Automating Scan to BIM Operations Using Grasshopper

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Abstract

Remote sensing technologies such as laser scanning and photogrammetry have advanced significantly in the field-to-BIM workflow in recent years, becoming key instruments for modeling as-built frameworks. They can be utilized to collect dense 3D measured data on the condition of a building, and the derived point cloud can be processed to generate the as-built BIM. It provides building information to report as-built conditions and serves as a skill set for data on problem-solving issues in civil engineering. This research presents an efficient and automated workflow for modifying and evaluating point cloud data, focusing on supporting scan-to-BIM operations. The workflow utilizes cubic voxel mesh creation and voxel subsampling techniques to ensure precise representation of scanned data. The validation of this reconstruction methodology using Grasshopper and Volvox demonstrates its potential to reduce manual labor and analysis typically required in conventional scan-to-BIM methodologies. The presented workflow simplifies the critical task of acquiring building profiles, an essential BIM result, and streamlines the overall process. The integration of the Volvox plugin has further augmented the capabilities of Grasshopper and Rhino, providing users with intuitive tools for manipulating point clouds. Automating certain operations through the presented workflow has significant potential to enhance the efficiency and accuracy of the scan-to-BIM methodologies. These findings have implications in architecture and design, demonstrating how technology can be leveraged to unlock new possibilities and streamline critical processes.

Keywords

point cloud data, as-built models, laser scanning, 3D scan, grasshopper

1 Introduction

Building information modeling and management (BIM) has become the prevailing norm for the planning and execution of construction projects on a global scale. It is viewed as both a chance and a task. The development and completion of engineering and design projects require a lot of time, money, and skill for the actual staff, but BIM modifies traditional procedures [1, 2]. This facilitates the management of construction-related professionals and asset planners in organizing all facility data and information throughout their lifecycle, from creation to disposal [3–5]. Traditional BIM applications collect and share basic information about a construction project. However, if construction robots are used, these applications may not be enough to handle all the data. A more comprehensive approach is needed because robots and sensors produce a lot of information that traditional BIM applications may not fully understand [6]. The civil engineering industry should invest in digital capabilities to continuously improve efficiencies and effectiveness through enhanced collaboration

at all stages of the construction cycle in order to lead the world in digital construction [7]. Many structures lacked BIM models and as-built BIM models for existing structures [8]. The as-built BIM development business has broadly accepted laser scanning technology to address the issue of a missing digital model [9]. To gather precise building attributes, principally geometrical, laser scanning info is utilized to create the as-built BIM model. This procedure is known as "scan-to-BIM" [10].

Modern as-built data gathering systems allow for the precise and complete capture of as-built parameters, supporting BIM. The two main categories of as-built data-collecting techniques are photo/video-grammetry, which is image-based, and 3D laser scanning, which is range-based. The earlier method uses computer vision techniques e.g., Structure from Motion to capture still pictures or video sequences and convert them into 3D point clouds. In contrast, the latter approach uses a range-based method to determine the 3D coordinates of the target

object or scene and produce a 3D point cloud as an output [1, 11]. To improve efficiency, research should focus on developing more efficient scanning processes, automating the re-orienting, finding, and labeling of targets, and creating a dynamic registration that removes the need for manual registration. The current manual process of creating as-built BIM from point cloud data (PCD) is subject to human error and incurs high costs, so future research should focus on eliminating the intermediate CAD modeling step and direct modeling in the BIM environment or developing automated as-built creation from PCD [12].

Gathering as-built data involves capturing an object's form and geometry as a point cloud [13]. Earlier, as-built data collection methods comprised in-situ surveys; measurements were carried out manually [14]. Visual inspections and laborious surveying methods, which were the most commonly used techniques for collecting as-built data, are highly dependent on the expertise and precision of the human operator. However, these methods are time-consuming, prone to inaccuracies, and making it challenging to make timely and accurate decisions [15]. Recent advances in as-built comprise the use of photogrammetry and terrestrial laser scanning, the two standard non-contact structural surveying methods, in an efficient way [4]. The use of parametric tools to optimize BIM is a topic covered in scientific literature. Dynamo was used to perform basic analytics and connect third-party reports in BIM models, an integrated Visual Programming tool from Revit [16, 17].

In this paper, Rhinoceros [18] and Grasshopper [19] (a software with its plugin for visual programming) are used to construct a point cloud framework with variable density to develop a novel methodology for preparing the point cloud data to use in BIM environment. Rhino+Grasshopper is a widely used platform for computer-aided design (CAD) and parametric design, which can be particularly useful for working with point clouds in an architectural or engineering context. Grasshopper provides a visual programming interface that allows users to create custom workflows and algorithms for point cloud processing and analysis, and to integrate point clouds with other Rhino and Grasshopper plugins. This can be particularly useful for designing and prototyping structures from point cloud data or creating custom analysis tools. Whereas, generic point cloud processing environments, such as CloudCompare, do not perform well in modeling. Also, it does not offer advanced tools for editing or sculpting point clouds. Then, detailed 3D meshes are created using the Terrestrial Laser Scanner

(TLS) data. Avoiding procedures with additional software e.g., Geomagic [20], MeshLab [21], etc., is of high priority. The procedure involves mesh creation from the point cloud. Besides that, many other editing parameters will be tested using the Volvox [22] plugin in Rhino+Grasshopper.

2 Methodology
2.1 Data collection
The recording of cultural and architectural assets has undergone a revolutionary change thanks to the development of new techniques. This transformation began with the need to manage the dimensional quality, leading to the emergence of advanced methods for data capture and analysis.

In this research, the data was collected using a terrestrial laser scanner (FARO 3D Scanner). TLS is an excellent tool for capturing the geometry of structures because of its range and accuracy [23]. As a result, this method was utilized in this study to complete the 3D survey. The scene was a small building; nine stations (scanner positions) for the XYZ global coordinate system were set up. Additionally, pictures were taken with the TLS to create an RGB surface model (Fig. 1). The TLS lidar data in .e57 format served as the primary data source.

2.2 Workflow
An end user familiar with or comprehending the workflow should be able to get results with little effort – the workflow alternates between the labor-intensive conventional Scan-to-BIM approach and fully automated AI-oriented approaches. The technique relieves the designer or any other BIM user of manual system analysis and design accountability.

In order to make the point cloud data compatible with the Autodesk environment, it must first be converted from its original .txt format to a format that Autodesk can recognize,

Fig. 1 Point cloud data of the small building

such as .las, .e57, or .rcp. This conversion process is necessary to ensure that the data can be properly processed and analyzed within the Autodesk environment. To convert the .txt file to .rcp, we can use Autodesk Recap [24], then import the .rcp file into Autodesk Revit [25]. This enables to create BIM by accommodating variations under various modeling techniques.

The workflow is made using Grasshopper and Volvox, a Grasshopper plugin, for importing and editing the point cloud data. The Volvox plugin is specifically designed to analyze and visualize large point cloud data sets. It can process data quickly and efficiently, making it ideal for working with large datasets in Rhino+Grasshopper. It offers automatic point cloud registration and multi-view registration. The Volvox plugin allows users to customize the appearance and display of their point cloud data, including the ability to change the color map, point size, and other visualization options, which can help highlighting specific features or areas of interest in the data within Rhino Grasshopper. Via Volvox, e57 point clouds can be imported, and the given percentage of points (through resampling) to be visualized from the point cloud data can also be set. In addition, file formats like LAS can also be imported using other plugins e.g., Heron; but for the discussed workflow, the point cloud data was imported using Volvox.

After importing the point cloud, sections (that are required by engineering applications) can be created by defining a point on the point cloud; this is done by creating a cloud plane. The thickness and plane of the sections can be determined using an algorithm in Grasshopper. The section's thickness can be adjusted per the requirement by setting a tolerance level (Fig. 2). Moreover, the section created can be placed at the same workspace at some adjustable distance from the original point cloud, which is also set with the help of a number slider. It is also possible to create multiple sections of the same point cloud by selecting numerous points in the cloud plane. Creating sections from a point cloud can provide valuable insights into the data, making it easier to analyze, interpret, and use for various applications.

The cloud engine option in Volvox is a processor for transformation by different instructions. So, by adding the cloud engine, subsampling can be executed. The instructions are not limited to single use only; multiple instructions can be added in the same workflow. The other instructions include cropping, moving, voxel sampling, etc. Voxel subsampling is flexible in choosing the number of points from the point cloud and allows selecting the distance between the points, thereby making the point cloud dense or light according to the requirements.

A regular voxel grid is used in voxel subsampling to generate an evenly subsampled point cloud. It is frequently used as a pre-processing sequence for many point cloud computational requirements. From voxel subsampling, a cubic voxel mesh can be generated, where the size of cubes in the mesh can be adjusted depending on the user needs (Fig. 3).

After creating a voxel mesh, this mesh can be smoothened using smooth mesh component; the number of smoothening iterations can be set. This parameter controls how many times the smoothing algorithm will be applied to the mesh. This component works by applying a Laplacian smoothing algorithm to the mesh vertices, which redistributes their positions based on the positions of their neighbors. The algorithm iterates over each vertex, calculating the average position of all neighboring vertices and moving the vertex toward this average. The amount of smoothing can be controlled by adjusting the number of iterations and the smoothing factor.

Fig. 2 Image from a point cloud with section plane YZ and adjustable thickness

Fig. 3 Cropped voxel mesh

Besides voxel mesh, a Delaunay triangulation can also be done. It is a method of connecting a set of points in a plane with non-overlapping triangles, such that no point is contained within the circumcircle of any triangle. Delaunay triangulation is often performed on point clouds to create a surface mesh that can be used for various applications, such as 3D modeling, visualization, and analysis (Fig. 4). 3D models created are first-stage results, forming the basis for further investigation. The 3D models may not provide the final answers or solutions to the research problem, they play a crucial role in supporting subsequent analyses and applications.

The complete workflow is shown in the picture below (Fig. 5).

3 Result

As derived products that can be used for engineering purposes, profiles can be created from the surveyed building in either direction automatically (Figs. 6 and 7). The horizontal profile was taken 1 meter above ground level, to acquire the building's basic contour in an automatic sense.
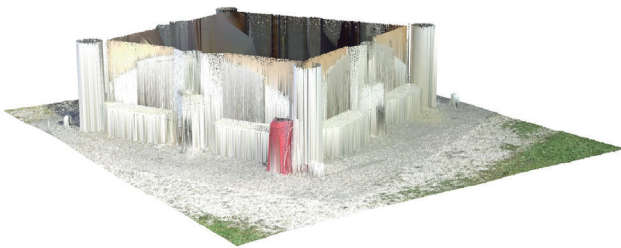

Fig. 4 Delaunay triangulation on cropped point cloud

The level and direction is optional, so this way a series of profiles could be created for various purposes (automatic blueprint creation, contour maps from scanned surfaces, sections from surveyed buildings, etc.). The algorithm for creating a profile is shown in Fig. 8.

In summary, the reconstruction method using Grasshopper and Volvox is a workflow for importing, editing, and analyzing point cloud data. It allows the user to create sections of the point cloud by defining a point and setting a thickness and plane for the section. The point cloud can also be subsampled using voxel subsampling, which allows the user to choose the number and distance between points in the subsampled point cloud. The resulting point cloud can be transformed using various instructions in the cloud engine, and a cubic voxel mesh can be generated from the subsampled point cloud. The mesh can then be smoothened, and the number of smoothing iterations can be set to achieve the desired level of smoothing. Above all, building profiles can be created automatically. This method can be used as a pre-processing step for various point cloud computational requirements and enables reducing the manual labor and analysis involved in the traditional Scan-to-BIM approach.

This workflow aims to simplify the process of using point cloud data in BIM by automating certain tasks and providing flexibility in adjusting the data for specific needs. It allows a more efficient and accurate approach to BIM, as manual system analysis and design responsibilities are reduced (fewer potential human errors), and the point cloud data can be easily edited and processed.
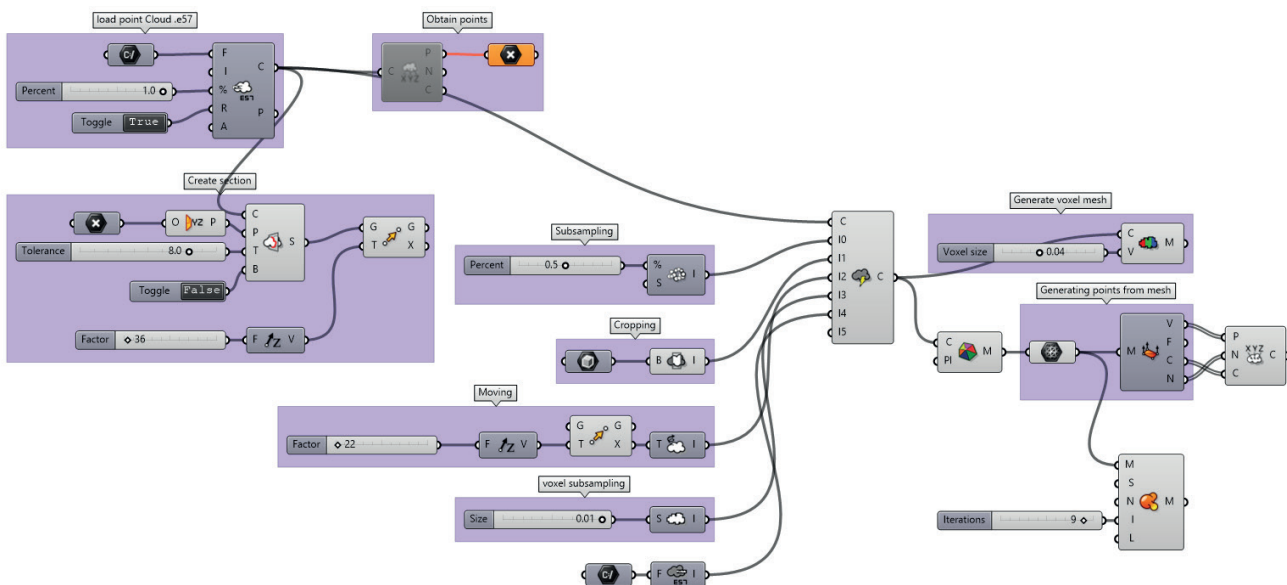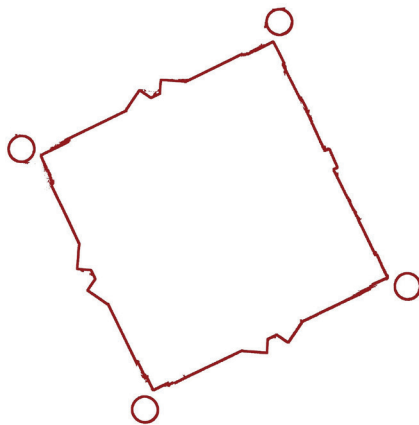

Fig. 5 Algorithm in Grasshopper workspace

Fig. 6 Horizontal profile of surveyed building created using Rhino+Grasshopper
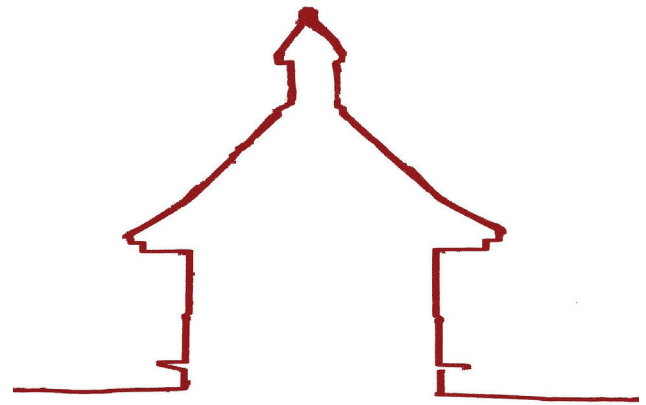

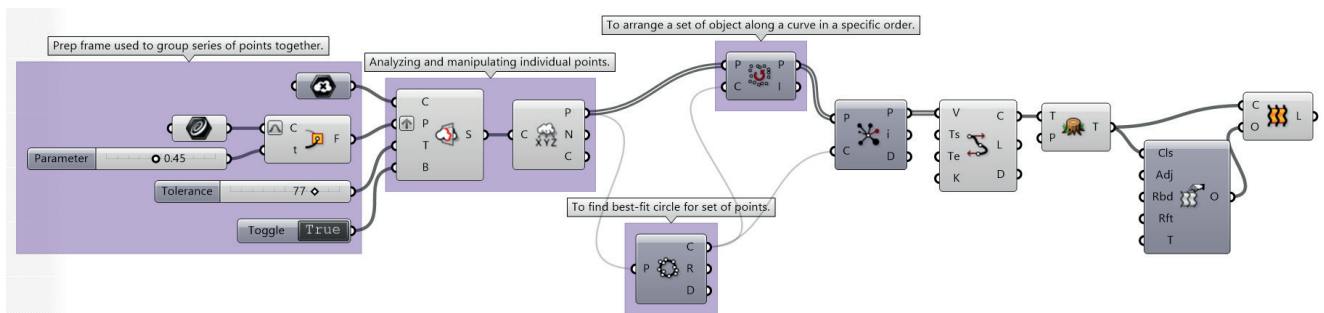**Fig. 7** Vertical profile of surveyed building created using Rhino+Grasshopper

Fig. 8 Algorithm for automatic creation of building profile

4 Discussion

Multiple BIM workflows apply point clouds, either by creating the BIM model of an existing building or monitoring construction progress (e.g., regular UAV survey of the construction site). Such point clouds are to be post-processed for further applications, e.g., resampling to reduce the size of the dataset by keeping only the valuable information or deriving 2D vectorized products (e.g., sections, views) for engineering purposes. These workflows can be highly supported by parametric design methods that support optimizing resource (time, cost, expertise) management.

Parametric modeling has an enormous potential [26]. It is up to BIM programmers to implement such processes to enhance operational capability as computers' abilities to alter massive point cloud data enhance. The workflow mentioned above can be further used for multiple Scan-to-BIM processes, e.g., automatically segmenting point clouds.

5 Conclusions

Grasshopper and Rhino are powerful tools that have revolutionized how designers and architects' approach parametric design and generative modeling. The ability to create complex forms, optimize building performance, and generate custom components has opened a world of possibilities for design and architecture. The Volvox plugin has further enhanced these capabilities by allowing users to easily create and manipulate complex geometries and structures.

The presented workflow has provided an effective and automated technique of modifying, and evaluating point cloud data, supporting the scan to BIM operations. It simplified the crucial step of establishing building profiles, which is essential to BIM. Moreover, using cubic voxel mesh creation and voxel subsampling techniques makes it possible to accurately represent the scanned data, lowering the risk of human error. Proving the reconstruction method using Grasshopper and Volvox helps to reduce the manual labor and analysis involved in the conventional scan to BIM methodology by automating some operations, which saves time and resources.

Overall, the Volvox plugin for Rhino+Grasshopper offers a range of advanced tools and features for working with point cloud data, including efficient processing of large datasets, automatic point cloud registration, and customizable visualization options.

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