Research on Semi-Automated Creation of BIM Models for Existing Buildings Based on Bi-Directional Information

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ABSTRACT Building Information Modelling (BIM) is widely used in construction engineering because of its ability to integrate geometric, spatial, and operational information. However, BIM reconstruction for existing buildings still faces limitations in practical implementation, especially low modelling efficiency and insufficient model usability during operation and maintenance. These problems are also relevant to laboratories and indoor facilities used for electromagnetic testing, antenna measurement, and propagation experiments, where accurate spatial information is required. This paper proposes a semi-automated BIM modelling method based on Dynamo programs and manually labelled point clouds. The method integrates point cloud data with drawing information to extract complete component details and generate BIM models of existing buildings through specialized modules. Case studies show that the proposed approach improves both modelling efficiency and information accuracy compared with conventional manual modelling. The resulting BIM models can support facility operation, maintenance, and spatial management, providing practical support for the digital reconstruction of existing buildings and engineering spaces related to electromagnetic wave and antenna applications.

INDEX TERMS bim, point cloud, semi-automated modelling, existing buildings, engineering facilities

I. INTRODUCTION

THE development of information technology in the construction industry is characterized by the integration of Building Information Modelling (BIM) technology, which has emerged as a pivotal element in this transformation. Construction informatization can be defined as the process of transforming the industry into an informatized, digital, and intelligent sector using technologies like networks and control systems; this parallels the digital transformation of the textile industry, which utilizes similar information technology for advanced manufacturing, smart factories, and digital product lifecycle management [1]. Since the advent of the twenty-first century, the People's Republic of China has incorporated building information technology into the national policy planning system and issued a series of guiding documents and regulations to promote the transformation of information technology in the construction industry [2].

Building Information Modelling (BIM) technology is regarded as a pivotal innovation in the transformation of information technology within the construction sector, enabling comprehensive information exchange and workflow management throughout a building's entire lifecycle – from design and construction through to management and maintenance. Practice demonstrates that applying BIM technology in new construction projects enhances collaborative efficiency across the entire lifecycle, providing a comprehensive informationsharing platform for all stakeholders [3]. Practice demonstrates that integrating BIM technology effectively fosters synergy between design and construction phases, significantly reducing costs and errors [4]. Furthermore, applying BIM within cultural heritage conservation enables multidisciplinary teams, including architects, engineers, and archaeologists—to efficiently manage heterogeneous data streams [5], thereby enhancing work efficiency.

This paper proposes a novel methodology for generating as-built BIM models by integrating point cloud data from existing buildings with design drawing information. The novel contribution of this work lies in the utilization of a visual programming language to automate the construction and stitching of the BIM model structure and facade. Extract layer information from CAD drawings to construct the building structure. Perform semantic segmentation on the building's exterior point cloud data through manual annotation. Subsequently, utilize Dynamo to automate exterior wall modelling based on the point cloud and integrate it with the building structure. This approach leverages the diverse data sources available for existing buildings, thereby assisting O&M personnel in reducing modelling time and mitigating the risk of model errors arising from manual modelling techniques. The following building case study will illustrate this approach.

II. LITERATURE REVIEW

A. AUTOMATED MODEL GENERATION FROM CAD DRAWINGS AND THE RESEARCH ADVANCEMENTS

The term 'drawing data' is typically used to denote either scanned paper drawings or vector computer drawings. In their study, Yin et al. [6] explored the process of generating three-dimensional models from scanned and vector two-dimensional floor plans. They also conducted a comprehensive evaluation of the strengths and weaknesses of various modelling software. Their research demonstrated the viability of modelling from drawing data.

A number of researchers have investigated methods for automatic reconstruction of BIM models from scanned paper drawings. Gimenez et al. used image processing algorithms to detect scanned drawings to automatically generate BIM models. The process includes steps such as image processing, feature extraction, and recognition modelling, which reduces the workload associated with BIM modelling. However, it requires developing different programs for different drawings, resulting in limited adaptability. A number of image processing methodologies have been developed in recent years that are based on deep learning. These have been designed to reduce the workload involved in manually processing scanned images. In the early stage of development, Liu et al. used a convolutional neural network (CNN) to vectorize scanned images for easy recognition by modelling programs [7]. Urbieta et al. trained a Mask R-CNN model to perform semantic recognition and segmentation of drawings. They then developed algorithms through Python to generate IFCs (interoperability framework components) which can be recognized by BIM software. Despite extensive research efforts, the automated recognition and segmentation of scanned drawings remains a challenging task, necessitating significant advancements in accuracy and efficiency to facilitate practical applications in engineering.

B. AUTOMATED MODEL RECONSTRUCTION FROM AS-BUILT DATA AND THE RESEARCH ADVANCEMENTS

The creation of as-built BIM models from as-built information typically involves the use of laser scanning equipment to measure the geometry and appearance of existing buildings and convert these measurements into a 3D form, i.e. a point cloud [8]. The point cloud constitutes a whole, and the automatic creation of BIM models necessitates simultaneous component identification and disassembly, a step that generally consumes a significant amount of time and labor costs.

A number of researchers have utilized deep learning-based artificial intelligence algorithms for the purpose of architectural semantic segmentation. For instance, image-based elevation semantic segmentation employs annotated elevation image datasets for the purpose of segmentation [9]. Furthermore, 3D shapes semantic segmentation methods are based on laser-scanned point clouds [10,11]. In the field of research, the combination of point clouds with Building Information Modeling (BIM) software for information modeling has been explored. Rocha et al. have developed algorithms through Dynamo to convert point cloud data into accurate BIM models, thereby reducing manual inputs and enhancing efficiency [12]. Their work involved the classification of building components, such as walls, floor slabs, columns and beams, and the development of modeling algorithms based on predefined families with manually classified point clouds. Mu Dun employed the Dynamo visual programming tool to construct an algorithm for automatic generation of a BIM solid model by slicing the contours of a 3D point cloud. The slicing modelling logic has been demonstrated to facilitate the modelling process for certain special components [13]. The utilization of diverse color schemes by deep learning algorithms in the context of automatic point cloud semantic segmentation represents a novel approach. This method integrates the point cloud data of multiple colors with the visual programming tools of BIM software, thereby facilitating an automated process of 'point cloud semantic segmentationrecognition-modelling'. The development of such methodologies remains an area of active research.

III. MATERIALS AND METHODS

This paper proposes a semi-automated procedure for the generation of information models of extant buildings, based on CAD drawings and 3D point clouds, which is accomplished in three steps. It is evident that advancements in technology and theoretical exploration have prompted the development of innovative architectural concepts. A notable example of this is the proposal by pioneers in the field of modern architecture to separate the building structural system from the maintenance system. Prominent examples of this approach include Corbusier's Domino System and Mies van der Rohe's Skin and Bone Theory [14]. These theories have exerted a significant influence on the industrial era's building production methods and have been instrumental in the continued utilization of the frame structural system. The majority of extant urban edifices are constituted of industrial frame structures, with structural and envelope systems exhibiting a relatively high degree of independence. In this study, the structural components (i.e. the bone) and the enveloping components (i.e. the skin) of a building are separated for the purposes of data processing and modelling.

The superstructure of a building (the part above the foundation) comprises elements such as columns, beams, roofs, and floor slabs, which are subject to vertical and lateral loads. Relevant engineering design codes are typically in place to strictly regulate the structural deformation of these elements [15]. The specifications explicitly stipulate millimeter-level control requirements for dimensional tolerances and installation accuracy of structural components (Table 1), ensuring high consistency between the completed structure and the design CAD drawings. Furthermore, any structural modifications occurring throughout the building's lifecycle generate comprehensive construction drawing change records, which serve as supplementary evidence for the design model. This approach safeguards the representativeness of the design model for the actual structure at both the institutional and practical levels.

TABLE 1. Allowable Deviations and Inspection Methods for Cast-in-Place Structural Formwork Installation

Item	Allowable Deviation (mm)	Inspection Method
Axis Position	5	Steel Ruler Inspection
Elevation of Top Surface of Bottom Formwork	±5	Level or String-pulling + Steel Ruler Inspection
Internal Section Dimension		
Columns, Walls	+10	Steel Ruler Inspection
Beams, Slabs	+4,-5	Steel Ruler Inspection
Verticality of Storey Height		
≤5m	6	Theodolite or Plumb Line + Steel Ruler Inspection
>5m	8	Theodolite or Plumb Line + Steel Ruler Inspection
Height Difference Between Adjacent Slab Surfaces	2	Steel Ruler Inspection
Surface Flatness	5	2m Straightedge and Feeler Gauge

When inspecting axis position, measure along longitudinal and transverse directions, and take the larger value.

From a practical standpoint, conducting comprehensive indoor point cloud scanning of building structural components presents significant limitations: on the one hand, factors such as interior fittings obstructing views and embedded wall components can result in incomplete scanning data, making it difficult to achieve precise scanning of the entire structure. On the other hand, conducting indoor scanning on a large scale across multiple units within a building requires substantial time and labor costs, impacting work efficiency. Moreover, key structural component data is readily accessible from CAD drawings, enabling automated modelling through information extraction from these blueprints.

The subsequent table provides a classification of the structural and envelope systems with key modelling data (Table 2). This data will be used in subsequent work to develop automated modelling from different data sources.

The details of the modelling data are as follows:

Size: specific size such as length, width, height, etc. of the component.

Position: the spatial positioning of the component in the building.

Shape: the shape of the component, such as rectangular columns, columns; straight walls, curved walls; circular sunshade, rectangular sunshade, etc.

Type: information about the material and facing practice of the component, e.g. concrete wall, brick wall, etc.

Boundary: Boundary of the floor or roof member.

Thickness: information about the thickness of the floor slab in the profile.

Opening: location and size of the opening in the floor slab or wall.

A. INFORMATION ACQUISITION AND PROCESSING

The determination of the source of information must be made on the basis of the modelling data of different components. In order to obtain the required CAD drawings, it is necessary to request these from the relevant operation and maintenance personnel. The layers with low modelling relevance should then be turned off, and the drawings converted to a format that can be recognized by the BIM modelling software. Mobile 3D scanning equipment should then be used to obtain the point cloud of the building façade. The scanning speed of the mobile equipment is fast, which facilitates the acquisition of point cloud data on a large scale in urban environments. The basic splicing and denoising of the point cloud should then be carried out.

B. INFORMATION MODEL GENERATION PROCESS

The process is divided into five stages. The following steps were taken in order to complete the task:

- Elevations and family files for each level were set up in Revit;
- Drawings were placed at different elevations and cleaned up;
- The structural system was modelled from the relevant data;
- Semantic segmentation and registration of point clouds;
- The envelope was modelled from the segmented point cloud of the color blocks.

The modelling of prototypes for drawings and different color block point clouds, respectively, was developed using Revit Dynamo, a visual programming tool for Autodesk Revit. This tool has been shown to have excellent compatibility with CAD and the capacity to process CAD drawing information using algorithms to generate model entities [16]. Furthermore, it has been demonstrated that Revit Dynamo can also read point cloud information by performing point-to-point processing.

C. INSTANCE VALIDATION

For the purpose of validation, a completed existing building was selected for the implementation of the automated modelling algorithm. The automatically generated BIM model, in conjunction with the corresponding point cloud and CAD drawings, was submitted to a panel of experts with an average of 12 years of industry-related experience for validation purposes. This process involved a comparison of the modelling time between automated and traditional manual modelling techniques, in addition to an assessment of the model's usability. The overall framework of the research process is illustrated below (Figure 1).

IV. RESULTS

The case selected for the study is a university cultural pavilion building (Figure 2) located in the southern part of Hebei Province, China. This building has minimal peripheral occlusion and a straightforward and unambiguous

TABLE 2. Structural and envelope component types, modelling data and information sources

	Building Structure System				Building Envelope System				
Component type	columns	beams	floor slabs	roof	internal walls	external walls	doors and windows	functional component	ornaments
Modelling data	size position shape type	size position shape type	boundary thickness opening type	boundary thickness opening type	size position shape type opening	size position shape type opening	size position type	size position shape type	size position shape type
Information source	drawing	drawing	drawing	drawing	drawing	point cloud drawing	point cloud drawing	point cloud drawing	point cloud drawing

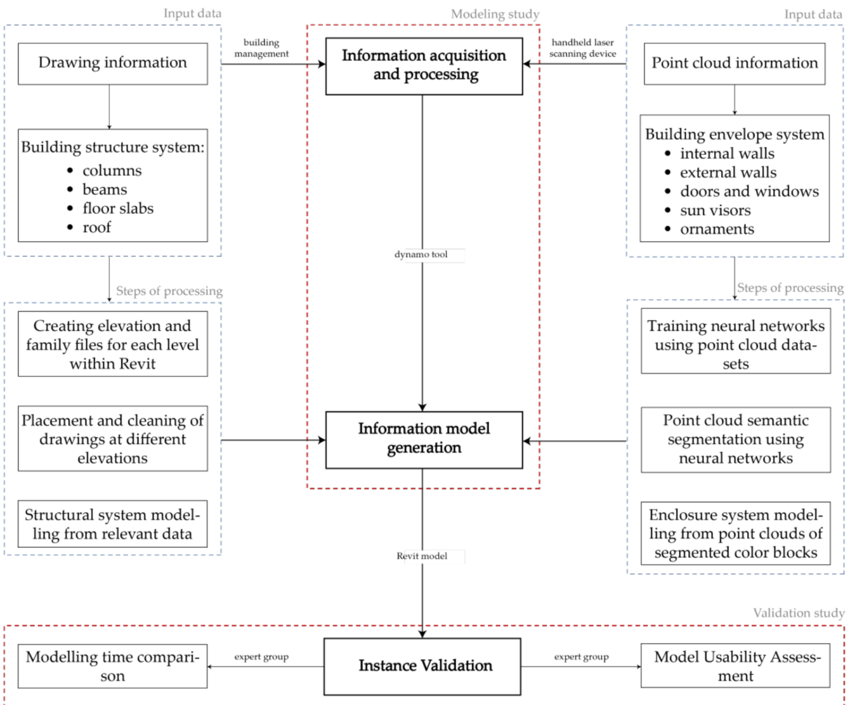

FIGURE 1. Overview of the Research Framework for Semi-Automated Creation Process of Building Information Modeling (BIM) for

design language, which facilitates the collection of point cloud information by laser scanning equipment. The edifice possesses a frame structure accompanied by sunshades, decorative embellishments and glass curtain walls on the façade. The diversity of building components has the potential to present a challenge to automated modelling processes, a characteristic that is exemplified by the building selected for the testing of the modelling algorithms.

The building façade survey was conducted utilizing a FEIMA SLAM100 (FEIMA ROBOTICS, Shenzhen, China) handheld LiDAR scanner, the SLAM GO APP for the documentation of the scan path, and a camera device in conjunction with a DJI Matrice 350 RTK drone (DJI, Shenzhen, China) for the purpose of building photographic recording. The software programmers Autodesk Recap, Trimble RealWorks and CloudCompare were utilized for the processes of stitching, cleaning, coloring and labelling of the point cloud.

A. *ACCESSIBILITY OF INFORMATION*

1) Drawing Information

The technical drawings of the building are vector CAD drawings provided by the building management, with a scale of 1:100, and including information on dimensioning, floor elevation, component practices, etc. The contents of the drawings include a ground floor plan, a first-floor plan, a roof plan, a sectional plan, a building elevation, a curtain wall elevation and the necessary node construction diagrams (Figure 3). In the architectural drawings under consideration, the various building components are delineated in layers with differently colored lines. The modelling program then uses this information to create the components according to their layer designations. This feature of vector drawings avoids the issue of semantic information overlap common in 2D drawings.

2) Point Cloud Information

This study utilised the FEIMA SLAM100 handheld laser scanning device, which achieves a positioning root mean square error (RMSE) $\leq$3cm, point cloud density $\geq$500 points/m^2, and scanning range from 0.1m to 100m. Its accuracy metrics fully satisfy the G3-grade geometric precision

FIGURE 2. Survey of university cultural pavilions, Hebei, China

requirements for all components within the LOD 3.0 as-built model. It accurately reconstructs the geometric volumes and spatial positioning relationships of the main building structure and various conventional components. Point cloud acquisition is conducted by traversing around the target building at a slow walking pace of approximately 0.5 meters per second. This was then solved, denoised, and cropped using SLAM GO POST PRO [17] to obtain the point cloud data of the building's current façade (Figure 4).

B. MODELING STUDY

1) Creating Elevation and Family Files for Each Level within Revit

In the Revit software, families constitute the fundamental element of an architectural project, with all model elements and annotation elements being composed of various families. As indicated by the content of the technical drawings, family files are created within Autodesk Revit 2024 for each floor elevation of the building and for each type of building component. These files can be easily extracted and utilized by Dynamo at different plan heights in subsequent modelling work.

The following table provides information on the creation of family files for different building components (Table 3):

TABLE 3. Information on the data required for the creation of family files for modeling building components

Building Components	Family information
Columns	Rectangular reinforced concrete columns; $b = 600$mm, $h = 600$mm
Beams	Rectangular reinforced concrete beams; $b = 300$mm and $h = 500$mm/700mm/1050mm
Floor slabs	Reinforced concrete floor slabs; thickness: 100mm
Roof	Reinforced concrete roof; thickness: 100mm
Internal walls	Aerated concrete block walls; thickness: 200mm
External walls	Self-insulating concrete composite block walls; thickness: 300mm
Curtain walls and windows	Curtain walls $b = 1000/800$mm, $h = 1500/600$mm; fixed windows $b = 600$mm, $h = 3300$mm
Sun visors	Aluminum alloy sunshade grille; size: 150mm$\times$300mm$\times$2100mm/2700mm
Ornaments	Aluminum alloy hanger; size: $r = 300$mm, $b = 60$mm

2) Placement and Cleaning of Drawings at Different Elevations

In order to prepare the structural system for modelling from the drawing information, it is necessary to link the CAD drawings of each floor plan of the building into Revit according to different elevations. This process involves the maintenance of layers of columns, beams, floor slabs, roofs, walls and the necessary annotations and window openings, and the closure of irrelevant layers (Figure 5). This procedure is undertaken to ensure the completeness of the graphics and lines, and the modelling work can then be carried out after the correctness of the drawings has been verified.

3) Structural System Modelling from Relevant Data

The specific building structure system component creation method is as follows:

1. Columns

The pavilion's structural design is characterized by a regular plan, with each floor being supported by 26 square reinforced concrete columns measuring 600 x 600mm,

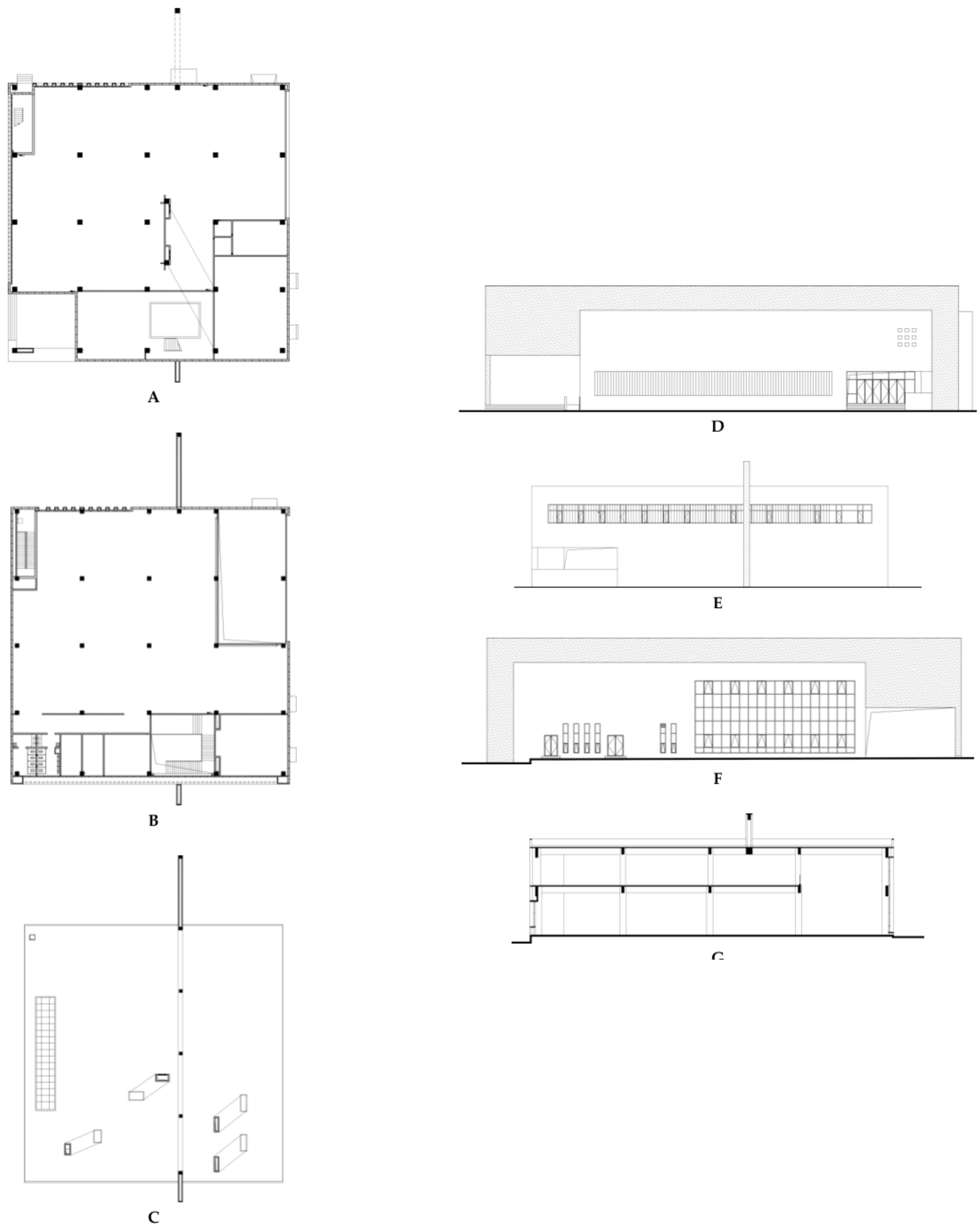

FIGURE 3. Main elements of the CAD drawings. (A) First floor plan; (B) Second floor plan; (C) Roof plan; (D) North Elevation; (E) West Elevation; (F) South Elevation; (G) Sectional Drawing

one of which is slightly taller than the others. Following the extraction of the curves of the column layer through the node 'CAD.CurvesFromCADLayers', the 'List.Flatten' and 'List.Chop' functions should be called in order to filter out the curves whose number is not 4. The 'Flatten' and 'List.Chop' functions are utilized to eliminate list items that do not correspond to a total of four (thus precluding the enclosure of the rectangle). Subsequently, the 'Curve.StartPoint' function is employed to ascertain the initial point of each group of curves. The center point of the enclosing graph is calculated using the 'ByPoints' and 'Polygon.Center' nodes. In order to filter and sort the length and width data of all rectangles, it is necessary to use the 'GetItemAtIndex' and 'String.Split' nodes. Subsequently, the 'Code Block Split' node should be utilized in order to filter and sort all rectangles by length and width data. Finally, the 'Code Block' node should be employed to type 'a+' x '+b+'mm' in order to obtain the modelling data of the column dimensions. The 'Family.ByName' node should be used to assign the structural column family name 'Concrete - Rectangle - Column' string. The 'List.GetItemAtIndex' and 'String.Split' nodes should then be connected to index the column dimensions to the corresponding structural column type. The 'FamilyInstance'. In order to create a structural column instance, it is first necessary to call the 'FamilyInstance.ByPointAndLevel' node, and specify the column

FIGURE 4. Building elevation point cloud

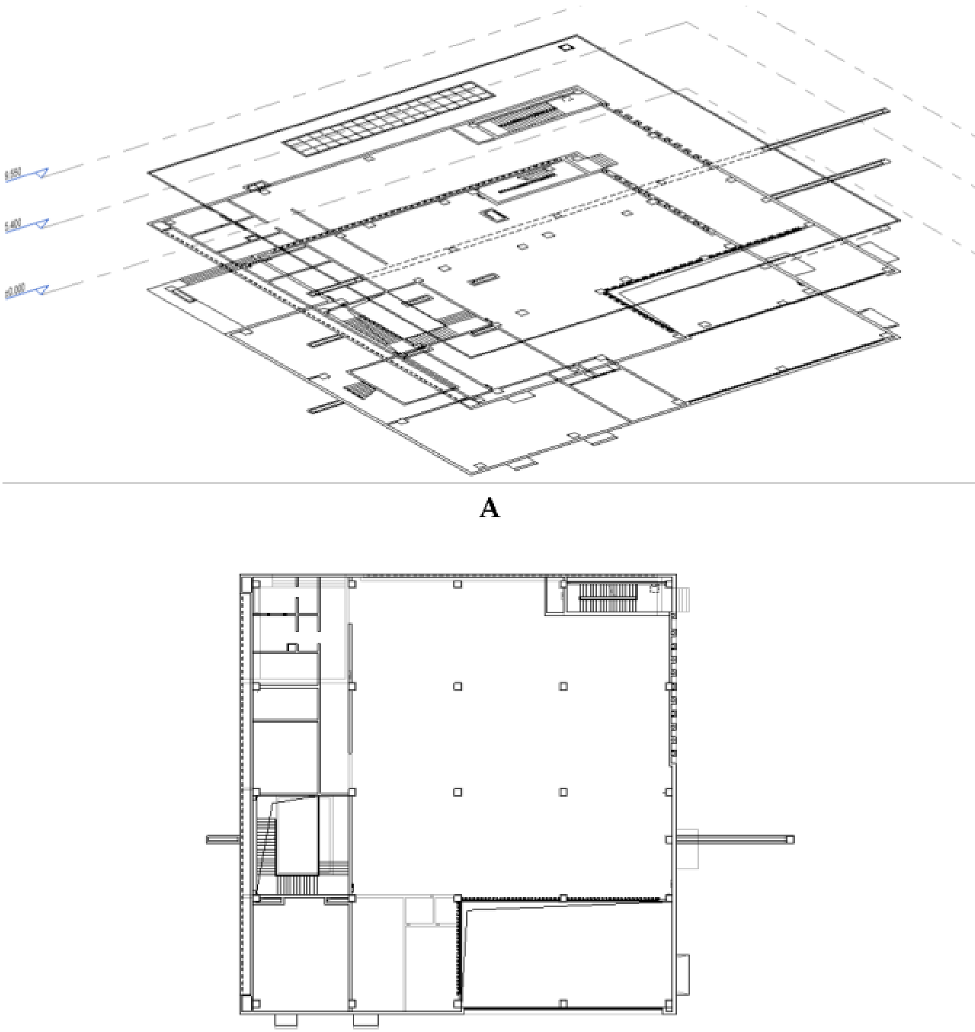

FIGURE 5. Placing and aligning CAD drawings in Revit by level. (A) Axonometric view; (B) Plan view

center point and column type. The ’Levels’ function can then be used to select the corresponding floor elevation. Finally, the operation is performed (Figure 6).

2. Beams

The beams in this building have three distinct cross-section sizes: edge beams measuring 300 x 1050mm, primary beams measuring 300 x 700mm, and secondary beams measuring 300 x 500mm. The beam sizes required for

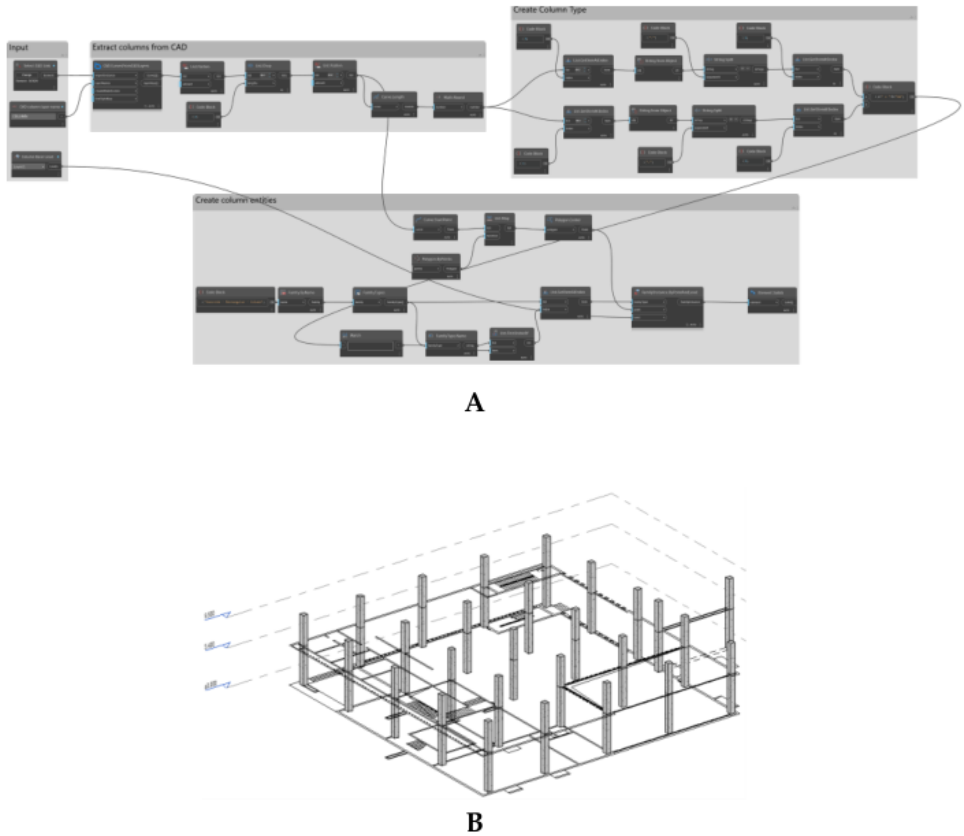

FIGURE 6. Dynamo workflow for creating columns and creating results. (A) Dynamo workflow for creating columns; (B) First and second floor columns creation results

the modelling in Revit must be created, the beam type must be named as the beam name in the CAD drawing, and the height and width values must be set accordingly. Initiating the process with the designated 'Select Model Elements' node, the modelling curves and annotations are selected into Dynamo. Subsequently, the curves are utilized for the purposes of matching and centerline search, while the text annotations are employed for the extraction of the types and insertion points. String from Object' and 'Element.GetParameterValueByName', 'List. The classification of the selected elements according to their corresponding family is achieved by utilizing 'GroupByKey' nodes. The sorting of curves and annotations in the CAD element list is defined by invoking 'List.IndexOf' twice. Subsequently, the specified items in the grouped list are extracted using 'Code Block', thereby completing the instance filtering and generating the curve list. The midpoint of each curve can be obtained by referencing the 'PointAtParameter' node, while the distance between the center points of all curves can be determined by utilizing the 'Geometry.DistanceTo' node.

Subsequently, the 'Code Block' node should be invoked. The function 'DistanceTo' is employed to calculate the distance between the center points of all the curves. Subsequently, the function 'Vector.ByTwoPoints' is invoked to generate a vector with two center points. Following this, the function 'Geometry.Translate' is utilized as the offset direction, and the offset value is input to obtain the beam center line. Translate' as the offset direction, and input the offset value for it to get the beam centerline. The utilisation of the custom node 'text.code' facilitates the retrieval of the content and coordinate value of the text comment. The function 'Geometry.DistanceTo' is employed to ascertain the distance between all the text comments and the center point. The 'List' function is also called upon. The following steps are required to pair the beam centerline with the text comment: firstly, utilize the 'List.Transpose' function, and then the 'List.GetItemAtIndex' function. Subsequently, the 'String' function should be called. Subsequent to this, the 'Substring' and 'FamilyType.ByName' functions must be utilised in order to convert to the corresponding beam type, 'StructuralFraming'. The 'BeamByCurve' and 'Element.SetParameterByName' functions are utilized to convert to the corresponding beam type. The 'StructuralFraming.BeamByCurve' and 'Element.SetParameterByName' functions are then employed to automatically generate beams from elevation, centerline and beam type (Figure 7).

3. Floor Slab

The edifice comprises two stories, with the structural design incorporating a 100mm-thick reinforced concrete floor

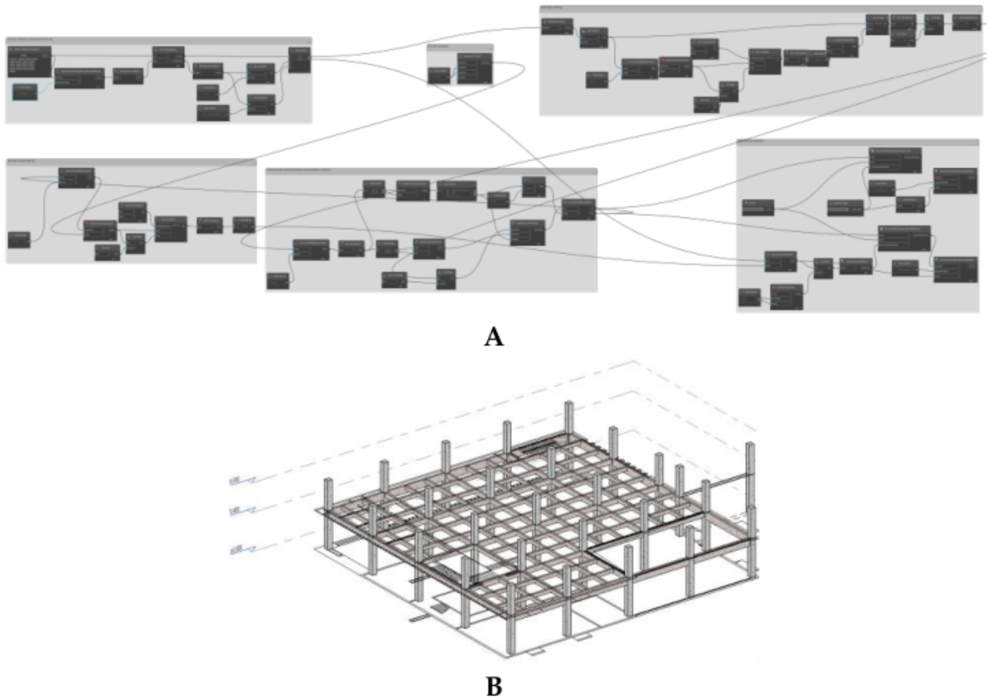

FIGURE 7. Dynamo workflow for creating beams and creating results. (A) Dynamo workflow for creating beams; (B) Beams creation results

slab. The floor slab layers are created in the CAD drawing according to the edge curves of the floor slabs. The ground floor slab contains all the interior spaces, and the first-floor slab has the openings for the stairwells and the showroom spaces. In order to extract the floor layer and flatten it, it is necessary to use the nodes 'CAD.CurvesFromCADLayers' and 'List.Flatten'. Following this, the elevation and the type of floor must be selected, and 'ByOutlineTypeAndLevel' must be called in order to create floor slabs at each level. Finally, 'Element.JoinGeometry' must be used to connect columns and floor slabs, in order to complete the automatic creation of floor slabs (Figure 8).

4. Roof

The logic of creating the roof is analogous to that of the floor slab, and the structural design is equivalent to a 100mm-thick reinforced concrete floor slab. Following the creation of a layer delineating the roof edge lines, the program should call 'CAD.CurvesFromCADLayers' to extract the roof layer. The elevation and roof type should then be selected, after which the program should call 'ByOutlineTypeAndLevel' to create the building roof (Figure 9).

5. Internal walls

The building comprises internal walls on both the first and ground floors, with the structure composed of 200mm-thick aerated concrete blocks. Following the extraction of the curves of the interior walls according to the nomenclature of the layers of the interior walls using the 'string' and 'Select Model Elements' functions, the center line of the curves of the interior walls is created using the same logic as the center line of the beams. The node 'Wall. The function of the 'ByCurveAndLevels' node is to determine the center line, wall type and height of the wall, thereby facilitating the automatic creation of internal walls. It should be noted that there will be some openings in the interior wall for the purpose of facilitating equipment maintenance. Following the extraction of the location of the apertures and the creation of entities through the geometry series nodes, the utilization of 'Element.CutGeometry' is requisite in order to complete the cutting of the apertures on the interior wall. The door and window curves of the corresponding layers are utilized to obtain the midpoints for component positioning in the case of indoor doors and windows. The insertion of doors and windows can be performed at the corresponding positions on the interior wall subsequent to the selection of the corresponding family type and elevation (Figure 10).

4) Semantic Segmentation and Registration of Point Clouds

The point cloud of the target building were manually annotated through the utilization of the Semantic Segmentation Editor [18]. The Semantic Segmentation Editor is a tool designed for the processing and annotation of 3D point cloud data, with the objective of enabling the user to achieve precise classification and labelling of the point cloud data. The PCD files, exported after each face and marked individually, are merged with Cloudcompare and saved as E57 files. These files can be visualized in Autodesk ReCap (Figure 11), with 16 colors representing different building components.

This study proposes a 'common reference point registra-

A

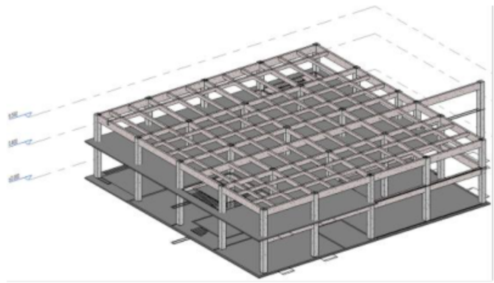

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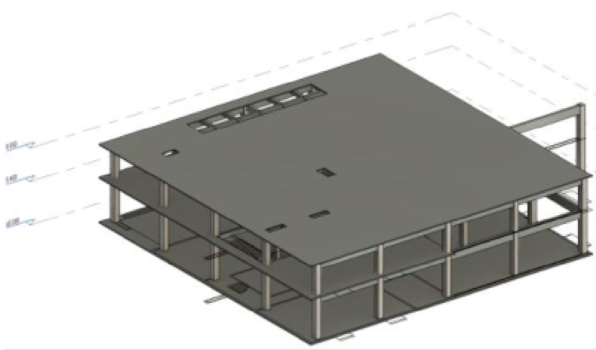
FIGURE 8. Dynamo workflow for creating floor slabs and creating results. (A) Dynamo workflow for creating floor slabs; (B) Floor slabs creation results

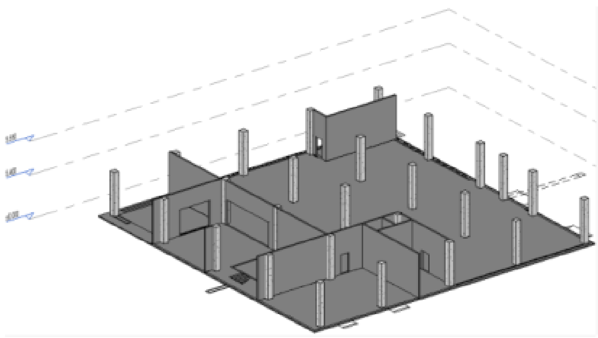
A



B

FIGURE 9. Dynamo workflow for creating roof and creating results. (A) Dynamo workflow for creating roof; (B) Roof creation results

A



B

FIGURE 10. Dynamo workflow for creating internal walls and creating results. (A) Dynamo workflow for creating internal walls; (B) Internal walls creation results

tion method' to address the alignment requirements between structural system models and maintenance system point clouds. The specific technical workflow is as follows: after completing the on-site full-scale scanning of the building envelope, selecting typical structural components exposed within the building as reference objects and conduct localized highresolution scanning of these; During the registration phase, the endpoints of this local structural point cloud serve as the unified coordinate origin (i.e., common reference point). Simultaneously, corresponding endpoints bearing the same designation within the CAD structural model are located and marked. By precisely aligning the coordinates of reference points across both datasets, spatial registration between the envelope system point cloud and the CAD structural model is achieved. This study selected a structural column on the first floor at the center of the building's western side as the reference object. Its clearly exposed contours both indoors and outdoors facilitate point cloud extraction, and within the structural system, it supports multiple components including upper floor slabs, the roof, and decorative walls, making it highly representative. The FEIMA SLAM100 handheld laser scanner was employed to scan the indoor reference column in standard precision mode. This mode features a field of view of 270° × 360°, a point rate of 320kpts/s, relative accuracy of 2cm, and absolute accuracy of 5cm. The device's integrated SLAM algorithm and automatic control point acquisition function enabled precise multi-station scan stitching without requiring manual target placement.

Enclosure System Modelling from Point Clouds of Segmented Color Blocks

Before importing the point cloud into Revit, it is necessary to split the point cloud with different color blocks into separate regions in Recap. This ensures that the Dynamo tool can capture the specific regions of the different color blocks. The facade point cloud is divided into three categories based on component types: exterior walls, door/window grilles, and curtain walls, with each category processed by a separate program segment.

The specific building envelope system component creation method is as follows:

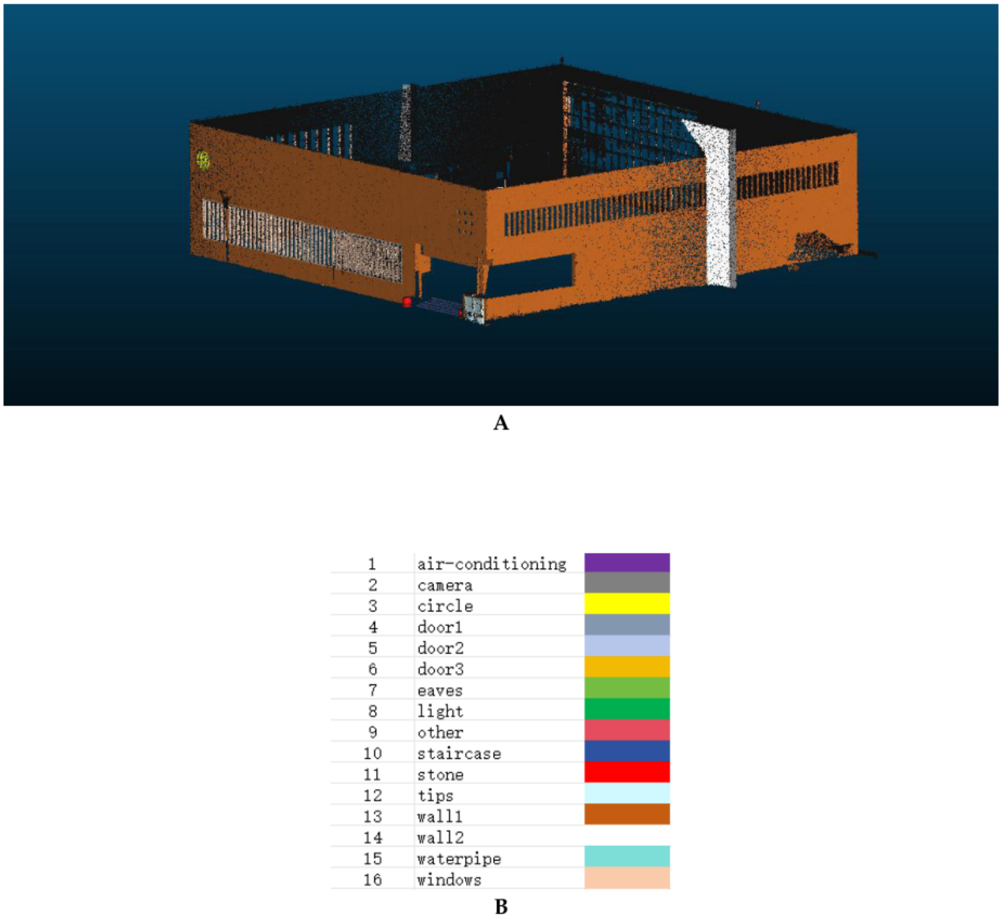


FIGURE 11. Point cloud color block differentiation and labelling. (A) Point cloud color blocking results; (B) Color blocks represent different components

1. Exterior Walls

The building's exterior walls are structurally designed as 300mm-thick aerated concrete blocks, incorporating external thermal insulation and facing tiles. An exterior wall family was created in Revit, and the Sastrugi package of Dynamo was used to isolate the wall regions within Revit with a sample point size of 5000, obtaining the data of the wall regions. Subsequently, the extreme distances of the points were calculated to determine the positions of the four corners, which were then connected into lines. Finally, the positions of the lowest and highest points were obtained to confirm the wall height, and the exterior wall creation was completed after selecting the family type using "Wall Types" (Figure 12). The building's exterior walls were spliced with the floor slabs using the first-floor elevation and the exterior wall layer from the CAD drawings.

2. Doors, windows, grilles

The building façade is composed of doors, windows and aluminum alloy grilles, with the corresponding door, window and grille families being established according to the information provided in the CAD drawings. The 'PC_Select_Points_By_Region' node must be called in order to obtain the point cloud region of the door, window and grille with a sampling point size of 200. Subsequently, the 'Point.Project' and 'FamilyInstance. In order to achieve the positioning of the element, it is necessary to project its position on the wall onto the project and the family instance. The function of SetParameterByName is to position the component in a specific area of the corresponding wall, thus facilitating the insertion of the door/window grille component (Figure 13).

3. Curtain walls

The glass curtain wall on the building's façade is characterized by a specific glass curtain wall type, designated 'PC_Select_Points_By_Region'. This element facilitates the isolation of the point cloud within the designated curtain wall area, utilizing a sample point size of 5,000. The glass curtain wall's design is analogous to the facade creation process, wherein the position of two corner points is determined by the 'BoundingBox'. In order to ascertain the position of the two corner points, the 'MinPoint' and the 'BoundingMax.MinPoint' must be used, and the 'Line.ByStartPointEndPoint' function must be employed to combine the elevation of the upper and lower limit points to create the curtain wall (Figure 14).

4. Other building blocks

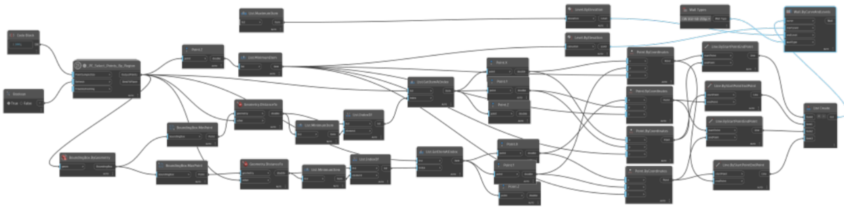


FIGURE 12. Dynamo workflow for creating exterior walls

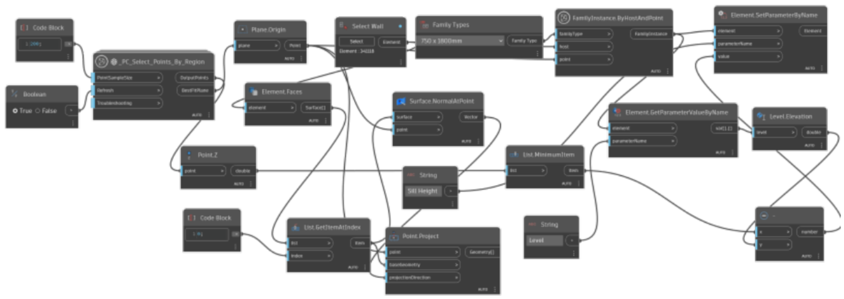


FIGURE 13. Dynamo workflow for creating doors, windows and grilles

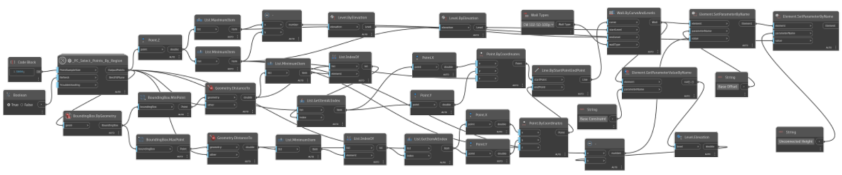


FIGURE 14. Dynamo workflow for creating curtain walls

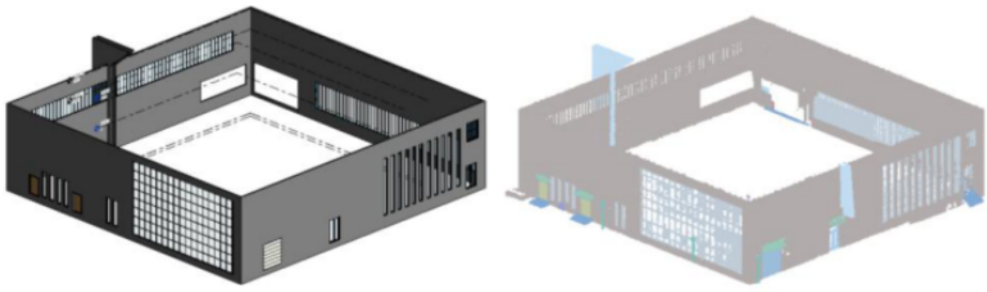
The interior and exterior staircases, balustrades, ramps, and canopies within a building occupy a relatively small proportion of the overall volume (2.8%). Their core functions bear no direct relation to the building performance assessment objectives of the CIM model. Moreover, such ancillary components are typically not created ad hoc during modelling. Instead, they are either supplied as standard models by component providers or prefabricated as preset components by modelers during the early project modelling phase. This research aims to achieve the precise positioning and automated placement of such preset components within the building model. Consequently, a manual creation method is employed for these components. Owing to their irregular shapes, exterior decorative elements frequently obstruct laser scanning. Consequently, capturing complete point cloud data for these components proves challenging during practical operations. Manual modelling supplementation based on construction drawings is therefore required. For the top-enclosing decorative wall, incomplete point cloud data was obtained due to scanning angle limitations. By integrating the existing wall height and thickness data from the extracted point cloud with the wall width data from the CAD drawings, manual modelling of this decorative wall was achieved. (Figure 15).

V. EFFICIENCY VERIFICATION

This study invited five experts from the construction engineering and BIM industries to participate in efficiency validation, with an average of 12 years of professional experience. The experts were divided into two groups. Group 01 comprised three BIM industry experts who compared and validated the operation time of the automatic modelling procedure and manual modelling in the overall building model and component model, respectively. Group 02 comprised two experts from the architectural engineering industry who evaluated the usability of the completed model in terms of model accuracy level, geometric representation accuracy, and depth of information of the components.

A. MODELLING TIME COMPARISON

Provide CAD drawings and point clouds to the BIM expert group for Group 01. The expert group performs manual modeling based on existing data and records the time. Researchers use programs for semiautomated modeling and record the time. Since manual modeling relies on operators identifying and interpreting existing data to distinguish components, program modeling requires operators to complete point cloud semantic labeling for Dynamo recognition, the overall modeling time for program modeling should include the preliminary point cloud labeling time (8.6 minutes). Beyond the overall building modeling time, the valida-



A

B

FIGURE 15. Elevation point cloud modeling and overall modeling results. (A) Elevation point cloud modeling results; (B) Overall modeling results

tion process separately tracks modeling times for columns, beams, floor slabs, roofs, interior walls, exterior walls, windows, sunshades, and other components.

The ensuing table (Table 4) illustrates the time (in minutes) demanded by component modelling and overall modelling for procedural modelling and expert manual modelling (with A/B/C denoting the three BIM experts), respectively, and compares the average time for procedural modelling with that of manual modelling. Modelling time (encompassing both program-based and manual modelling) fully accounts for the time required for preliminary manual operations such as necessary CAD drawing cleanup and the deactivation of irrelevant layers.

Manually creating a BIM model from existing information took an average of 64 minutes for three experts. Program-based modeling (including preliminary tagging time) took 31.9 minutes. In comparison, programbased modeling demonstrated outstanding efficiency, saving 50.2% of modeling time. For component modeling specifically, program-based modeling consistently saved 66.7% to 81.8% of the operation time compared to manual modeling. Programmatic modeling enables a single operator to perform batch operations on multiple targets simultaneously, delivering superior modeling efficiency when handling multiple objects.

B. MODEL USABILITY ASSESSMENT

The results of the program modelling and the available drawing information were provided to the Group 02 architectural engineering experts, who assessed them according to the Chinese BIM model delivery standard [19]. The experts' initial assessment was of the completeness of the modelling results. This was achieved by checking that no missing components were found in the model based on the drawings and point cloud information.

The outcome model incorporates component-level model elements and indicates connection relationships, meeting Level of Detail 3.0 (LOD3.0) precision. The geometric representation of model components meets the requirements for two-dimensional and symbolic recognition, satisfies coarse identification needs such as spatial positioning and primary colors, and also fulfills detailed identification requirements

TABLE 4. Comparison of time and efficiency required for procedural modelling and manual modelling

Components	Program modeling time	Manual modeling time A/B/C (average)	Program/Manual (Average)
Columns	2.2	7.2/6.8/7.6 (7.2)	30.6%
Beams	3.0	9.5/8.8/9.2 (9.2)	32.6%
Floor slabs	0.5	1.4/1.6/1.5 (1.5)	33.3%
Roof	0.3	1.2/1.2/1.4 (1.3)	23.1%
Internal walls	1.6	6.5/7.0/7.2 (6.9)	23.2%
External walls	2.5	12.2/13.0/12.8 (12.7)	19.7%
Doors and windows	1.8	8.5/8.8/7.8 (8.4)	21.4%
Sun visor ornaments, stairs	1.2	6.6/6.5/6.8 (6.6)	18.4%
Overall building	31.9	64	49.8%

for construction and installation processes, procurement, and more. The geometric representation precision of components reaches Grade 3 Geometric Representation Accuracy (G3) standard [19]. Thus meeting the needs of fine identification such as construction and installation process and procurement. The model components contain information such as unit identity description, project information, entity system relationship, composition and material, performance or attribute, etc., and have reached level 2 component information depth (N2) [19]. Following a thorough evaluation, the expert group concluded that the resultant model, modelled by the program, meets the delivery standard of O&M models for existing buildings.

VI. CONCLUSION

This paper utilizes bidirectional information from drawings and point clouds to develop a semi-automated creation process for BIM models of existing buildings, addressing the challenge of low efficiency in current manual creation methods. The results demonstrate that modeling programs developed using visual programming languages for existing building BIM models can semi-automatically create and assemble structural and envelope components from diverse information sources, significantly enhancing the efficiency of BIM model creation. The modelling program developed in this study has been verified through case studies, thus confirming its feasibility and practicality in practical applications.

Against the backdrop of digital transformation in the construction industry, the demand to integrate numerous existing buildings with BIM technology to enhance operational efficiency has become increasingly prominent. By employing innovative tools to batch-create information models for existing buildings, we can better advance the application of BIM technology in the construction sector and promote high-quality development within the industry. Research indicates that modeling information for existing buildings comprises both drawing data and point cloud data. In this study, we evaluated building component attributes to determine methods for creating structural system components and envelope system components from different information sources, implementing these approaches using Dynamo tools. Case studies validate that under conditions of complete information and clear acceptance criteria, our methodology effectively enhances modeling efficiency. However, due to the complexity of buildings and human factor differences, the efficient creation of BIM models and the ensuring of model availability for a large number of existing buildings remains a significant challenge. Although semantic segmentation of point clouds using artificial intelligence algorithms is feasible, the scarcity of large-scale annotated datasets for training and model validation limits the efficiency and accuracy of point cloud recognition and segmentation. With advances in computing technology and optimisation of AI algorithms, achieving industrial-grade performance in automated point cloud recognition has become a clear developmental trajectory. Future development of more efficient automated tools is likely to become a research focus. Integrating such tools with existing building operations, maintenance, and performance simulation requirements could promote the application and adoption of BIM technology throughout the entire building lifecycle.

AUTHOR CONTRIBUTIONS

Conceptualization –Kong Lingtao, Mu Qingyi and Liu Yinhui; methodology – Kong Lingtao, Mu Qingyi and Liu Yinhui; investigation – Kong Lingtao, Mu Qingyi and Liu Yinhui; writing-original draft preparation – Kong Lingtao, Mu Qingyi and Liu Yinhui. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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