Methods of As-is BIM Reconstruction Using Point Cloud Data for Existing Buildings

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Abstract: In recent years, as the construction industry shifts from the construction of new buildings to the maintenance and use of existing buildings, the demand for creating Building Information Modeling (BIM) has continued to grow. This article summarizes various research work in different fields and gives an overview. This paper introduces the current research status of creating As-is BIM, then summarizes the corresponding algorithms and data processing methods for creating As-is BIM using 3D reconstruction technology; finally, the detailed research progress and the existing research results and knowledge gaps are discussed, and potential future development opportunities are proposed.

1. Introduction

Building Information Modeling (BIM) is a digital representation of building facilities, which encodes all relevant information in the entire life cycle of a building from construction to demolition. BIM is widely recognized because it is not only expected to save a lot of cost and increase productivity in construction projects, but also can provide an intelligent digital platform to meet the needs of various stakeholders[1]. Currently, only few buildings have used BIM as for large numbers of existing buildings, most of them are still using traditional methods for construction, operation and maintenance. One of the biggest features of these buildings is that they are not with initial BIM (As-design BIM), due to poor information availability and accessibility, the operation and maintenance of these buildings are not efficient, and there is much room for improvement[2]. Therefore, it is necessary to create BIM for existing buildings.

Creating BIM for an existing building means to create As-is BIM for the object building. Modelers need to collect existing documents and materials firstly, however, creating large-scale BIM with many details is labor-intensive, and the process of manually tagging semantic information into BIM is very labor-intensive and time-consuming[3]. In addition, it is prone to get an error or missing segmentation results with manual segmentation operations[4], and incorrect BIM will reduce the efficiency of the decision-making process in the building operation and maintenance stage, including the daily needs of residents and the response to emergency situations[5], what could be worse is that the latter may cause unnecessary losses and serious accidents. As a result, the development of automatic modeling methods in order to achieve high precision and automatic creation of As-is BIM has become a hot frontier researched by many researchers in recent years.

In fact, creating As-is BIM is actually a process of 3D reconstruction, it uses data collection equipment to collect 3D spatial data, and a 3D representation of the object’s appearance can be generated by using these obtained data. It is mainly divided into two categories for 3D reconstruction: geometric model reconstruction and semantic model reconstruction. The geometric model only
contains geometric shape information, while the semantic model contains not only geometric information but also object-based semantic information[6]. The process of creating BIM is actually a semantic model reconstruction process because of the rich semantic information contained in BIM. Tang et al.[7] summarized the reconstruction technology of using 3D point cloud data obtained by the laser scanner to create As-is BIM, but this article did not carry out specific research, and the process of the overall point cloud divided into several point cloud of building components has been ignored in this paper. Cheng et al.[8] proposed a method that can automatically identify different types of monorail tunnel components and create parametric BIM, but the method's recognition accuracy of complex and small components, and the handling of occlusion problems still need to be improved. Lu and Lee[9] summarized the construction of As-is BIM for existing buildings based on image technology, but the article mainly focuses on buildings rather than all building components, and lacks detailed steps, such as point cloud preprocessing. Xue et al.[10] proposed a segment-free and derivative-free optimization(DFO) method for converting BIM generated in 2D images into optimization problems suitable for BIM components, which is related to architectural and topological constraints. However, the inputs, variables, the objective function and other parameters currently used in this method need to be further developed.

2. Techniques for point cloud data collection

3D point cloud is the most commonly used type of 3D data to create As-is BIM, which can be collected by digital cameras[11] or laser scanners[12]. Compared with ordinary digital cameras, laser scanning technology is leading in terms of efficiency and accuracy. However, the cost of using laser scanner to collect data for large-scale complex structures is much higher than the digital cameras, which limits its promotion and use; in addition, for laser scanning technology, there is no single scanning site can scan all surfaces of building facilities, so the data must be acquired by multiple locations scanning. Meanwhile, there also have many noise data and frequently loss of data such as textures in the process of data collection[13]. On the other hand, the transformation of image technology into point cloud data has considerable prospects[14], data from multiple sources can now be used to overcome some inherent problems with data from a single source. For example, the use of RGBD cameras can provide depth images of the scene, while the point cloud generated from depth layer(D) with the surface RGB color layer(RGB) and the laser scanner are highly complementary, and an accurate and complete 3D point cloud will be generated, which is unified point clouds obtained from these two different sources into an enhanced data as the input of subsequent preprocessing process[15].

3. Point cloud data processing

Generally, the point cloud obtained by image technology or laser scanner cannot be directly applied in BIM reconstruction process, the data whatever the collecting methods is needed to be preprocessed. The process, in addition to model creation, generally includes three steps: preprocessing, parametric representation and segmentation & object recognition, shown in the Fig.1 below.

3.1. Point cloud data preprocessing

For the point cloud obtained by laser scanning technology, noise filtering and outlier removal is the first step of preprocessing, then the point cloud data needs to be registered. Registration is the core
process of laser scanning 3D reconstruction of the geometric model, which aims to combine the data set in different coordinate system into a same coordinate system. Taking the point cloud of a site as the standard and the data of other sites are translated and rotated to the reference site coordinate system according to the feature points or the overall geometric shape.

Point cloud registration for point[16] or surface[17] features is to find matching features in the two point cloud data to match them. Due to the large number of plane components in the architectural environment, surface-based point cloud registration is particularly suitable for registering building point cloud. For the image and video data obtained by image technology, the main task of geometric modeling is to identify the elements in the image and convert the original 2D data into 3D point cloud data. Lowe et al.[18] proposed Scale Invariant Feature Transformation(SIFT) to detect local features and convert them into scale-invariant coordinates for matching. Local features are the form of representation that can effectively match between images. For ordinary architectural images, Fard et al.[19] created an image-based automatic reconstruction technology by extracting SIFT features from a single image and using SfM to restore camera parameters. Bay et al.[20] developed the Speed Up Robust Features(SURF) for fast object recognition and 3D construction. Brilakis et al.[21] proposed a framework to detect the SURF from video frames, then restore its structure and motion, and achieve the data conversion from 2D to 3D.

3.2. Point cloud data semantic segmentation and object recognition

Point cloud semantic segmentation and object recognition is a process of enriching BIM semantic information, the semantic information refers to the high-level feature semantics at the conceptual level, that is the category of objects, which is also the information that closest to human understandings. One of the ways to enrich BIM semantic information is to add it manually[22]. Although the results of manual processing are accurate usually, but it is still very tedious, and the cost of artificial semantic enrichment may far exceed the value that rich BIM semantics can produce[3]. Therefore, the automatic or semi-automatic point cloud segmentation method is an effective method to improve the efficiency of 3D reconstruction. Traditional segmentation algorithms usually include region growing[23] and K-means clustering[24], Hough-transform[25] and RANSAC[26]. For example, the basic principle of region growing algorithm is to merge pixels with similar properties to form a specific region, and the K-means clustering algorithm is to classify each point in the point cloud into one of a predefined class of clusters according to the distance from the cluster centroid.

In addition, the point cloud semantic segmentation deep neural networks that has developed rapidly in recent years, and they are also the methods for efficiently segmenting point cloud data. Comparing with traditional point cloud feature segmentation algorithms, the advantage of deep learning lies in the use of big data to learn the features that can extract the hidden information from data in detail and accurately than manually constructed regular features, so deep neural networks has achieved an very accurate and efficient results in the object classification and recognition problems of computer vision[27]. The point cloud semantic segmentation neural network mainly includes projection-based methods, which are based on voxel and multi-view images, and the point-based methods such as PointNet[28], PointCNN[29], SPG[30], et al. are using point cloud data as the directly input of the network. However, the problem of As-is BIM reconstruction is closer to the instance segmentation of point clouds rather than semantic segmentation, instance segmentation network is equivalent to dividing the same label components into independent instance individuals on the basis of semantic segmentation of point cloud. Compared with semantic segmentation, instance segmentation is more challenging because it requires more accurate and fine-grained point cloud reasoning[31]. The specific methods of point cloud semantic segmentation are summarized in Table 1 below.

| Traditional methods | Region-based method | Region growth[23] |
|---------------------|---------------------|-------------------|
| Edge-based method   | Hough transform[25]  |
| Model-based method  | RANSAC[26]          |
3.3. Point cloud data parametric representation

BIM is an object-oriented representation based on the volumetric or solid model representation of the scene[1], it aims to encode the overall view of the buildings and facilities. The volumetric or solid model is usually constructed by constructive solid geometry(CSG)[32] and boundary representation (B-Rep)[33], and these models rely on geometric representation. BIM geometric representations can be divided into explicit shape representations and implicit shape representations, CSG and B-Rep are the two most common explicit representations. Explicit representations are very suitable for modeling 3D objects, meanwhile, the opposite implicit representation is often used for 3D object recognition and classification[34-35]. Explicit representation can be further subdivided into parametric representation and non-parametric representation, the geometric shape information representation method has been extensively studied. In BIM, parametric representation refers to a model shape description method with a small number of parameters, used to represent architectural elements including lines, planes, and three-dimensional cubes, more complex surfaces can be represented by Bezier spline curves, and the more common method is NURBS[36]. NURBS is a generalization of Bezier spline curves, which use sparse control points to control smooth surface of surface shape. For highly complex shapes that can not be represented by parametric models, non-parametric representation is usually used for supplement to improve the entire model, such as triangle meshes. In the case of dealing with large-scale point cloud, due to the lack of compactness of these representations, parametric representation and non-parametric representation are usually combined to achieve a reasonable trade-off in visualization[37].

4. Existing challenges and research prospects

The reconstruction of semantically rich BIM from 2D images or 3D point clouds represents a research field that is becoming more and more popular in architecture, engineering, and construction industry[38], but it is not yet possible to use fully automated and economical method to create complete BIM currently, there are still some problems and challenges that needs to be solved:

1. The overall level of automation is still low. At present, the 3D reconstruction process in the construction industry is not yet fully automated, the research on this topic is still in the early stage, which will increase the construction model operation time, and increase the probability of errors in the obtained 3D representation model. For example, the operations of point cloud preprocessing require human intervention, in addition, point cloud segmentation is still heavily relies on artificial feature extraction, it requires a lot of manual work.

2. The type of modeling object is single. Most of the existing modeling work only focuses on modeling the simplest plane of the building, but in actual situations there are more complex structures and components in the buildings. For complex structures, some walls are not vertical, and some walls do not intersect the ceiling, which makes it difficult for traditional algorithms to extend the algorithm with new rules or modify the rules to make it work in a new environment. Some works begin to try to model the complex components and details in the building. For example, Faber et al.[39] use constrained surface fitting and genetic algorithms to fit the parameter model of the door point cloud. Huber et al.[40] focus on building interior construction modeling, the research objects is limited to architectural details components such as walls, floors, ceilings, doors and windows. Böhlm et al.[41] use density-based edge detection to find vertical and horizontal lines in the depth map of the building facade, and then classify the resulting rectangles as windows or non-windows.

3. Modeling accuracy needs to be further improved. Nowadays, the accuracy of 3D reconstruction technology has reached many engineering application standards, but for other applications with higher accuracy requirements, such as land subsidence assessment, the accuracy of existing algorithms and methods still needs to improve accuracy. This is because on the one hand, the accuracy of the
algorithms and methods used to generate and process point cloud is not enough yet, on the other hand, due to the point cloud data itself is prone to missing and occlusion, the data is generally incomplete. It is important to obtain 3D representations for the hidden architectural elements that are invisible behind the decorative layer, such as pipes and cables in the MEP system, however, the occlusion problem is still a big challenge in the process of automatically creating As-is BIM[42]. Creating a synthetic point cloud by combining the virtual point cloud generated by BIM with the real collected point cloud data to replaced the occluded, hidden, or missing part of collected data[43], by this way, we can obtain a complete point cloud segmentation data to provide help for As-is BIM reconstruction by improving network segmentation performance and accuracy. This idea will be more widely discussed and applied in point cloud data processing in the future. The other direction to acquire 3D representation of the internal structure of the object is using 3D perspective scanning, so that not only the size of the internal structure of the object can be obtained, but also can realize the internal force analysis of the structure.

5. Conclusions
As the development and use of BIM in new construction projects become more and more widespread, the construction industry begins to concern and discuss the realization of digital and intelligent management by creating As-is BIM for existing buildings and using BIM in the operation phase, maintenance phase and building renovation or demolition plans. This article summarizes the detailed research progress, the existing research results and knowledge gaps in the use of 3D reconstruction technology to create As-is BIM in civil engineering, then enumerates the problems facing the As-is BIM reconstruction, and finally analyzed the future research directions. The fully automated As-is BIM reconstruction is imperative, but this is still one of the main challenge in the construction industry currently.

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