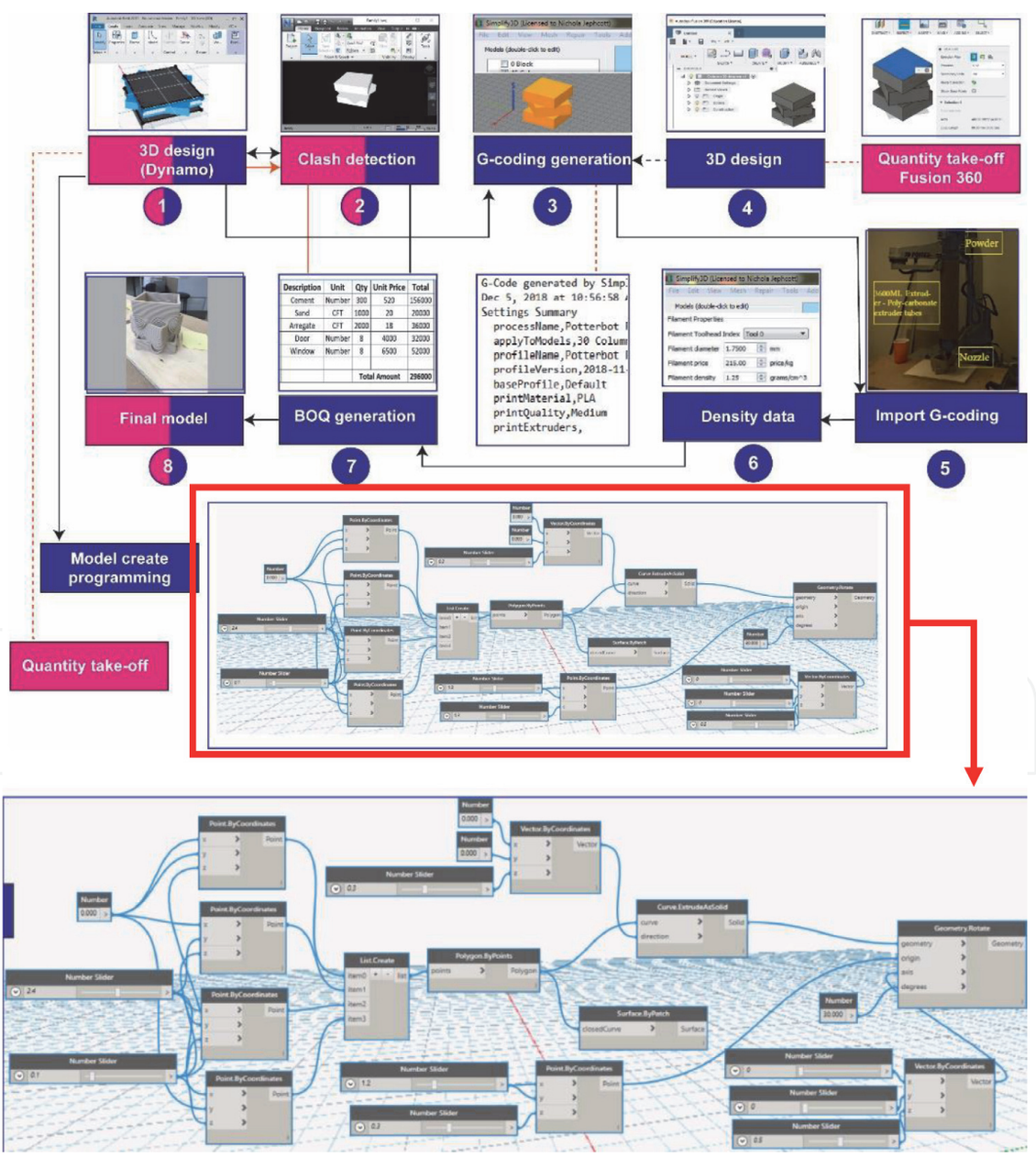


Figure 4.
Dynamo and fusion quantity take-off.

The Dynamo for element quantity take-off programming consists of six stages:

1. Select the 'Select Model Elements' node from the Dynamo library, and select the target element in the 3D model.

2. Select the 'Watch' node to list the detail code of each item.

3. Connect the 'Watch' node to the 'Element. Get Parameter Value By Name' node. The results listed below are the area (parameter name) of each visible element.

4. In this scenario, the value or the outcome of the parameter name is area.

5. Select the 'Math Sum' node to calculate the total area of the 3D model.

6. This programming is also suitable for the users to gain other material information, such as the type of material.

5. Case studies

Two case studies are contained in this section. One is applied this detailed quantity take-off to one target multilayer wall in the facade case study; the other one is regarding the combination of 5D BIM-3DP integrated workflow.

5.1 Case study 1: multilayer wall quantity take-off

In the facade installation project, there is an external wall consisting of different layers such as cladding, sub-framing, waterproofing membrane, stud-framing, insulation, and plasterboard. However, the area quantity (m2) of these layers cannot be the same, especially when it connects with other walls. The accuracy of the element's quantity take-off in this project may decrease by the LOD issue [4]. For instance, the quantity take-off could be accurate for doors, windows, or structural framing, but not the external cladding, or internal plasterboard, where there are many details. **Figure 5** shows different wall types at two different levels.

The highlighted area is wall type 8.25, and according to the wall type schedule document, it consists of external cladding, sub-framing, waterproofing membrane, stud wall, insulation, and plasterboard. The Dynamo script can help to extract the element quantity. For example, if quantity surveyors allow that the area of wall type 8.25 is 500, all the other layers of this wall should be 500 m2 as well (**Figure 5a**). However, wall type 9.03a (**Figure 5b**) on the right side of wall type 8.25 is a concrete wall. It has the plasterboard inside. However, wall type 8.16 (**Figure 5b**) is behind wall type 9.03a (and perpendicular to it), which reduced the quantity of plasterboard on wall type 9.03a compared to the other layers. The conventional 5D BIM estimating software, such as Cubit, cannot detect these detail differences. Thus, the quantity information of some walls' layers might be slightly inaccurate if we use conventional 5D BIM software to get the quantities. Although it is helpful to use BIM for estimating as it reduces time and human mistakes, it is essential to consider its limitation for some specific works. The Dynamo in this case study can detect a small difference between the wall layers. The quantity take-off for each layer would be more accurate than the conventional 5D BIM estimating software.

Figure 6 is shown how to use the Dynamo script to extract the detailed quantity of a multilayer wall. Users can add extra nodes from the Dynamo library for other

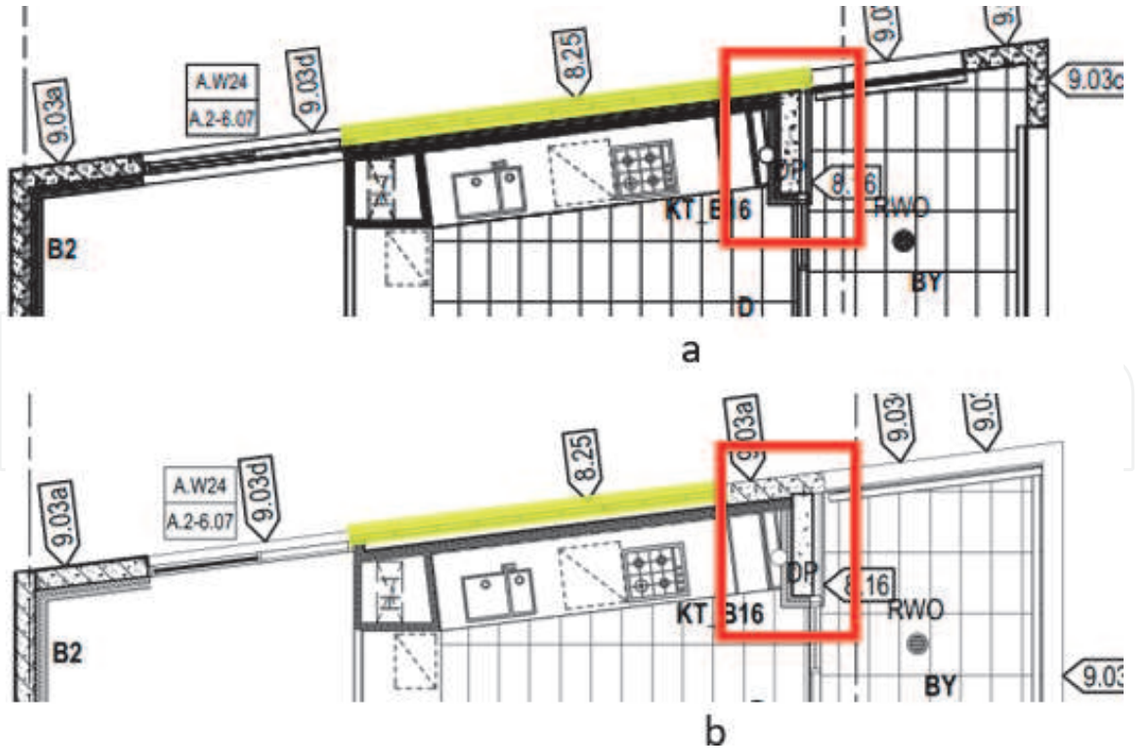


Figure 5.
Detail plan and section drawings. (a) Planning drawing levels 02, 04, and 06. (b) Planning drawing levels 03 and 05.

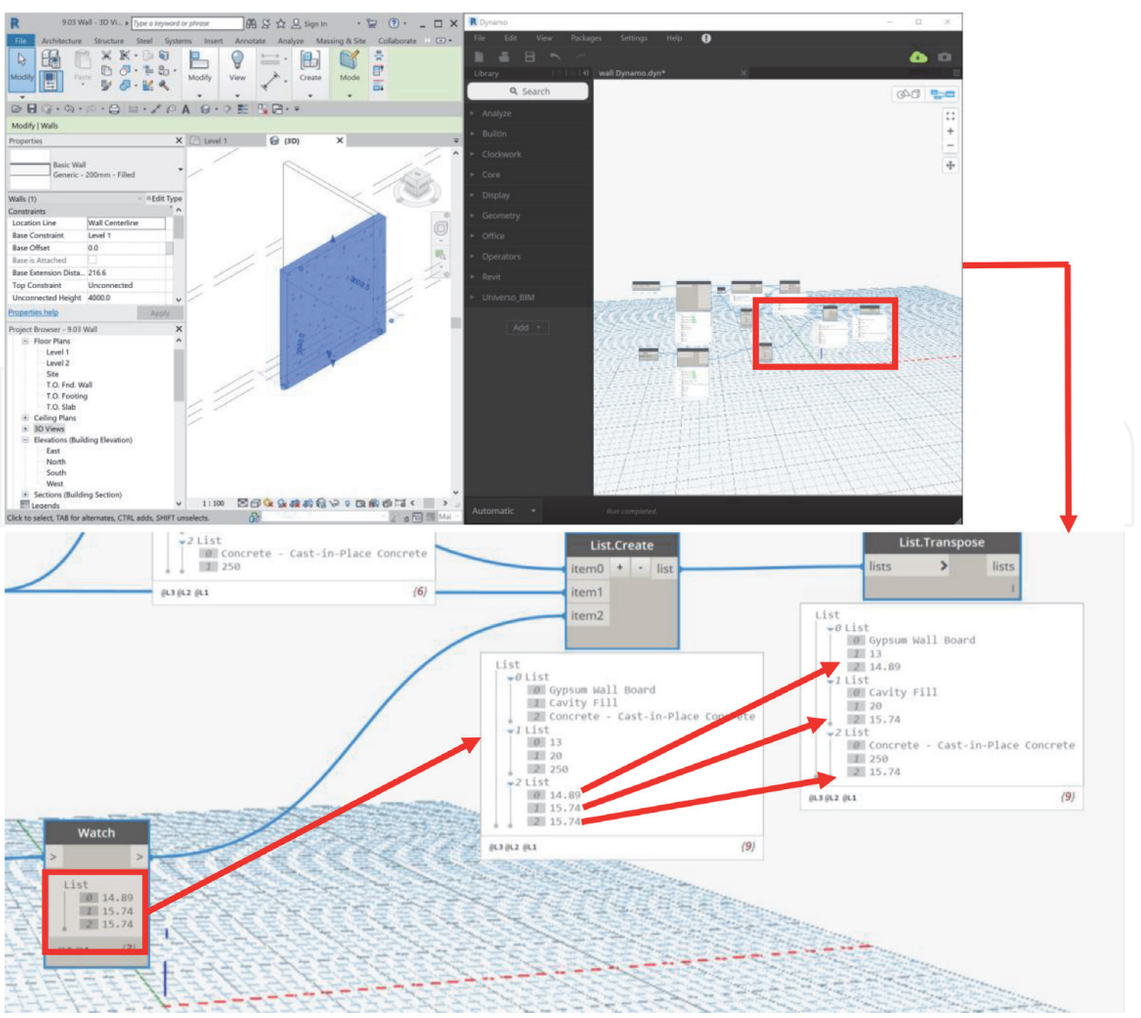


Figure 6.
The quantity take-off for multiple layers of the wall through dynamo.

purposes. This Dynamo script was developed based on the script in **Figure 3**. The updated Dynamo script can list all the target layers' information of multiple walls at the same time, including the name, width, and area of each layer. The rest of the script is the same with **Figure 3**. **Figure 6** shows that the area of each layer's quantity is slightly different: the gypsum wallboard is 14.89 m^2, but the other two are 15.74 m^2. It states the Dynamo script can be accurate on two decimal places for the quantity estimation. For instance, in this case study, the differences between 14.89 m^2 and 15.74 m^2 are 0.85 m^2. **Figure 6** is only shown one multilayer wall's Dynamo script. The users can create as many as groups they want to check the entire project walls' layer information at the same time. The quantity data can be exported into an Excel extension, which allows the quantity surveyors to insert the price per unit to the file and to generate a Bill of Quantity (BOQ).

5.2 Case study 2: 5D BIM-3DP workflow

Research designed a workflow that combines the 5D BIM with 3DP by Dynamo. As mentioned above, the 3DP might be applied to tradition construction [45]. The 3DP technologies are advance on small-size components, which requires an accurate quantity take-off. This 5D BIM-3DP integrated workflow can be used to estimate the 3DP elements' quantities, to improve the accuracy of the cost estimation. In addition, the 3DP can print scaled-down models of some special parts to improve communication efficiency. The Dynamo script for the quantity take-off is based on the script in **Figures 3** and **6**. Sometimes, the LOD of the Revit architecture model is not enough to create the 3D model. The users also can use the Dynamo script to create a model (see **Figure 4**) and then measure it.

Figure 4 demonstrated the integration of the 5D BIM (Dynamo for quantity take-off) with the 3DP.

The 5D BIM-3DP integrated workflow consists of eight stages:

1. Create a 3DP model using Dynamo (see **Figure 4**) or Fusion 360 (Step 4). Fusion 360 is more suitable in the manufacturing industry, which is appropriate for accurate quantity take-off [51]. The Dynamo script in **Figure 4** is a process for model creation since the quantity take-off script is the same as in **Figures 3** and **6**. The model should be imported into Navisworks by '.rvt' or '.rfa' field extension.

2. Conduct the clash detection in Navisworks; 4D schedule information in the Navisworks is added into BOQ [52]. Then, the users can revise the model in Revit based on the clash detection results. The 3D model should be saved as '.stl' extension in Revit (by installing a plugin—STL Exporter [53]) and Fusion 360.

3. Input the 3D model into Simply3D.*STL* extension, and the model would be sliced into the 2D printable layers; the G-coding will be generated automatically.

4. The models also can be created by Fusion 360 as mentioned above, and then repeat step 3 and make sure the models are ready to be printed. The quantity information of the models also can be found in Fusion 360. However, this software is more suitable for manufacturing industry's models.

5. Import the G-coding into the 3D printer by USB, and the final models can be printed.

6. The schedule, and other cost information, such as the density of the ink materials, is collected.

7. Generate and finalize a BOQ of 3DP samples based on the quantity take-off results from the Dynamo (the same steps as in **Figures 3** and **6**) and other cost information.

8. Final physical models in the desired scale are printed.

6. Findings

1. Conventional 5D BIM software and applications cannot extract the small element's quantities accurately at the same time. 5D BIM-3DP integrated workflow has been introduced based on the nature of 5D BIM and 3DP. The users can use the Dynamo to extract accurate quantities from small and precise elements at the same time. For instance, in case study 1—Multilayer wall quantity take-off—the Dynamo script can list the precise quantity of each layer of the multilayer wall at the same time. It is easier for the quantity surveyors, builders, and contractors to understand and check the construction details and then improve the accuracy of the cost estimation and project quality. Also, case study 2—5D BIM-3DP workflow—demonstrated this workflow also can be applied to the 3DP components.

2. Also, the Dynamo can help the users grab the other information quickly, such as the type of material. It helps the BOQ preparation and decision-making at the early stage of the project.

3. In the AEC industry, communication misunderstanding is a significant issue. It is because everyone is thinking in different ways. This 5D BIM-3DP integrated workflow can also be used to print and estimate the scaled-down or laboratory scale models for the complicated or specific components as the communication tool in the construction site or meeting to enhance the communication efficiency.

7. Conclusion

This chapter summarized the advantages and challenges of 5D BIM in the AEC industry. Also, the current conventional 5D BIM applications and software are not suitable for the detailed quantity take-off. The Dynamo, which is one of the Revit Add-ins, can help the users to extract the accurate quantity take-off. For instance, the Dynamo script in case study 1 lists the precise quantities of each layer of the multilayer wall at the same time. In addition, the status of the 3DP in the AEC industry had been evaluated. Since the 3DP has the potential to develop with the traditional construction industry, and 3DP in advance on the small and precise elements printing, the accuracy quantity take-off is very essential. The Dynamo also can be used to create and estimate the 3DP elements and components. The 5D BIM-3DP integrated workflow introduced in this chapter can help the quantity surveyors to get more accuracy quantity take-off for the 3DP. Moreover, the 5D BIM-3DP integrated workflow has the potential to reduce errors and misunderstanding during the communication. Besides, the highly accurate estimation of a 3D model at the early stage of the project would help the users to choose the best alternative design.

The 3DP scaled-down samples can be used to deliver and exchange the participant's idea during the meeting or in the construction site, which can improve communication efficiency. This 5D BIM-3DP integrated workflow is mainly focused on material quantity. Although the 5D BIM-3DP integration can reduce the labour to save the costs, more equipment is required in the construction site and the depreciation costs also need to be considered. Thus, the cost pattern may be changed. Thus, the other costs, such as equipment and labour salary, should be considered and investigated in the future as well.

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