

Acceleration of BIM-GIS integration with low-code application development


Benson KH Hung

Workplace Learning and Assessment Project Team (Engineering Programmes), Vocational Training Council, Hong Kong, People's Republic of China

ABSTRACT

BIM-GIS integration has been discussed for many years, but only a few research studies and practical applications have been completed in Hong Kong. As per the local BIM standard, LoD-G 200 is sufficient for the requirements of GIS planning and analysis. Therefore, this research aimed to streamline the model transformation and simplification from the BIM domain to the GIS domain, automate and systematise the data filtering for model transformation, and build an open-sourced prototype for BIM-GIS transformation via a low-code application called Dynamo in Revit. This paper reviews the exterior shell extraction algorithm proposed by the HKUST BIM Group but focuses on using Dynamo to achieve the purpose. Since Dynamo is common in the local industry, it is easier to understand and further improve the BIM-GIS integration locally. Based on the outcome of this research, auto-transformation has been successfully developed. Compared to the existing workflow to create a simplified model in the GIS domain, the application of auto-transformation is expected to reduce by over 50% the time spent and the number of modellers required. Also, users can easily customise the selection for auto-transformation. Additionally, this paper provides guidance and corresponding recommendations for the further development direction.

KEYWORDS BIM; GIS; BIM-GIS integration; low-code application; auto-transformation

CONTACT Benson KH Hung  bensonhung@vtc.edu.hk

Received 28 March 2022

1. Introduction

Building Information Modelling (BIM) is not a new technology and has been used in Hong Kong since December 2017. The Development Bureau (2018) announced that BIM adoption had become necessary in capital works projects exceeding HKD30 million since 2018. BIM models are holistic and contain much information, including asset information and geometries, which are helpful for data analysis in GIS. However, the BIM models in the industry are mainly used for design visualisation, multidiscipline coordination, phase planning, and cost estimation, with a focus on construction processes and facility management.

The Highways Department and Lands Department have used Geographic Information Systems (GISs) for years to acquire and manage georeferenced data and generate data aggregations represented as 2D thematic maps. Karan et al. (2015) stated that GISs can search for the optimal location for temporary facilities, monitor logistics, and simulate hazardous areas on a site. The most well-known application of GISs in recent years is the Interactive Map Dashboard for COVID-19. With the rise of 3D modelling, the evolution of GISs has climbed from 2D and 2.5D to 3D modelling. The variety of analyses has been enriched and extended to zone planning, electricity consumption, noise, building shadow, etc. However, these analyses require only a simple model rather than a detailed model containing unnecessary information like interior and building services. For instance, the 3D geometry in zone

planning and electricity consumption analysis targets at better graphical presentation, which means that excessive information is not used. The concern is only the building outline in Noise Analysis and Shadow Analysis since they look at a wide area instead of a particular spot. Therefore, model simplification could help solve the industrial pain points caused by data flooding, such as an increasing appetite for storage, network speed, model loading time, and the computation capability of workstations. Bigger is not always better.

The provision of data should be filtered based on the actual need. As the BIM-GIS communication in Hong Kong is still at the beginner stage, neither the engineer nor the surveyor understands the detail of integration. Under the common goal of Smart City, BIM models are directly sent to the surveying team. However, the occurring problems are inextricable in the current situation as both teams are unable to work on this time-consuming coordination. For instance, the Revit file could be an independent file that only allows one user to operate at a time or a central file that enables multiple users to modify the model. Without a central file, the local files cannot be directly modified or saved. However, the local files are sent to the surveying team without detaching them from the central files. Besides that, non-editable Navisworks files are sent for modifying purposes, leading to extra loading time, etc. These numerous problems have prompted surveyors to create their own version of the simplified 3D model for the GIS domain. The simplification of a model by a surveyor is based on one's personal judgement, so the resolution of

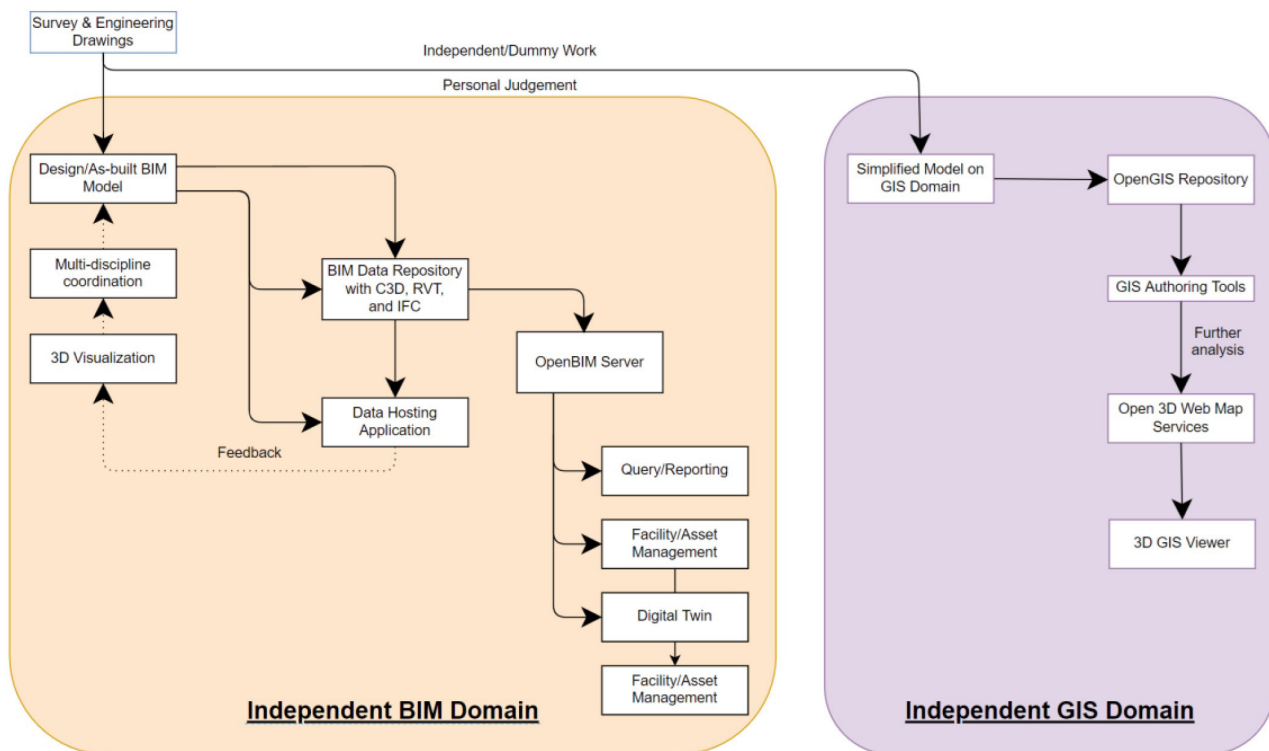


Figure 1. Separated workflow of industry practice.

the resulting model varies if different surveyors prepare it. Moreover, this model is used for GIS analysis only. Therefore, both teams are not notified about the differences until serious problems are found in a separated workflow, as shown in Figure 1.

2. Literature review

2.1. Background

In the last decade, Construction 4.0 was believed to be the way out for the construction industry for digital transformation to improve productivity by applying Building Information Modelling (BIM) technologies. BIM can be utilised to integrate the information from design, construction, operation and maintenance, and refurbishment along the whole lifecycle of buildings (Craveiroa, 2019). For the past few years, the GIS has been widely used for 2D analysis, like urban planning, land resource management, logistics, monitoring traffic flow, and more. However, 3D spatial analyses are seldom involved because the bulky data size of the BIM model became a burden to the GIS domain. Take residential building highway noise analysis as an example. The E&M services and interior design are too detailed for analysis as the noise level simulated at each floor would be representative enough. The excessive data would only slow down the computation for some useless information. Though the computation capability rises every

year, the data size of a large district is still too large, and it has become an obstacle to BIM-GIS integration.

In previous research on BIM-GIS integration, the Industrial Foundation Classes (IFC) format was the main focus as a breakthrough to the GIS field since the IFC format is the primary interoperability tool among the software for BIM. Unlike in foreign countries, Autodesk Revit has dominated the market in Hong Kong. The IFC format is less efficient as the formalised procedures are applicable to the minority. Besides, the developed methods are not written in a common language of the industry and raise the difficulty of understanding and practical application by the local industry and local BIM users.

2.2. BIM automation

Ignatova (2018) carried out a study on the processing and extraction of BIM data by using Autodesk Revit Dynamo. Autodesk Revit, a popular BIM software, is best known for its significant implementation and versatile functions. Autodesk Revit also supports indirect access to BIM data. Revit has many tools for processing numerical and graphical data. Based on the known built-in parameters of the BIM object, a tabular view schedule can be customised, sorted, and exported. However, the BIM model created in Revit is stored in a licensed and closed data format (*.rvt).

Moreover, the Autodesk company provides an alternative option to allow users to control the Revit model

using the modules of the Revit Application Programming Interface (API) via programming. The API can access the BIM data geometric models for the generating, modifying, and erasure of model elements as well as the attributes of BIM objects through the querying and updating of the information concerning BIM objects. It can generate other formats of BIM model data, and more is possible through the API. For instance, Dynamo is one of the Revit API software platforms which is open source for controlling the BIM model and its data. Instead of complex code, it provides a visual programming tool using ready-made simple blocks, called nodes written in Design Script language. They can be picked up from the library ribbon and linked up with each other based on defined rules. When adding a new parameter value, the connection will process calculations, combining the other parameter values and its data. The build-up of a new value for customised parameters will trigger additional functions. Dynamo allows users to write scripts (programming language) using Python and Design Script for more complex tasks (Ignatova, 2018).

A similar study also demonstrated that construction elements can be automatically generate site production schedules for later processing through BIM integration and Autodesk Revit API. The paper proposes a methodology to automatically generate the schedule by considering the topological relationships among building elements. Autodesk Revit was used to develop a BIM model for construction elements, based on which the previous relationships among numerous elements are automatically created and used to formulate the site production schedule by the API. The exported schedules can be imported into works planning software for further processing, such as labour, equipment, and material planning (Liu and Issa, 2014). The method of study concentrated only on the in-planning stage of construction activity and post-construction stage, while project life cycle was ignored.

2.3. BIM integration methods

Back in 2007, Döllner and Hagedorn (2007) started proposing the use of web platforms as containers for both the BIM in the IFC format and GISs in the CityGML format. Through the web viewer, both models could be a demonstration in the same view. However, the computation capability was a challenge during those days. Therefore, after years of research, Karan et al. (2015) proposed a method for BIM-GIS integration based on the Semantic Web Technology. This technology became widely used after 2020 in the BIM industry for more interconnected applications. Our approach aligns with the principles of the Semantic Web, particularly the “link” technique used for data integration in BIM-GIS interoperability. It could avoid the expensive subscription for the BIM software as some viewers need to explore the models but not modify them. However, it is not an efficient way to achieve interoperability since the more platforms involved, the higher the complexity of operation which defeats the purpose of solving the pain point of the industry.

Goedert and Meadati (2008) demonstrated that the method of BIM integration for facility maintenance purposes is linked with construction documents. He showed that the as-built BIM model added new customised fields, including technical specifications, shop drawings, and submissions in Autodesk Revit. Customised fields are created and allocated to all BIM objects like floors, doors, and ceilings. Each field is set to conform to the Uniform Resource Locator (URL) data format. Thus, this format builds up the link between each digital file and BIM object. The connection between the documents through the file path stored in the field allows quick access to the searched information. The specifications, shop drawings, and submissions are integrated by linking the file path address to the corresponding fields. The construction documents are stored locally as a URL type to maintain the data's integrity. Hence, a user is able to search for queries like technical specifications, shop drawings, and submissions which can be retrieved at any time by searching the corresponding fields of a BIM object throughout the building life via BIM. This integration method is a good solution when dealing with large data and reducing the model size.

Another similar study suggested the typical BIM integration of non-graphic maintenance information for facility management. Additional customised fields are created and added to the as-built BIM object for integration of the required operation and maintenance data in Autodesk Revit (EMSD, 2019). Building components and asset information are integrated with maintenance data in BIM objects after construction. As the facility management system recognises these additional customised fields and its value in BIM mode, the data will be automatically propagated in the facility management system when the BIM model is uploaded to the system (Motawa and Carter, 2013).

As proposed by Amirebrahimi et al. (2015), the data model was used to integrate BIM into GISs. Unlike other approaches, the data model integration involves lots of calculations and digs deep into the level of graphical detail (LoD-G), which is also focused on by Hagedorn et al. (2009). As described in the research, their objective was to integrate a 3D model into a GIS and therefore, the LoD-G is one of the main concerns, though they failed the conversion, and thus further study on the feasible logic is needed. However, the point of LoD-G has raised another concern in this research. In the ArcGIS, the model is contingent on the specific shape type and the way that the information is structured within the system, which is surface models in Multipatch. This means that the corresponding converted BIM from the GIS model would be at most LoD-G 100. The benefit of this approach is fully integrating the graphical model into the GIS so that a 3D-viewing GIS is achievable. However, this might not be helpful for analysis purposes in actual practice. The weakness of this approach is the unknown reason for damaged conversion. Therefore, the integration is practical enough when the information or geometry between two domains is consistent.

A graphical model is not necessary to be integrated into the GIS. Moreover, file size and network speed are also huge concerns when displaying everything on a single platform. In the GIS specification (Highways Department, 2019), not all the information is required, so the additional loaded details could be redundant if no further analysis is needed. Therefore, the choices of what to export should be included in the BIM-GIS transformation. The HKUST BIM group conducted the most successful research on BIM-GIS integration in cooperation with the Construction Industry Council. They studied the mapping of the exported BIM model in the IFC format to the GIS platform in the CityGML format and Deng et al. (2016) has solved the georeferencing problem of an exported model from BIM.

The HKUST BIM Group has other research (Deng and Cheng, 2016) covering the Level of Detail transformation in a GIS model, which is similar to the “Level of Development” mentioned in the BIM standard (Construction Industry Council, 2020). The excessive information within a building is unnecessary for GIS analysis but slows down the computation because of its bulky file size. For instance, building shadow analysis only focuses on the shadow cast by a building’s outline; noise analysis focuses on a general effect on nearby buildings rather than a specific room; the 3D facilities for the zone planning are used for a better presentation. Therefore, the Level of Development of the exported model would be one crucial factor for further development into a Smart city yet lacking solutions for BIM users to understand and get involved in the BIM-GIS integration.

In September 2021, the Civil Engineering and Development Department and AECOM studied the BIM horizontal harmonisation for BIM-GIS integration (Construction Industry Council, 2021). The study suggested a standardised workflow for BIM-GIS integration. The prerequisite of the model transformation is described as using a conversion engine, yet further details of the engine itself are not mentioned. Therefore, the way of conversion is worth further study for putting the suggested workflow into practice.

2.4. BIM-GIS integration through graphical programming

Graphical programming is an algorithm development approach that enables the delivery of applications faster and with minimal hand-coding. More specifically, graphical programming largely replaces the need to create custom code with a collection of ready-to-go scripts, solution blueprints, visual workflow automation tools, and other user-friendly features. Dynamo is a powerful application that can build an open-sourced prototype for BIM-GIS transformation and run as a plug-in for other software like Revit. It is also described as a visual programming tool that aims to be accessible to non-programmers and programmers alike. Users can define custom pieces of logic

through the visual script behaviour and script using other programming languages like Python. In short, graphical programming application development is a way to design and develop applications with little or no coding with the following benefits:

2.4.1. Reducing the wastage of resources

In the current environment of Hong Kong, there is no linkage between the works for modelling in BIM and GISs. Therefore, conventional surveys must be conducted twice: one for local construction sites and another for regular updating of the Lands Department. The obtained survey record is further processed as engineering drawings for the modelling of BIM. On the other hand, point clouds are transformed into topographic maps or 3D modelling in GISs. This dummy work undoubtedly wastes time, cost, and human resources. The same object is created again and again on each platform. With many design revisions, it consequently causes repeated works and an enormous waste of resources.

2.4.2. Consolidating multiple sources of information

No matter whether in the design stage or construction stage, there will be many design versions created, and a coherent version is a key to successful coordination when a design fault is found. The independent modelling work on each domain leads to multiple sources of information. If the registry work of modelling update is not properly organised, the discrepancy between the two models would be a disaster as no one can know which one is correct. Eventually, more resources would be needed to figure out the solution.

2.4.3. Improved efficiency

One of the features of construction work in Hong Kong is its efficiency. Usually, there will not be sufficient time for the coordination and design revision work, not to mention the modelling work. In addition, the level of development required in GISs is lower. The creation of a model in the GIS domain involves data filtering. This process is time consuming, and its filter criteria vary per modeller or project requirement. Therefore, manually updating both domains would generate an enormous workload and slow down the construction work.

3. Research objectives

In Hong Kong, not many papers on BIM and GIS integration have been published in regard to the local standards. The normal feature of both techniques is the information container, yet there is not much contribution on bridging two domains due to the recent mandatory adoption

of BIM in Hong Kong. Our unique contribution lies in showcasing how the application of Dynamo can bridge the BIM-GIS gap, making advanced technology accessible to non-programmer practitioners in the construction industry. This sets the stage for improved integration and transparency. Apart from the technical aspect, the industry is also facing different challenges in the coordination aspect. In the organisational structure, engineering and surveying are performed by separate teams. The modeller updates the BIM model under the engineering team, while the surveying team is responsible for the GIS analysis. It is common practice that both teams work on their own model. Engineers will investigate the BIM model clashes in order to refine the design, while surveyors will analyse the best transportation route through the GIS authoring tools for conveyance of the construction materials to the site. Our paper primarily addresses the integration of BIM and GISs in Hong Kong's construction industry. While the paper's title suggests a broader focus on graphic programming in BIM projects, we emphasise the crucial role of Dynamo as a graphic programming tool. Dynamo serves as a practical solution for streamlining 3D modelling in the GIS domain within the Hong Kong context, demonstrating how graphic programming enhances data exchange and integration between BIM and GISs. To tackle the problems encountered in the construction industry, this research aimed to:

- Streamline the 3D modelling in the GIS domain by transforming the Revit model (as further illustrated in Figure 2 and Figure 3);
- Automise and systemise the data filtering for model transformation;
- Build an open-source algorithm for BIM-GIS transformation using Dynamo, aiming at promoting transparency and free accessibility to the latest technology development for BIM and GIS integration; and
- Remove the barriers to entry for “non-programmer” practitioners in the local construction industry with diverse functions and self-paced automation based on Dynamo.

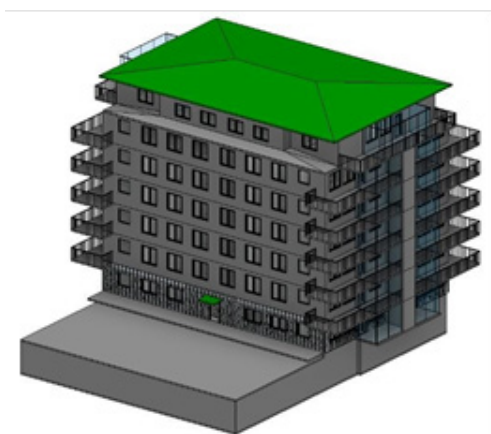


Figure 2. As-built model before auto-transformation.

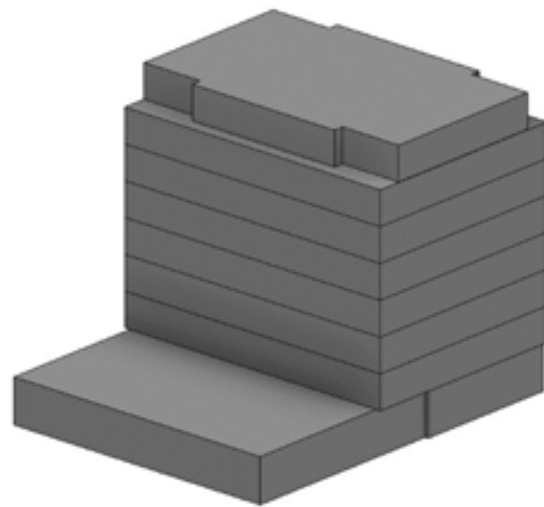


Figure 3. Simplified model after auto-transformation.

4. Methodology

4.1. Existing techniques of the precedent (from GIS to BIM)

In the previous research conducted by the HKUST BIM group, the transformation of the model took place on the GIS platform, and an open-source Java library was employed for the coding. They worked on the exported 3D model in the IFC format and CityGML bi-directional transformation, but how about doing this another way, starting right from the BIM platform instead of using secondary data?

On the other hand, this research started by approaching from the BIM side. As Autodesk Revit has dominated the Hong Kong market, the chosen platform for this research was Revit and the low-code programming add-in Dynamo. Dynamo is a widely used coding language in the local BIM industry, and it facilitates further development by other BIM users. Besides that, it is a visual program wherein no commands or specific programming grammar are needed to be learned or memorised. So, using Dynamo would significantly lower the threshold of joining the development. Moreover, this add-in is open-source and free of charge, hence reducing the budget needed for the research.

We recognise that Dynamo is a well-established tool with a history of use in various research projects. Our intention was not to focus on introducing Dynamo but to illustrate its practical application in the specific context of BIM-GIS integration in Hong Kong. In fact, both BIM-GIS integration and the utilisation of Dynamo are still in the process of development. The true value of our study lies in demonstrating how graphic programming, with Dynamo as a prime example, offers a solution for simplifying building models and transforming data in the integration of BIM

and GISs. Our application within the proposed framework stands as the central contribution of our research. We aim to address a specific industry challenge encountered in Hong Kong, where standards for BIM-GIS integration are continually evolving.

For the program logic of simplifying the complicated BIM model to a building outline only, the concept applied follows the HKUST BIM Group first. The whole process is divided into three main steps: the formation of a bounding sphere, identification of the exterior walls, and creation of a new building outline. While we briefly discuss the communication and file management challenges, our focus remains on their impact on BIM-GIS integration. These challenges underscore the need for a streamlined solution, like graphic programming, to overcome data silos and interoperability issues.

4.1.1. Outcome 1 - formation of a bounding sphere

An outer bounding sphere is created per the building dimension and its centroid. From the observation of the available buildings in Hong Kong, two main categories of building can be classified. The first main type is the low-rise building whose height is less than its width or length. In contrast to this is the high-rise building. Based on the classified building types, the radius of the outer bounding sphere should not simply relate to the building height. Instead, the width and length of the building are also considered.

This research begins with a simply shaped building. The radius of the outer bounding sphere is set as the maximum length between obtained coordinates on the same floor. Its centre is set at the centroid of obtained coordinates on the same floor. At the same time, its height is set at the average value of all heights. Outcome 1 involved the extraction of the model geometries of all walls. In the Dynamo function list, the walls can be filtered by Category and Get Location to obtain the coordinates of the walls. Besides that, the automatic selection of all walls is achieved

by combining Categories and All Elements of categories. Figure 4 shows the test of geometry extraction. Under the Watch node, the coordinates of wall alignments are read out as x, y, and z coordinates, which matches the need for further processing in Outcome 2. This means that the data extraction is feasible.

4.1.2. Critical analysis for outcome 1

The coding of Outcome 1 is straightforward. The purpose is to create an outer bounding sphere that fully covers the whole building. As the full height, maximum width, and the maximum length of the building are used as references for the radius of the sphere, there is no doubt regarding the success of this step. However, two concerns affect the accuracy of the simplified model when importing in the GIS domain.

Firstly, the exported coordinates do not fall into the Hong Kong 1980 grid. This might be because the location of the model under testing is not correctly located. Apart from that, the setting of the Revit file like Project North is rotated per the project local grid. These parameters are recommended to be noted before running the auto-transformation.

Secondly, the exported coordinates are the centreline of the wall instead of the exterior wall surface. Therefore, the simplified model would be slightly smaller unless the coordinates are offset outward corresponding to the wall thickness. So, extra attention should be paid to these concerns.

4.1.3. Outcome 2 - identification of exterior walls

Random observing points are set on the outer bounding sphere surface to identify the exterior wall, and check lines are emitted from the observing points to every wall in the model. As visualised in Figure 5, the thick black lines are the walls of a building, while the dotted line is the outer bounding sphere. Arrows with annotations of L31

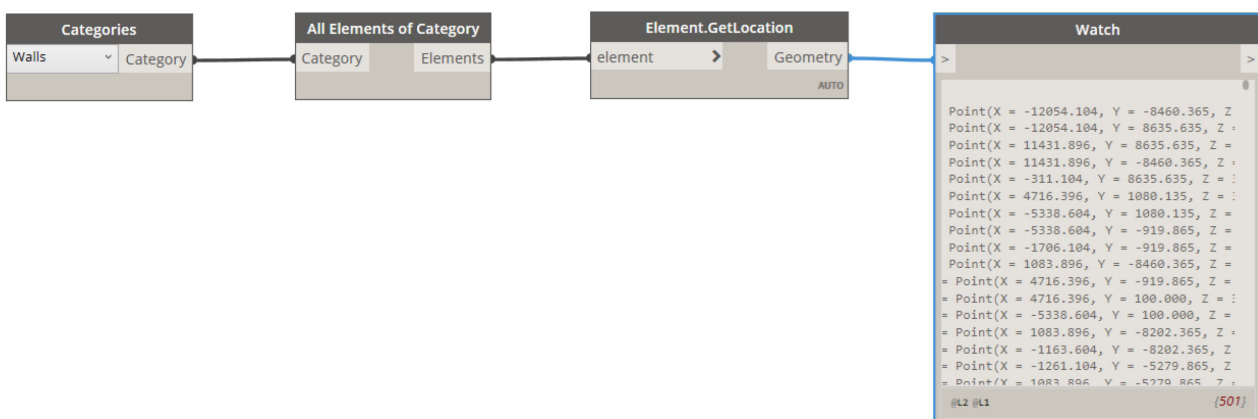


Figure 4. Basic concept of geometry extraction in Dynamo.

and L32 are the first and second check lines emitted from observing point 3. W1 and W2 are annotations of the walls under testing.

If the check line does not clash with any object such as arrows L31 and L32, the corresponding walls W1 and W2 are registered in the exterior walls list. In the case of arrow L12, the check line clashes with wall W4, so W3 is not added to the exterior walls list. The number of observing points becomes critical as it affects the loading time, especially when handling the numerous walls in high-rise buildings. Six observing points are assigned at the top, bottom, front, back, left, and right of the outer bounding sphere surface to obtain comprehensive scan data. After going through all the observing points, the coordinates of the listed exterior walls are ready to create the building outline.

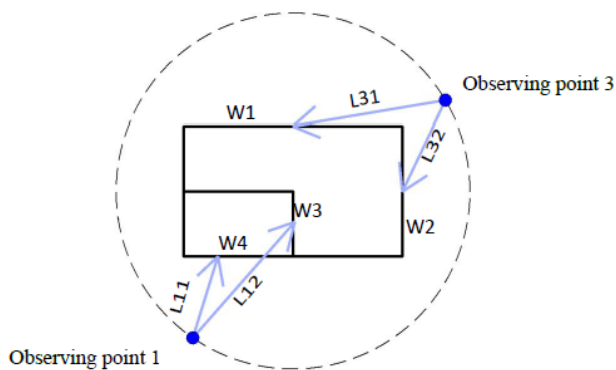


Figure 5. Graphical presentation of the outer bounding sphere method.

Outcome 2 involved observing points on the sphere's surface, formation of a check line, detection of clashes, and registry of coordinates. The observing points can be created by transforming the sphere into a mesh model, reducing the sphere's division, and exporting the mesh model's vertices. A check line can be created by connecting lines between the coordinates of observing points and centroid of individual walls. The DoesIntersect function checks the clashes, and the FilterbyBoolMask node creates the exterior wall list. Neither a tailor-made function nor further calculation is required. The highlight of this part is the number of observing points which only affects the loading time. Therefore, Outcome 2 has the highest feasibility among all options.

4.1.4. Critical analysis for outcome 2

The number of observing points is the critical consideration of this stage. As explained earlier, the observing point is designated to surround the building from six different directions. After testing on a model in practice, it is found that the points from top and bottom do not contribute to the whole transformation because they

can only locate the roof and the foundation. For a seven-storey residential building, the loading time of filtering out the exterior wall is about 55 seconds for all six observing points. After being reduced to four observing points, the loading time becomes 38 seconds, which is about 30% of the time saved. The enhancement is expected to be more significant for taller buildings that contain more wall components. Therefore, it is recommended to narrow the number of observing points to four for fully covered scanning.

4.1.5. Outcome 3 - formation of a new building outline

The exterior wall list is then divided according to its level to flatten the coordinates, for instance, one group for the 1st floor, one for the roof floor, etc. The difficulty of modelling for each floor is the logic of coordinates' connection. Figure 6 shows a typical modelling flowchart for a case similar to the Type 1 building indicated in Figure 7. Two algorithms are studied in the current stage to connect all coordinates, and their mechanisms are explained.

The first algorithm is connected based on the separation between coordinates. This process can be started by sequentially connecting the nearest points. The outline of that particular floor is then recreated. By repeating the creation of each floor and extrusion vertically, a simplified building is built.

Depending on the floor plan shape, another algorithm could help with the "Flexi Block" buildings, which are difficult to handle using the first approach. The connection of coordinates follows the angular rotation from the centroid, as shown in Figure 8. The blue cross symbol is the centroid of the floor plan. Check lines are emitted from the centroid, and its angle to true north is measured and sorted. Then the coordinate is connected with the sorted order and extruded to the designated height, thus creating the simplified building outline as shown in Figure 9, together with the real-life plan view of the said building in Figure 10.

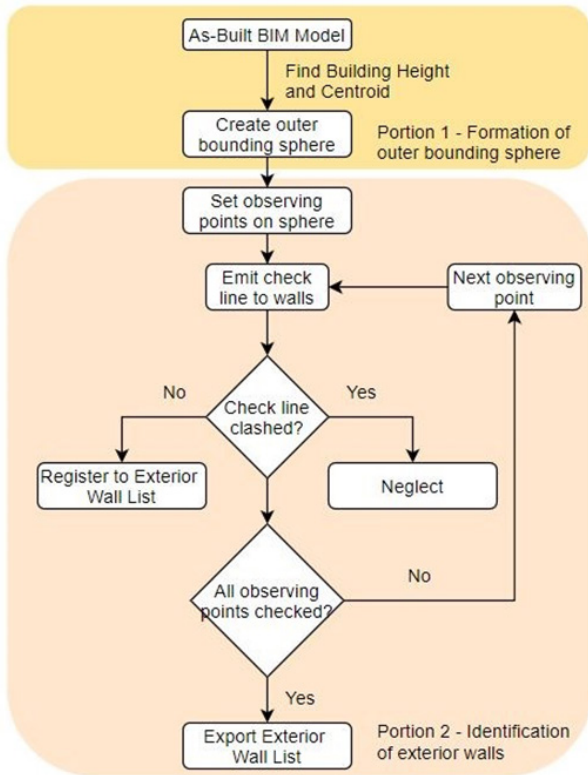


Figure 6. Flow chart of identification.

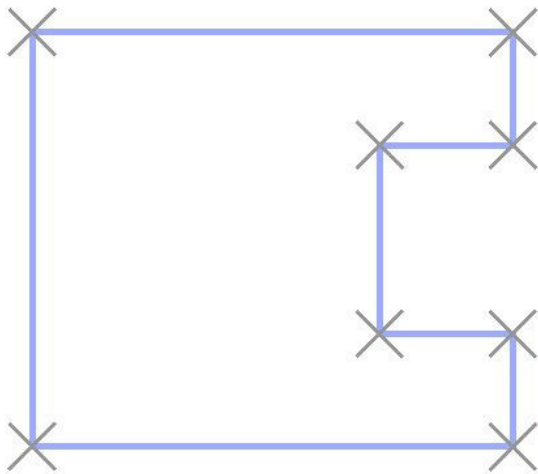


Figure 7. Type 1 floor plan.

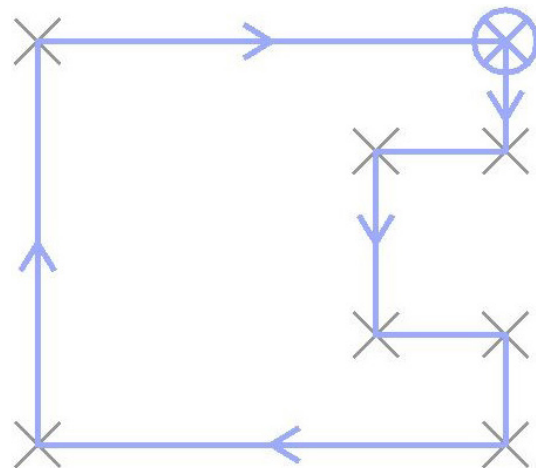


Figure 8. Connection prior to the nearest point.

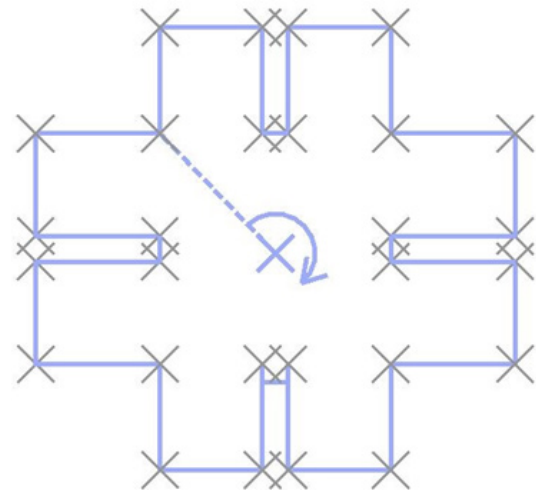


Figure 9. Connection by angular rotation.

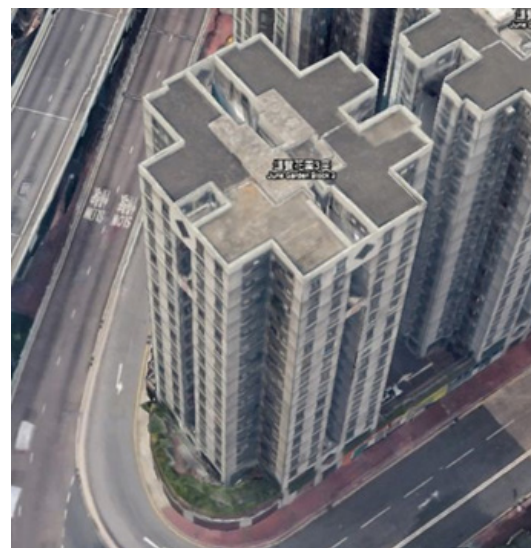


Figure 10. “Flexi Block” buildings in Hong Kong.

Outcome 3 is the most complicated part of this research because it involves the complicated sequencing logic of the points to be connected. As mentioned earlier, there are two approaches applied for such purpose. Both seem feasible, but the outputs are not as expected. The main reason is that single-layered logic is not sufficient to sort the points. To increase the feasibility of the concept, double- or triple-layered logic might help with the sorting, but the basic functions in Dynamo do not support it. Therefore, a further study of the algorithm is needed, and a further process to integrate the simplified model to ArcGIS will be required.

If Outcome 3 is coded to function as expected, the research purpose is achieved. The local BIM users could create a simplified model through automation to avoid the problem of personal judgement, duplicated works, and time-consuming coordination for integration into GISs. Moreover, the simplified model is more consistent with the LoD-G, more accurate and updated. It could also help align the GIS analysis and the BIM design refinement since there is only one source of information. Based on this condition, the GIS analysis becomes valid, and surveyors could submit feedback on the analysis result to BIM users for further design refinement. For better clarification of the change of the workflow after employing auto-transformation, Figure 11 visualises the changes. The integrated working environment is shown in Figure 12.

4.1.6. Critical analysis for outcome 3

Outcomes 1 and 2 are mainly data extraction, while Outcome 3 is the computation and analysis of the data set. The logic of coordinate connection mentioned previously is “pre-tested”, and the obtained result is not satisfactory. For the first algorithm that connects the nearest point, its success depends on where it starts. For instance, the results in Figures 13 and 14 reflect a risk of forming a “zero area” zone. Moreover, the orientation of most buildings in Hong Kong varies according to the carriageway direction, so it is not easy to control the starting point. The first algorithm either successfully creates the extrusion section or leads to software collapse based on the pre-test result. Therefore, this algorithm cannot be used as single-layered logic to sort the connection sequence. The second algorithm also failed when handling the same sample building. For angular rotation check, the key to this algorithm is the location of the centroid. Compared with the rectangular shape, the centroid of the sample building shifted towards the left, thus worsening the sequence. This result also coincides with the conclusion of not being suitable for single-layered logic for sorting.

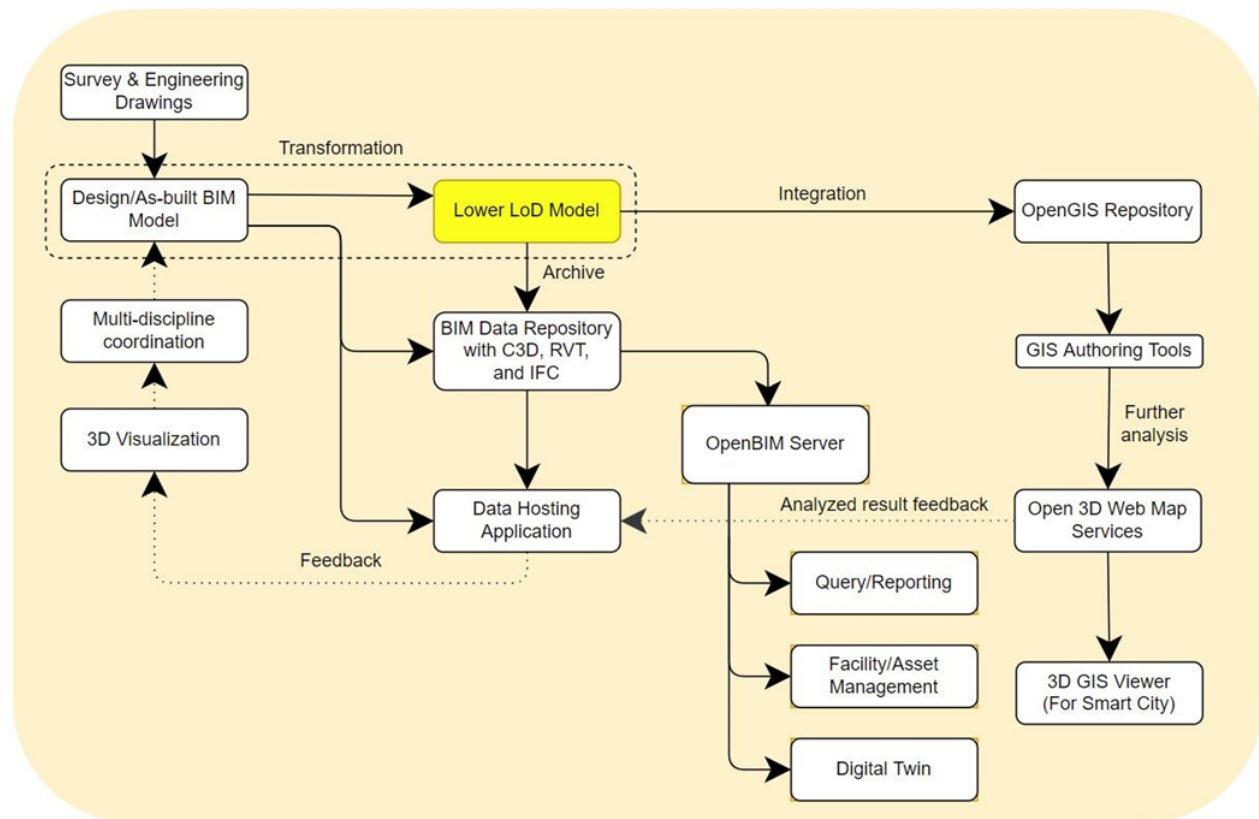


Figure 11. Flowchart of integrated workflow after employing auto-transformation.

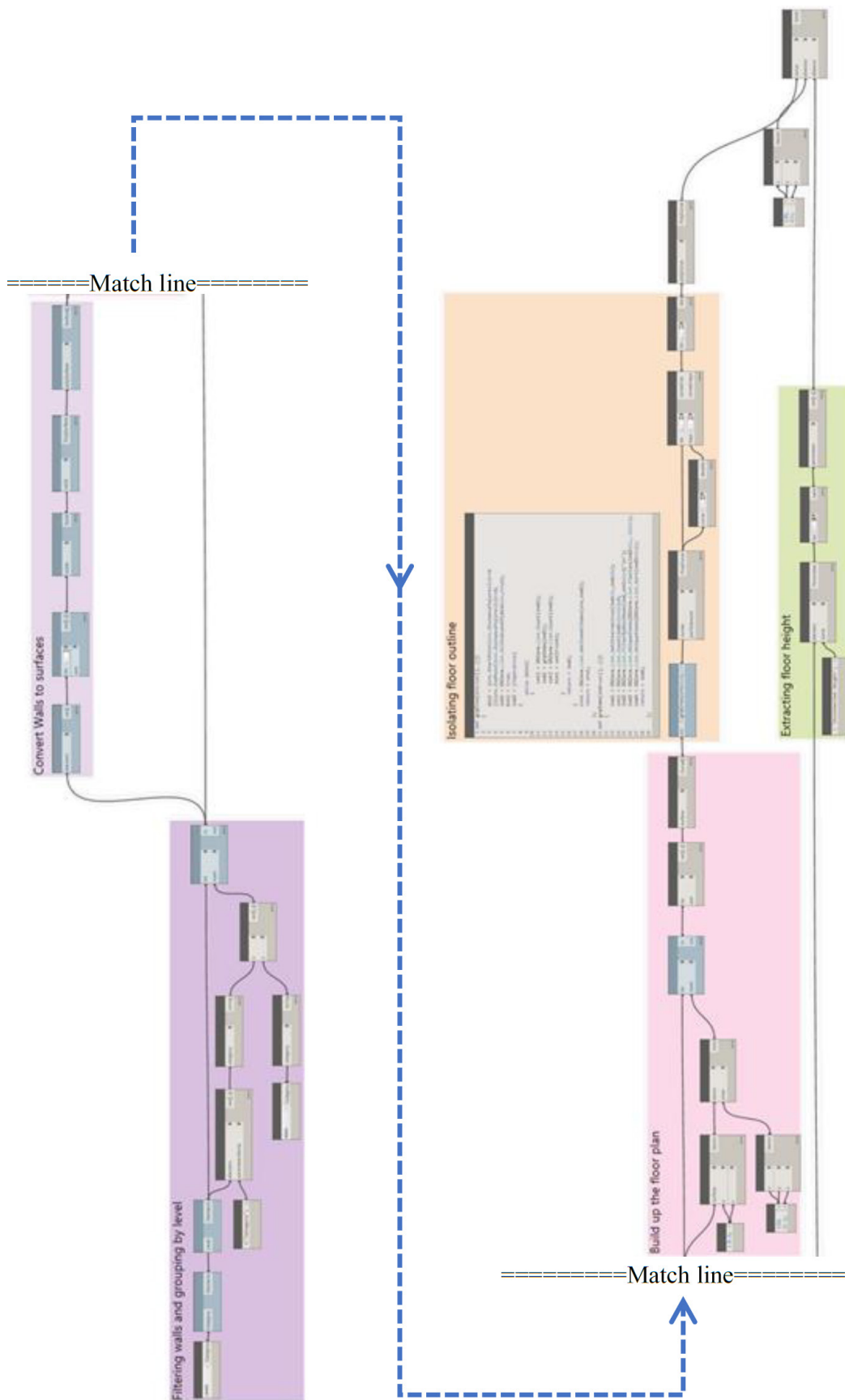


Figure 12. The integrated working environment of Dynamo.

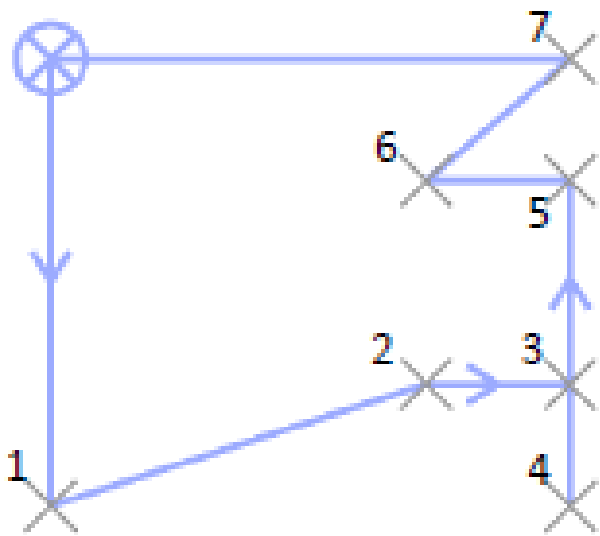


Figure 13. Failed connection by nearest point logic.

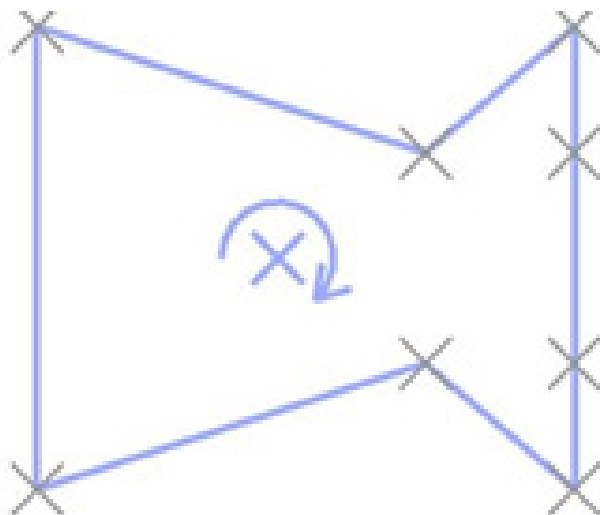


Figure 14. Failed connection by angular rotation.

There are two proposals to deal with the problem: develop a customised function in Dynamo through Python coding or revamp the data extraction. The first proposal is to solve the problem of the single-layered logic process in Dynamo. As mentioned above, both angular rotation and nearest point methods are not sufficient to sort the points into a correct sequence. Therefore, multiple-layered logic is the next step of breaking through. The general idea is to sort the points by sorting both the separation between points and the angle from the centroid simultaneously. Meanwhile, other logic, like regular checking of tips (90°, 60°, 45°, etc.) and exchanging two adjacent lines per angle in between, can also be introduced to form a good building outline.

Another proposal is extracting the wall alignment rather than the coordinates as shown in Figure 15 and Figure 16. This proposal can fundamentally avoid the intractable sorting logic by generating the lines of walls.

The follow-up process becomes chaining the existing lines, while joining lines can be achieved by looking up the same terminal coordinate of the following line. Before extracting the wall alignment, the walls can be exploded into six surfaces first. The offset problem mentioned before can also be solved by using only the exterior surface for data extraction. However, more in-depth study should be conducted to convert the chained lines into useable area for extrusion. A critical issue was found. The clashes of check lines are unable to be counted in Dynamo, which leads to the failure of exterior wall filtering.

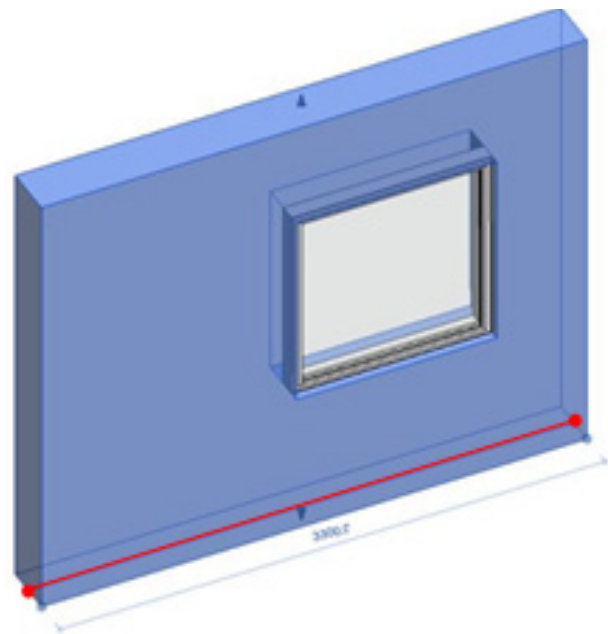


Figure 15. Indication of the exported coordinates of a wall.

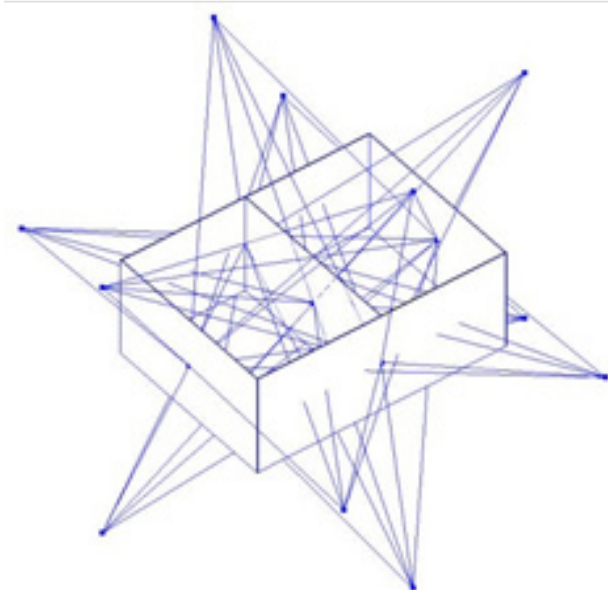


Figure 16. Simplified checkline formation.

To ensure that the research purpose could be achieved, an alternative approach was proposed. Instead of filtering the exterior wall through clash detection, the extracted floor plan from the model was used to capture the building outline. The alternative approach tested on a single floor theoretical model is promising. During the development of the above approaches, the idea of exploded surfaces leads to a totally new methodology concept which is simpler and directly leads to the success of exportation of the building outline. Therefore, it calls for the proposed schemes to solve the limitations.

4.2. Proposed method based on solid union (from BIM to GIS)

The proposed schemes were inspired by obtaining the bottom facet of a wall. As shown in Figure 17 and Figure 18, if the explosion of walls into facets continues for all the walls and combines all the base facets, a floor plan is composed of all walls. However, the overlapped wall edges are the main disturbance from obtaining a correct outline. Therefore, the walls are all converted to temporary solid in Dynamo. Moreover, all the temporary solids are combined into a giant solid.

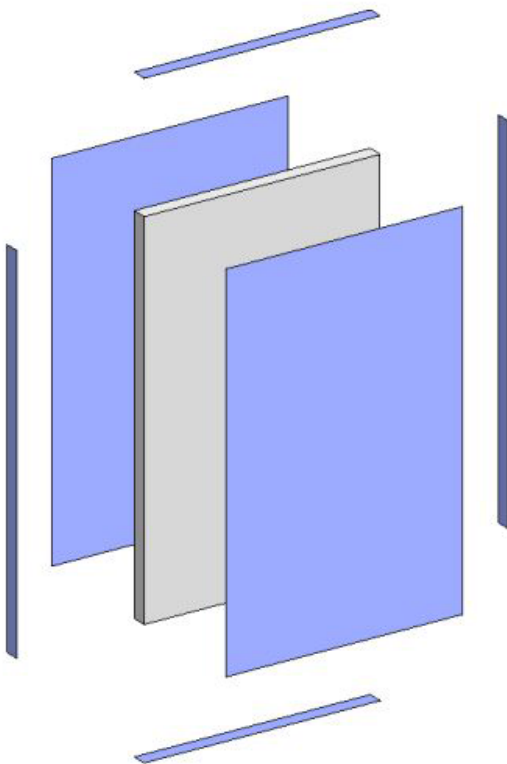


Figure 17. Exploding a wall into six surfaces.

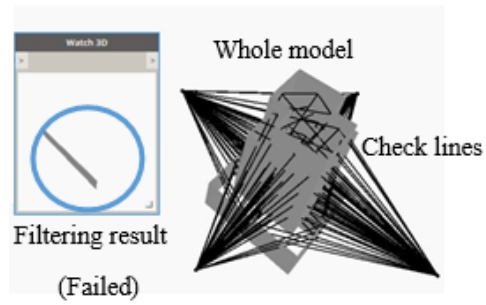


Figure 18. Comparison between whole model and filtered result.

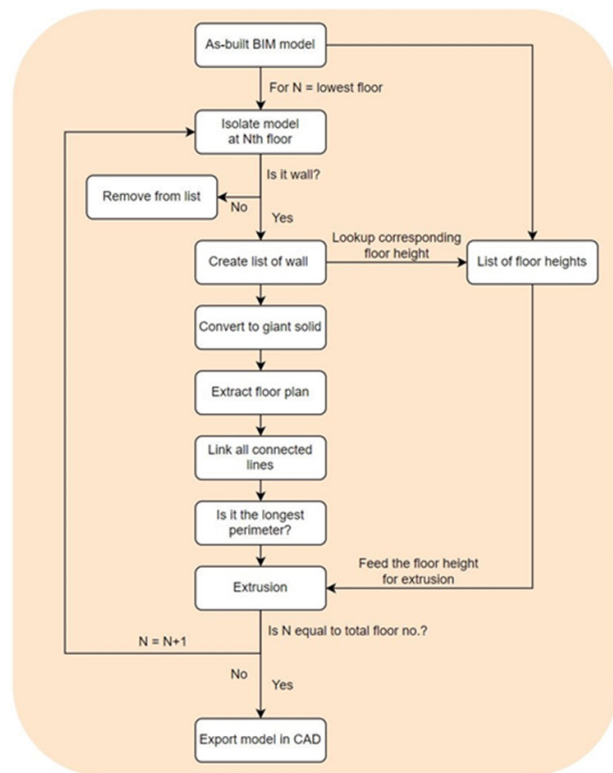


Figure 19. Flowchart of the proposed schemes based on solid union.

By breaking down the solid, or in other words, slicing the giant solid horizontally, a particular floor plan is obtained. By connecting the lines at each terminal, the exterior wall outline is obtained by comparing the length of the joined line. The remaining work is extruding the planar outline per corresponding floor height. For simplicity, the whole process is presented in Figure 19. The flowchart ends at exporting the CAD file because it is the most common data exchange format between the BIM and GIS domains.

In addition, to respond to buildings with a special appearance like the Lippo Centre in Admiralty of Hong Kong, the work is grouped per floor. In other words, the floor plans of the same building could be different. The

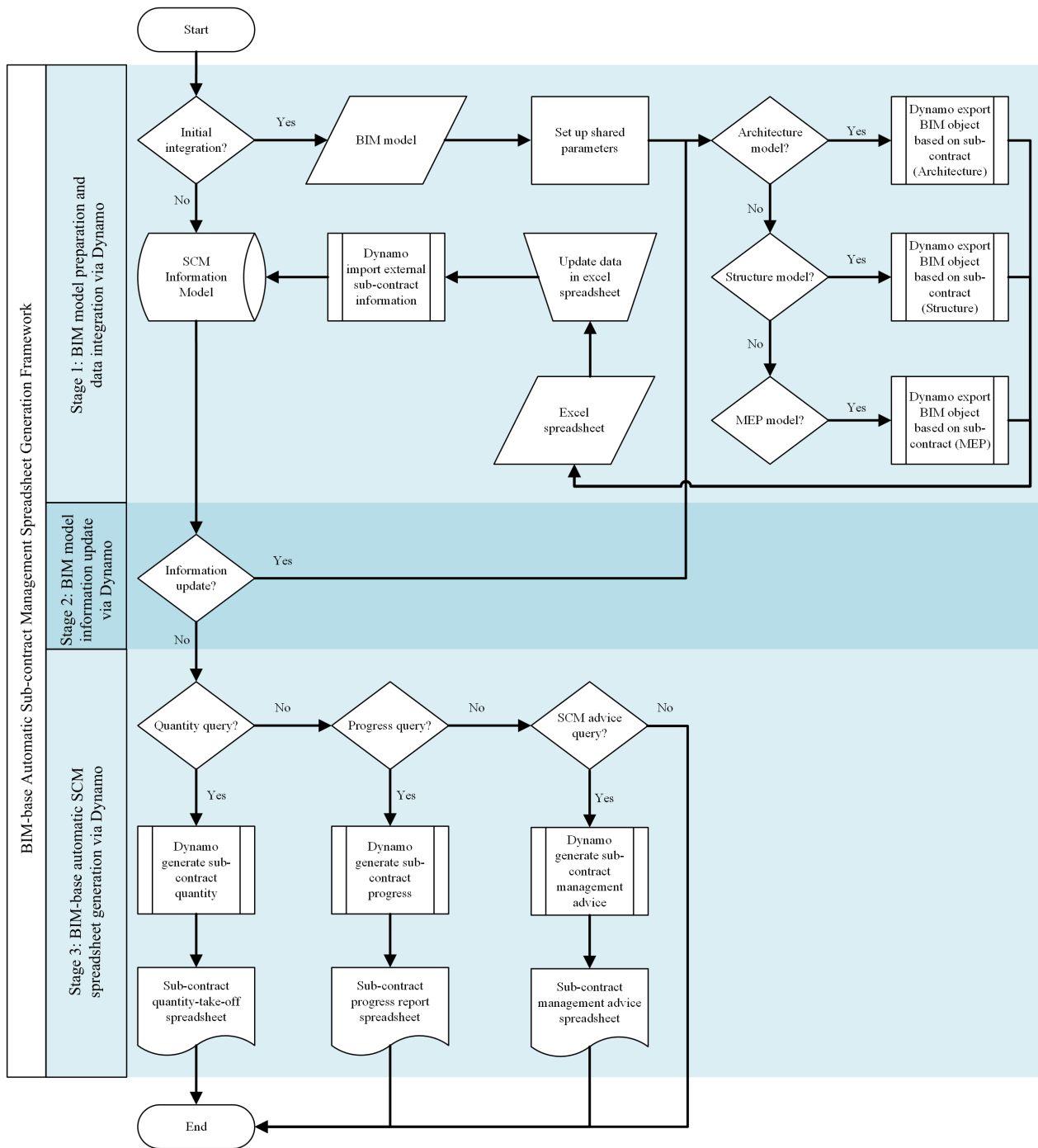


Figure 20. The algorithm of the proposed scheme.

purpose of such division is based on the GIS applications, Noise Analysis, and Shadow Study. The corresponding analysis calculations are highly dependent on the model shape of buildings. Between a highly detailed as-built model and an oversimplified block, a floor-based model benefits lightweight and more accurate results.

The proposed framework consists of three stages: (1) BIM model preparation and data integration via Dynamo;

(2) BIM model information updating via Dynamo; and (3) BIM-based automatic model generation via Dynamo. The algorithm of the proposed scheme is graphically presented in the flowchart of Figure 20. Though the concept of “For-loop” is used for a clearer explanation, it is not precisely the operation mechanism in Dynamo due to the program feature. Yet, this flowchart is more straightforward for a non-programmer BIM user to understand.

5. Results and analysis

Unlike the complexity issue faced in the existing techniques, the coding framework’s arrangement is direct and requires less user involvement in this approach. From the element sorting, floor height looking up to the formation of a simplified model, all the processes are predetermined. The only option for the user to define is the saving location of the exported .dwg. Other than that, the user only needs to press the program’s button and wait until the auto-transformation is completed.

In the testing period, an illustrated model as shown in Figure 21 and Figure 22 is created to examine the output. By the feature of floor-based creation, the shape of the illustrated model can be perfectly built without the disturbance of interior walls. Moreover, the computation time is further reduced when compared with the primary approach because the operation step is much less. For the same model under testing as in Figure 23, the time required to export a .dwg file is only 18 seconds. Therefore, almost 50% in terms of time is saved when compared with using the primary approach, while chaining the lines and extrusion of the model are not counted for the primary approach.

The data filtering is changed from auto-wall-filtering (as shown in Figure 24) to selection-based filtering (as shown in Figure 25) to further enhance the possibility of customised input for the auto-transformation. Not only are the walls used to recreate individual floor plans, but also every selected element with each floor-based solid is used. To effectively select a particular element, the visibility panel in the Revit could be used as shown in Figure 26. By clicking intended categories like walls, structural foundation, façade systems, etc., only the clicked items will be visible in the 3D view. Then, the section of the intended element could be achieved by simply fencing all elements in views. The auto-transformed model would be generated by pressing the “Run” button.

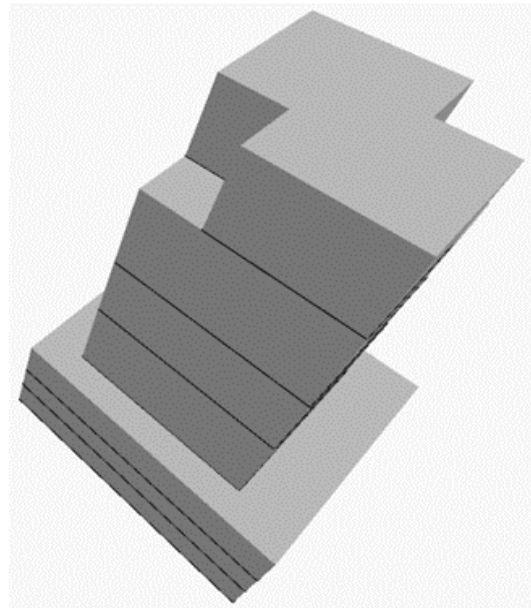


Figure 21. 3D model before auto-transformation.

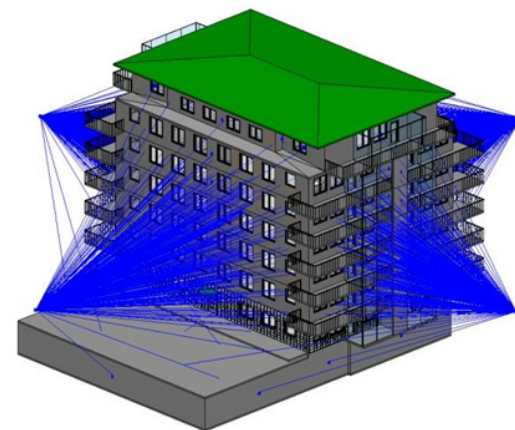


Figure 22. 3D model after auto-transformation.

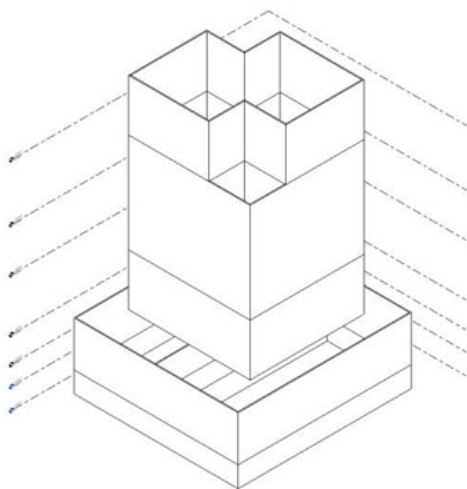


Figure 23. 3D model before auto-transformation.

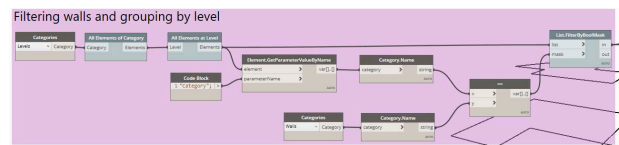


Figure 24. Auto-wall-filtering feature.



Figure 25. Selection-based filtering.

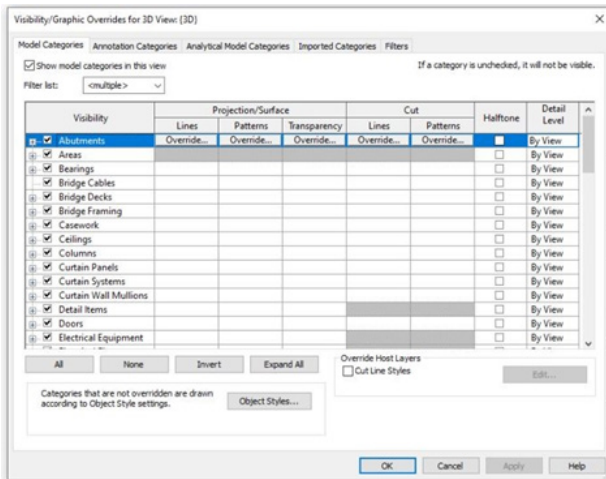


Figure 26. Visibility panel in Revit.

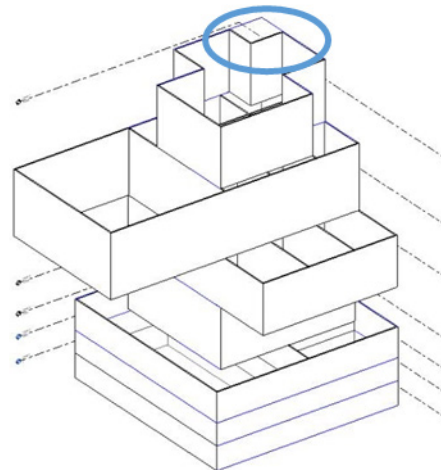


Figure 27. Random model test for floor plan formation.

The result was encouraging with the models successfully transformed. The floor-based model is suitable for further GIS analysis with a significant file size reduction. The processing time was also reduced significantly from minutes to seconds with the possibility of script adjustment for buildings with complicated shapes. In terms of how the models are represented in GISs, it is a question about the functions of the 3D terrain model we intend to have in GISs. In practical application, we usually do not deal with 2D contour files as they provide no instant information for modelling. Instead, we are working on a 2.5D topography file in which elevated lines or contours are available for the actual level representation. The way in which we form the 3D terrain is not simply via extrusion of spatial facets but through triangulation. The created terrain is a surface model and we will use it for cut or fill calculation because the topographical information is flattened in the GIS domain.

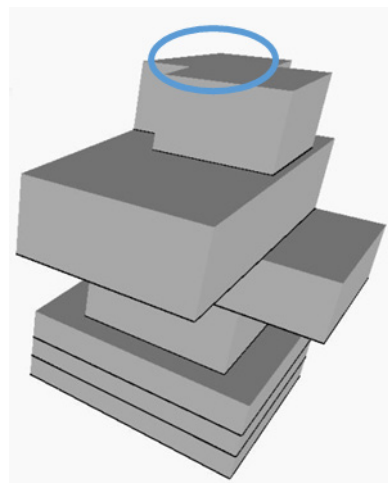


Figure 28. Distorted model.

However, there is a problem found when testing the script. Its number of lines bounds the line chaining process, yet it is not controllable. An octagon is the limit of the formation of a floor plan. Figure 27 and Figure 28 show the problem when the number of lines is more than eight. This problem might be able to be solved if more time is given. The key study to deal with this is the “Node to Code” feature in Dynamo as shown in Figure 29. This feature basically allows the user to condense the program with a more efficient and parametric Dynamo graph. Besides, more parameters could be created for ease of computation controlling.

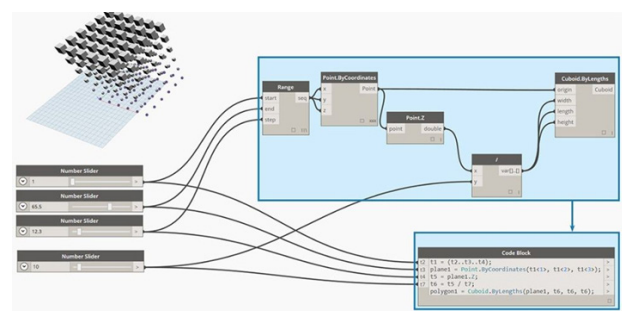


Figure 29. Demonstration of “Node to Code”.

6. Practical examples

For the purpose of testing the script, a simple model with exterior walls, interior walls, and floors is created as an entry-level development. As shown in Figure 30, the interior walls are highlighted in red. A successful transformation would eliminate all the items in red so that only the building outline remains.

After initiating the Dynamo interface (as shown in Figure 31) and the developed script, simply zoom into the circled area, press “Select”, then fence all the necessary elements. The element IDs of selected elements would then appear as a confirmation of selection. Finally, press “Run”, and the computation will start sequentially.

After completing the computation, the transformed model would appear as a duplicated block since the original model should not be disturbed in practice. Open the visibility panel and switch off all elements that could isolate the transformed blocks, and the model can be exported as .dwg, .ifc, .nwc formats depending on the needs. The screen captures of the procedures are visualised in Figure 32 to Figure 35.

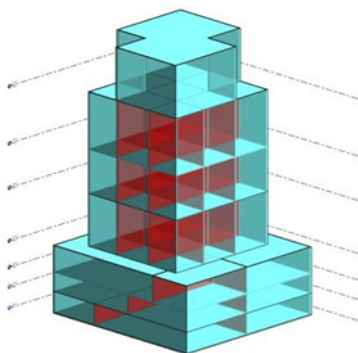


Figure 30. Testing Model.

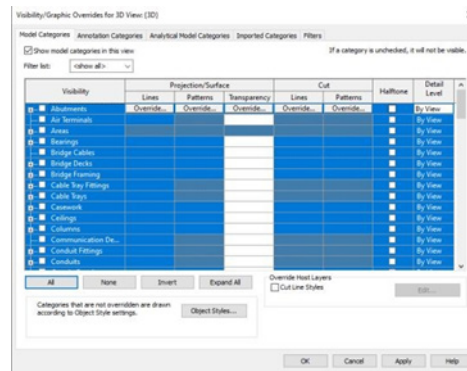


Figure 33. Switch all elements off in the visibility panel.

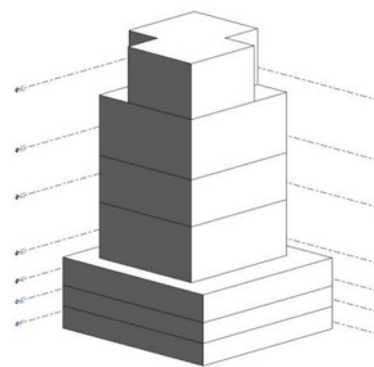


Figure 34. Isolated transformed model.

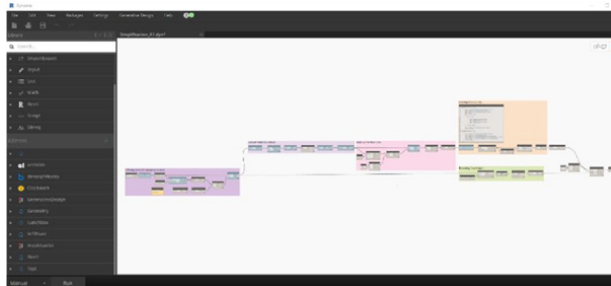


Figure 31. User Interface of the developed script.

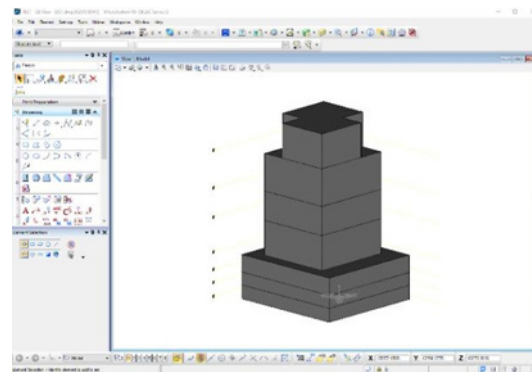


Figure 35. Exported .dwg file ready for use in the GIS domain.

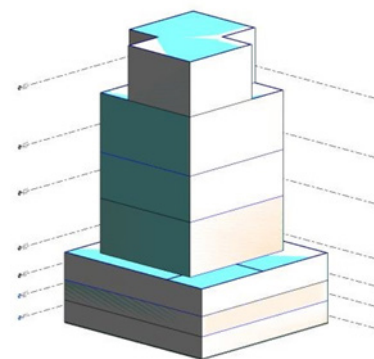


Figure 32. Obtained result after running the script.

7. Further development

As an open-source entry to BIM-GIS integration for BIM users in the local industry, this research has potential for further development in various aspects apart from direct application in the GIS domain. These include but are not limited to the following:

The first direction of further development regards presentation. So far, the Lands Department has put lots of effort into similar work in other domains like Autodesk 3ds Max. As expected, those models are not convenient for

viewing in Revit, and sometimes the displaying issue makes them unusable. Despite the practical application in Revit, the elevation photo of the buildings could be reused with raster images of the simplified model for better appearance and recognition. The benefit of such development is creating small-sized yet distinguishable models through Dynamo. An automation study on this topic would be worthwhile in relation to handling numerous buildings in Hong Kong.

The second direction is revamping the auto-transformation created in this research. The current process focuses on one individual building at a time, so in other words, the transformation should be repeatedly run many times for all the buildings within a district. Further development could include improving the efficiency but transforming multiple buildings at a time.

The third direction is creating a user interface, like a button, in Revit to minimise the in-depth understanding of Dynamo through the use of the Application Programming Interface (API). This concept is similar to creating a form in Excel by using the Visual Basic application. The benefit of such development is to improve the collaboration and internal communication within an enterprise. However, the use of the API necessitates the reading of the add-in manifest file and .dll files which are the output of compiled code in Visual Studio. Such compiling work converts the written code from C#, and therefore, understanding programming language would be a minimum requirement to commence the study.

8. Conclusion

This research has developed a graphical programming application to streamline 3D modelling in the GIS domain by transforming the Revit model. The low-code application has also achieved the purpose of systemising model building and customising data filtering features. The developed protocol will be uploaded and made accessible to the local industry, providing easy entry to technology development for BIM-GIS integration and diverse functions and automation.

The floor-based transformation of the Revit model is achieved by solid extraction in the low-code application Dynamo. A customised selection functional group is also developed for flexible definition of the transformation. The benefit of floor-based modelling is that it provides a lightweight model with sufficient detail to obtain a more accurate analysis result. As the level of development of graphics follows industry standards, the problems regarding the integrity of various contractors can be solved. Additionally, the developed low-code application eliminates the need for creating an isolated model for the GIS domain by simply transforming the Revit model. One of the most significant advantages of applying this low-code application is achieving a single source of information to avoid confusion or data mismatch due to updating design versions.

Our research presents a framework that integrates BIM and GISs to enhance efficiency through a centralised database and automation. It demonstrates an integrated method for information integration and updating and algorithms for decision making in BIM projects. The BIM automation approach via Dynamo in the framework improves productivity and illustrates the development opportunities and potential scenarios in relevant research domains. The contribution of this study includes the development of data integration between BIM and GIS and the framework for automatic spreadsheet generation via Dynamo. We conducted a comparative analysis to emphasise the advantages of our approach over several novel approaches. This analysis will clarify the benefits of graphic programming, offering practitioners and researchers an informed choice for their integration needs.

In other words, this research is not only an automation development to minimise the workload of BIM users and enhance the working efficiency of the industry, but also collaborates with the practical workflow for BIM-GIS integration by ensuring a single source of information and creating a common data environment for BIM users and surveyors.

Notes on contributor



Mr Benson KH Hung has gained expertise in 3D-based design and digital applications for transport systems and infrastructure, traffic and pedestrian flow simulation, road safety enhancement, and the application of qualitative research methodological techniques for sustainable and smart transportation. He combines transportation models with BIM and leads the digital transformation, BIM adoption, and transportation innovation with BIM for research projects and program development. Benson has substantial teaching experience at degree, higher degree, and sub-degree levels at higher education institutions, with course formulation, curriculum development and module design, and academic and project supervision and administration. He has experience in research, and scholastic and professional activities such as conferences and workshops, providing services to the local professional community which include serving as a Transport Policy Committee Member of the Chartered Institute of Logistics and Transport in Hong Kong (CILTHK) and Construction Industry Council BIM Assessment Panel Member of Certification of BIM Coordinators (CCBC) and Accreditation of BIM Coordinator Courses. In view of his outstanding teaching achievements and strong industry linkages, he was awarded the Teaching Excellence Award 2016/17 and the Staff Excellence Award 2020/21 by the Vocational Training Council, respectively.

References

- [1] Amirebrahimi S, Rajabifard A, Mendis P and Ngo T (2015). *A Data Model for Integrating GIS and BIM for Assessment and 3D Visualisation of Flood Damage to Building*. Locate 15, pp.78-89. [online]. Available at: <<https://www.researchgate.net/publication/281976889>>.
- [2] Construction Industry Council (2020). *CIC BIM Standards - General*. Hong Kong.
- [3] Construction Industry Council (2021). *BIM Horizontal Harmonization for BIM/GIS Integration*. [Online]. Webinar on BIM Talks: Celebration of BIM Achievement – BIM Projects 2020 Winners' Sharing. Available at: <https://www.bim.cic.hk/en/bim_showcases/bim_talks_detail/62?sorting=last_update&back=%2Fen%2Fbim_showcases%2Fbim_talks%3Fsorting%3Dlast_update>.
- [4] Craveiroa FD (2019). Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. *Sustain*.
- [5] Deng Y and Cheng JCP (2016) Automatic Transformation of Different Levels of Detail in 3D GIS City Models in CityGML. *International Journal of 3-D Information Modeling (IJ3DIM)*. [Online]. Available at: <<https://www.igi-global.com/article/automatictransformation-of-different-levels-of-detail-in-3d-gis-city-models-in-citygml/153182>>.
- [6] Deng Y, Cheng JCP and Anumba C (2016). Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison. *Automation in Construction*, 67, pp.1-21.
- [7] Development Bureau (2018). *Technical Circular (Works) No. 12/2018*. Hong Kong, the HKSAR Government.
- [8] Döllner J and Hagedorn B (2007). Integrating urban GIS, CAD, and BIM data by service based virtual 3D city models. In: *Urban and Regional Data Management-Annual*. pp.157-160.
- [9] Electrical & Mechanical Services Department (EMSD) (2019). *BIM-AM Standards and Guidelines*. Hong Kong.
- [10] Goedert JD and Meadati P (2008). Integrating construction process documentation into building information modeling. *Journal of construction engineering and management*, 134(7), pp. 509-516.
- [11] Hagedorn B, Trapp M, Glander T and Dollner J (2009). Towards an indoor level-of-detail model for route visualization. *2009 Tenth International Conference on Mobile Data Management: Systems, Services and Middleware*, pp.692- 697.
- [12] Highways Department (2019). *Geographical Information System (GIS) Specifications for Engineering Surveys of Highways Department*. Hong Kong, the HKSAR Government.
- [13] Ignatova EV (2018). *Workspace planning based on the analysis of BIM collisions*. In: Materials science forum. Trans Tech Publications Ltd. 931, pp. 1286-1290.
- [14] Karan EP, Irizarry J and Haymaker J (2015). BIM and GIS Integration and Interoperability Based on Semantic Web Technology. *Journal of Computing in Civil Engineering*. [Online]. Available at: <<https://www.researchgate.net/publication/280612643>>.
- [15] Liu R and Issa RRA (2014). Design for maintenance accessibility using BIM tools. *Facilities*, 32(3/4), pp. 153-159.
- [16] Motawa I and Carter K (2013). Sustainable BIM-based evaluation of buildings. *Procedia-Social and Behavioral Sciences*, 74, pp. 419-428.