The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-4/W15-2025
20th 3D GeoInfo Conference 2025, 2–5 September 2025, Kashiwa, Japan

Exploring Constructive Solid Geometry for Building Reconstruction from Point Clouds: Preliminary Results

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KEYWORDS: Scan-to-BIM, as-built BIM, segment anything model, building reconstruction, 3D indoor modelling, IFC

ABSTRACT:

As-built BIM reconstruction supports building digitalization, enabling efficient management and maintenance of existing buildings. Manual reconstruction from point clouds is both error-prone and cost-intensive, while automatic reconstruction remains challenging despite recent advancements. This paper explores the use of Constructive Solid Geometry (CSG) for automatically reconstructing IFC-compatible models from indoor point clouds of existing buildings. The proposed approach starts with segmented point clouds corresponding to rooms, doors, and windows, then CSG operations are used to reconstruct key building components as solids, including slabs, walls, doors, windows, and interior spaces. These solids are subsequently converted into corresponding IFC entities. The method is evaluated using two case studies, achieving a centimetre-level accuracy and a runtime of approximately 9 seconds per case study. The proposed method provides a promising ability to advance the Scan-to-BIM pipeline, as it enables accurate reconstruction of building components while preserving topological relationships during an efficient runtime.

1. INTRODUCTION

Digitalisation in the construction industry aims to improve efficiency, reduce costs, and enhance decision-making across all a project's phases. Building Information Modelling (BIM) stands out as a core enabler of the digital transformation, offering a structured workflow for managing and integrating both geometric and semantic information of the building components throughout their lifecycle. BIM promotes interoperability among diverse systems, primarily using standardised formats like Industry Foundation Classes (IFC). The IFC-compatible BIM enables efficient data exchange and integration and has gained widespread adoption in the industry (Borrmann et al., 2018). IFC provides a comprehensive schema for representing both geometric and semantic information about buildings, driving researchers to reconstruct point cloud data into IFC-compatible models (Bassier et al. 2018; Lu & Brilakis, 2019; Nikoohemat et al, 2020).

As-built BIM has become a key element for advanced digital applications, such as building documentation, management, and analysis. The creation of an as-built BIM of an existing building typically consists of three steps: 1) data capturing, 2) data processing, and 3) BIM reconstruction. The first step involves methods of data collection, such as laser scanning. Then, the captured data needs to be efficiently segmented and classified. Numerous methods and workflows have been presented for point cloud segmentation in the literature, such as 2D-based methods (Macher et al, 2017; Gourguechon et al, 2023; Albadri et al., 2025), 3D-based methods (Frías et al, 2020; Túñez-Alcalde et al, 2024), and AI-based methods (Sun et al, 2024). For example, Albadri et al. (2025) employed the Segment Anything Model (SAM) for automatic segmentation of indoor point clouds. SAM is a promising AI tool for image segmentation, offering significant zero-shot performance. However, more robust and general approaches are still needed to advance in the automatic third process of the as-built BIM creation (Wen et al. 2024). Automating the BIM reconstruction process effectively supports the digital transformation in the construction sector.

In the literature, several studies presented methods for 3D model reconstruction from point cloud data. A Boundary Representation (B-Rep) is a commonly used technique for representing shapes based on their boundaries, including information about vertices, edges, loops, and their topology relationships. Valero et al. (2016) proposed a B-Rep-based approach to reconstruct building elements from segmented point clouds, including floors, walls, and ceilings. The reconstruction process involved extracting information on element plane equations and connectivity between elements, including intersection details between the building elements. Similarly, Wong et al. (2025) used the B-Rep for reconstructing building components from indoor point clouds. Information on index, type, and 3D vertices of the closed-loop boundary is extracted from the point cloud for each building element. In addition, the host elements are also identified to indicate the spatial relationships for openings.

Another 3D representation method is Swept Solid Representation (SSR), which was proposed for building reconstruction from indoor point cloud data (Ochmann et al., 2016; Tang et al., 2022). SSR, also known as Extrusion Representation, constructs a 3D solid by the extrusion of an enclosed 2D cross-section along a specified direction. For BIM reconstruction, attributes of each building element are obtained from point clouds and structured for element representation. For instance, the attributes of walls include ID, type, centreline points, and height (Tang et al., 2022). On the other hand, Khoshelham and Díaz-Vilariño (2014) and Tran et al. (2019) proposed methods for 3D modelling of interior spaces based on a simple shape grammar.

Constructive Solid Geometry (CSG) is a 3D representation technique that models complex shapes of objects by combining basic primitive solids using Boolean operators such as union, intersection, and difference. CSG is often used in Computer-Aided Design (CAD) and 3D computer graphics (Yin et al., 2020; Chen et al., 2024). Several studies have used CSG for reconstructing 3D models from unstructured data, including point clouds (Fayolle & Friedrich, 2024). Wu et al. (2018) proposed an approach to construct CSG models from point cloud data. They used the patch fitting technique presented by (Li et al., 2011) to first detect surface patches from point clouds, including planar, spherical, conical, cylindrical, and toroidal patches, and then created basic primitive solids corresponding to these patches. The method next employs Boolean operations to create CSG models of individual objects, such as mechanical parts and furniture. Similarly, Xiao and Furukawa (2014) presented an algorithm to reconstruct indoor environments using CSG tools from point clouds. However, these two approaches are prone to patch and line detection errors, resulting in the loss of structures.

In response, this work presents a method for automatically reconstructing point clouds into an IFC-compatible model based on CSG representation, aiming to facilitate a more efficient and effective as-built BIM reconstruction process. The proposed method starts with segmented point clouds corresponding to rooms, doors, and windows, and automatically reconstructs an IFC model that contains key building components such as floors, ceilings, walls, openings, doors, windows, and interior spaces, with the advantage of preserving topology.

The rest of the paper is organized as follows. Section 2 explains the proposed method. Results are presented, evaluated, and discussed in Section 3. Finally, section 5 summarizes the conclusion of this work.

2. METHOD

Our approach consists of three key stages: 1) Cuboid primitive creation, 2) Boolean operation application, and 3) IFC Entity assignment. The first stage involves creating cuboid primitives from labelled point clouds. Boolean operations are then applied to combine these primitives, thereby reconstructing solid geometrical representations of building elements. Finally, the resulting solid geometries are converted into IFC Entities (Figure 1).

2.1 Cuboid primitive creation

Segmented point clouds of room, door, and window components are the input of the proposed method. A solid cuboid primitive (P) is created using eight vertices for each room, each door, and each window. These vertices are identified by extracting the bounding box of each component.

The cuboid primitives representing rooms are used to reconstruct floors, walls, and ceilings. A solid cuboid primitive, Pr_i, represents an individual room within a storey, where $i = 1, 2, \ldots,$ N and N is the total number of rooms in the storey. R denotes the set of all Pr primitives in the storey, as demonstrated in Figure 1A using a two-room indoor example.

The proposed approach assumes that a room is typically enclosed vertically by slabs (floor and ceiling) and horizontally by walls. Subsequently, the corresponding building elements can be reconstructed by expanding each Pr outward by t millimetres in appropriate directions and further applying Boolean operations. The method starts by horizontally expanding all Pr primitives by t, resulting in expanded primitives, Pr'. The new set of Pr' primitives is denoted as R_1. All Pr' primitives are subsequently expanded vertically by t in two directions: top expansion produces a new set of primitives denoted as R_2, while bottom expansion generates another set denoted as R_3, see Figure 1A. These four sets of primitives, R, R_1, R_2, and R_3, are next used to reconstruct solid geometries of slabs and walls, as explained in Section 2.2.

On the other hand, the method also assumes that doors and windows are embedded into walls. The method creates cuboid primitives of doors and windows based on their vertices. A solid cuboid primitive Pd represents an individual door, while a Pw represents an individual window, see Figure 2A. These primitives are used to reconstruct solid geometries of doors and windows and subtract their openings within the host walls, as explained in Section 2.2.

2.2 Boolean operation application

Union and *Difference* operations are applied to reconstruct the solid geometries of the building elements. Firstly, the *Union* operation (U) is applied to R, R_1, R_2, and R_3 to produce composite solids (S), resulting in S_0, S_1, S_2, and S_3 (see Figure 1B). Then, the *Difference* operation (-) is applied to reconstruct the solid geometries of the floor and ceiling (Equations (1) and (2), respectively).

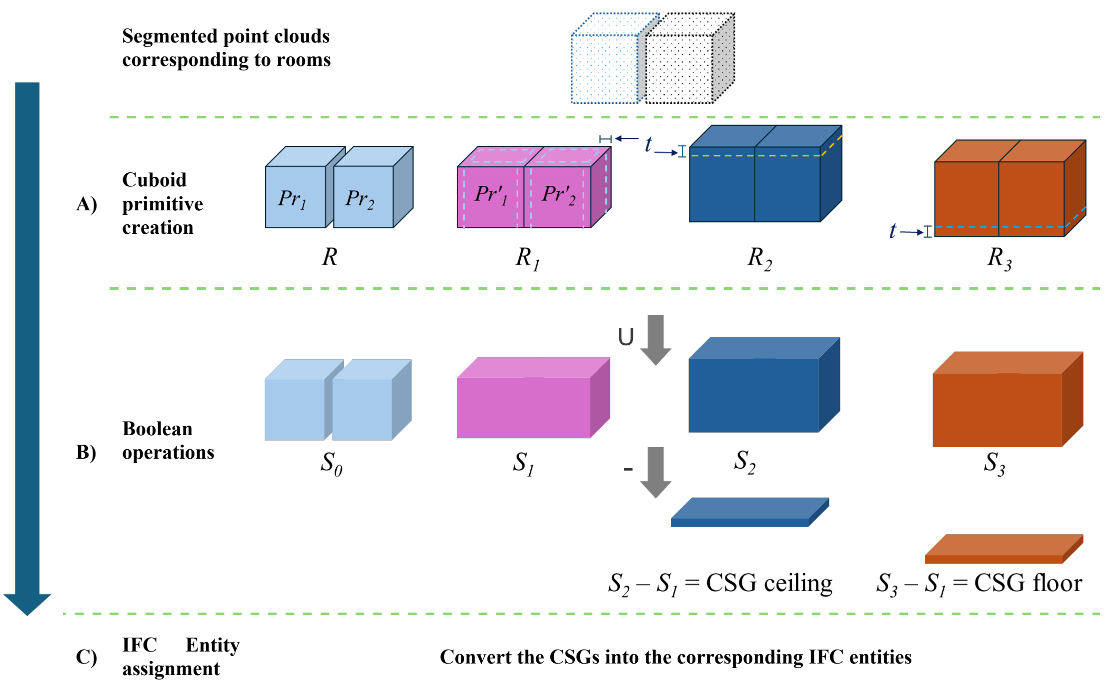


Figure 1. Overview of the proposed reconstruction workflow.

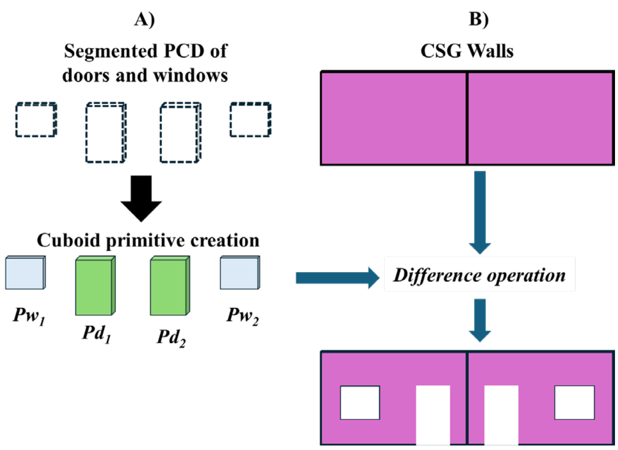


Figure 2. Reconstruction of doors, windows, and openings. A) shows creating solid cuboid primitives, and B) shows applying Boolean operations.

$$\text{CSG Floor} = S_3 - S_1 \tag{1}$$

$$\text{CSG Ceiling} = S_2 - S_1 \tag{2}$$

The method next reconstructs solid geometries of walls (CSG walls) using the Pr_i and Pr'_i primitives belonging to R and R_1. Preliminary CSG walls of a room are reconstructed as the difference between the Pr'_i and Pr_i primitives that correspond to room i (Equation 3). To avoid duplication or overlap of walls between adjacent rooms, the final CSG walls of the current room are obtained by removing CSG walls already assigned to previous rooms, as defined in Equation (4). S_0 is then updated to include newly reconstructed CSG walls (Equation 5).

$$\text{Preliminary CSG walls}_i = Pr'_i - Pr_i \tag{3}$$

$$\text{CSG walls}_i = \text{Preliminary CSG walls}_i - S_0 \tag{4}$$

$$S_0 = S_0 \cup \text{CSG walls}_i \tag{5}$$

Where $i \rightarrow$ N, N represents the number of rooms.

The CSG walls of each room have resulted in a single continuous wall. To individualize these walls, a separation process is performed using the Pr_i primitives belonging to the set R. The separation process starts by horizontally expanding the Pr_i to create four new primitives. Each new primitive is expanded by t in three of the following cardinal directions: right, left, upward, and downward along the X-Y axes. The *Difference* operation is then applied between the CSG walls$_i$ and these four primitives, resulting in four individual CSG walls for the room. This approach is applied iteratively to all rooms, thereby separating the continuous CSG walls into individual walls for each room.

Finally, openings are reconstructed by applying the *Difference* operation between the resulting CSG walls and the solids of *Pd* and *Pw* (Figure 2B). CSGs of doors and windows are reconstructed using *Pd* and *Pw,* respectively.

2.3 IFC entity assignment

In this step, the CSGs of all building components are used to reconstruct IFC-compatible models. Each CSG is converted to its corresponding IFC entity. Our method uses IFC entities, including *IfcSlab*, *IfcWall*, *IfcDoor*, *IfcWindow*, and *IfcSpace,* to reconstruct the IFC model. The CSGs of the floor and ceiling are assigned to *IfcSlab*, and CSG walls are assigned to *IfcWall*. The CSGs of doors and windows are assigned to *IfcDoor* and *IfcWindow*, respectively. Finally, the *Pr* primitives are assigned to *IfcSpace* to represent the interior spaces.

3. RESULTS AND DISCUSSION

Experiments were conducted using two one-storey multi-room case studies (CS1 and CS2), which are aligned with the coordinate system. These case studies feature layouts with rectangular-shaped rooms (Figure 3), since these building layouts are common and representative of many real-world buildings. Both case studies were automatically segmented into corresponding rooms, doors, and windows using the SAM-based method presented in (Albadri et al., 2025), and the segmentation results are presented in Tables 1 and 2. These segmented point clouds were used as input data to our approach.

	Rooms	Doors	Windows	No. of points (millions)
CS1	14	12	14	14.5
CS2	11	8	18	14.2

Table 1 1. The input data of both case studies, CS1 and CS2.

IFC-based models were automatically reconstructed from the input point clouds for both case studies, as shown in Figure 4. For these experiments, the t value was set to 250 mm, based on the assumption that this dimension represents a standard thickness of walls.

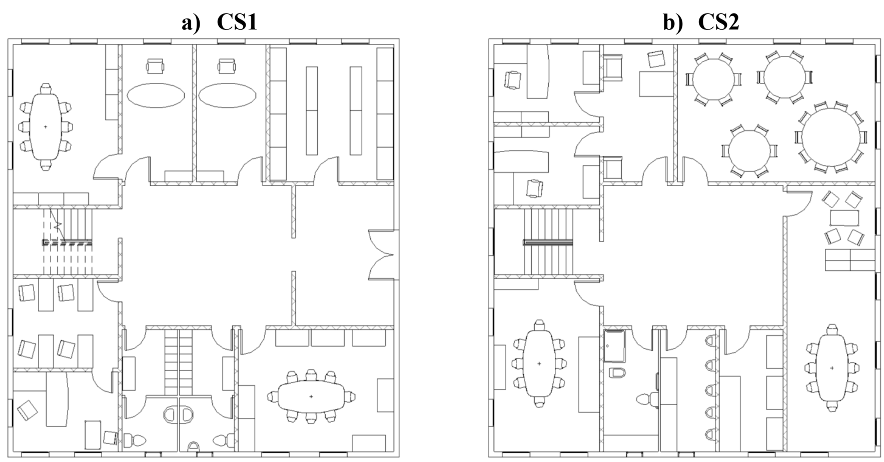


Figure 3. Layouts of both case studies, a) CS1 and b) CS2.

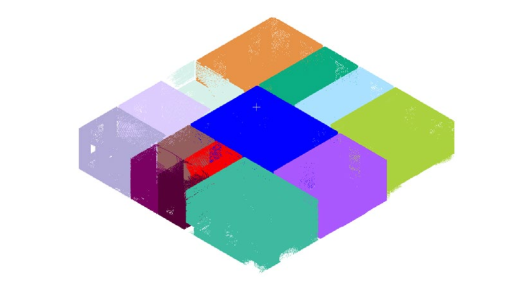
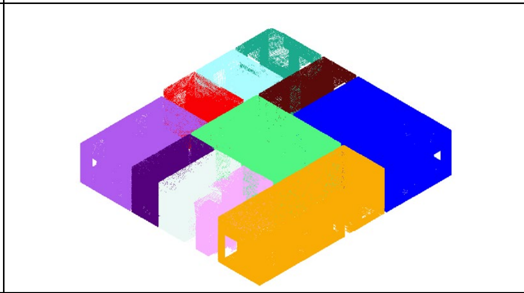
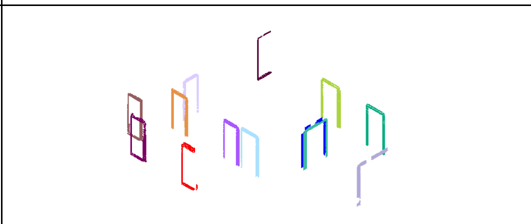
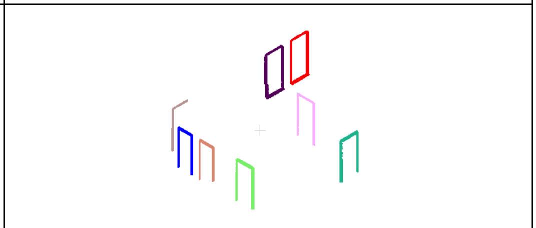
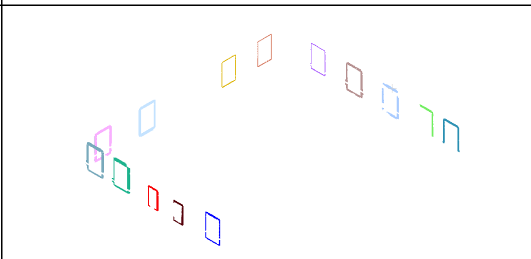
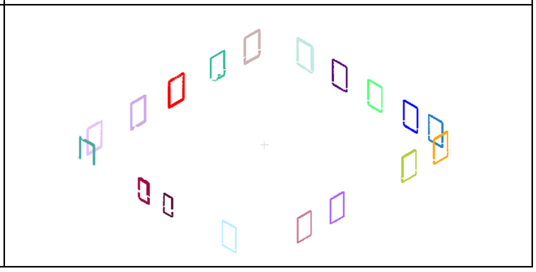
		a) CS1	b) CS2
Segmented point clouds	Rooms		
	Doors		
	Windows		

Table 2. Input point clouds for a) CS1 and b) CS2.

The reconstruction process started by creating the Pr_i primitives of the segmented rooms and then expanding these cuboids by the t to reconstruct slab and wall CSGs. *Union* and *Difference* operations were used for reconstructing the building elements as previously described in the method section. Next, door and window primitives (Pd_i and Pw_i) were created using the segmented point clouds corresponding to the doors and windows. *Difference* operation was employed to reconstruct the openings of these doors and windows in their host walls. Finally, the resulting CSGs were assigned to the corresponding IFC entities.

The building components were geometrically and semantically reconstructed in the resulting IFC models, including slabs, walls, doors, windows, and interior spaces. Additionally, the whole process was completed in approximately 9 seconds for each case study. These experiments were performed on a laptop equipped with an Intel Core i9-13900 processor and 32 GB of RAM.

Visual inspection confirms that the geometry and topology information of the building components are correctly reconstructed and semantically structured across both case studies, see Figures 5 and 6. Floors and ceilings are directly reconstructed as individual slabs and structured as *IfcSlab* in the resulting IFC file (Figure 5). Similarly, all segmented doors and windows are reconstructed into *IfcDoor* and *IfcWindow*, representing their geometries and topological relationships (door-window-wall embedding). Additionally, openings corresponding to these doors and windows are reconstructed within the correct host walls, indicating the efficient preservation of openings-wall embedding relationships. However, the doors and windows that were not detected and segmented during the segmentation process were consequently not reconstructed in these experiments.

a) CS1 b) CS2

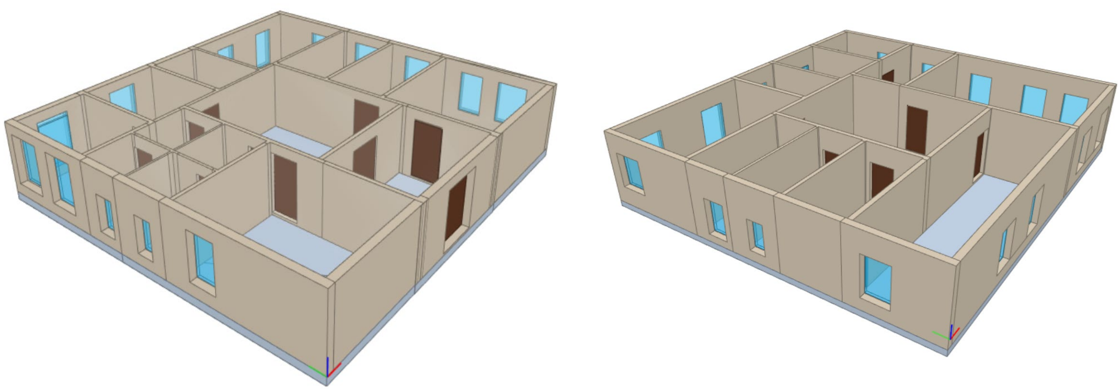


Figure 4. The resulting as-built BIM models for a) CS1 and b) CS2 (ceilings omitted for visualization).

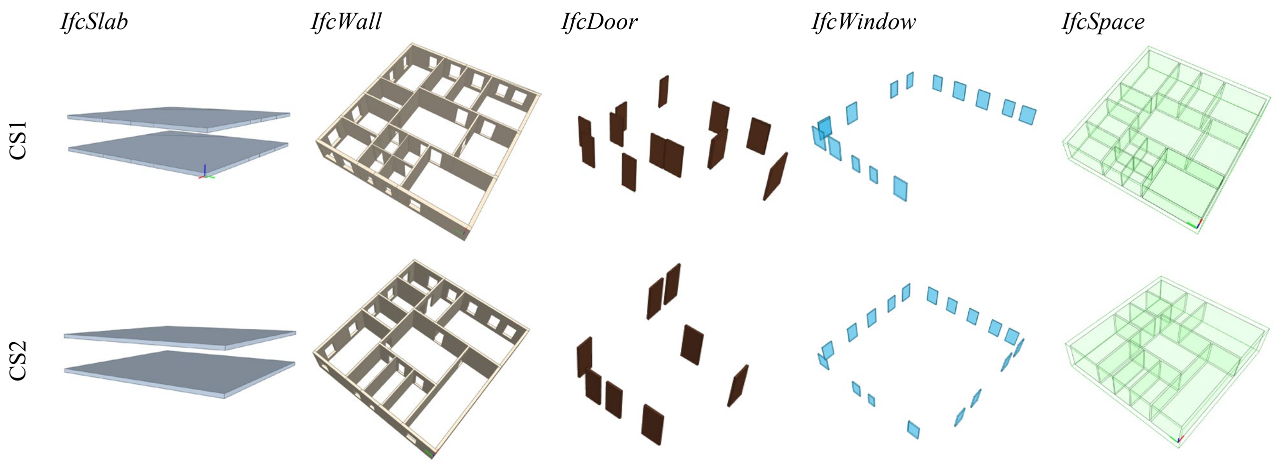
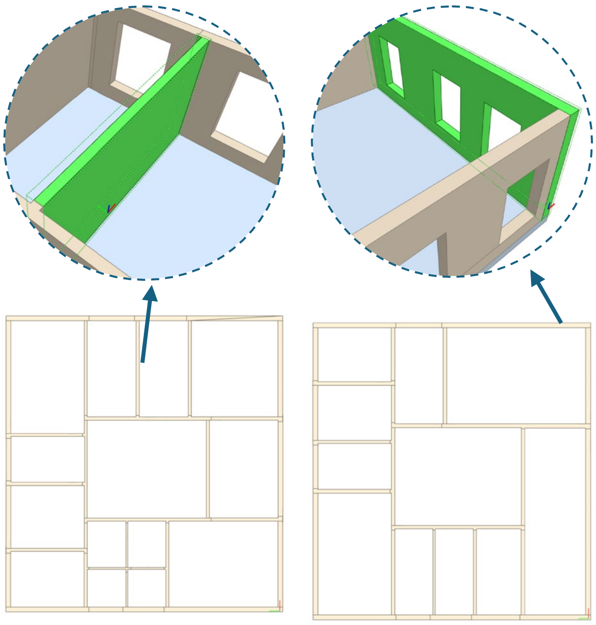


Figure 5. Reconstructed building components for both case studies (CS1 and CS2)

As-built walls are efficiently reconstructed across both case studies. No gaps or overlaps are observed between intersecting or consequent walls, as well as between walls and slabs, indicating geometric consistency in the resulting models (see Figure 6). The reconstructed wall thicknesses range from 80 to 200 millimetres for all internal walls, as shown in Figure 7. In contrast, the external walls are reconstructed with a thickness equal to the *t* value because the input data (segmented indoor point clouds) does not provide information about the external wall thickness.



a) CS1 **b) CS2**

Figure 6. Reconstruction results of the internal and external walls. a) and b) show top views of CS1 and CS2, respectively. (Other building components omitted for visualization.)

The results of interior space reconstruction are shown in Figure 5 for both case studies. All interior spaces are reconstructed and structured as *IfcSpace* in the resulting IFC files, involving 14 and 11 spaces in CS1 and CS2, respectively. These results indicate successfully reconstructing all spaces in both case studies when compared to the room details presented in Table 2.

In addition to visual inspection, quantitative evaluation was performed to assess the reconstruction method introduced in this study. Interior spaces and wall thicknesses were analysed to evaluate the accuracy of the reconstructed models in comparison with the ground truths. Metrics of Mean Absolute Error (MAE) and Mean Relative Error (MRE) were used for this evaluation. MAE measures the average absolute difference between ground truth values and reconstructed values, as shown in Equation (6). MRE quantifies the average proportional deviation between reconstructed values and ground truth values, as illustrated in Equation (7).

$$MAE = \frac{1}{N} \sum_{i=1}^{N} | G_i - R_i | \quad (6)$$

$$MRE = \frac{1}{N} \sum_{i=1}^{N} \frac{| G_i - R_i |}{G_i} \quad (7)$$

Where G and R represent the ground truth values and reconstructed values for building components, respectively. N represents the number of these components in the case study.

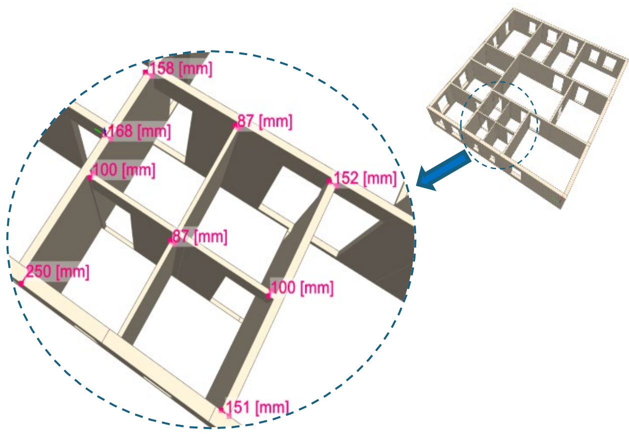


Figure 7. Wall thickness reconstruction in CS1.

First, volumes of the interior spaces and values of wall thicknesses were obtained for the ground truth and the reconstructed models. The MAE and MRE metrics were then calculated for interior spaces and wall thicknesses, and the results are presented in Table 3.

The quantitative evaluation results indicate a significant performance of the proposed reconstruction method. The MAE and MRE values show relatively low deviations between the ground truth and reconstructed models across both case studies.

https://doi.org/10.5194/isprs-archives-XLVIII-4-W15-2025-1-2025

However, these deviations reflect the accuracy of the point cloud segmentation process, highlighting the importance of point cloud processing techniques in achieving more accurate reconstruction outcomes. Despite these deviations, the proposed method demonstrates an acceptable accuracy in both spatial and structural reconstruction.

Overall, the results illustrate that the CSG representation is promising to address key limitations faced in automating as-built BIM reconstruction, particularly in reconstructing geometries and preserving topological relationships. Furthermore, the presented method is controlled by only one parameter, t, which can be set based on the standard wall thickness, indicating the method's adaptability to buildings with similar configurations to those used in this study. Different case studies are still needed to confirm the approach's robustness and generalisation across a range of various building configurations, including concave-shaped rooms and non-Manhattan buildings.

	CS1		CS2	
	Interior space	Thickness	Interior space	Thickness
MAE	0.13	1.5	0.49	2.6
MRE	0.35 %	11.8 %	1.1 %	19.6 %
*MAE in m^3 and cm for interior space and thickness evaluation, respectively.				

Table 3. Evaluation results of the proposed reconstruction method.

Finally, the CSG-based reconstruction offers a potential impact and practical value for advancing scan-to-BIM pipelines. As it relies solely on the vertices of rooms, doors, and windows to directly construct IFC-based models of building components, eliminating the need to extract detailed geometry and topology information for every building element from the point cloud. This direct process reduces susceptibility to occlusions and noise, such as the presence of furniture, and makes it less dependent on intermediate steps of point cloud segmentation. Additionally, it supports interoperability, which is particularly valuable for practical BIM-based applications. On the other hand, the full automation and efficient runtime of the method represent significant developments to the Scan-to-BIM workflow. Minimizing manual intervention and processing time enables faster and more scalable creation of as-built BIM models. This ability supports the ongoing digital transformation in the construction sector, facilitating more efficient documentation, management, and analysis of existing buildings.

4. CONCLUSION

This study explores the use of CSG representation for automatically reconstructing as-built BIM models from segmented point clouds of existing buildings. The proposed approach employs the CSG to represent building geometries while preserving topology relationships for accurate reconstruction. In this method, CSG tools are used to reconstruct building components as solids, which are subsequently converted into corresponding IFC entities. The input to the method consists of labelled point clouds corresponding to rooms, doors, and windows. The output is an IFC-compatible model that contains both geometric and semantic information about slabs, walls, doors, windows, and interior spaces. The method is validated using two case studies, showing a centimetre-level accuracy and a runtime of approximately 9 seconds per case study.

Three key advantages of the proposed method can be identified: first, reconstruction of building components while preserving topological relationships; second, reducing the dependency on extracting detailed geometric and topological information from point clouds for building element reconstruction; and third, automation and runtime efficiency. Subsequently, the CSG-based reconstruction provides a promising capability to advance the Scan-to-BIM workflow for practical applications, supporting digitalization in construction.

For future experiments, the CSG will be explored to reconstruct different building configurations, including those with concave-shaped rooms and non-Manhattan World geometries.

Acknowledgement

This work was partially supported by human resources grant RYC2020-029193-I funded by MCIN/AEI/10.13039/501100011033 and FSE 'El FSE invierte en tu futuro', by grant ED431F 2022/08 funded by Xunta de Galicia, Spain-GAIN, and by the projects PID2021-123475OA-I00 funded by MCIN/ AEI /10.13039/501100011033/ and by FEDER 'Una manera de hacer Europa' and CNS2022-135730 funded by MCIN/AEI /10.13039/501100011033 and by European Union NextGenerationEU/PRTR. The statements made herein are solely the responsibility of the authors.

References

Albadri, M. S. A., González-Cabaleiro, P., Túñez-Alcalde, R. M., Fernández, A., & Díaz-Vilariño, L. (2025). A SAM-Based Approach for Automatic Indoor Point Cloud Segmentation. *ISPRS Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* (In press). Presented at ISPRS Geospatial Week 2025.

Bassier, M., Klein, R., Van Genechten, B., & Vergauwen, M. (2018). IFCwall reconstruction from unstructured point clouds. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *4*, 33-39.

Borrmann, A., Beetz, J., Koch, C., Liebich, T., & Muhic, S. (2018). Industry foundation classes: A standardized data model for the vendor-neutral exchange of digital building models. *Building information modeling: Technology foundations and industry practice*, 81-126.

Chen, J., Shen, Z., Zhao, M., Jia, X., Yan, D. M., & Wang, W. (2024). FR-CSG: Fast and Reliable Modeling for Constructive Solid Geometry. *IEEE Transactions on Visualization and Computer Graphics*.

Fayolle, P. A., & Friedrich, M. (2024). A survey of methods for converting unstructured data to CSG Models. *Computer-Aided Design*, 168, 103655.

Frías, E., Balado Frías, J., Díaz-Vilarino, L., & Lorenzo, H. (2020). Point cloud room segmentation based on indoor spaces and 3D mathematical morphology.

Gourguechon, C., Macher, H., & Landes, T. (2023). Room Point Clouds Segmentation: a New Approach Based on Occupancy and Density Images. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 93-100.

Khoshelham, K., & Díaz-Vilariño, L. (2014). 3D modelling of interior spaces: Learning the language of indoor architecture. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40, 321-326.

Li, Y., Wu, X., Chrysathou, Y., Sharf, A., Cohen-Or, D., & Mitra, N. J. (2011). Globfit: Consistently fitting primitives by discovering global relations. In *ACM SIGGRAPH 2011 papers* (pp. 1-12).

Lu, R., & Brilakis, I. (2019, July). Generating bridge geometric digital twins from point clouds. In EC3 Conference 2019 (Vol. 1, pp. 367-376). European Council on Computing in Construction.

Macher, H., Landes, T., & Grussenmeyer, P. (2017). From point clouds to building information models: 3D semi-automatic reconstruction of indoors of existing buildings. *Applied Sciences*, *7*(10), 1030.

Nikoohemat, S., Diakité, A. A., Zlatanova, S., & Vosselman, G. (2020). Indoor 3D reconstruction from point clouds for optimal routing in complex buildings to support disaster management. *Automation in construction*, *113*, 103109.

Ochmann, S., Vock, R., Wessel, R., & Klein, R. (2016). Automatic reconstruction of parametric building models from indoor point clouds. *Computers & Graphics*, 54, 94-103.

Sun, Y., Zhang, X., & Miao, Y. (2024). A review of point cloud segmentation for understanding 3D indoor scenes. *Visual Intelligence*, *2*(1), 14.

Tang, S., Li, X., Zheng, X., Wu, B., Wang, W., & Zhang, Y. (2022). BIM generation from 3D point clouds by combining 3D deep learning and improved morphological approach. *Automation in Construction*, *141*, 104422.

Tran, H., Khoshelham, K., Kealy, A., & Díaz-Vilariño, L. (2019). Shape grammar approach to 3D modeling of indoor environments using point clouds. *Journal of Computing in Civil Engineering*, *33*(1), 04018055.

Túñez-Alcalde, R. M., Albadri, M. S., González-Cabaleiro, P., Fernández, A., & Díaz-Vilariño, L. (2024). A Top-Down Hierarchical Approach for Automatic Indoor Segmentation and Connectivity Detection. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *10*, 289-296.

Valero, E., Adán, A., & Bosché, F. (2016). Semantic 3D reconstruction of furnished interiors using laser scanning and RFID technology. *Journal of Computing in Civil Engineering*, 30(4), 04015053.

Wen, Y., Wang, M., Ariyachandra, M., Wei, R., Brilakis, I., & Xiao, L. (2024). Knowledge driven rule-based building geometric digital twin construction & state of art review. Apollo - University of Cambridge Repository. https://doi.org/10.17863/CAM.111239

Wong, Mun On, Yifeng Sun, Huaquan Ying, Mengtian Yin, Hui Zhou, Ioannis Brilakis, Tom Kelly, and Chi Chiu Lam. "Image-based scan-to-BIM for interior building component reconstruction." *Automation in Construction* 173 (2025): 106091.

Wu, Q., Xu, K., & Wang, J. (2018). Constructing 3D CSG models from 3D raw point clouds. In *Computer Graphics Forum* (Vol. 37, No. 5, pp. 221-232).

Xiao, J., & Furukawa, Y. (2014). Reconstructing the world's museums. *International journal of computer vision*, 110, 243-258.

Yin, G., Xiao, X., & Cirak, F. (2020). Topologically robust CAD model generation for structural optimisation. *Computer methods in applied mechanics and engineering*, *369*, 113102.