A Systematic Review of Automated BIM Modelling for Existing Buildings from 2D Documentation

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Abstract –

Building Information Model (BIM) with rich geometric and semantic information of facilities has increasingly been used to establish the City Information Model (CIM). Although BIMs for new buildings are becoming more available, BIMs for most existing buildings can only be modelled from 2D drawings and specifications. Manual BIM modelling is an error-prone and time-consuming process, which becomes more challenging for the city scale. Recently, automating the 3D BIM modelling process for existing buildings from their 2D drawings has been an emerging research trend. To understand the state-of-the-art and guide future research, this paper presents a systematic review of automated BIM modelling for existing buildings from 2D drawings. Fifty-five publications, including 34 journal articles and 21 conference papers identified from Scopus from 1998 to 2021, were reviewed and analysed. A chronological distribution shows that most papers (60%) aimed to generate 3D geometric models, and BIM modelling with semantic information appeared in 2015 and increased dramatically. This review classified the existing work into three aspects: geometric modelling, semantic modelling, and model quality checking. The results show fully automated conversion of 2D drawings to semantically enriched BIM has not been eventuated, future work may consider overcoming the following challenges: (1) height information is either set as default or entered manually, and complex components such as staircases are barely studied; (2) most research only focused on floor plans and ignored semantic information contained in other drawings; (3) drawing errors have not been well addressed, and the validation of the generated model is still cumbersome.

Keywords –

Building Information Model (BIM); Existing building; 2D drawings; City information model (CIM)

1 Introduction

An accurate 3D information model at the city scale has the potential to support a wide range of applications such as infrastructure planning, policy evaluation, disaster management, energy demand estimation, situational awareness, and multiple domain integration [1]. Building information models (BIMs) of buildings and civil infrastructure have been widely acknowledged as a key data source to establish the City Information Model (CIM) [2]. Although the BIM of recently completed or new buildings has been modelled in the design process and can be directly used for CIM, the BIM of most existing old facilities is often unavailable. Therefore, the automation of BIM modelling for existing buildings has drawn growing attention in the past years.

Currently, there are two main methods of BIM modelling for existing buildings, i.e., (1) on-site surveying and (2) as-built documentation.

The first method is through on-site surveying. To generate BIM for existing buildings, the collection of sufficient spatial information is essential. Various sensors (e.g., laser scanning [3], photogrammetry [4], etc.) have been adopted to collect 3D point cloud data, and then building components are detected and modelled. Although the 3D model generated through on-site surveying could represent the current state of existing buildings, the modelling process is time-consuming and labour-intensive, especially when it comes to digital modelling at the city scale. Besides, those surveying approaches can only detect the exterior and interior surface geometry. Structural components, such as beam and column, are usually hidden from view for aesthetic reasons, which makes measuring their geometry impractical. Additionally, missing points are common in the data collection process, and, more importantly, the point cloud does not contain any semantic information. There have been some strategies suggested to add engineering rules in the modelling process using point cloud, however it is still challenging to develop a semantically-rich BIM using this approach [5].

The second method focuses on generating BIMs from 2D drawings since as-built documentation contains abundant geometric and semantic information, which better describe the building. Since manually extracting building information from 2D drawings and modelling all facilities at the city scale is error-prone and challenging, automated BIM modelling from design or as-built documentation has seen a growing research interest. Gimenez et al. [6] provided an in-depth review of advanced technologies toward each step of the generation of 3D building models from 2D scanned plans in 2015. However, literature aimed to achieve 3D modelling from drawings has not been well analysed, and many semi-automated and automated methods have been proposed during the last few years. Kang et al. [7] reviewed the recent development of 3D indoor reconstruction but mainly focused on technologies based on on-site surveying. A comprehensive review of recent advances in BIM modelling from as-built documentation is required urgently.

To fully understand the contributions and limitations of current research studies, this paper provides a systematic review of automated BIM modelling for existing buildings from 2D documentations. The 2D documentations refers to various types of drawings, including digital drawings, paper-based drawings, architectural drawings, structural drawings, and floor plans. The structure of this paper is organised as follows: Section 2 presents the overall design of the literature search. Section 3 describes three aspects of BIM modelling: geometric modelling, semantic modelling, and model quality checking. Section 4 discusses the limitations of existing research studies and points out possible further research opportunities. Finally, Section 5 summarises the finding with a conclusion.

2 Review methodology

This research adopted the five-step review methodology to conduct a systematic review [8]. First, a keyword search-based approach was adopted to collect relevant publications. Searching attributes and their corresponding values are listed in Table 1.

The main keywords were, for example, ‘2D’, “drawing”, “floor plan”, “floorplan”, “BIM”, “building information model”, “3D model”, “construction”, “reconstruction”, “creation”, “generation”, and “modelling”. The Scopus database was selected for literature searching, and papers not published in English were omitted. Since this review focused on the 3D model generation for existing buildings from as-built documentation, only four relevant subject areas, Engineering, Computer Science, Social Science, and Environment Science, were considered. Other subject areas, such as Mathematics, Material Science, and Physics and Astronomy, were excluded. Journal articles and conference papers are both included in this review.

Table 1 Literature search methods

Search attributes	Values used in the search
Database	Scopus
Keywords and Boolean operators	(“2D” AND (“drawing” OR “floorplan” OR “floor plan”) AND (“BIM” OR “building information model” OR “3D model”) AND (“generation” OR “creation” OR “reconstruction” OR “construction” OR “modelling”))
Search scope	Article title, abstract, or keywords
Published year	From all years to present
Subject area	Engineering, Computer science, Social Science, Environment Science
Document type	Journal article; Conference paper;
Language	English

The initial literature search has resulted in a total of 456 papers. Then, the title and abstract of the literature search results were analysed to identify relevant publications. The filtering criteria are as follows:

(1) Publications aimed to construct a 3D model from 2D drawings were included.
(2) Articles that only mentioned creating a 3D model from 2D documentation but did not focus on were excluded.
(3) Other publications, such as those focused on converting the building design process (from CAD to BIM), were excluded.

In addition, the snowballing technique was employed to find additional papers through the reference and citation lists. As a result, a total of 55 papers, including 34 journal articles and 21 conference papers, were retained for in-depth review and analysis.

Figure 1 shows the chronological distribution of all included papers, which are classified into “Semantic BIM” or “Geometric model”. The group of “Geometric model” included publications focused on construct 3D geometry such as indoor or surface model, other publications aimed at creating a BIM with semantic information fell into the group of “Semantic BIM”. Research on 3D model construction from 2D drawings started in 1998, and all identified papers published before 2015 aimed to create the 3D geometric model, such as indoor or surface model. The semantic BIM modelling from 2D drawings first appeared in 2015, and a dramatic increasing trend can be observed. Then, all identified publications are reviewed critically according to three aspects of BIM modelling: geometric modelling, semantic modelling, and model quality checking. Key limitations regarding each aspect are concluded, and future work aimed to address these limitations are illustrated.

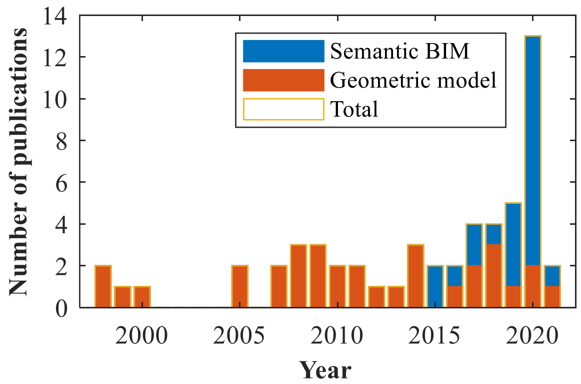

Figure 1. Chronological distribution of included papers

3 BIM Modelling from 2D documentation

In this section, the state-of-the-art BIM modelling for existing buildings from 2D drawings is summarised in terms of three aspects, namely geometric modelling, semantic modelling, and model quality checking. Geometric modelling aims to construct the 3D geometry of buildings. In contrast, semantic modelling focuses on extracting and attaching semantic information (e.g., room identity, component dimension, construction material, etc.) contained in 2D drawings as properties of objects in the 3D model. Once the 3D model is constructed, the model quality checking process is performed to verify its completeness and correctness.

3.1 Geometric modelling

3D building geometric model has been envisioned as the data management platform for facility management. However, manually modelling existing buildings is error-prone and time-consuming [9]. In the past decades, there has been a growing interest in automating 3D modelling based on 2D drawings. Existing research studies regarding geometric modelling are summarised in Table 2.

The first step in the 3D model generation is identifying and extracting building component information from 2D drawings. Since the geometry of different components is usually divided into different layers during computer-aided building design, layer information in CAD drawings has been widely used for component recognition [9–12]. However, errors on layer classification need to be corrected in advance, and layer information is unavailable for hand drafting. Another solution is using geometric features and symbols to identify building components. As the most common features in 2D building drawings, line segments were used for identifying walls [13–18], columns [19], and rooms[20]. Symbols were adopted to detect grid lines, then building elements (such as columns, beams, and walls) can be further identified [21,22]. But these methods are not applicable for building components with irregular shape and will lead to false matches due to missing or inconsistent information in as-built documentation. With the rapid development of artificial intelligence (AI), the adoption of AI for drawing analysis shows a significant increase. Walls and openings are detected from floor plan image based on a convolutional neural network [23,24]. Rho et al. [25] developed a machine learning-based classifier to extract text information for component detection and localisation. Zhao et al. [26] detected structural components (e.g., columns and beams) from the framing plans based on Faster R-CNN, further created IFC BIMs for multi-story buildings. However, the existing application of AI only focused on detecting specific part of information. A unified solution for identifying all component information and texts is preferred for automating 3D model generation.

After components were identified, most research projects extruded the labelled 2D floor plan to generate the 3D building model [9,10,12–19,21,23-26]. However, the floor elevation and height of openings were either set as default or entered manually. Lu et al. [22] proposed to generate three orthogonal views (the top, side and front view) of each component from the 2D architectural drawings. Then, the 3D model of all components can be constructed and integrated to obtain the 3D building model. But this method only suits the modelling of simple geometry due to the challenge regarding the generation of three orthogonal views of building components from 2D drawings. In addition, the combination of floor plans and elevation drawing was proposed by Bortoluzzi et al. [20] to create BIM with room layout and exterior openings for existing buildings. Yin et al. [11] constructed a façade BIM model by locating exterior components in floor plans and extracting height information from elevation drawings. However, height information of interior building components (e.g., interior openings, beam) cannot be identified from elevation drawings. The combination of more as-built documentation is preferred to obtain all required information for automated 3D modelling.

Another vital part of 3D building model generation is the matching and integration of different floors. Most existing research studies only considered 3D modelling of one floor, and few papers studied the matching of

Table 2 Summary of geometric modelling

Themes	Approach	Description of the approach	Research
Drawing analysis	• Based on layer information	The geometry of different components is stored in different layers of CAD drawings, but it is not applicable for manual drafting;	[9–12]
	• Based on geometric features	Geometric features and symbols are used to identify building components, but irregular components cannot be detected;	[13–22]
	• Artificial intelligence	Using artificial intelligence to identify building components, which is suitable for all types of drawings and irregular components;	[23–26]
Generating the 3D building model	• Extrusion of 2D drawing	Extrude the labelled floor plan to generate the 3D model, but height information (e.g., floor elevation, the height of openings) is either entered manually or set as default;	[9,10,12–19,21,23-26]
	• Modelling from three orthogonal views	Generate 3D model of components from three orthogonal views, then integrate all component models to obtain a 3D building model, but it's hard to extract the three orthogonal views from 2D drawings;	[22]
	• Combine floor and elevation drawings	Detect building components from floor plans, then extract heigh information of external components from elevation drawings, but internal components haven't been considered;	[11,20]
Integrating different floors	• Floor plan-based matching	Align other floor plans to the first inputted floor plan based on drawing features or use global coordinates to locate components;	[11,15,16]
	• 3D feature-based matching	Match 3D model of different floors based on geometric features like pips, staircases, corners and bearing walls;	[17]

different floors to generate a 3D model of the entire building. The matching approaches could be divided into two groups.

(1) Floor plan-based matching. For example, Zhu et al. [15] and Li et al. [16] aligned other floor plans to the first inputted floor plan by intersection points between axes; Yin et al. [11] used the global coordinate system to locate components of each floor plan.

(2) 3D feature-based matching. For instance, Dosch et al. [17] proposed to match models generated from different floors based on features like pipes, staircases, corners and bearing walls.

3.2 Semantic modelling

In addition to geometric modelling, semantic modelling is the next stage of BIM modelling for existing buildings. Following the construction of the geometric models, a common approach is to classify building components [10,11,13,18,24,25], or attach identities to space objects [14,15,17,20,22,23]. To generate semantically-rich BIM and further improve its functionality, other semantic information contained in 2D drawings are extracted and modelled accordingly. For example, Li et al. [16] built a profile containing building type, size and other semantic information along with the constructed 3D model. Lu et al. [21] generated Industry Foundation Class (IFC) model from 2D drawings and further attached material information of components through on-site surveying. By analysing component lists (including column list, beam list, slab list, and wall list) and floor plans, Byun et al. [19] created the IFC model with the material property of concert and rebar for reinforced concert structures. Yang et al. [9] focused on the semantically-rich 3D BIM modelling from 2D CAD drawings. Structural components and corresponding axis were first detected and generated, then semantic information of components (e.g., coding number, element cross-section, element reinforcement information) was linked to the axis as parameters.

3.3 Model quality checking

Once the 3D building model is constructed, it should be checked manually, semi-automatically, or automatically to verify its completeness and correctness. Research on model quality checking can be divided into three areas.

(1) Checking the drawing quality before the 3D modelling. Once any errors contained in 2D drawings are corrected, the 3D model generation can proceed using the drawings, mitigating the risk of inheriting errors or

inconsistencies [12,18].

(2) Comparing with ground truth. Gimenez et al. [14] proposed to compare the automatically labelled drawing with manually annotated one to evaluate the component identification results. To evaluate the constructed 3D model, the number of components in the input 2D drawings and output building model are compared [14,19]. Rho et al. [25] and Yang et al. [9] checked the constructed BIM model by comparing it with a manually modelling result.

(3) Checking without ground truth. The philosophy is to evaluate consistency and conflicts according to basic rules, which is mainly used for checking building design results with building codes [27]. Nikoohemat et al. [28] proposed an approach for checking the geometric, semantic and typological consistency of the constructed 3D model based on formal grammars defined through existing international standards.

4 Discussion

Although a number of automatic and semi-automatic approaches for BIM modelling from as-built documentation have been proposed, further research is still needed toward fully automated modelling of semantically-rich BIMs for existing buildings. This section summarises the limitations and challenges of current research along with possible future research directions.

Although building geometric information is distributed in various drawings, most existing research only used floor plans for geometric modelling. The height information, including floor elevation and height of openings, is either set as default or entered manually. Few publications have proposed to extract floor elevation from building elevation drawings [11,20]. To automatically identify the height information of all building components, future research could focus on the combination of various 2D as-built documentation. Another challenging problem is that only common building components are modelled, and complex components, such as staircases, are ignored in current research. The modelling of these building components should be further studied to create a complete BIM model for existing buildings.

In contrast to geometric modelling, semantic information modelling for existing buildings has not been given the attention it needs. Most research studies only detected room identity and component category from floor plans. The generated BIM can be used for energy consumption simulation [14] or indoor navigation [23]. However, to support facility management and disaster simulation, semantic information like space function and activities, occupancy characteristics, building materials, and properties of various building elements are required. Future efforts are needed to integrate all information in multiple drawings and explore the modelling of a semantically-rich BIM data model.

Errors in drawings are inevitable, and existing research only focused on detecting and correcting specific types of errors [12,18]. A comprehensive illustration of various forms of errors in 2D drawings and their corresponding influences in 3D modelling is preferred. To evaluate the accuracy and quality of the constructed 3D model, comparing it with ground truth is reliable but requires extensive manual work, especially when the reference model does not exist. Compliance checking could be conducted fully automatically and is envisioned as an ideal solution for model evaluation. However, existing research only considered simple building component compliance [28]. To provide a more reliable model evaluation report, a comprehensive analysis of building compliance rules is required. In addition, methods aimed at automatically checking all relevant building compliance aspects are needed in future studies.

5 Conclusion

BIM modelling for existing buildings from 2D drawings and specifications has attracted growing research interest. It has the potential to support the development of CIM. This paper provides a systematic review of 55 relevant publications to understand the state-of-the-art to guide future research. A chronological distribution is used to illustrate the research trend. It has been found that most papers (60%) aimed to construct 3D geometric models, such as indoor or surface models, and semantic BIM modelling first appeared in 2015 and increased dramatically.

Recent advances in three aspects of BIM modelling, namely geometric modelling, semantic modelling, and model quality checking, have been reviewed and analysed critically. Limitations and challenges of existing research on each aspect have also been identified, as follows:

(1) For geometric modelling, the height information (e.g., floor elevation, the height of openings, etc.) are either set as default or entered manually. Besides, most research studies only focused on few categories of building components. Modelling of complex components such as staircases has barely been studied;

(2) In contrast to geometric modelling, semantic modelling has not been given the attention it needs. In particular, since most research only considered floor plans, rich semantic information in other drawings has been ignored;

(3) Errors in drawings have not been well addressed, and the validation of the generated 3D model is still cumbersome.

To overcome these drawbacks, the integration of all as-built documentation should be solved for automatic semantically-rich BIM modelling. In addition, more research efforts are recommended to explore the quality evaluation of the generated BIM model.

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