AUTOMATED GENERATION OF BIM MODELS FROM 2D CAD DRAWINGS

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Abstract. Existing buildings are often lacking BIM models. This paper proposes a method to semi-automate the generation of BIM models from 2D CAD drawings. The method has two parts: the first part, 2D CAD drawing preparation, involves cleaning the drawings to obtain simplified 2D input geometry and the second, 3D BIM model generation, involves generating and extracting parameters to generate 3D BIM components. This research focuses on the semi-automation of the second part. The the model is generated storey by storey, with each building element type being processed. A demonstration was carried out for a case-study building. The main modelling strategies used by the method are described and key challenges are discussed.

Keywords. BIM; CAD drawings; conversion; generation; Grasshopper.

1. Introduction

In Singapore, BIM models are currently a requirement for submission to the Building and Construction Authority (BCA) for both Architectural and Engineering plans for any project above $5000m^2$. However there are a large amount of existing buildings, built before BIM became more common and such regulations were enforced, without any 3D BIM model documentation. This includes a large number of public housing blocks by the Housing Development Board (HDB) with over 1 million appartments. There is a general need to create BIM models of such existing building to facilitate their management and maintenance.

Currently, one of the most time consuming aspects of the BIM model creation process is the 3D modelling from the 2D drawings. Making changes and adding properties after the 3D model is built is typically a faster process (Fan 2009). Thus, the project aims to explore a possible workflow to automate as much as possible the process of generating a basic 3D BIM model from existing 2D CAD drawings. A partial automation of this model creation process will help to speed up the modelling process.

A number of researchers have developed methods for generating 3D models from 2D drawings (including both CAD and raster images) (Yin 2009). Some

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of the main focus areas are pattern and shape recognition, topology-based space detection (Horna 2009), and the use of graphs and maps to assess adjacency and relationships between geometrical information (Lewisa 1998; Domínguez 2012). In most cases, algorithms have been proposed and implemented in stand alone prototype tools. With regards to the 3D modelling, the geometry is often highly simplified (for example, being limited to extruded 3D forms), and in addition the focus is often on geometric modelling rather than BIM modelling. Very little research focuses on using the existing parametric modelling and BIM software tools for converting 2D drawings into 3D BIM models.

This paper proposes a semi-automated method for generating BIM models from 2D drawings using simple algorithms that can be implemented within existing software that users may already be familiar with. Section two gives an overview of the proposed method and section three presents an example demonstration. The demonstration goes through the steps of generating a 3D BIM from the 2D drawing of an existing building. Section four discusses the results and highlights the key challenges. Finally, section five briefly summarises the key conclusions.

2. Proposed Method

A building is typically made up of basic elements such as columns, walls, floor slabs, roofs, windows and doors. In order to generate a 3D model from a 2D drawing, one needs to be able to identify which parts of the drawing corresponds to what building elements. This is especially true for a BIM model in which different elements are assigned different information and properties and thus this categorisation is very important.

Typically, 2D CAD drawings of existing buildings will contain a large number entities, including geometric entities, hatches, dimensions, text labels, and so forth. Even by eye, identifying and interpreting the individual construction elements can sometimes be difficult. Fortunately, such drawings will usually group lines and shapes into layers and blocks. In order to make this process more tractable, we first require the user to perform some additional cleaning operations, as well as some minimal redrawing. As such approaches are usually already an industry standard, mostly only small adjustments need to be made.

The workflow is split into two main stages as shown in Figure 1. The first stage involves the preparation of the CAD drawings, and includes three steps: cleaning, layering, and redrawing. The cleaning step removes all necessary elements such as hatches, dimensions, text and drawing borders. The layering step places the 2D geometry for different building elements onto separate layers. For example, there should be one layer for columns, one for walls, and so on. This ensures that the procedures that generate each element type only need to process geometry from specific layers. The redrawing step will require some simple geometry to be added for cases where it is difficult to detect building elements automatically. Some examples include joining and closing polylines for columns, for floor slabs, and for wall segments (for example, when they are broken by doors and windows).

The second stage automates the generation of the BIM model. This includes reading the cleaned CAD drawings, the retrieval of 2D geometry defining the different elements from the corresponding layers and the extraction of parameters (such as insertion points, reference curves and dimensions), and the generation of individual BIM elements.

The whole process creates a basic BIM model. From the resultant basic model, a more detailed model can then be easily developed using existing BIM software tools.

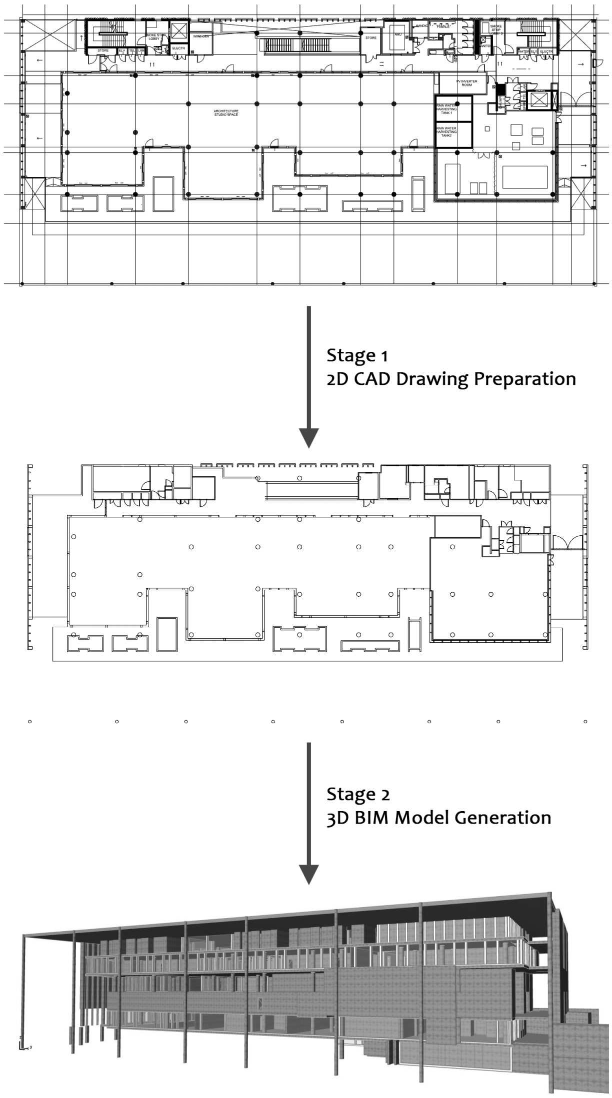

Figure 1. Workflow for semi-automated generation of BIM models.

3. Demonstration

For the demonstration, the chosen building is the new Net-Zero Energy Building of the National University of Singapore School of Design & Environment, named SDE4. Serie Architects with Surbana Jurong in Singapore won the open competition to design the building in 2013. The building has a gross floor area of 8,500sqm and is fairly regular in form, which made it a good starting point. It has six storeys with all the basic building elements the project aims to generate, including prominent curtain walls on each floor with different mullion patterns. The building is currently under construction.

With regards to software tools, the research developed a prototype implementation using Rhino Grasshopper and ArchiCAD. However, a similar approach should be able to be implemented using any combination of software.

3.1. GRASSHOPPER-ARCHICAD

Grasshopper is a visual programming plug-in for Rhinoceros and can be linked to ArchiCAD using the ARCHICAD - Rhinoceros - Grasshopper Connection, which we will refer to as *ACC*. This connection allows parameters generated in Grasshopper to be applied to ArchiCAD building elements. Each building element is generated by corresponding Grasshopper nodes that take in different geometry and values as input settings.

While Grasshopper is primarily used to parametrically model buildings or elements in architectural practice, in this demonstration it is mainly used as a programming API and for its connection to ArchiCAD. For the programming, an add-on for Grasshopper was used, called GhPythonm, that allows one to run Python scripts. This allowed for more complex conditional and looping constructs that are important for the shape detection and calculation processes.

3.2. STAGE 1: CAD DRAWING PREPARATION

A set of 2D CAD drawings of the building were obtained. They include eight plans, six floor plans and two roof plans. In each drawing, building elements were located on different layers with block instances used to insert windows, doors and curtain wall segments.

For this research, the focus was on the second stage, developing the procedures for generating 3D BIM models from 2D drawings. The first stage, preparing the 2D CAD drawings, was therefore done manually. In future research, possible strategies for further automating this process will be investigated.

3.3. STAGE 2: BIM MODEL GENERATION

The 3D BIM model generation took place using Grasshopper, linked to one Rhinoceros file containing all the 2D CAD drawings from the first stage of the process and generated the building elements in ArchiCAD. The next three sections describe the generation process and challenges for each type of building element in the BIM model.

3.3.1. Slabs and Columns

For slabs and columns, a set of Grasshopper nodes were used to scan the geometric entities in the appropriate layers. For each entity found, the type of element was detected through geometric analysis. Required parameters, such as insertion points, dimensions and shape, were extracted from the geometrical entities and inserted into the inputs for the corresponding ACC slab and column nodes, thereby generating the slabs and columns as shown in Figure 2.

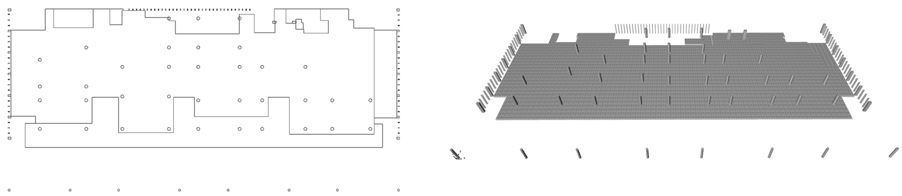

Figure 2. Slabs and columns on plan (left) and generated slabs columns (right).

3.3.2. Walls and Curtain Walls

For walls and curtain walls, a more complex manipulation is required to due to the fact that each BIM element is defined by more than one geometric entity. For example, a wall has the bounding lines for each side of a wall, and a curtain wall has the mullions that define the curtain wall patterns.

Walls are typically defined on plan with two parallel lines. The analysis process extracted all lines from the appropriate layer and parallel lines were paired using a heuristic which accounts for the distance between the lines. Some examples of the rules used by the heuristic are depicted in Figures 3 and 4. Required parameters such as wall reference lines and thickness were then generated from these pairs of lines. The parameters were then connected to the corresponding ACC wall nodes, hereby generating the walls. The process is shown in Figure 5.

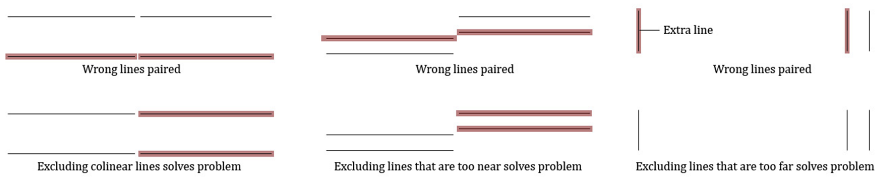

Figure 3. Some conditions to guide the line pairing process.

Curtain walls are typically defined on plan as a collection entities such as mullions and panels. This makes the generation of a curtain wall elements difficult. As mullions are one of the important features of the curtain wall and can be easily obtained from the plan, they were used as one of the key entities for extracting multiple inputs for the curtains walls. However, mullions alone were not enough as they are often broken up into disconnected blocks. Therefore, a manually drawn line that defined the start and end of the curtain wall and connected the relevant mullions was required in the generation process. An analysis process was then created that was able to derive the mullion pattern as a list of distances, along with the other dimensions, to generate the curtain walls using the ACC curtain wall nodes. The process is shown in Figure 6.

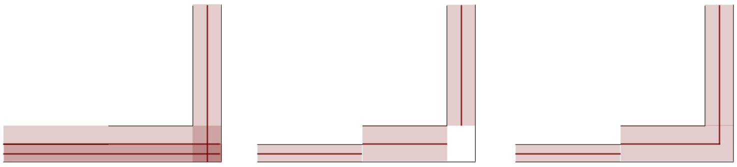

Figure 4. Extending the shorter paired line to allow for wall segments of differing thicknesses and correctly resolved corners.

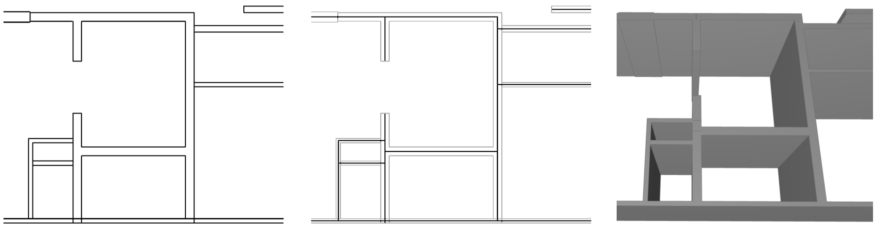

Figure 5. Walls on plan (left), paired walls and reference lines (center) and generated walls (right).

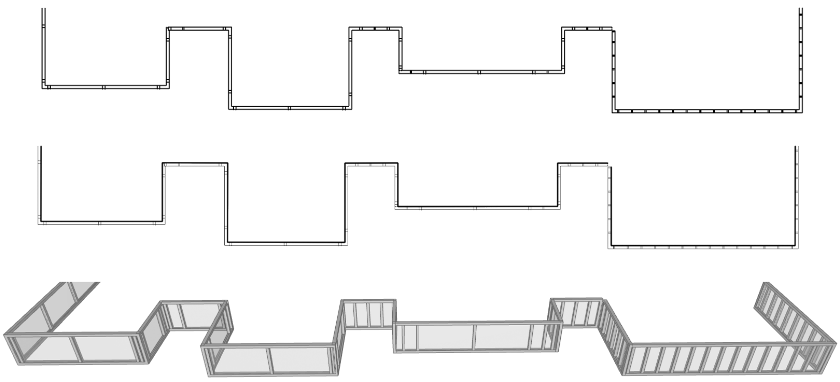

Figure 6. Curtain wall input (top) with manually drawn line (middle) and generated curtain wall (bottom).

3.3.3. Doors and Windows

In BIM modelling, doors and windows are usually constructed as objects, placed into a wall. In 2D drawings, they are typically drawn in a way that creates gaps between lines and breaks walls into multiple shorter parts. Some editing is therefore required to close these gaps before generation. Doors and windows also needed to be paired to the walls that they are located in as the walls have to be specified in the generation process. This was done by finding the closest reference line (created while generating walls) to each block. Other parameters, like width, were then found and the doors and windows were generated as shown in Figure 7.

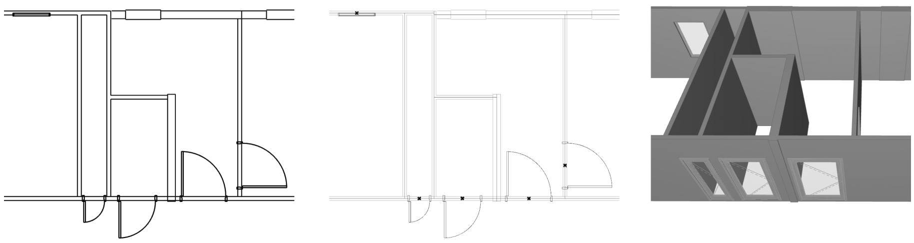

Figure 7. Doors and windows input (left) with insertion points (center) and generated result (right).

4. Results

For each floor plan, the preparation of the 2D CAD drawing, using a purely manual process, took on average about one hour.

Once all the 2D drawings were prepared and imported into Rhinoceros, the process of generating a basic BIM model of the whole building only took 15 minutes. This process involved triggering various nodes in Grasshopper and syncing the data with ArchiCAD.

Once the basic BIM model was generated, manual editing was required to fix certain aspects that could not be handled by the automated procedure. One such case was height settings. The automated procedure generates building elements using default heights. In certain cases, elements such as planters and railings were included in the wall layer. For such elements, the default heights are incorrect, in which case manual adjustment is required. In addition, some manual fixing of other minor errors relating to elements with incorrect dimensions or positions (such as thin washroom partition walls) was also required. Overall, this process took under an hour. The final result is shown in figure 8.

The generation created 648 columns, 42 slabs, 1030 walls (of which 12 were wrongly paired and required editing), 129 doors (of which 1 was wrongly paired and needed to be removed) and 61 curtain walls (of which 1 was flipped and had to be corrected).

Previously, a similar model was done manually in ArchiCAD and took about 2 days by a team of two.

4.1. LIMITATIONS AND ERRORS

The case-study experiment demonstrates the feasibility of semi-automating the process of generating BIM models from 2D CAD drawings. However, the case-study also highlights key challenges. These included curtain wall generation and door swing directions.

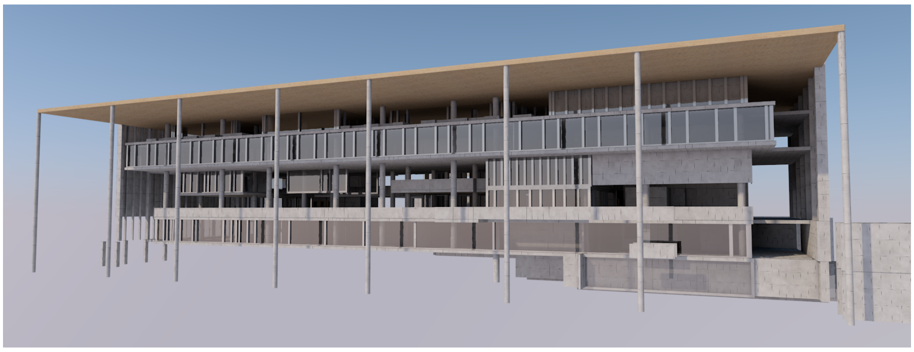

Figure 8. Resulting BIM model after manual adjustments.

4.1.1. Curtain walls

Curtain walls can be simple but many designs now require complex curtain wall systems with many segments of different dimensions or even tessellating panels of different sizes and materials. Generating simple curtain walls is fairly easy in BIM software but defining specific patterns of panels and supporting elements can be difficult or tedious, requiring the manual input of each dimension into the tool's dialog box or even the manual adding and deleting of individual elements for more complex patterns.

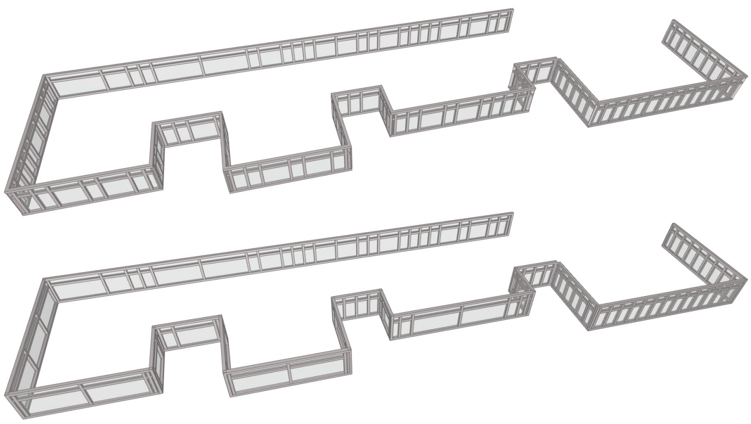

Figure 9. Incorrect pattern (top) and intended pattern but unresolved corners (bottom).

Currently, a list of distances between mullions is taken as the input for the mullion pattern but due to ArchiCAD's curtain wall generation process, the input pattern was not applied correctly to curtain walls with corners. Breaking the curtain wall in to multiple shorter curtain walls such that there will be no corners helped mitigate this issue. However, the corners did not resolve correctly and thus resulted in overlapping mullions, making this method not ideal. The difference between the two methods is shown in figure 9. In the future, if there could be a way to change the curtain wall generation process or to resolve corners, the curtain wall creation process might be more effective.

4.1.2. Door swing

Door swing directions are an important aspect of door modelling. There are many regulations and decisions that influence or are influenced by door swing directions (fire escape regulations and door specifications for example), thus it is crucial that BIM doors are generated with the correct opening direction. In BIM software, the door swings can be interactively defined when they are created, by clicking on one side of the door. However, such clicks cannot be easily automated. Currently, using ArchiCAD and Grasshopper, door and window swing can only be defined through the manual creation process or changed manually in ArchiCAD. This means that any door or window created through Grasshopper to be locked to default swing direction settings that are not very easy or intuitive to control (based off wall inside-outside orientation that is in turn based off line direction) and very limited. An example is shown in Figure 10.

If an option to define swing direction in Grasshopper could be implemented in the future, door and window creation could be a lot more precise. In the meantime, GDL and custom object creation presents an option for further exploration through parameters such as "ac_openingside".

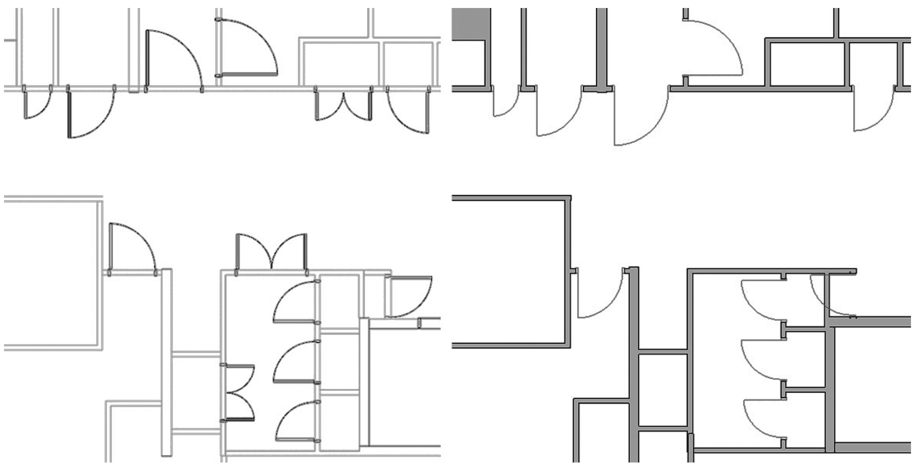

Figure 10. Door swings in 2D drawings (left) and in plan view of BIM model (right).

5. Conclusions

The demonstration has shown that BIM elements can be generated from 2D drawings with a certain degree of success using existing software tools. However, there are still many aspects that are inaccurate, unimplemented or require manual intervention. Some of these are due to simplifications made in the generation process, and could be further improved in the future.

One such simplification was the use of bounding boxes. Due to difficulty with orienting and calculating distances and dimensions using just simple algorithms, some elements used the bounding box method to obtain the required inputs quickly. However, this limited the elements to orthogonal configurations. Many buildings nowadays are not orthogonal and may include curved or angled elements. The algorithms and calculations required to define these geometrically for generation are more complex as compared to straight, orthogonal elements.

Another simplification was the use of manually drawn lines in the generation of the curtain walls. It could be possible to introduce an algorithm to study the adjacency between the various blocks to automate the detection process. Another possibility is to study the ratio between area and lengths to differentiate mullions from panels, in a case where blocks are not available or to increase accuracy.

Adjustments to the automation process can also be made to extend its workability to more complex buildings or a wider range of situations and elements, such as adjustable ranges or introduction of machine learning to make the wall pairing more accurate or even taking elevations and sections into account for height inputs.

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