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Using Dynamo for Automatic Reconstruction of BIM Elements from Point Clouds

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Abstract: The integration of 3D laser scanning and digital photogrammetry in the architecture, engineering, and construction (AEC) industry has facilitated high-quality architectural surveys. However, the processes remains constrained by significant costs, extensive manual labor, and accuracy issues associated with manual data processing. This article addresses these operational challenges by introducing automated Building Information Modeling (BIM) techniques that minimize manual input through the use of Dynamo for Autodesk Revit. We developed algorithms that efficiently convert point cloud data into accurate BIM models, enhancing productivity and reducing the potential for errors. The application of these algorithms is analyzed in a case study of the Old Lifeguard Station of Fuseta, showcasing notable reductions in modeling time and improvements in accuracy. The findings suggest that automated scan-to-BIM methods could provide a viable solution for enhancing BIM workflows across the industry, with the potential for wider adoption given their impact on efficiency and model quality.

Keywords: scan-to-BIM; architectural reconstruction; automation; point cloud; visual programming language; 3D laser scanning; LiDAR

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Citation: Rocha, G.; Mateus, L. Using Dynamo for Automatic Reconstruction of BIM Elements from Point Clouds. *Appl. Sci.* **2024**, *14*, 4078. https://doi.org/10.3390/app14104078

Academic Editor: Valentin Gomez-Jauregui

Received: 26 March 2024
Revised: 2 May 2024
Accepted: 9 May 2024
Published: 10 May 2024

1. Introduction

Throughout the history of construction, various authors have delved into the survey and graphic documentation of existing buildings [1–5]. In recent years, new technologies, like 3D laser scanning and digital photogrammetry, have gained popularity for capturing pre-existing structures due to their efficiency and non-invasive nature. These technologies can perform surveys with high accuracy and precision, capture all the details of complex and large buildings, and are less time-consuming than traditional measurement techniques [6,7]. The resulting outputs from these surveys vary widely. They commonly include documentation created using Computer Aided Design (CAD) software [8–10], three-dimensional models [8,11,12], or Building Information Modeling (BIM) models [13–17], which are widely used in the architecture, engineering, and construction (AEC) industry.

The use of BIM, together with light detection and ranging (Lidar) and digital photogrammetry, commonly known as scan-to-BIM [18], brings many gains to the process of the digital reconstruction of pre-existing buildings, even if, in some cases, the BIM software is used only for the modeling tasks. Some of the benefits are the possibility of working on a complete 3D model of the building and not just on isolated plans, a better level of accuracy, speed in obtaining building sections and elevations, ease of detecting errors and deviations, and the possibility of collaborative work, among others [19]. Despite this, many professionals still point out some barriers that make it difficult to fully adhere to this new way of working, such as the cost of migrating to new platforms, the need for specialized professionals or training of the existing team, the lack of customer demand, and the type of project they work on not justifying the change [20,21]. In addition, professionals who have already incorporated scan-to-BIM in their companies mention that some weak points in this process make the work harder, such as the excessive time consumed in manual modeling tasks, the inaccuracy and difficulty of modeling organic elements or with unconventional shapes, and the lack of automation tools that are efficient and reliable [19]. With recent technological changes, government incentives and requirements, and new paradigms in the AEC industry [21–23], there has been an increase in requests for BIM models as the main product generated from architectural surveys, and as more companies make the transition to BIM, the trend is that this product will be increasingly requested.

The BIM model must contain geometric information and reflect the complexity of the built architectural object, with its attributes, parameters, materiality, and constructive characteristics [24–26]. It should also be considered that the model is an abstraction of reality; thus, it does not and should not represent all aspects of the object but rather represent it in its simplified form. No model can faithfully reproduce all aspects of its reference, and the purpose for which it will be used must be well defined from the beginning, as this avoids the creation of an inappropriate model for the situation [27]. When dealing with graphical representations for construction, a common practice is to create the lines and geometry with an orthogonality approach, but orthogonality does not exist in the real world. Even the most perfect construction made with precast elements presents deviations, either in its manufacture or due to deformities presented after use and time. Some questions arise from these observations. How can we represent a construction that contains deviations and irregularities? What is the deviation tolerance for each situation? These questions become more critical when we use contemporary digital tools that, for the most part, encourage the element to be drawn following an orthogonal logic because this facilitates the computer's processing and avoids certain inaccuracies [28].

These concepts mentioned in the previous paragraph help us to understand the importance of defining tolerance and accuracy. The tolerance represents how much accuracy the model has to the existing object, and the tolerance level guides the modeler in making decisions [29]. Accuracy is more than tolerance; it is directly related to the intention for which the model is intended. By defining "intent", we can begin to determine suitable means and methods to achieve the specified accuracy and assist stakeholders in better determining what level of accuracy will be required in each situation. A model's excess accuracy often disrupts the clients' workflow and consumes excessive time, consequently increasing the final product's cost [28]. Several authors use the term level of accuracy (LOA) to classify the accuracy of the model [30–34]; some use their own classification while others use specification guides intended for this purpose, such as *The U.S. Institute of Building Documentation Level of Accuracy (LOA) Specification Guide* developed by the U.S. Institute of Building Documentation [28].

As well as the LOA, another basic definition for the correct functioning of a BIM workflow is the Level of Development or Level of Detail (LOD). The LOD is a term used to define the level of detail or development used in the models; a BIM object can be modeled at different levels of detail and with varying types of complexity and information embedded in the element. The correct definition of the LOD to be used saves time and effort, ensures that the delivered model is following its purpose and what was requested [27,29], and directly interferes with the costs and efforts required for BIM modeling [35]. In addition to the LOD, there are other concepts that some authors use to help classify BIM elements by separating the geometric construction from the integrated information, namely, the Level of Geometry (LOG) and the Level of Information (LOI). The LOG refers to the level of detail and complexity in representing geometric information, while the LOI refers to the level of detail and specificity of non-geometric information associated with model elements in a BIM model [36,37]. Although these concepts are very interesting for separating geometry from information data, for the development of this research and the analysis of the models created, we chose to use the LOD concept to describe the level of detail of the models because it is a more widespread and established definition in the AEC industry and academia.

BIM goes beyond geometric reconstruction. However, this does not remove the need to guarantee a 3D model faithful to the metric characteristics of the object studied and that meets the project's needs according to the accuracy, tolerance, and intention. Despite being an integrated and collaborative methodology, BIM is still centered on a digital model. It is possible to manage the construction in its life cycle, from design and construction to maintenance and post-use management [38,39]. Any BIM model built must meet these needs, and models made from point clouds are no different.

The internal organizational structure of BIM tools works by classifying and grouping model elements according to their function in the building. In this way, when creating a model for a door, the software interprets the model as a door and not as a generic model. This happens to all other elements like walls, floors, windows, roofs, stairs, pillars, and beams [40]. The logic used in BIM tools follows the same structure used in real constructions. Maintaining this logic is essential so that the digitally created element can perform its function correctly and, in this way, can integrate a BIM methodology without compromising other processes and tasks.

Computer graphics and computer programming can play an essential role in optimizing today's scan-to-BIM processes. The current mainstream BIM software, Autodesk Revit and ArchiCAD, integrate with the visual programming language tools Dynamo and Grasshopper, respectively, which are used to develop codes and algorithms for automating tasks in BIM projects. There are good examples of works that use other software and other approaches to computer programming to automate point cloud modeling [15,38–41], and there are several authors who use Dynamo in their studies for complementary tasks in modeling and in the BIM workflow [42–47]. However, there is a lack of studies that used Dynamo as the main tool to automatically model the geometry from point clouds.

In exploring the advancements and applications of 3D laser scanning and digital photogrammetry in the AEC industry, this paper acknowledges a significant gap in the automation of BIM from point clouds. Despite the rapid adoption of scan-to-BIM technologies, professionals in the field continue to face challenges in terms of efficiency, cost, and the manual labor involved, which hampers accuracy and increases project timelines [15,19]. This research was motivated by the pressing need to address these issues through the development of automated tools that facilitate the conversion of raw data into functional BIM elements.

This research aimed to develop automation approaches for modeling architectural elements from point cloud data with Autodesk Revit 2020 and Dynamo [41,42]. The use of Dynamo in the creation of automation algorithms for Revit brings some advantages, such as the compatibility between the two tools, since Dynamo is a native tool of Revit, the possibility of using and creating the BIM elements of Revit in their correct categories and types without the need to use generic 3D elements, the lack of need to use other external software to complement the work, and the possibility of sharing the algorithm with other users who use the same tools so they can also test them.

Our contributions are crucial for advancing BIM technologies. Firstly, we introduce novel algorithms developed in Dynamo for the automated modeling of architectural elements from point clouds, significantly reducing manual input and associated errors. Secondly, we validated these algorithms against traditional methods through a comprehensive case study of the Old Lifeguard Station of Fuseta, showcasing not only improved accuracy but also considerable time savings. Lastly, our approach leads the way in incorporating these automated solutions into mainstream BIM software, making it easier for others to adopt throughout the industry. By detailing these contributions, this article fills a critical void in current research, setting a new benchmark for future developments in scan-to-BIM processes.

2. Materials and Methods

This research was conducted in five phases (Figure 1). The first phase involved architectural surveying using 3D laser scanning and the registration of scans and creation of the point cloud. The second phase focused on developing computational algorithms for geometric reconstruction from the point cloud. The third and fourth phases consisted of a case study modeled using two different approaches: one automated using algorithms and the other manual, without any automation techniques. The fifth and final phase was dedicated to validating the results through data analysis and comparisons between both approaches using selected technical and methodological variables. This research was conducted over the years 2022 and 2023. The initial versions of the algorithms were developed in 2022 and were further refined in 2023, alongside the validation studies.

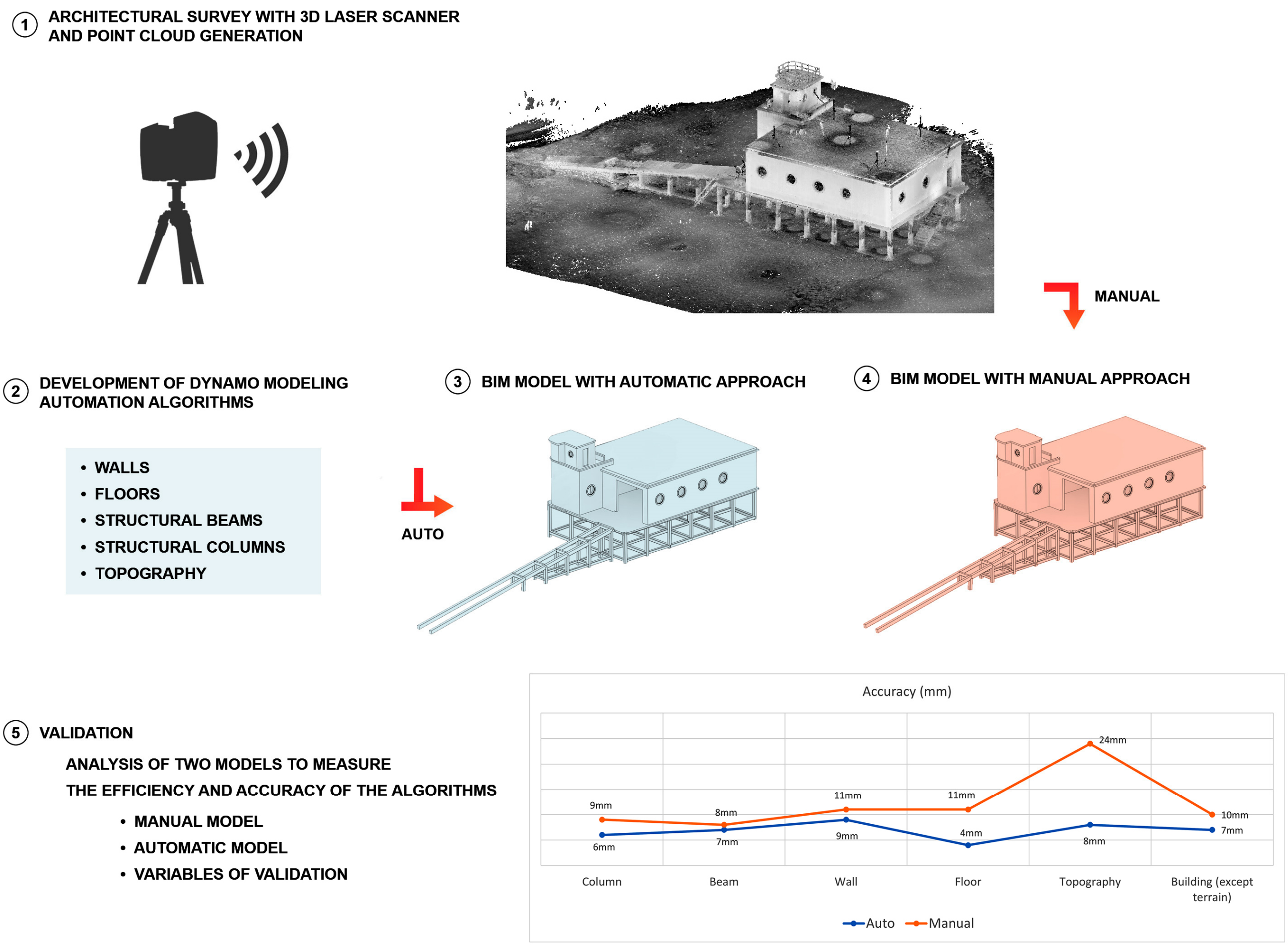

Figure 1. Summary of the five phases of this research.

In the modeling approaches we utilized, we classified them into three categories: manual, semi-automatic, and automatic. Manual modeling is performed without any algorithmic assistance. In the semi-automatic approach, the operator must provide more complex manual inputs to enable the algorithm to function, such as manually drawing the floor perimeter or adjusting the dimensions of elements created by the algorithm. The automatic approach involves minimal operator interference, limited only to common tasks across all approaches such as selecting points, choosing a base family for modeling, and defining the top and base levels of the element. It is conceivable to design algorithms that do not even require the user to select the family of levels. It is also common for a single project to have multiple levels, including intermediate levels within the same floor, making it essential to allow the operator to choose the top and base levels of an element, even if it is created automatically. For this reason, even though there are these minor inputs required from the operator, we still classify these approaches as automatic.

The chosen case study was the Old Lifeguard Station of Fuseta, located in the south of Portugal in the Algarve region (Figure 2). Unlike traditional buildings, this has some peculiarities that make it challenging while bringing various elements for testing. The first feature noted was that it is elevated from the ground, leaving its entire lower structure of concrete beams and pillars exposed, and because it is located on Fuseta-Ria beach, it has much degradation in its structure that is in constant contact with the ocean water. The access to the building's main floor is via a ramp and stairs located on its perimeter, and the access to the roof floor is via an internal staircase. The slabs have different levels and slopes, and they have many deformities; the roof slab has a significant slope for the flow of accumulated rainwater. The building also contains a series of walls with different thicknesses and some curved walls. Due to its high degree of degradation and poor construction process, the base structure of the building, containing the beams and pillars, presents many deformations, deviations, and rotations in their axes, which requires more careful modeling to represent them in their correct dimensions and positions.

Figure 2. Survey of the Old Lifeguard Station of Fuseta building, Portugal.

The architectural survey was carried out through laser scanning using a Faro Focus3D S120 laser scanner (FARO Technologies, Lake Mary, FL, USA), a Trimble R8 GNSS GPS (Trimble Inc., Westminster, CO, USA) to record the control points, and photographic equipment and a DJI Phantom Four drone (DJI, Shenzhen, China) to make the photographic record of the building. All algorithms were developed and tested on a computer with an Intel(R) Core(TM) i7-7700K CPU @ 4.20 GHz, 48G B RAM, NVIDIA GeForce GTX 1060 6 GB graphic card, and Windows 10 as the operating system. The software chosen for BIM modeling was Autodesk Revit due to its high acceptance in the market [19] and because it contains the visual programming tool Dynamo. Dynamo allows the creation of programming algorithms in order to perform tasks that are not allowed or that are too complex to be performed with the basic functions of Revit. Autodesk Recap v.22 and CloudCompare 2.12 alpha software [43,44] were also used to manipulate, clean up, and segment the point cloud and calculate the created model's accuracy.

The geometric reconstruction of the captured architecture needs to occur in a pragmatic and organized way, following the concepts and definitions pre-established in the previous item. Linked to these concepts, variables relevant to the methodological development of this investigation were selected from the literature review. These variables guided the research both in the development stage of studies and approaches and assessing and validating the results. The selected variables were divided into process and performance variables. Process variables are used to guide the researcher in their experiments, as they influence how the approach to the object will be made, including the use of techniques and tools. In this group, we had Level of Development (LOD), modeling type, element type, segmentation, and classification of the point cloud. The performance variables are related to the model's efficiency within the established process, with functions of quality control, analysis, and performance measurement. The variables chosen for this step were Level of Accuracy (LOA), time consumed, parameterization, and BIM element (Table 1).

Table 1. The conceptual and methodological variables selected for the model evaluation.

Variable	Indicator	Variable type
Level of Development (LOD) [18,45,46]	LOD 100, 200, 300, 350, 400, 500	Process
Modeling type [7,15,18,47]	Manual, automatic, Semi-automatic	Process
Element type [18,28,46]	Wall, Floor, Column, Beam, Topography	Process
Segmentation and classification of the point cloud [18,45]	Complete point cloud, Segmented and classified point cloud	Process
Level of Accuracy (LOA) [25,28,29,48–50]	LOA 10, 20, 30, 40, 50	Performance
Time consumed [45,51]	Hours and minutes	Performance
BIM element	Yes–No	Performance
Parameterization [45,46,52,53]	Yes–No	Performance

Among the process variables used, we have element type, a variable that classifies the existing elements in the building so that the modeling phase occurs independently of the other elements. Within BIM, a 3D model is not just a solid; it is linked to information, data, parameters, and geometric and non-geometric characteristics of the element it represents [26,38]. Thus, the function that a door represents in the BIM environment is different from the function of a wall, and this applies to all existing elements in the model. The modeling task is directly linked to the Level of Development (LOD) variable, as it is through the prior definition of the LOD to be achieved that the elements to be modeled are defined, and how this process should take place. Each building element has a specific LOD and the level of accuracy that is measured in each of them independently [18,28,46]. The modeling type variable classifies how modeling takes place [7,15,18,47]. It can occur manually, automatically, and semi-automatically; it can use a single tool or external tools to bring the desired result. The segmentation and classification of the point cloud variable refers to a preliminary moment in the modeling phase; this is a stage of active interaction of the modeler with the survey product, and the variables of the first phase also influence that. Here, the objective was to perform the necessary procedures to prepare the data to be used in the 3D modeling. The segmentation, cleaning up, and classification of the point clouds can happen manually or automatically [18,45]; this influences the time spent at the end of the process, and it also increases the performance of automatic approaches, as unwanted points and objects will not be processed by the algorithms.

The next step after modeling is validating the model through measurements and analysis with the application of the performance variables. This validation goes through three main concepts, which are (i) time consumed, (ii) geometric fidelity, and (iii) element functionality. The first variable used is the Level of Accuracy (LOA) [30–34], which measures the model's accuracy to the captured object. The LOA is not a fixed value, like the LOD; the definition of which LOA to be used varies according to the type of element being modeled, the type of building, and the needs and objectives for which the model is intended. This research used The U.S. Institute of Building Documentation Level of Accuracy (LOA) Specification Guide developed by the U.S. Institute of Building Documentation as a reference to identify the LOA of the model. The following variable is BIM Element, which is responsible for identifying if the model created is in its correct classification within the BIM system and if it behaves according to a native element in the software intended for that category. For example, a wall must be in the wall family category in the BIM workflow. It must allow the assignment of parameters and necessary information, as well as allow the creation of new internal layers with different thicknesses, in addition to interacting with other elements of the system (doors, windows, sweeps) in the same way as a native wall created with the manual approach would interact.

The following variable is parameterization, which within the BIM environment represents the degree of adaptability and transformation of the element and its ability to aggregate non-geometric information [45,46,52,53]. The effectiveness of BIM in AEC industry workflow is also related to agility and reproducibility. The BIM elements are not just static objects but should, if possible, be able to be adapted in their forms, sizes, and functions to be used in other situations; having parameterizable elements is essential for the efficiency of a BIM methodology [26]. Finally, we have the variable time consumed, which essentially refers to the time consumed in converting the point cloud into a BIM element. Reducing the effort–time binary becomes an essential part of the process when it comes to modeling optimization. Time is also directly related to the product's final cost since, in the BIM workflow, there are several actors involved, a qualified workforce, and the usual demands of a competitive market. It is essential to look for solutions that can reduce the time consumed with some tasks, or at least to not consume more time than usual, and that bring benefits in other spheres of the process. A viable solution, which is reasonable in terms of time consumption and requires less effort from employees, can contribute to disseminating the use of reality capture techniques applied to existing buildings.

3. Case Study

Following the architectural survey and subsequent processing and registration of the scans, a point cloud file was created to serve as the foundation for the BIM modeling phase. The survey itself utilized 89 scan stations. Statistics from the final C2C registration revealed a mean distance point error of 1.8 mm and a maximum distance point error of 10.2 m. The original point cloud generated comprised a total of 394,228,283 points, while the subsampled point cloud, adjusted to a density of 10 mm, included 42,232,997 points.

As well as any task of the BIM workflow, the modeling phase needs to be planned so that the final product will be consistent and used without significant incompatibilities in future work stages. In this research, we identified which the main elements of the building would be, which of them could have their reconstruction automated, and which would be manually modeled in the traditional way in Revit. In addition, the desired level of detail was established, which would be between LOD 200 and LOD 300 [46]. From this point on, the building was analyzed, divided, and classified according to its main elements: walls, floors, columns, beams, doors, windows, stairs, ramps, handrails, and topography. After that, we decided to develop modeling algorithms for the walls, floors, columns, beams, and topography; the other elements, such as doors, windows, stairs, ramps, and handrails, would be modeled using manual approaches because the types of algorithms we were going to develop would not be able to automate the modeling of these elements, at least not at this phase of the research.

The automation algorithms were developed using Dynamo, a visual programming language tool for Revit. Dynamo handles point clouds by performing point-to-point readings, but this method is impractical for very large datasets containing millions of points due to processing limitations. To manage this, some preprocessing steps, such as subsampling the point count, cleaning out unwanted points, or dividing the cloud into segments based on construction elements, are typically considered. However, these operations, particularly cleaning and segmenting by construction element, are time-consuming. Given that time efficiency is crucial for validating methodologies, this research opted to bypass these less common office procedures like segmentation and classification by building elements, as the majority of professionals rarely engage in these tasks [19]. Preliminary cleaning to remove unwanted points was not conducted, with the exception of topography, allowing the algorithm to be tested under maximum stress conditions. However, all the algorithms included a noise and artifact reduction operation, which we will discuss in more detail later when detailing the operations.

The only preprocessing operation performed before integrating the point cloud into Revit was the reduction of its density to a medium level (10 mm between points), a common practice in scan-to-BIM projects to avoid software performance issues. This density reduction and any necessary classifications were executed using Autodesk Recap prior to importation into Revit. By avoiding segmentation and cleaning, this approach closely aligns with the typical scan-to-BIM workflow, thereby allowing us to assess the effectiveness and efficiency of the algorithms under the most challenging conditions.

The point cloud can be used in its entirety, without the need to separate and classify elements individually. However, it is crucial that the elements are clearly visible and free from holes, empty spaces, or occlusions. For example, if an element such as a column embedded in a wall is not visible, it will not be possible to select the points corresponding to the column for the algorithm to identify its dimensions. The more visible the element and the more completely its faces are scanned, the better the performance of the algorithms will be. For walls, both faces need to be visible; for columns and beams, three faces are required, although in some cases it is possible to use the algorithm even if only two faces of these elements are visible.

3.1. Basic Operation and Structure of the Algorithms

The algorithms developed, with the exception of those for topography and flooring, which are somewhat simpler, follow a similar operational logic that can be divided into three stages. The process begins with the user selecting the points of the element to be reconstructed. After this selection, the Dynamo scripts analyze the geometry of the element, detecting basic information such as dimensions, positioning, insertion axes, existing rotations, among other aspects. Each element has specific characteristics; therefore, the information extracted from the point cloud varies depending on each case. For this reason, each algorithm has specific and customized operations. The final step involves incorporating the information gathered in the second step into the BIM element, facilitating the creation of appropriate family types for each situation, with the correct dimensions and characteristics and in their proper Revit categories. The basic stages of the algorithms can be divided according to the following structure (Figure 3):

1. Point cloud selection. In this stage the selection of points and the choice of project parameters necessary for modeling the family will be made.
2. Collecting geometry information. In this stage, the algorithm analyzes the geometry and takes the necessary measurements to integrate them into the BIM model.
3. BIM model creation. In this stage, dimensions and parameters are added to the element, the right family type is created, and it is properly positioned in the Revit environment.

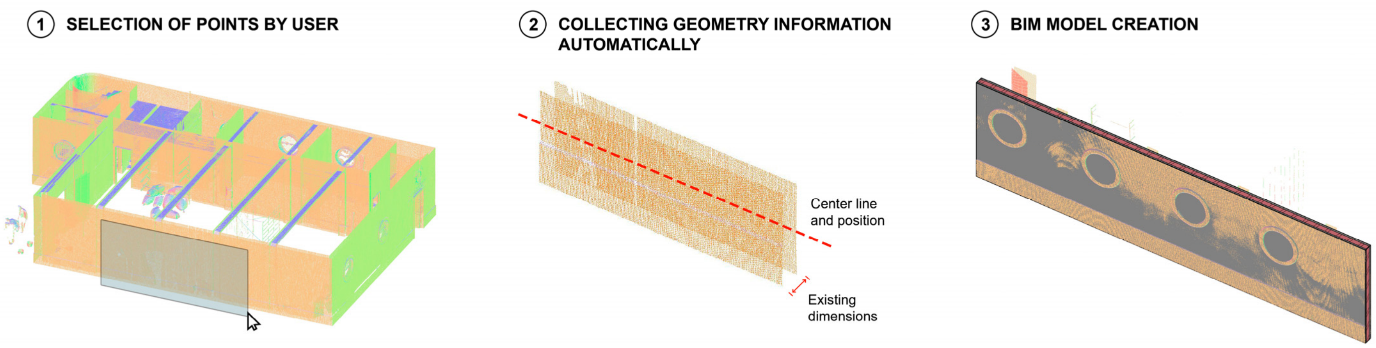

Figure 3. Summary of the three basic stages of operation for BIM modeling automation algorithms.

In addition to the Dynamo native command blocks called nodes, some external node packages were used to perform specific tasks:

- Sastrugi [54]: Used in stage one for point selection operation in the point cloud.
- Spring Nodes [55]: Used in stage two to group points by proximity for artifact cleanup and to identify existing rectangular profiles and rotations in beams and columns; in stage three, it was used to convert a numeral into a string, for duplicating and renaming the new types of families. It was also used to identify the floor perimeter for creating the topography subregion.
- Landform [56]: Used in stage two to collect the Cartesian coordinates of a point and to identify a midpoint on a curve.
- Clockwork [57]: Used in stage three to round a dimension according to rounding standards, and to create a new family type with the correct dimensions collected in stage two. It was also used to adjust the surface of the floor points based on the deformations measured in the point cloud.
- GeniusLoci [58]: Used in stage three to identify the correct layer of the BIM family for thickness adjustments.
- SteamNodes [59]: Used in stage two for conditional operations to choose between rectangular and circular profile columns.
- LunchBox [60]: Used in stages two and three to remove null numbers.

Users should select points for the element to be modeled in Revit's 3D view environment using the click-and-drag method, where a selection box is created by dragging the mouse cursor across the workspace (Figure 4). To ensure accurate selection, it is recommended to use Revit's section box tool to define your working plane and viewing area, isolating the region containing the element. It is crucial that the selected points accurately reflect the object's geometric shape and cover all its faces comprehensively. Points from unrelated elements should be avoided to maintain focus on the intended model. Each element must be selected one at a time because, in the current version, the algorithms are not capable of modeling multiple elements simultaneously. Although tests have been conducted to enable simultaneous modeling of multiple elements, these adaptations resulted in unsatisfactory performance due to an excessive load on computer processing, significantly slowing down the workflow and requiring more powerful computers. To circumvent these issues, the algorithm's capability has been restricted to handle only one element at a time for now.

3.2. Topography

The topographical surface modeling in Revit without plugins or external tools is usually quite laborious due to the great irregularity that a terrain commonly has. This modeling is time-consuming, and obtaining a model with high accuracy is not an easy task. Some commercial tools solve this problem, such as the Scan Terrain [61] plugin for Revit, but this research sought to develop an alternative in which it is not necessary to use third-party paid commercial tools. In addition, the algorithm brings greater flexibility and control over what will be modeled, which will be important when we take advantage of this algorithm to assist in the automatic modeling of floors and roofs.

The Revit topographic surfaces have a particular behavior; they have a more flexible and organic logic, differentiating them from other elements that work from a Boolean geometric logic with parameters assigned to their dimensions. The topography tool works by building a mesh with three-dimensional Cartesian points distributed along its entire selected area that, in the end, generates a three-dimensional topographic surface. After understanding the tool's working logic, it was possible to develop a strategy to collect the points related to the topography in the point cloud and convert them into a topographical surface in Revit (Figure 5).

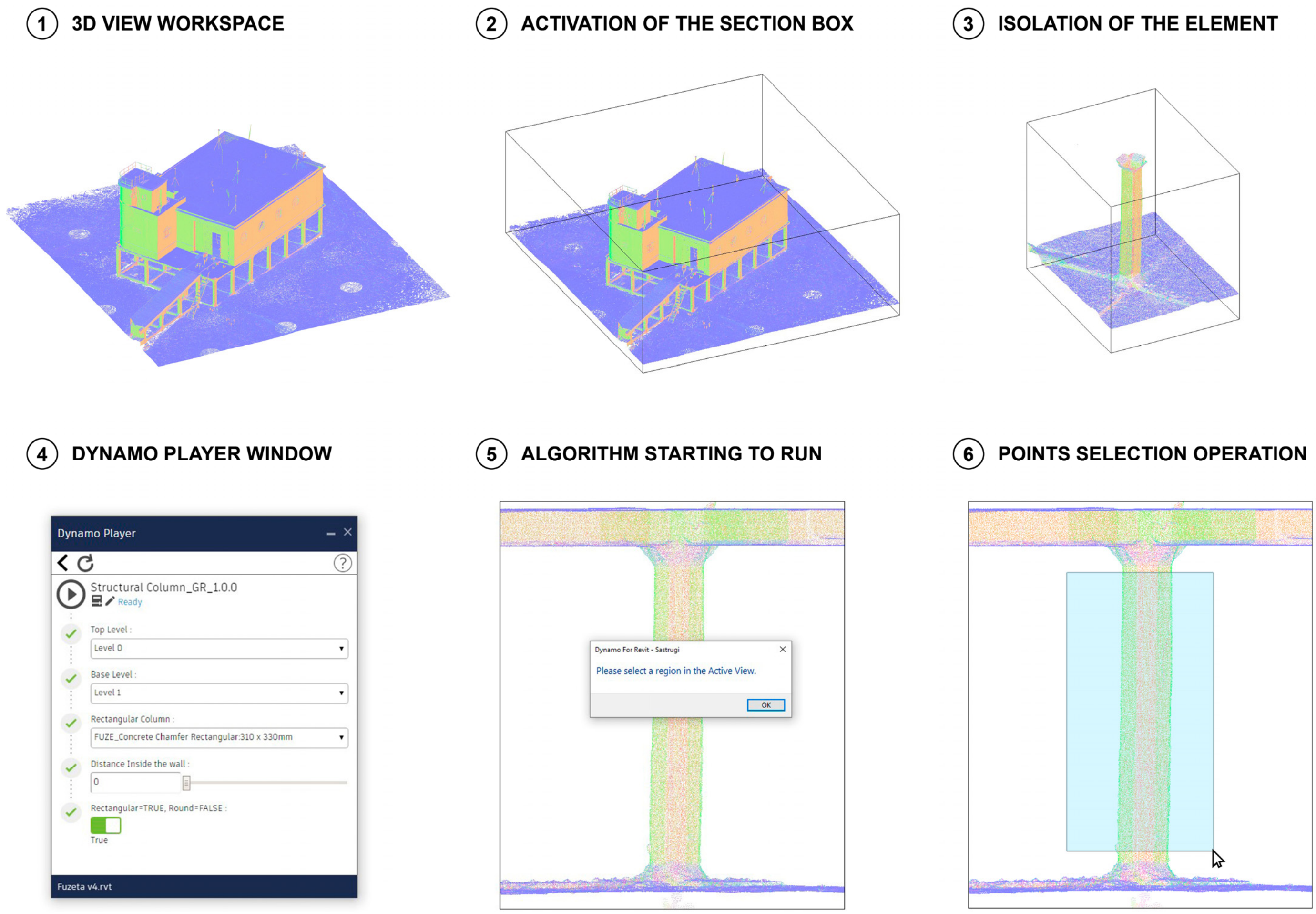

Figure 4. Example of the point selection procedure in the point cloud for using the algorithms.

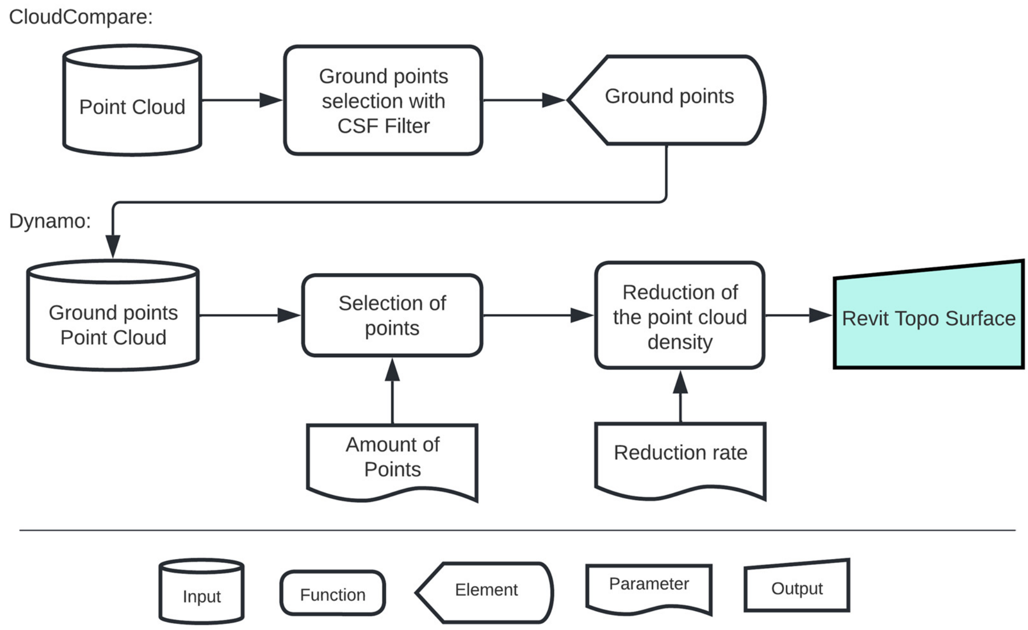

Figure 5. Diagram of the solution developed for the topography automation modeling algorithm.

The main point for the whole operation of automatic modeling algorithms is the selection of points. As a topographical surface often has many differences in elevation and irregularities, it is unlikely that the selection will be made properly without any unwanted points being selected. Therefore, only for these cases is it necessary to carry out a classification and selection operation of the terrain points in advance. This research used the CloudCompare software v2 to automatically select the ground points with the Cloth Simulation Filter (CSF Filter) plugin [62], as it is an automatic method and has good performance; the workflow was not compromised as it consumes little time in its execution. Beginning with Autodesk Recap 2023, this automatic terrain point classification can be performed within the software itself, eliminating the need for external tools like CloudCompare, which greatly optimizes the process. As this research was conducted before the release of the 2023 version, this function could not be utilized. After using the plugin, a new segmented point cloud is obtained, and work with Revit and Dynamo can be started (Figure 6). The point cloud is inserted into Revit and it is imported into Dynamo. An operation of point reduction was also developed so that the operator has control over the number of points that will be used in topography creation. A topographical surface does not need a high point density to have good accuracy; besides that, a topo element with fewer points and being faster to create compromises the computational processing less. After the subsample operation, this final point list was used to create the BIM topography in its correct category within Revit (Figures 7 and A1).

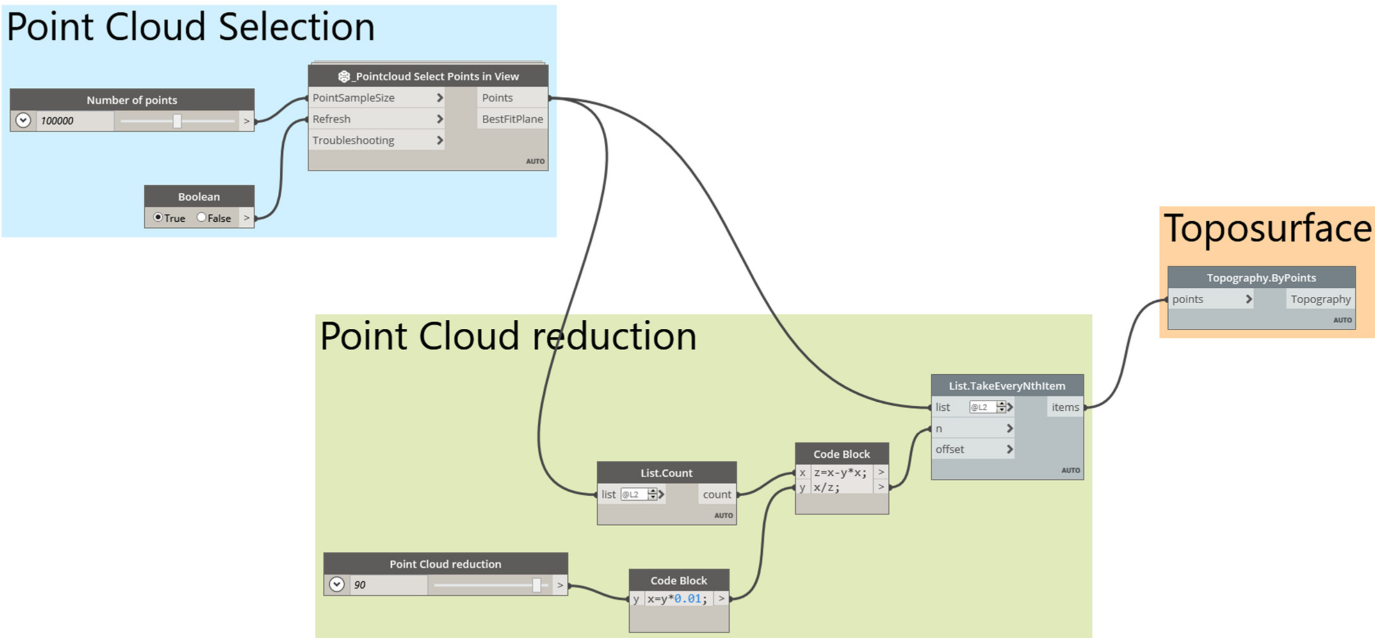

Figure 6. Dynamo's automatic topography modeling algorithm for Revit using point clouds.

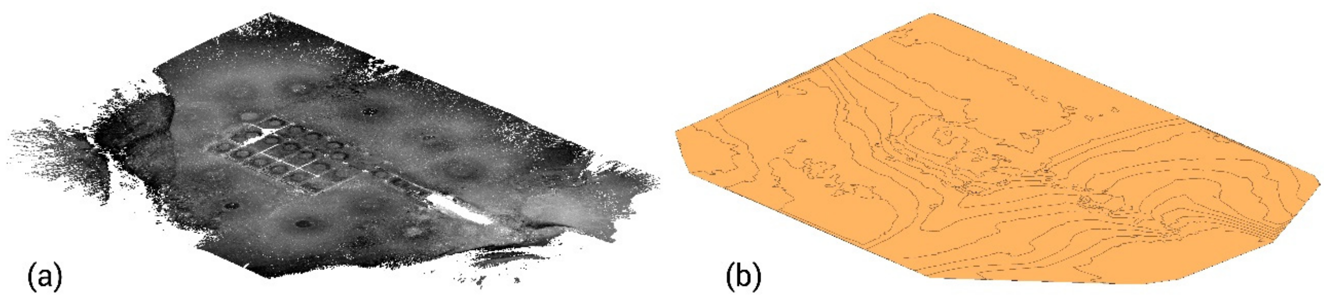

Figure 7. (**a**) Segmented point cloud classified with ground points, (**b**) BIM topo surface created in Revit using the algorithm developed with Dynamo.

3.3. Structural Columns

The Old Lifeguard Station of Fuseta building is raised from the ground and supported by twenty-eight structural concrete columns, fourteen columns that support its access ramp, and eight columns visible on its main floor. These columns have a chamfered rectangular profile with variations in length and width. In addition to corrosion and deformations at several points, the columns are not distributed in an orthogonal grid and present considerable deviations from their axis with the vertical direction and rotation along the axis (Figure 8). The modeling of these structural columns in a traditional and orthogonal way, ignoring their deviations in their axes and rotation, would bring a high level of inaccuracy and infidelity; besides that, identifying all deviations and rotations would consume too much time in the process and could bring results that are not accurate. For these reasons, an automatic solution for geometric detection and modeling is the best approach in this case.

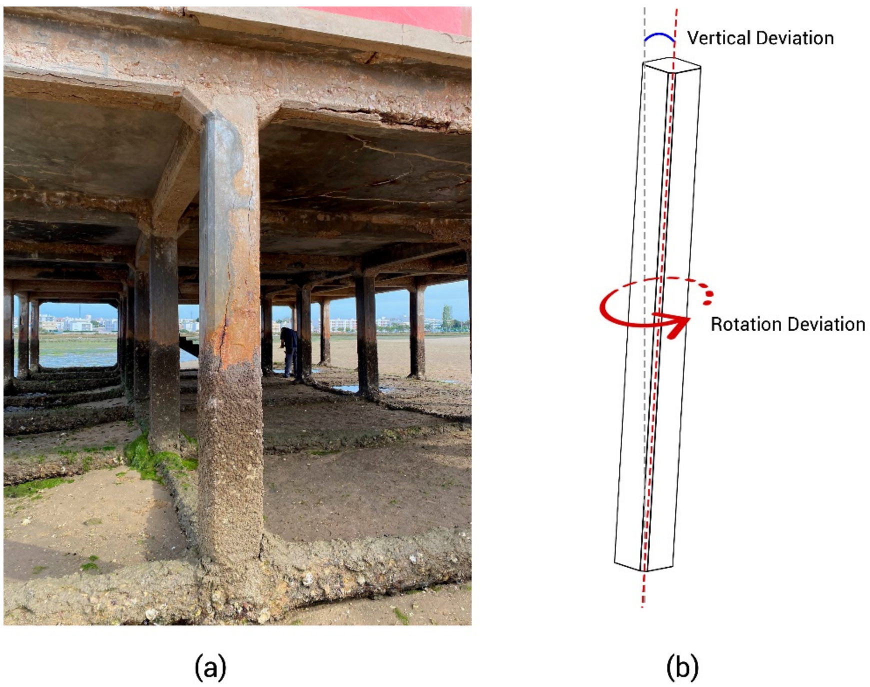

Figure 8. (**a**) Image showing the type and state of conservation of the structural columns from the base of the building. (**b**) Illustrative image of the existing deviations in the columns.

The algorithm for the automatic detection and modeling of the columns was developed so that it is not necessary to perform point cloud cleaning operations beforehand, unless in cases where there is a lot of noise, and artifacts that can make it challenging to identify the shape of the columns.

After inserting the point cloud in Revit, a selection of the corresponding points of the column was made. When running the algorithm, the user chooses the base and top levels of the column, the family to be used as a base, and the points used for the automatic detection of the geometry. For the script to have a good performance, the selection of points must be made to avoid including unnecessary points; even so, an automatic cleaning operation of artifacts and surplus points was developed, preventing the points that do not correspond to the columns from compromising the process. This noise and artifact cleaning operation was written and placed at the beginning of the code and is present in all the developed algorithms. It essentially groups by proximity the points in the selection and deletes those that are at a pre-determined distance greater than the set value, in this case, 15 mm (since the density of the point cloud used was 10 mm), but this value can be adjusted according to the needs of each project. After this cleaning-up operation, the automatic detection of the column profiles and their dimensions begins. As the objective was also to identify the existing vertical deviation, it was necessary to obtain two profiles in each column, the first being close to the base of the column and the second close to the top. The location of the profiles in the *Z*-axis is performed through a variable parameter defined by the operator because, in this way, there is more control over the best place to perform the measurement, an important factor in cases like this where the columns have deteriorated in their base due to marine corrosion. With the two profile positions identified, it is possible to create the axis where the column fits and automatically position the created column families with their correct names and dimensions. To calculate the dimensions of column profiles, the algorithm measures the average distance between the captured points in the point cloud and the detected column insertion axis; then, it performs a value rounding operation. The algorithm automatically applies a rotation operation to its axis after having the column positioned and aligned with the axis previously determined. The first rotation value is automatically obtained with the same custom node used to draw the top and bottom column profiles, the Points.MinAreaRectangle node. A second value is calculated from the intersection of the vector of the two central points of these top and bottom profiles and the vector of the *Y*-axis. The final rotation angle is obtained by comparing the first and the second values. The last step is automatically creating the column family in Revit with its correct category, dimensions, slopes, and rotations (Figures 9, 10 and A2–A4).

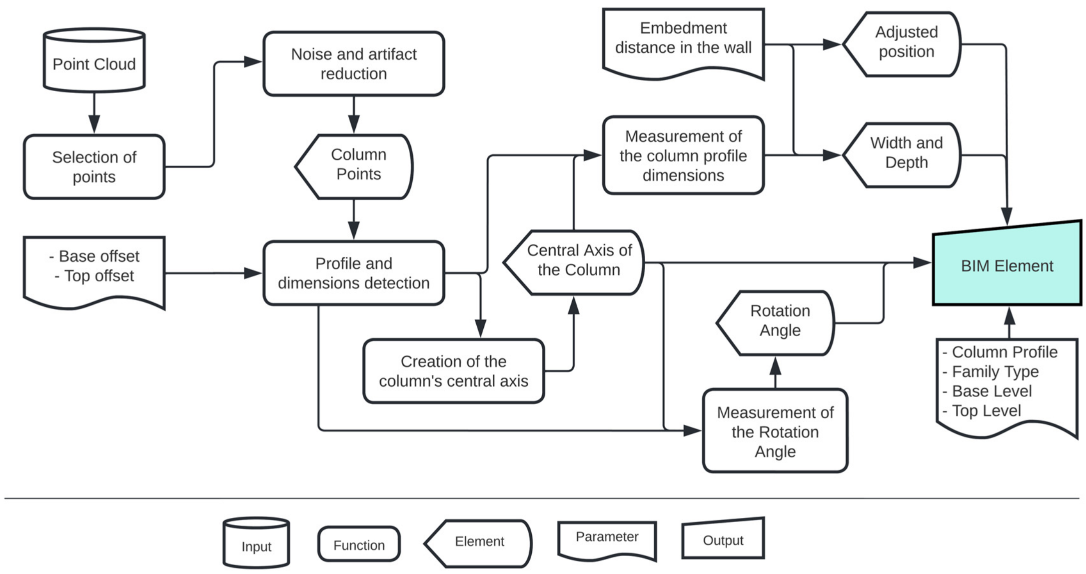

Figure 9. Diagram of the solution developed for the structural column automation modeling algorithm.

The columns on the main floor of the building are embedded in the walls, and since 3D laser scanning only captures the visible surface of the structure, the point cloud does not show the actual dimension of the column. To bypass this problem, a parameter was inserted in the code related to the distance of this offset inside the wall, which is defined by the operator using other data sources such as existing plans or inspections made in the structure. With this option, the column is created with its actual dimensions and positioning, even if it is built into the wall (Figure 11). The embedded columns also have a plaster covering, but in this study, this covering was ignored, and the column was modeled with the dimensions of the visible external face of the geometry.

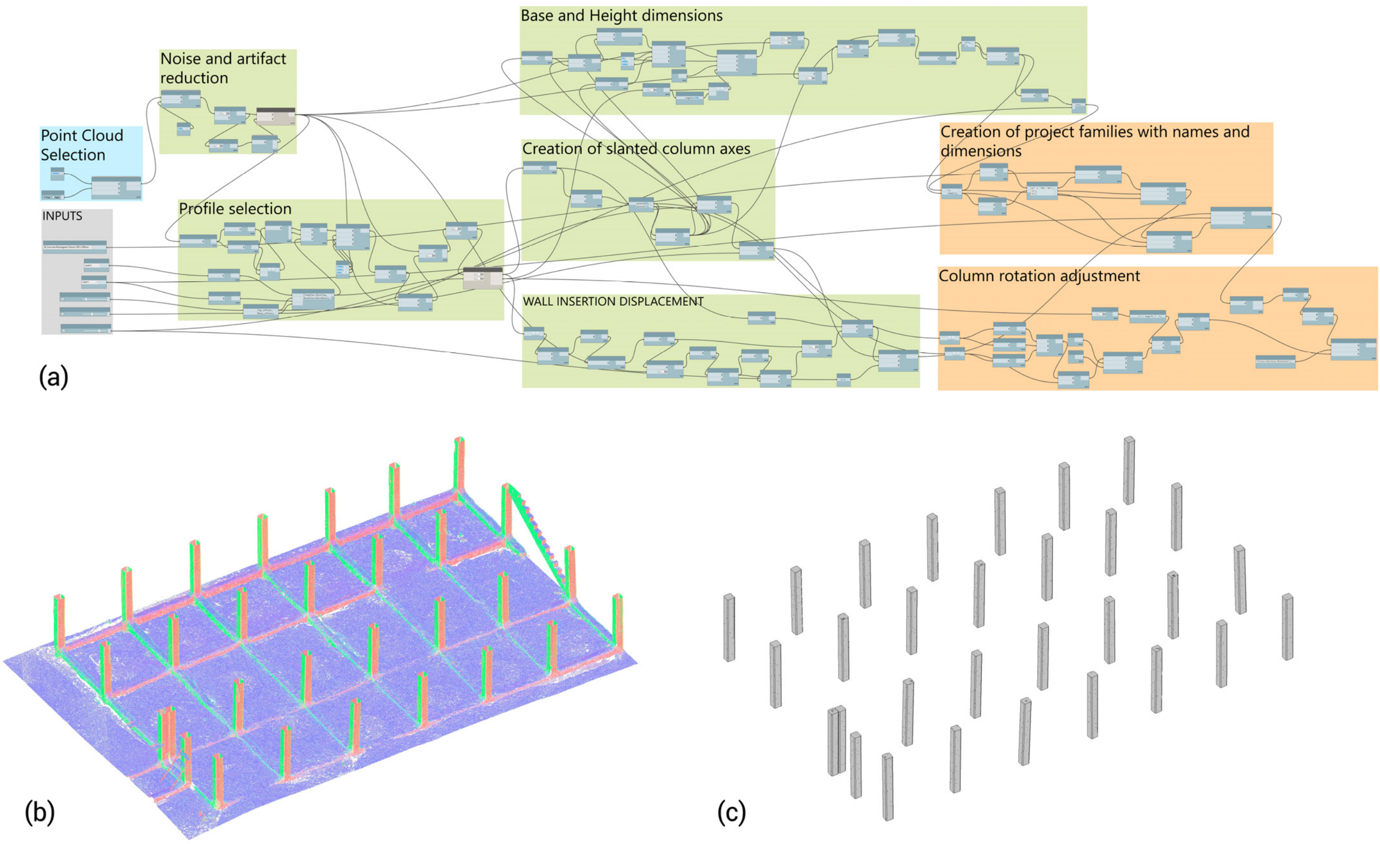

Figure 10. (**a**) Algorithm developed with Dynamo for automatic detection and modeling of structural columns. (**b**) Point cloud used. (**c**) The BIM elements created in Revit using the Dynamo algorithm.

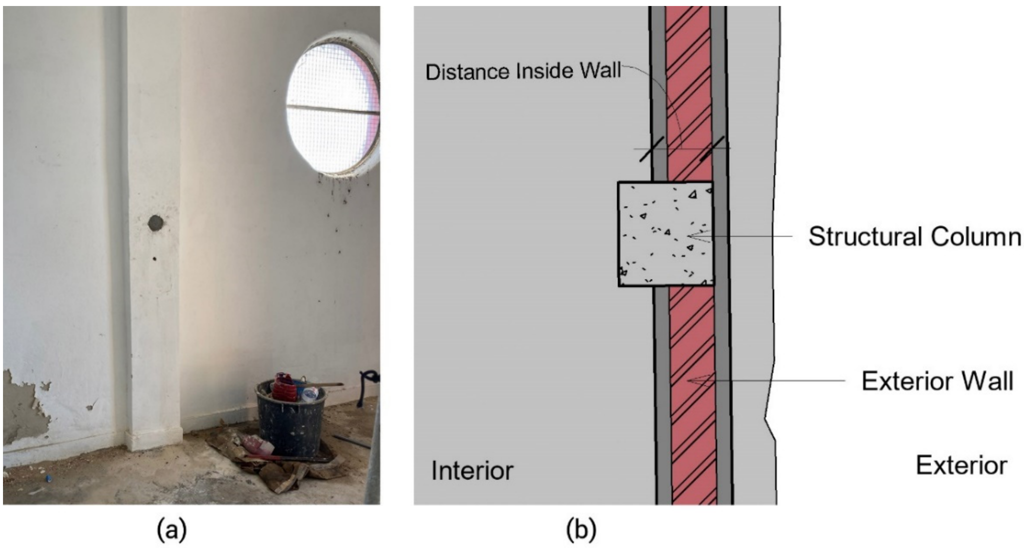

Figure 11. (**a**) Photo of the column built into the wall. (**b**) The floor plan showing the embedded column and the distance inside the wall is controlled by the user with defined parameters when using the algorithm.

3.4. Structural Beams

The building contains structural beams in concrete with rectangular profiles that support the structural slabs, and which are supported by the structural columns both on the lower and upper levels. In addition, there are also beams at the ground level connected to the columns to stabilize the structure, and beams that support the building access ramp. As with the columns, the beams have deviations in their horizontal axis, but they have a minimal deviation in their rotation axis; for this reason, these deviations in the axis of rotation were ignored. They also have many points of deterioration and oxidation, especially those located close to the ground and consequently in contact with water (Figure 12). The automation code needed to take these issues into account to develop solutions to circumvent this problem. As the algorithm works based on the captured geometry, deformities in the structure could compromise the detection of the real beam profile.

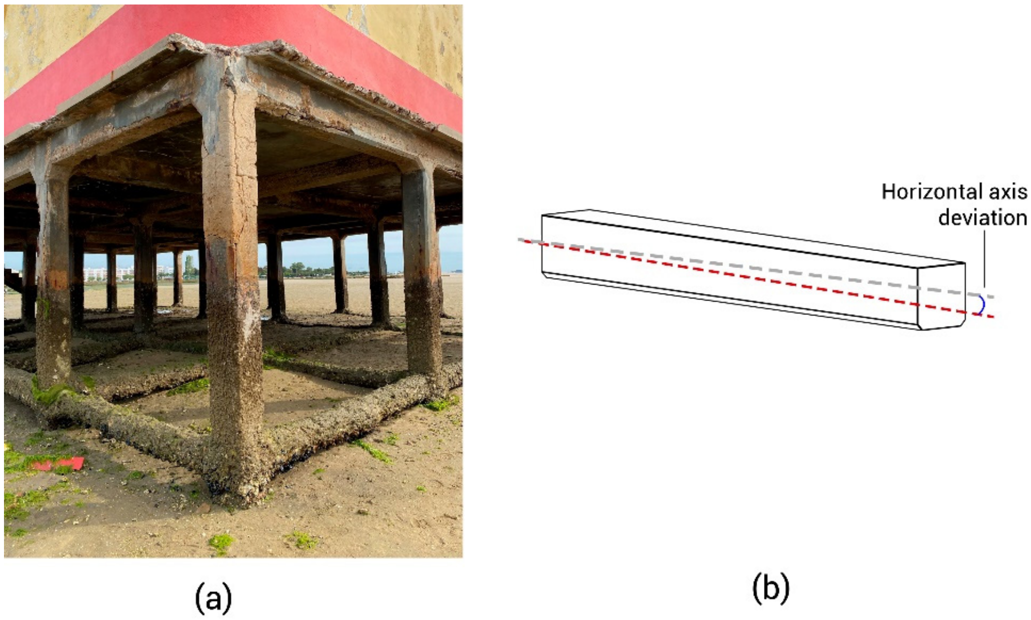

Figure 12. (**a**) Image of the structural beams of the building and their conservation conditions. (**b**) Illustrative image of the existing deviations in the structural beams.

The strategy of the solution for the detection and reconstruction of the beams is similar to that adopted for the columns, with the difference that now the worked element is arranged on the horizontal axis while the first is on the vertical axis. However, the same principle was used to the new element after some modifications such as adjustments to the work planes, different ways of grouping points, and rotation and transposition of elements to meet the requirement of working with the horizontal axis.

The beginning of the code is the same as the previous one, starting with the insertion of the point cloud in Revit and then with the selection of the points related to the beam to be rebuilt. Just like with the columns, although the algorithm includes an artifact cleanup feature, it is important for performance reasons to avoid selecting points that are not related to the beam. In the next step, the algorithm automatically selects points in two different positions, one at the beginning of the beam and another at the end; this distance can be adjusted by the operator. This action is crucial because it is from the position of these points that the two beam baselines will be created, one at its center and the other at its top. With these baselines, it is possible to extract the existing deviations in the beam placement. For this operation to succeed without errors or distortions, it is necessary for an inspection made by the operator in the element beforehand; this avoids selecting points from places where the beam is very degraded and without its original shape, as this could create distortions, compromise the baselines placement, and cause an error in the detection of the actual dimensions of the beam profile. After defining the center and top baselines, the algorithm measures the dimensions of the beam section and calculates the existing deviations. Finally, the BIM element is automatically positioned in place from the top baseline with its correct dimensions, deviations, and rotations, and is exported to the Revit environment as a family in its correct type and category (Figures 13, 14 and A5–A7).

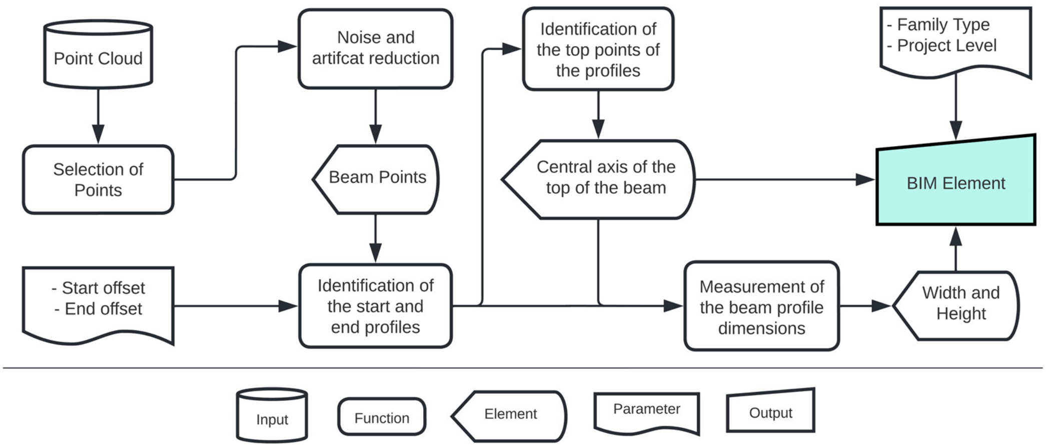

Figure 13. Diagram of the solution developed for the structural beam automation modeling algorithm.

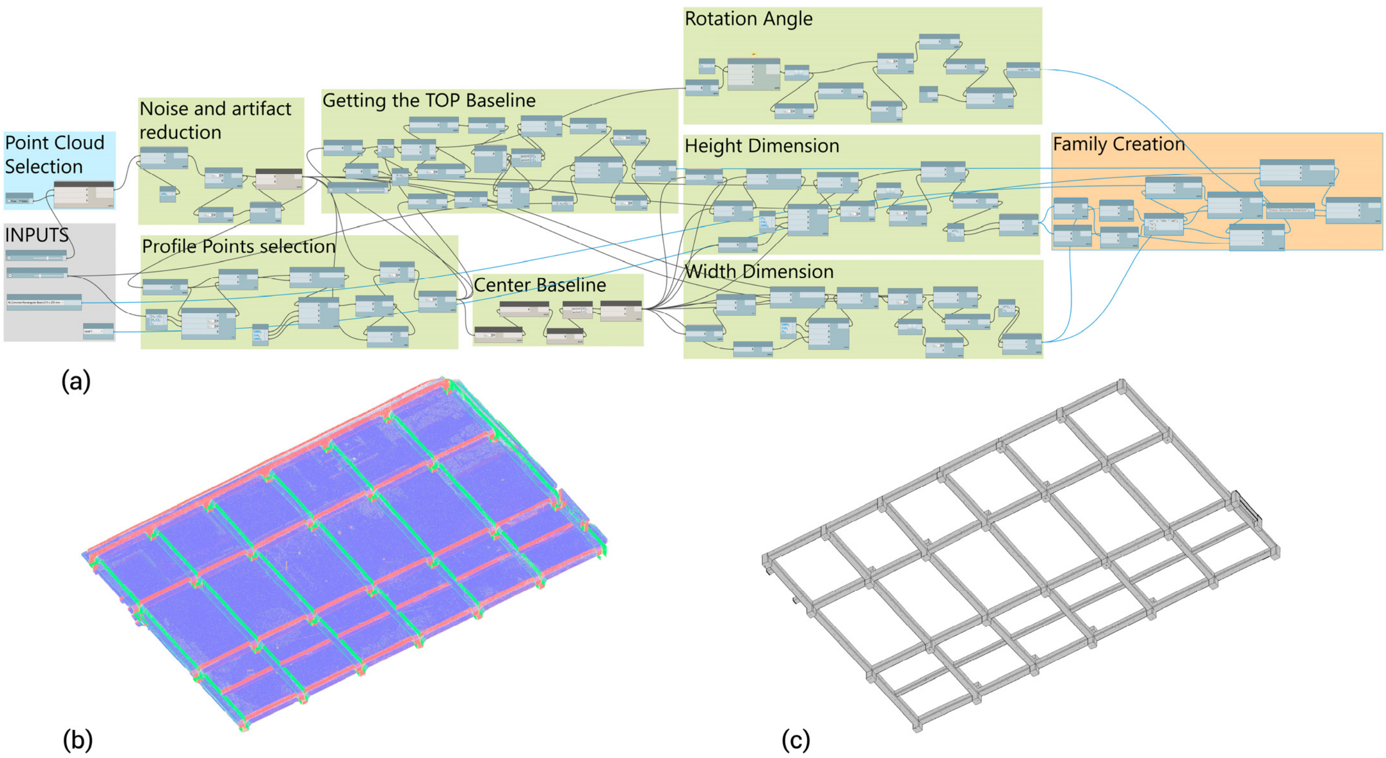

Figure 14. (**a**) The algorithm developed with Dynamo for automatic detection and modeling of structural beams. (**b**) Point cloud used. (**c**) BIM elements created in Revit using the Dynamo algorithm.

3.5. Walls

The code developed for the automatic wall detection and modeling followed the same logic used for the cases of columns and structural beams but with some necessary adjustments due to this element's geometric and non-geometric characteristics.

The algorithm works individually wall by wall, so the operator must select the points related to the wall that needs to be modeled in the point cloud. To optimize the code's operation, it is important to avoid selecting unwanted points from other elements or other walls and avoid including doors and windows in that wall. For this, it is necessary to carry out a previous inspection in the point cloud to define the best place and height to make the selection, which in most cases is above the final height of the doors and windows. It is also essential to select points from both sides of the wall, inner and outer sides. Although more points bring more precision, the algorithm also works with a reduced number of points. After this selection, the code performs a cleaning-up procedure of unwanted points and artifacts and isolates the points related to the wall profile at their starting and ending insertion points. With these profiles defined, the central wall baseline is extracted, and the automatic measurement of the wall thickness occurs. With this information obtained, the code creates the wall type with the correct nomenclature and thickness using the wall family type previously chosen by the operator and automatically positions it in its correct axis with its final height linked to the base and top levels, which were also defined by the operator when choosing the wall family type to be used (Figure 15).

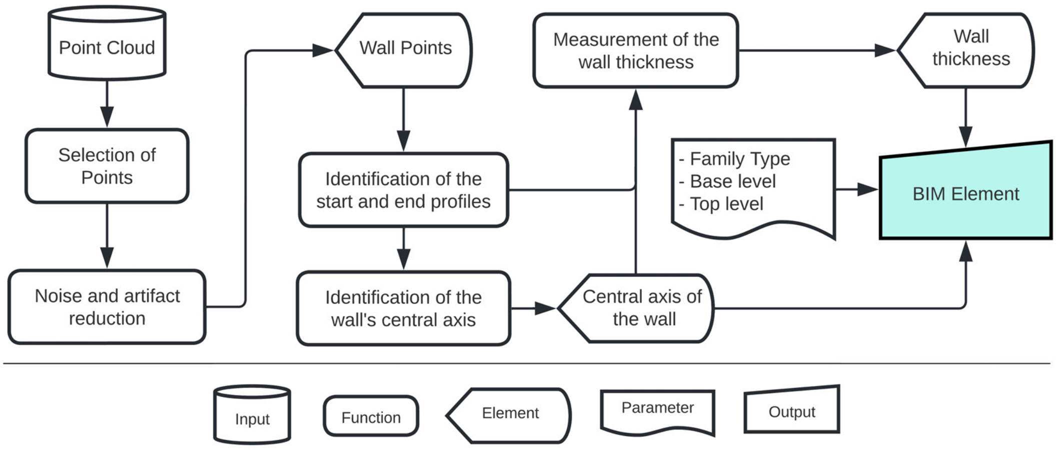

Figure 15. Diagram of the solution developed for the wall automation modeling algorithm.

The algorithm works with Revit wall families, whether they are simple or with their composite layers. The user selects the wall family to be used, and the algorithm automatically creates the type of wall family with the real thickness if no wall with the desired thickness is detected. The final thickness of the modeled element will always match the thickness detected in the point cloud. Thus, when composite walls are used, the thickness variation is made in the inner structural layer keeping the outer finishing and substrate layers intact. As in 3D laser scanning surveys, only the outer layer of the elements is captured; the choice of the family with the correct layers to be used depends on other information such as wall prospects or existing technical plans. Another characteristic of this code is that it was developed to model straight walls, so it does not model curved walls or existing vertical deviations (Figures 16, A8 and A9).

3.6. Floors and Roofs

In Revit, the floor and roof elements have a peculiar behavior as they accept changes in their shape with the addition of internal points at different heights. With this function, it is possible to create slabs and roofs with irregular shapes, which is not the case for other elements such as walls, beams, and columns. A code that recognizes the points related to the floor and changes the element's shape with the corresponding real heights was developed from these element characteristics. Unlike the other automatic approaches, in this case, a semi-automatic strategy was used because it is necessary to perform manual modeling with the perimeter limits of the floor before using the algorithm. The function of this algorithm is to define the surface of the floor with its deviations and slopes; however, it does not work to calculate the thickness of the floor or the interior layers.

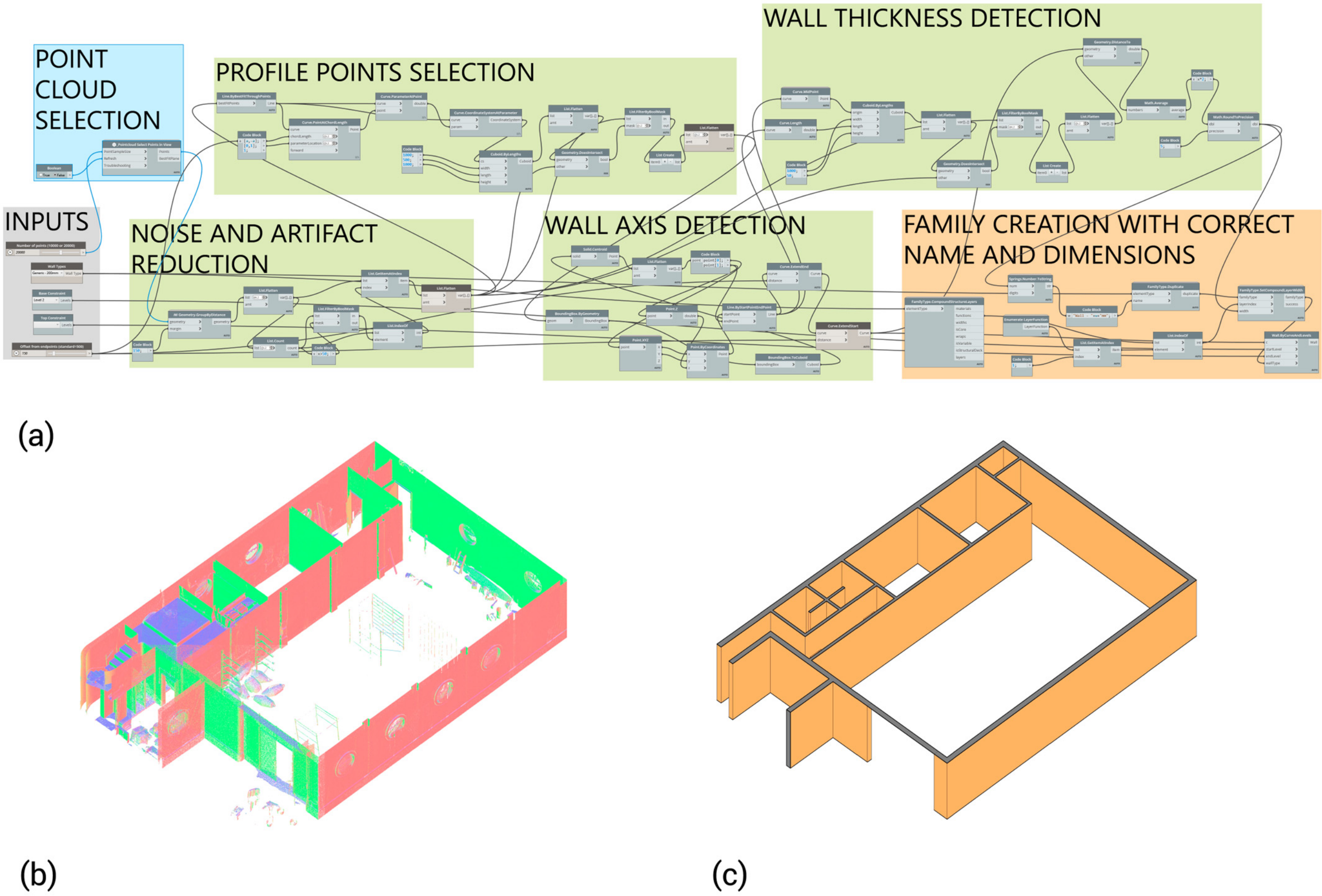

Figure 16. (**a**) The algorithm developed with Dynamo for automatic detection and modeling of walls. (**b**) Point cloud used. (**c**) BIM elements created in Revit using the Dynamo algorithm.

This algorithm works in three steps (Figure 17), the first of which is creating an auxiliary topography at the location of the floor to be modeled. The auxiliary topography has a temporary character. It enables the recognition and extraction of the spot elevations of the internal points on the slab, allowing it to capture and model all its deformities. In this step, the same code as the automatic modeling of the topography is used, but in this case, it is only performed in the region of the studied element. The second step is to create a region in the auxiliary topography with the limits of the floor perimeter. In this step, the operator must model the floor with its external limits with a manual approach. This step is necessary to delimit the area where the algorithm will operate and choose the type of floor used in the model. With this preliminary model and the auxiliary topography created, the second step of the code is used to create the region in the topography with the actual boundary of the existing floor. Finally, in the third step, the algorithm adjusts the floor so that its interior and perimeter points correspond to the auxiliary topography points, placing it in precisely the right site with high accuracy (Figures 18 and A10–A12).

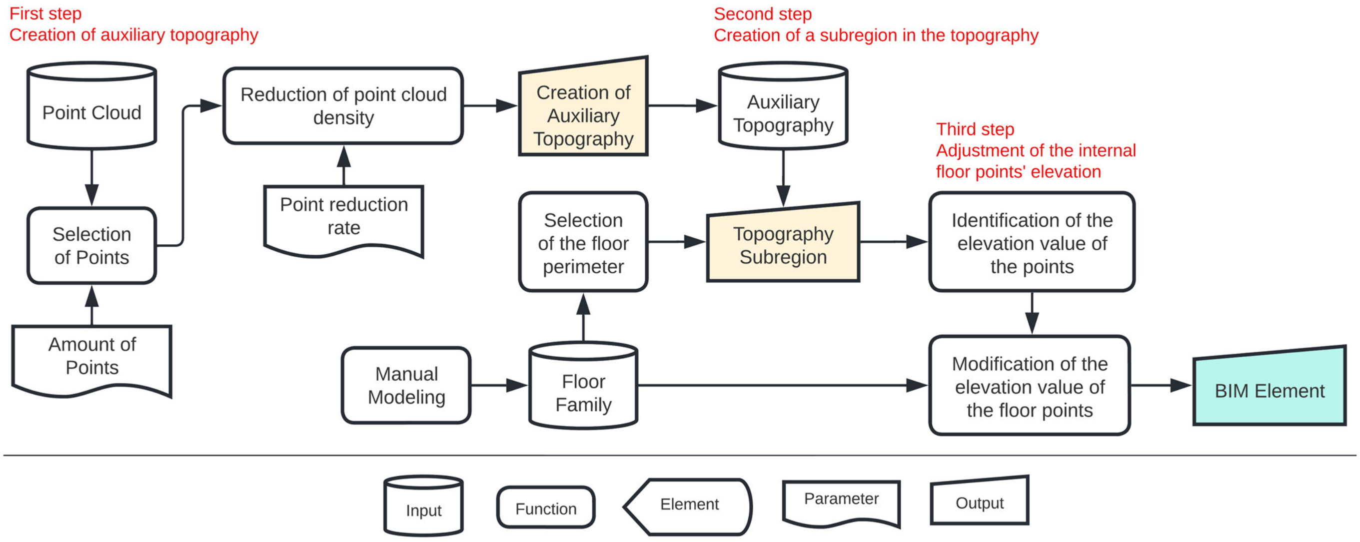

Figure 17. Diagram of the solution developed for the floor and roof automation modeling algorithm.

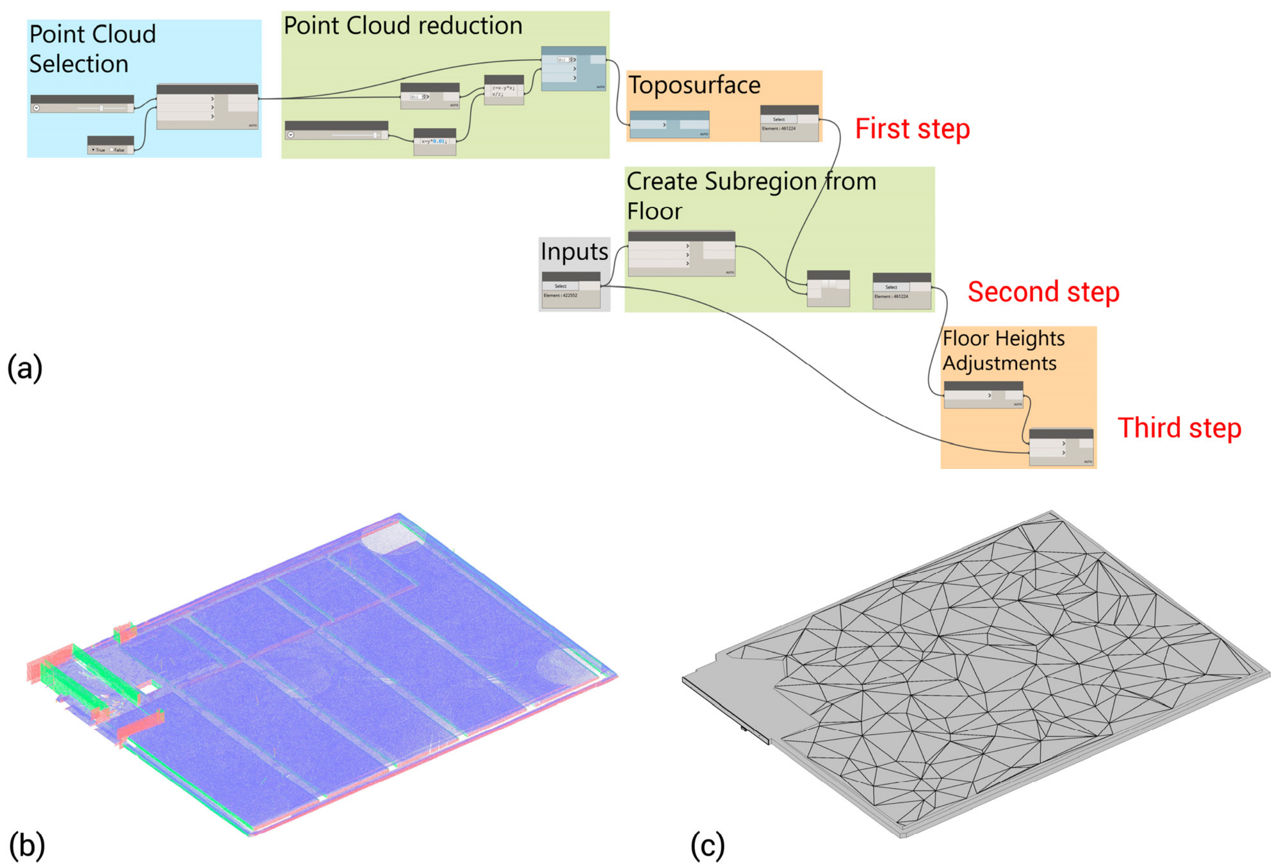

Figure 18. (**a**) The algorithm developed with Dynamo for automatic detection and modeling of floor and roof. (**b**) Point cloud used. (**c**) BIM elements created in Revit using the Dynamo algorithm.

4. Results

The physical characteristics of the Old Lifeguard Station of Fuseta building were analyzed on a case-by-case basis to define the modeling approach used for each element. It was chosen to prioritize automatic and semi-automatic modeling approaches for the most part. The manual modeling approach was used only in cases where there were physical limitations of the element, a lack of necessary points in the point cloud, or a pre-defined modeling strategy within the BIM workflow. Thus, the final model of the building had elements created with the three types of methods: automatic, semi-automatic, and manual approaches (Figure 19).

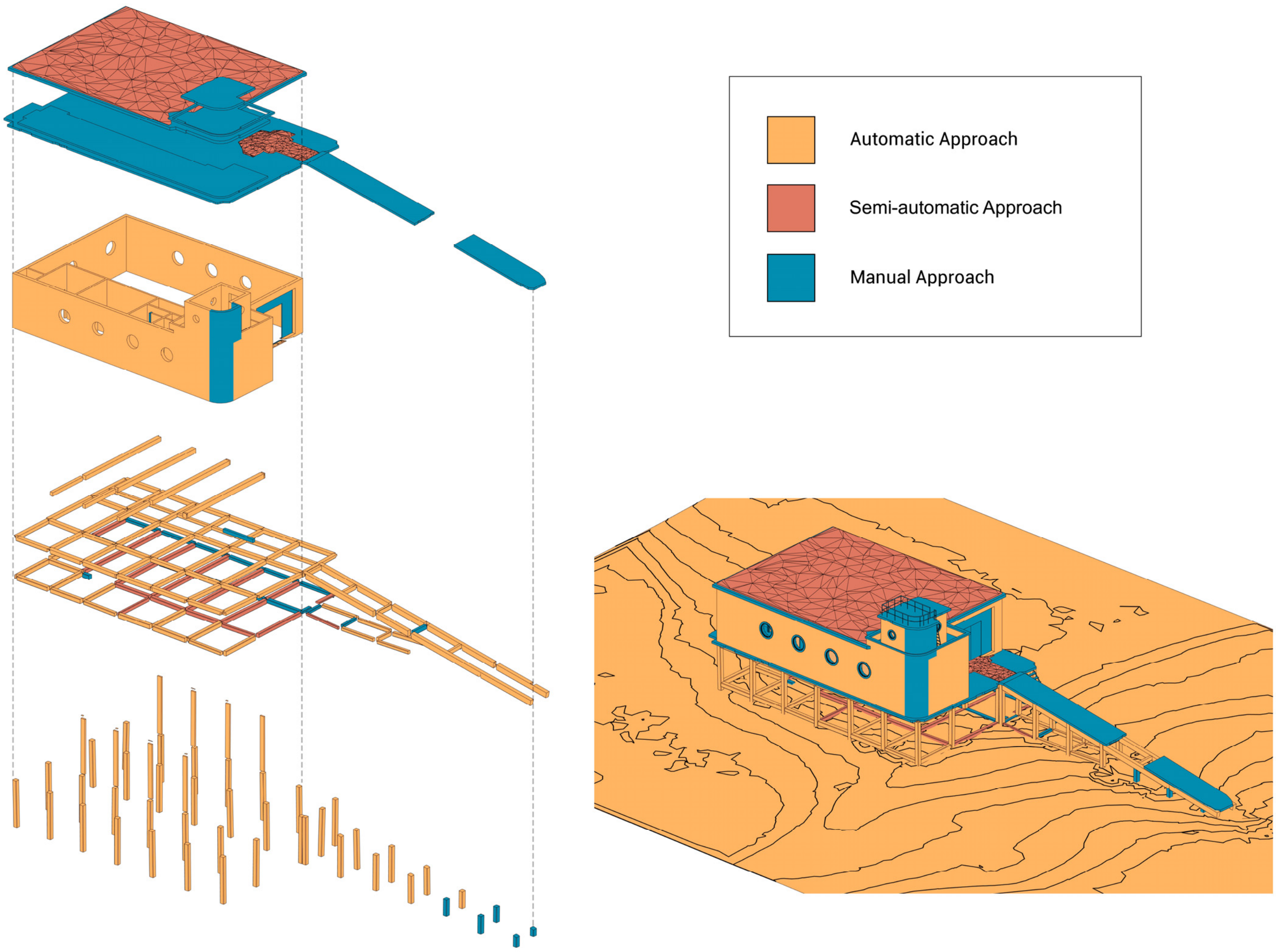

Figure 19. BIM model of the Old Lifeguard Station of Fuseta building created with automatic, semi-automatic, and manual approaches.

The building contains two types of structural concrete columns, one type located at the base of the building and the other on the main floor that supports the roof slab. The base and the support columns of the access ramp have rectangular profiles with chamfered corners. The columns on the main floor have a rectangular profile without chamfers. The algorithm developed for the columns can be used for both cases and allows the operator to choose which type of family should be used for the 3D reconstruction. A generic rectangular column was chosen for the main floor columns, and for the octagonal columns, a particular family was created. The building has 68 columns; 45 of them were created automatically with Dynamo script, and 5, located at the base of the access ramp, had to be created manually because they did not have enough points in the point cloud for the algorithm to recognize their shape and reproduce their geometry. Other than these columns, 18 were embedded columns and were not considered because they would need to be manually inserted using external data other than the point cloud. All columns were created as a native BIM element of the Revit software in its structural column category, and in all cases they were made with an automatic method. It was possible to position the element with its proper inclinations, deviations, and rotations.

The building's structural beam system is characterized by having three types of concrete beams of rectangular sections, one type located at the base of the building close to the ground, another type supporting the main floor slab and the access ramp, and a third located inside the building that supports the roof slab. The beams close to the ground, like the base columns, have a rectangular chamfered profile; the main floor support beams also have a rectangular profile but with chamfers only on their lower corners; and the building's internal beams are rectangular without chamfers. Specific families were created for the beams with a chamfer; a standard family of a rectangular profile from Revit was used for the type without a chamfer. In total, 127 beams were modeled, 90 of which were modeled with the automatic approach, 19 with the semi-automatic approach, and another 18 with the manual approach. The same algorithm was used for automatic and semi-automatic modeling; the difference between the approaches occurred in cases where the algorithm could not accurately identify the actual dimension of the beam profile, which was corrected manually afterward. These inaccuracies occurred only in the beams that were partially buried in the ground, which compromised the automatic detection of the dimension of the profiles, but this fact did not affect the identification of the correct position and height of the insertion of the beams. In a few cases, the beams were almost completely buried, or their profile significantly deteriorated by sea water and weather; in these cases, it was impossible to use the algorithm, and a manual modeling approach was chosen. Both beams and columns elements were modeled at the LOD 200 level of detail, which includes the correct type of structural concrete system and approximate geometry of structural elements (e.g., depth and width) [46], and does not include the sloping surfaces, connections, reinforcement, and other elements contained in higher LODs. When modeling the beams, the algorithm only reconstructs the section of points selected by the user, so at the end of the process, it is necessary to extend the start and end points of each beam to meet at the junction with the columns. This task is performed with Revit's "extend" command and takes little time and does not cause any model problems or inaccuracies.

The building has masonry walls with a thickness variation from 110 mm to 140 mm for the interior walls and 225 mm to 250 mm for the exterior walls, and they do not show large deviations in their vertical axis. Internally, the walls divide the existing spaces that are currently empty and the existing bathrooms (Figure 20). The algorithm was able to digitally reconstruct almost all existing walls except for curved walls, as it was made only for recognizing straight-line walls, and a partition wall of the building's access gate with point cloud occlusions. The walls were created without the doors and windows, which were ignored by the algorithm and later manually inserted into the project. The code uses the wall family chosen by the operator and creates the specific family types with the appropriate thickness for each of the cases. If the chosen wall is a generic wall without layers, all the walls will follow this typology; if the choice is for a composite wall with the inner layers, the algorithm keeps the chosen wall layers and applies the thickness variation to the inner structure layer.

The strategy developed for reconstructing the building's floors was slightly different from that used in the other elements. For this case, a combination of manual and algorithmic approaches was chosen according to pre-established criteria regarding the type of element, its function within the building, and the operating logic that the element performs within a BIM workflow. The algorithmic modeling developed aimed to reproduce all the deformities of the floors with great precision. Within the BIM methodology, this characteristic is not always expected or necessary because significant irregularities make it difficult to manipulate objects and compromise the proper functioning of subsequent operations. For this case, it was necessary to establish an acceptable level of model simplification, approximation, and tolerance according to the objectives for which the BIM model will be destined. The research identified which building floors needed to be represented without all the deformations, which would be modeled with the manual approach, and which floors would be modeled by the algorithm to represent all their deformities faithfully. The floors of the main floor and the access ramp were modeled manually and without the deformities on their surfaces, while the roof slab and a small access ramp at the front door were modeled by algorithm because we identified the representation of their deformities as necessary for this case. The BIM element created with the algorithmic approach is a floor family chosen by the operator and has all the physical and operating characteristics as the elements created manually.

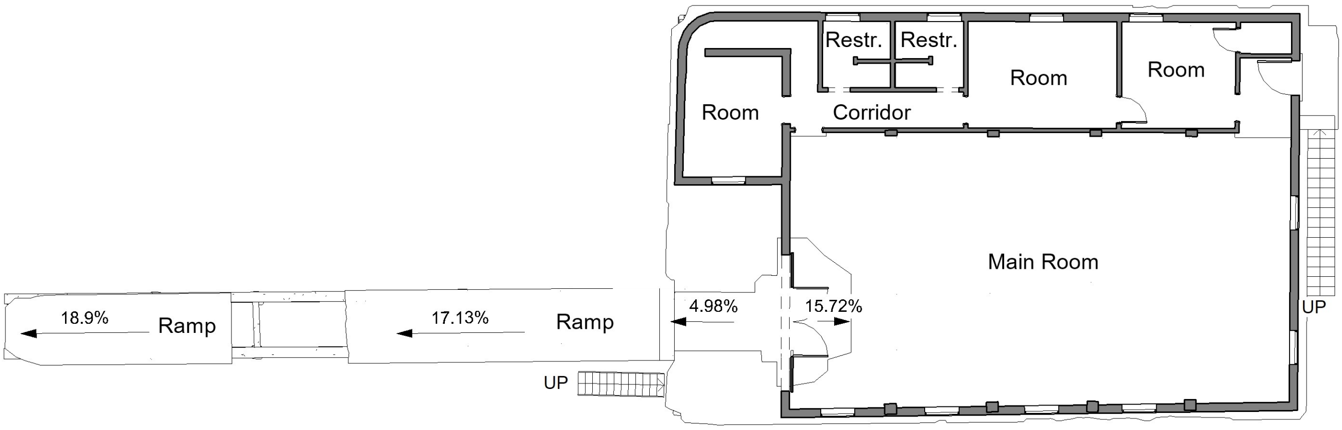

Figure 20. Floor plan of the main level of the Old Lifeguard Station of Fuseta building.

Besides outlining the components of the structure, we employed an algorithm to replicate the surrounding landscape of the building. By utilizing this algorithm we expedited the recreation process with accuracy, eliminating the need for manual adjustments to elevation points that would have otherwise been time consuming. Subsequently, we manually modeled features of the building such as doors, windows, stairs, and handrails to finalize the model with the desired level of detail.

The final model is a mix of elements modeled by the algorithm with automatic and semi-automatic approaches and elements modeled manually (Figure 21). The elements modeled by the algorithm showed a high accuracy rate and few deviations measured from the building's point cloud. The floors and columns showed the highest average accuracy, with 4 mm and 6 mm, respectively (Table 2), while the accuracy was 7 mm for the structural beams, 9 mm for the walls, and, finally, 8 mm for the terrain and topographic surface. To measure the performance of the algorithm in the beams' reconstruction, only the support beams of the main floor and roof were considered; the beams at the base of the building and the ramp were not included in this calculation because they had many problems with occlusion, corrosion, and deformities due to constant contact with sea water. In these cases, it was not possible to accurately calculate the accuracy and performance of the algorithm. After using the algorithmic approaches to create the final model, it was possible to reach an accuracy of 93.3% for accuracy of up to 25 mm and 80.6% for accuracy of up to 12 mm, and the average accuracy of the entire model was 8 mm; excluding the terrain, these values were 94.7%, 82.9%, and 7 mm, respectively. The total time spent modeling these elements was 5 h and 40 min. This time does not include the algorithm development time, as the idea is that the codes are reused in other cases and other situations, not just one-off solutions for this project but as a reusable approach. The rest of the building elements were modeled using the manual approach. The reason why some elements could not be reconstructed with the algorithms varied in each case. Some were due to their geometric characteristics that made it impossible to use the algorithm, others due to occlusion problems or a lack of points in the point cloud in the case of beams and columns, and others due to design decisions such as the slabs and access ramp. In addition, complementary elements such as doors, windows, stairs, and handrails that were not part of the automation studies were also included manually in the final model.

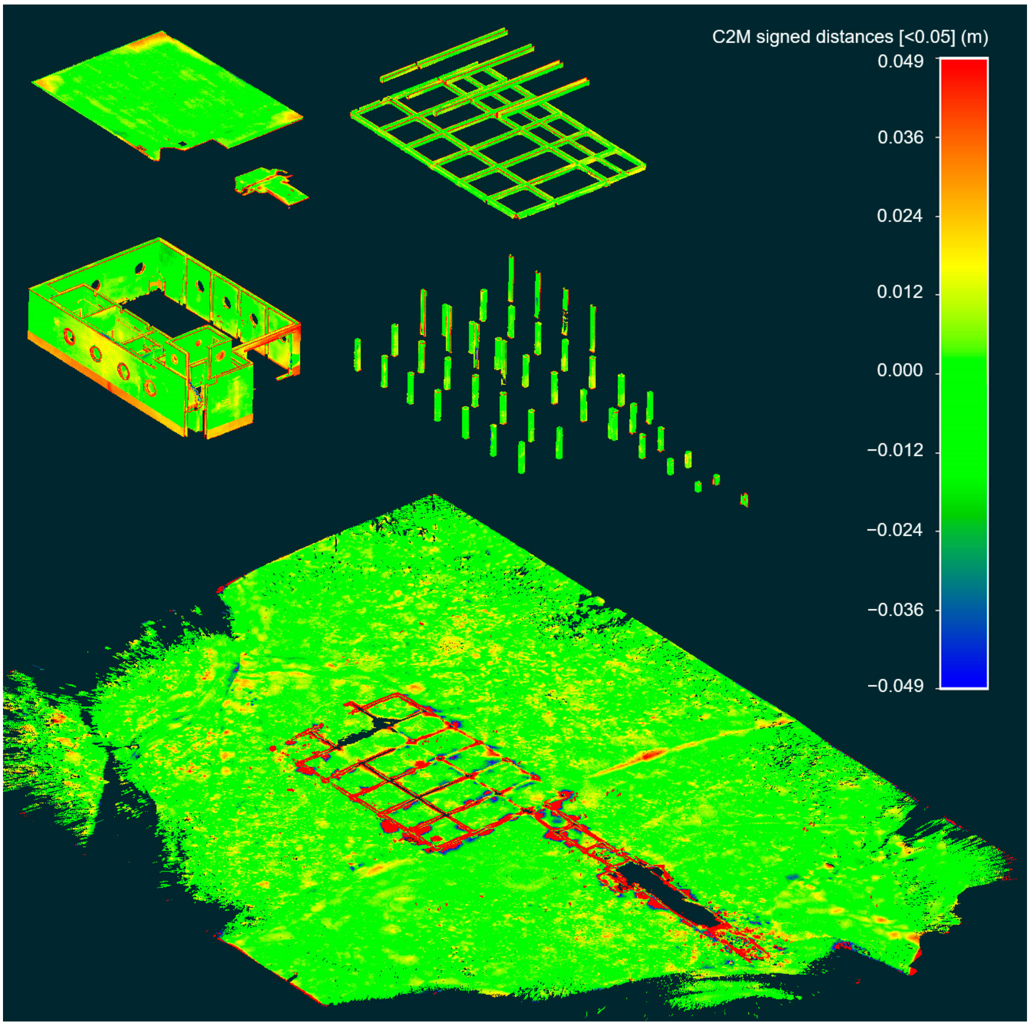

Figure 21. Level of accuracy of elements modeled by the algorithm with automatic and semi-automatic approaches compared to the point cloud obtained from the terrestrial 3D laser scanning of the existing building.

Table 2. Level of accuracy and the time consumed in the modeling using algorithms with automatic and semi-automatic approaches.

Element	Approach	Accuracy (% of Points) Up to 12 mm	Up to 25 mm	Average Accuracy	Time Consumed
Columns	Automatic	90.4%	96.9%	6 mm	1 h 19 min
Beams	Automatic	85.0%	94.0%	7 mm	3 h 11 min
Walls	Automatic	73.2%	90.6%	9 mm	33 min
Floors	Semi-automatic	92.3%	97.6%	4 mm	25 min
Topography	Automatic	84.3%	93.7%	8 mm	12 min
Building (except terrain)	Auto and Semi	82.9%	94.7%	7 mm	5 h 28 m
Total	Auto and Semi	80.6%	93.3%	8 mm	5 h 40 min

In order to measure the actual efficiency of the algorithms, the research created, in addition to the model built with the codes, a model built manually in the traditional way. The elements modeled in this new model were the same as those modeled with the algorithms, which allows a comparison between the two approaches in terms of precision, accuracy, and time consumed. These models created with a manual approach performed worse than those created by the algorithm in terms of accuracy and positioning (Figure 22). The overall average accuracy of model elements created with manual modeling was 18 mm, a difference of 10 mm compared to the model created with automatic and semi-automatic algorithms. If we exclude the terrain and only consider the building, the model presents a better accuracy of 10 mm, but it still has a 3 mm difference from the automatic model. The elements that presented the best accuracy were the beams and columns, with an average of 8 mm and 9 mm. The walls and floors presented the same accuracy value of 11 mm, while the topography was the element with the lowest performance, with an average of 24 mm of accuracy. The overall average performance of the model was 73.1% for an accuracy up to 25 mm and 49.5% for up to 12 mm, and an average accuracy of 18 mm; if only the building was considered, excluding the topography, this model presented a performance of 90.8% for an accuracy of up to 25 mm, 70.5% for up to 12 mm, and an average accuracy of 10 mm (Table 3). The total time spent in manual modeling was 6 h and 35 min. This time consumed can increase in cases where it is necessary to have better accuracy and precision.

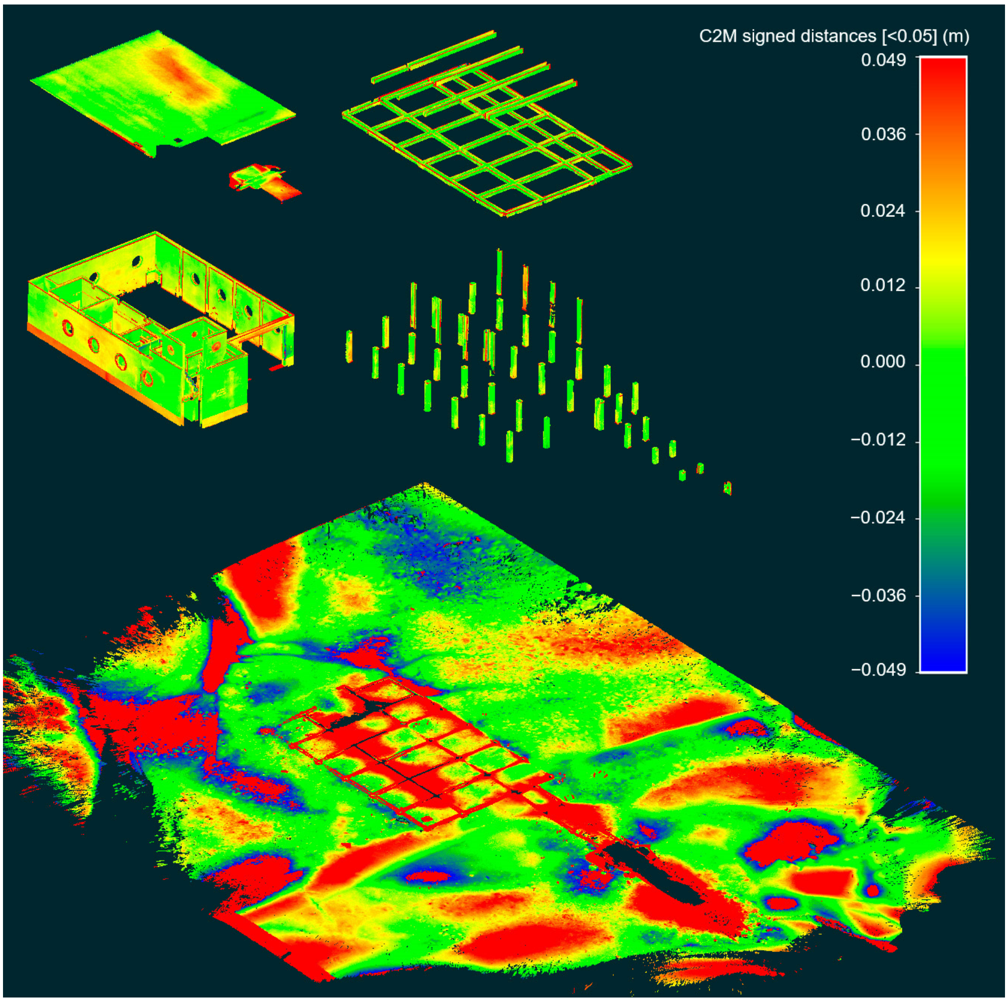

Figure 22. Level of accuracy of elements modeled with the manual approach compared to the point cloud obtained from the terrestrial 3D laser scanning of the existing building.

In general, in terms of time consumed to complete the model, the automatic method was 25% faster than the manual method, and 18% faster excluding the topography, (Tables 2 and 3). The element that showed the greatest variation between one method and another was the topography, which took only 12 min in the automatic method, while in the manual method the time consumed was 40 min, and if there is a need to improve the accuracy of the model, this time will increase. Although for some elements the gains in terms of time consumed are not significant, modeling manually requires complete attention and active interaction by the modeler, while with automatic methods much of this time consumed is just waiting for computational processing. Thus, the automatic method demands less from the operator in terms of concentration and, consequently, reduces the probability of failures due to a lack of attention. Another factor to note is that the time consumed with automatic methods can be reduced using more powerful computers, while the time consumed with manual methods can increase if the modeler is not so experienced.

Table 3. Level of accuracy and the time consumed in the modeling using a manual approach.

Element	Approach	Accuracy (% of Points)		Average Accuracy	Time Consumed
		Up to 12 mm	Up to 25 mm		
Columns	Manual	77.8%	93.6%	9 mm	1 h 59 min
Beams	Manual	82.3%	92.8%	8 mm	3 h 20 min
Walls	Manual	62.8%	89.7%	11 mm	42 min
Floors	Manual	69.9%	87.8%	11 mm	25 min
Topography	Manual	32.4%	57.4%	24 mm	40 min
Building (except terrain)	Manual	70.5%	90.8%	10 mm	6 h 26 m
Total	Manual	49.5%	73.1%	18 mm	7 h 6 min

The overall efficiency of the model created by the algorithm was higher in terms of performance and accuracy. When using an accuracy of 25 mm as a reference, we noticed that the automatic and the manual methods were accurately equivalent. The building model made with the automatic approach (excluding the topography) performed only 3.9% better than the one with the manual approach. When changing the accuracy category to 12 mm, a more significant variation in the model's precision can be seen; for this category, the model from automatic methods was 12.4% better in performance than the model created manually; this value increased to 31.1% if the entire model with the topography is considered (Figure 23). The average accuracy of each element was also calculated individually, and, in all cases, the automatic methods returned better values in terms of accuracy than the models created by the manual method. The structural beams had a minor variation in their average accuracy with a value of 1 mm, and the rest of the elements presented a variation between 2 mm and 7 mm, except for the topography, which had a variation of 16 mm between the two approaches. The element that presented the highest variation was the topography; the automatic approach increased the model accuracy by 66.7%. The floors also had a high variation, in this case, 63.6%. These numbers reflect that modeling organic and irregular shapes in a traditional way, besides being a laborious and time-consuming task, can produce an inaccurate result. The structural columns also present a significant variation between the approaches; for this element, the automatic methods produced a model 33.3% more accurate than the manual approach. The elements that presented a minor variation were the walls and structural beams; however, for these cases, the automatic method was still more accurate, at 18.2% and 12.5%, respectively. In terms of the average accuracy for the entire project, the building model created with the automatic methods was 30% more accurate than the one created manually. This value increases to 55.6% if the topography surface is considered (Table 4).

Table 4. The average accuracy of models created by automatic and manual methods, the difference in accuracy between methods, and rate of accuracy increase.

Element	Automatic Method	Manual Method	Accuracy Difference (mm)	Accuracy Increment (%)
Columns	6 mm	9 mm	3 mm	33.3%
Beams	7 mm	8 mm	1 mm	12.5%
Walls	9 mm	11 mm	2 mm	18.2%
Floors	4 mm	11 mm	7 mm	63.6%
Topography	8 mm	24 mm	16 mm	66.7%
Building (except terrain)	7 mm	10 mm	3 mm	30.0%
Entire Model	8 mm	18 mm	10 mm	55.6%

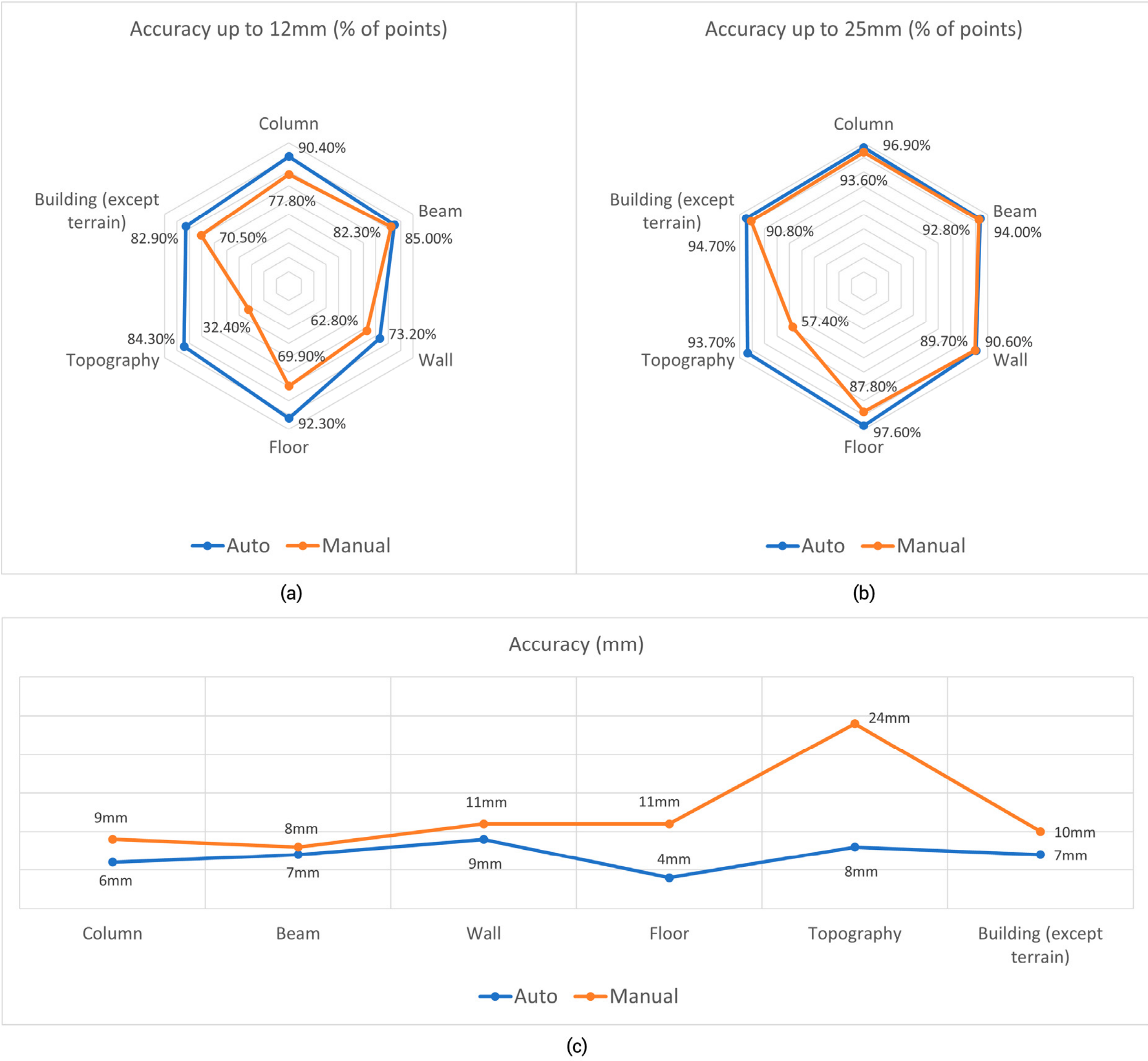

Figure 23. Charts comparing the accuracy between models created by automatic and manual modeling approaches. (**a**) Percentage of points for accuracy of up to 12 mm. (**b**) Percentage of points for accuracy of up to 25 mm. (**c**) The average accuracy of all elements.

5. Discussion

The pursuit of optimizing scan-to-BIM processes does not always involve reducing the time spent on modeling. Although speed is important, the optimization objectives also include representing the captured elements with high geometric fidelity, structural coherence, functionality, and performance; all these objectives must be achieved while maintaining a tolerable level of accuracy, approximation, and simplification of the model. The high complexity of buildings, especially when it comes to historical heritage buildings, makes it difficult to expand the use of BIM for building surveys and projects with existing buildings; in a recent survey, only 40% of the professionals interviewed indicated using BIM in more than three-fifths of their projects, and this number drops to 25% when it comes to heritage buildings [19].

The Old Lifeguard Station of Fuseta building showed different challenges in each element's modeling, reflected in different solutions and approach strategies in each case. Despite being a small building with a low complexity of details, it is rich in terms of various shapes and structural solutions. The characteristics found in this case, such as levels with different elevations and steps, deformities, and inclinations in the slabs, building structures with spots of corrosion and abnormalities, and deviations and irregularities in the beams and pillars, brought a problematic complexity to the research, but, at the same time, they were decisive for a better and more complete development of the algorithms.

The algorithm's performance depends on the computer's data processing capacity, the point cloud size, the number of points to be processed, and the number of elements that must be created simultaneously. Thus, a segmented point cloud with unwanted points removed is easier for the algorithms to work and benefits the 3D reconstruction process. However, cleaning and segmenting the point clouds can consume much time in the process, and usually many companies decide not to perform this step. In a recent survey, 64.5% of professionals said they rarely segment the point clouds by building elements, 48.9% said they rarely segment by building floor or levels, and 22% rarely perform any cleaning procedure to remove unwanted points [19]. For this reason and to perform a stress test with the worst possible scenario, we used the algorithms with the complete point cloud, without any editing, cleaning, or segmentation, except for the topography modeling.

After creating the models, the analysis of the results began, and a phase was foreseen in the investigation to validate the developed methodology and measure the efficiency of the algorithms. As mentioned in Section 2 of this article, the validation was carried out based on three main performance concepts, which were the time consumed, geometric fidelity, and element functionality, through variables selected from the conceptual and methodological references used in this study, which were the element type [18,28,46], modeling/approach type [7,15,18,47], point cloud classification and segmentation [18,45], Level of Development (LOD) [18,45,46], Level of Accuracy (LOA) [25,28,29,48–50], BIM element, parameterization/parameter assignment [45,46,52,53], and time saved [45,51].

The elements were analyzed individually by their categories and their function in the building. They were also classified according to the approach and point cloud type. The type of approach was divided into automatic or semi-automatic; the elements made with the manual approach were not objects of analysis because the objective was to validate the performance of the process automation algorithms. The level of development of the models built with the experiments varied between LOD 200 and LOD 300, according to the definitions of the American Institute of Architects [63], as they correctly represent the three-dimensional geometry of the element, its thicknesses, and dimensions, but without the characteristics of superior LOD data such as the 3D representation of internal elements, join, or connections details. The topography model represents its 3D surface and does not contain site equipment, external structures, and existing foundation elements, classified as LOD 100.

Regarding the level of accuracy of the model, all elements fit within the LOA range recommended by the U.S. guide Institute of Building Documentation (USIBD) [28]. The elements ranged between LOA30 and LOA40, where LOA30 represents an accuracy between 15 mm and 5 mm and LOA40 between 5 mm and 1 mm. In all cases, the elements were created in their correct BIM categories and with the possibility of assigning parameters and attributes in the same way as any native element of Revit. It is possible to incorporate the model into a BIM workflow without any interference or incompatibilities, combine its elements with other existing elements, and increase its LOD as the project develops. The automatic approach was 25% faster than the manual approach, and this gain can have a big impact on larger or more complex projects (Table 5).

In addition to the comparative analysis between the two models, a quantitative assessment of the algorithms' efficiency in BIM modeling of building elements was also performed (Table 6). The automatic approach demonstrated strong performance in the number of elements it could digitally reconstruct. The automatic method managed to model 90% of the building's columns, 70.9% of the existing beams, and 75.8% of the walls. For the beams, the algorithm was applied to an additional 15%, but due to occlusions, it could not fully reconstruct these elements, managing only to position them and define their inclinations. In these instances, the dimensions had to be measured and set manually because the beams were buried underground and in poor condition, leading to their classification under the semi-automatic method.

Table 5. Table with the validation variables for analyzing the performance of the elements created in the model with the algorithmic approaches.

Element Type	Approach	Point Cloud	LOD	LOA	BIM Element	Parameter Assignment	Time Saved
Columns	Automatic	Completed	LOD 200	LOA30	Yes	Yes	40 min
Beams	Automatic	Completed	LOD 200	LOA30	Yes	Yes	9 min
Walls	Automatic	Completed	LOD 300	LOA30	Yes	Yes	9 min
Floors	Semi-automatic	Completed	LOD 200	LOA40	Yes	Yes	0 min
Topography	Automatic	Segmented	LOD 100	LOA30	Yes	Yes	28 min
Total	-	-	-	-	-	-	1 h 26 min

Table 6. Classification of the elements in the model created with the algorithm according to the type of approach used for modeling.

Element Type	Automatic Approach	Semi-Automatic Approach	Manual Approach	Percentage of Elements Modeled Automatically
Columns	45	0	5	90%
Beams	90	19	18	70.9%
Walls	25	0	8	75.8%
Floors	0	2	5	-
Topography	1	0	0	100%

The algorithms demonstrated robust performance when applied to the Old Lifeguard Station of Fuseta—a small yet complex structure due to its physical characteristics and state of preservation. However, it can be adapted for buildings of various sizes and architectural complexities. The size of the building does not directly affect the outcome; the primary factor is that the algorithm may need to be applied more frequently, extending the project's duration.

For more complex geometries, it is essential to analyze the type of element to be modeled. The column algorithms are applicable to any column with rectangular, square, or circular profiles, whether made of concrete, steel, or wood. For columns with other profiles, such as C or H shapes, the algorithms require modifications to be applicable. The same is true for beam algorithms. Wall algorithms can be used on any straight wall that has both faces scanned.

It is important to note that regardless of the building's scale, the algorithms likely cannot reconstruct the structure entirely due to common issues like occlusions or non-visible structures, such as hidden walls and columns obscured by furniture. They serve as auxiliary tools for complex tasks, such as detecting tilts and rotations in columns, modeling floor deformities, or optimizing repetitive tasks like modeling simple walls.

In a scan-to-BIM project, the quality of the point cloud is essential to ensure that the final product meets the expected level of detail and quality [64]. Similarly, the effectiveness of the algorithm also depends on the quality of the point cloud. It performs better with a clean point cloud in a building where all architectural elements are exposed and free from significant occlusions. For this study, a point cloud was used without prior cleaning to test the automation in a challenging scenario, but cleaner data typically enhance the automation processes' performance.

While the algorithms discussed are limited to the architectural elements studied in this article, Dynamo can be used to develop solutions for these and other elements not covered, such as modeling from point clouds of plumbing pipes, electrical conduits, air conditioning ducts, and vaults. Each element requires a distinct strategy, and it is crucial to assess the time investment's payoff in terms of time savings on repetitive tasks, accuracy improvements, or the ability to model complex features that would be difficult manually.

With these results, the automatic modeling algorithms through a point cloud, in addition to generating adequate and compatible models for the BIM workflow, bring benefits in terms of the level of accuracy, geometric placement, precision, and time consumed. They also proved to be more accurate and faithful to the actual dimensions of the objects if compared to the models created with the manual method. Computer programming proved to be a viable alternative to solve problems and overcome existing difficulties in tasks that could be arduous in conventional ways. Although it brings these benefits, automation is not something that works without an operator, and it should not be. The presence of a qualified professional to manage all phases and data of the process and guide the decisions that the programming codes will make is fundamental for the operation's success. Their experience in architecture, engineering, or construction is a determining factor for the BIM model created at the end of the process to be coherent and to meet all the required needs of the industry.

The AEC industry is continually trying to optimize processes and reduce the time spent converting point clouds into BIM models, while also ensuring the geometric fidelity and accuracy of digital models in relation to pre-existing objects [19]. This investigation has revealed that there are promising paths to explore, such as the use of visual programming language tools to develop creative solutions that overcome the limitations of current BIM software. These algorithms, with their open and accessible language, allow users to modify them as desired to perform similar tasks with different characteristics. These codes serve as a preliminary step for further research and the development of strategies and alternatives that leverage the developed reasoning to create more robust and definitive tools. These would not be limited to Dynamo, but could be implemented as add-ons or plugins that can be more permanently integrated into Revit.

6. Conclusions

The optimization of geometric reconstruction and BIM modeling from point clouds can happen in several stages of the scan-to-BIM process through different methods and tools. This research explored ways to circumvent the known problems of this process and developed optimization approaches that can be performed both in the point cloud manipulation steps and in the geometric modeling itself. This article presented a case study focused on developing computational algorithms using Dynamo's visual programming language for problem-solving and process optimization in the scan-to-BIM workflow.

The results of the models obtained using the algorithms were quite positive. The models presented a high level of precision and accuracy. They were also created as BIM elements in their correct Revit categories and not simply generic geometric models that do not interact correctly within the BIM workflow. The process was not time-consuming, which significantly contributed to simplifying and making the scan-to-BIM work more dynamic.

The result of this research was the development of the following algorithms to be used with Dynamo and Autodesk Revit:

- Topographical surfaces modeling algorithm.
- Rectangular or square profile structural columns modeling algorithm.
- Rectangular or square profile structural beam modeling algorithm.
- Slabs, structural floors, and roof modeling algorithm.
- Regular walls (non-curved) modeling algorithm.

All codes brought gains to the process compared to traditional methods and approaches. In addition, the computational processes, and the use of the programming environment as a tool to overcome problems and challenges, proved to be highly efficient. It is possible to use Dynamo to develop future solutions by exploring other types of elements and problems in different design phases. The contributions that the algorithms developed in this study brought were as follows:

- Creation of models with higher precision and accuracy than traditional methods.
- Low time consumption, 25% faster than the manual approach.

- Automatic measurement of element dimensions and automatic creation of types in selected families.
- Automatic detection of vertical, horizontal, and rotational deviations in columns and beams.
- The use of native Revit elements and families without the need to use generic external 3D models.
- Possibility of integrating the created elements into the BIM workflow without any incompatibility.
- Automatic modeling without using other external software or commercial plugins available on the market.

The research results discussed significantly contribute to the wider adoption of automation tools in the AEC industry for scan-to-BIM. The developed techniques streamline the BIM modeling process by reducing manual labor, which is often time-consuming and prone to inaccuracies. The automation not only enhances the precision and speed of converting point clouds into detailed, usable BIM models, but also addresses common challenges such as modeling geometrically complex or irregular forms.

Moreover, this research highlights the potential for a broader application within the industry, encouraging the uptake of scan-to-BIM techniques. This can lead to improved collaboration and efficiency in building projects, particularly as the fidelity and detail of automated models increase. The case study utilized demonstrated the practical implementation and validation of these techniques, likely encouraging further exploration and adoption of such technologies by professionals seeking similar benefits in accuracy and efficiency.

Although the research presents promising results, future studies must be developed to explore the use of these algorithms in other buildings with different typologies, ages, sizes, and characteristics, in addition to studying ways to adapt the existing algorithms to other building elements that may contain a geometric logic and BIM modeling similar to those already studied, such as columns and structural beams with other profiles, curved and inclined walls, air ducts, water, and plumbing pipes, among others. It is also important to develop other approaches that include elements that have not been studied in this article and have a structural and design logic different from those mentioned, such as doors, windows, and stairs.

Author Contributions: The work presented in this paper was carried out in collaboration between both authors. L.M. conducted the building survey and point cloud alignment. G.R. designed the research method, wrote the manuscript, developed the codes in Dynamo, and created the quantitative and qualitative analyses based on the results under the supervision of L.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by FCT/MCTES (grant number UIDB/04008/2020) and the APC was funded by the Research Centre for Architecture, Urbanism and Design (CIAUD) at the Lisbon School of Architecture, Universidade de Lisboa (FA/ULisboa).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available and can be downloaded through the following link: https://github.com/gustavomrocha85/dynamo-scan-to-BIM-01 (accessed on 8 May 2024).

Acknowledgments: The authors would like to thank the FCT/MCTES and CIAUD for their financial support.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Detail of the algorithm for modeling topographies.

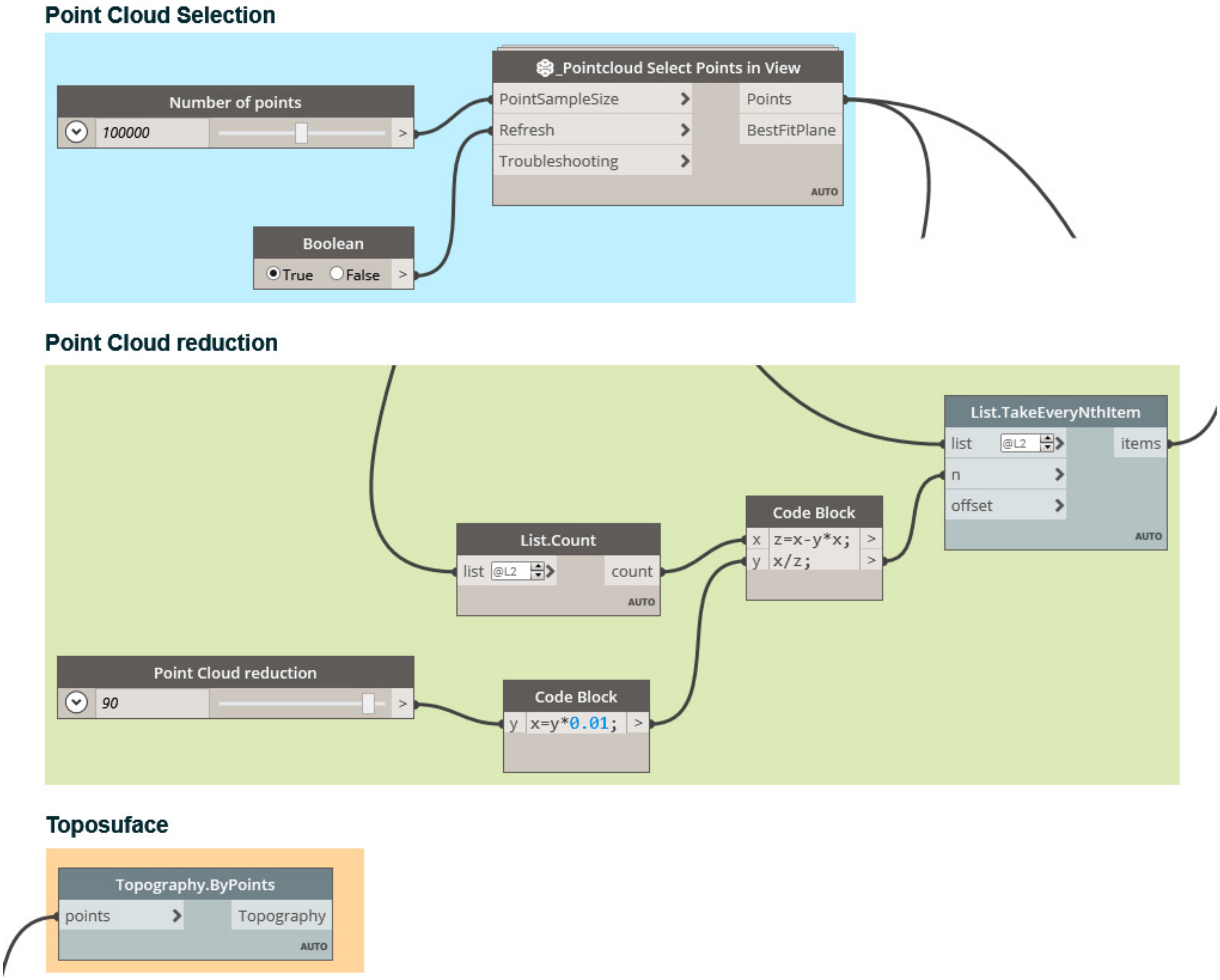

Figure A1. Topography modeling algorithm.

Appendix B

Detail of the algorithm for modeling structural columns.

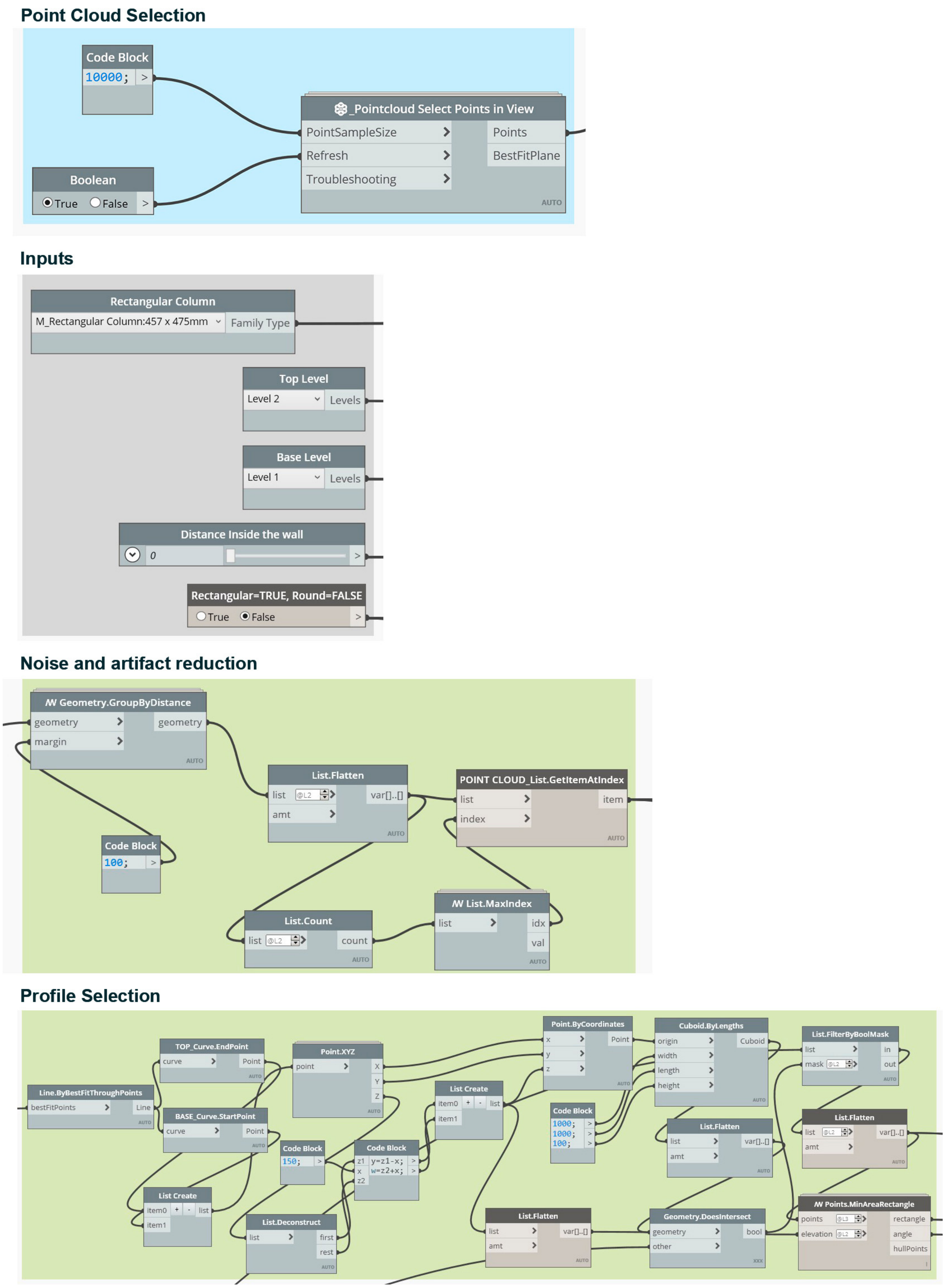

Figure A2. Structural column modeling algorithm—part 1.

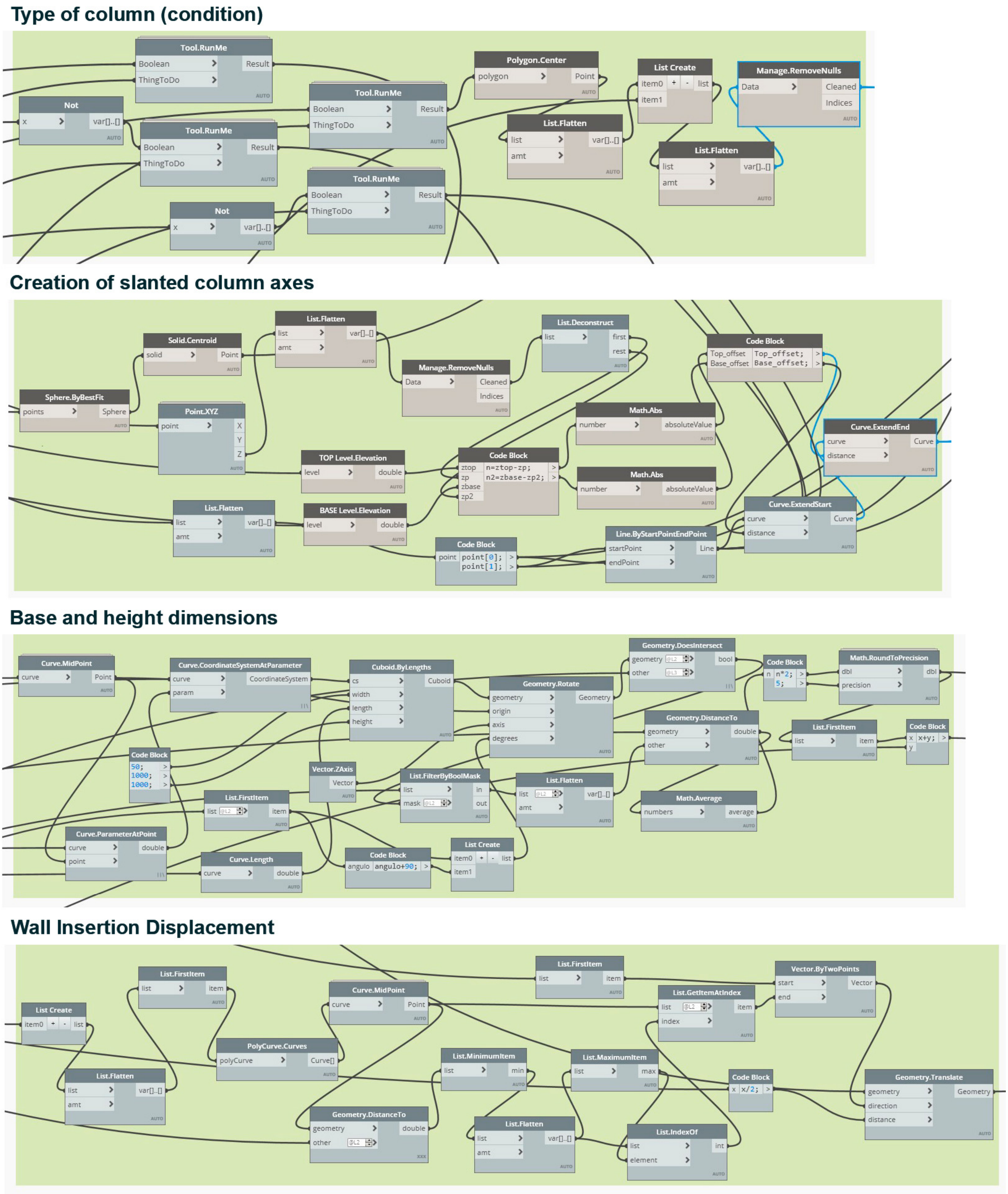

Figure A3. Structural column modeling algorithm—part 2.

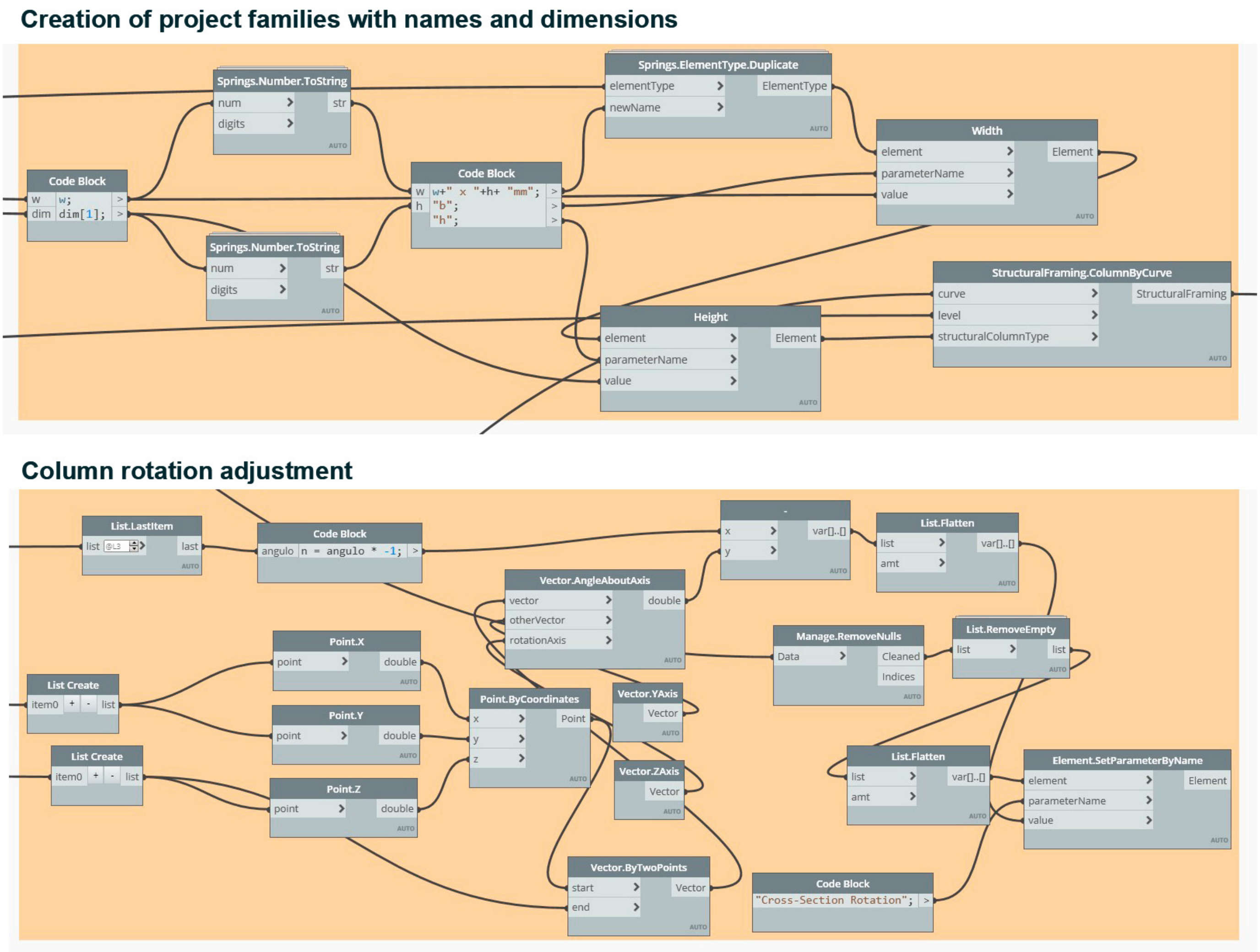

Figure A4. Structural column modeling algorithm—part 3.

Appendix C

Detail of the algorithm for modeling structural beams.

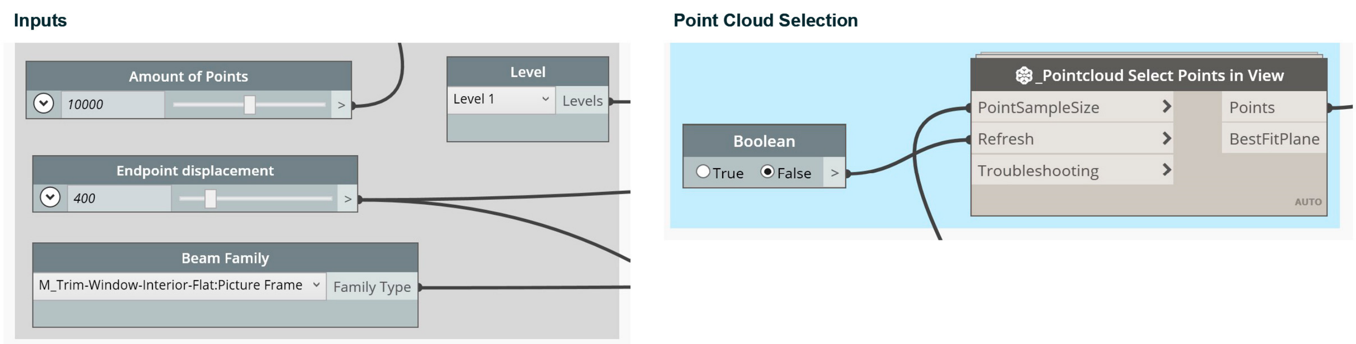

Figure A5. Structural beam modeling algorithm—part 1.

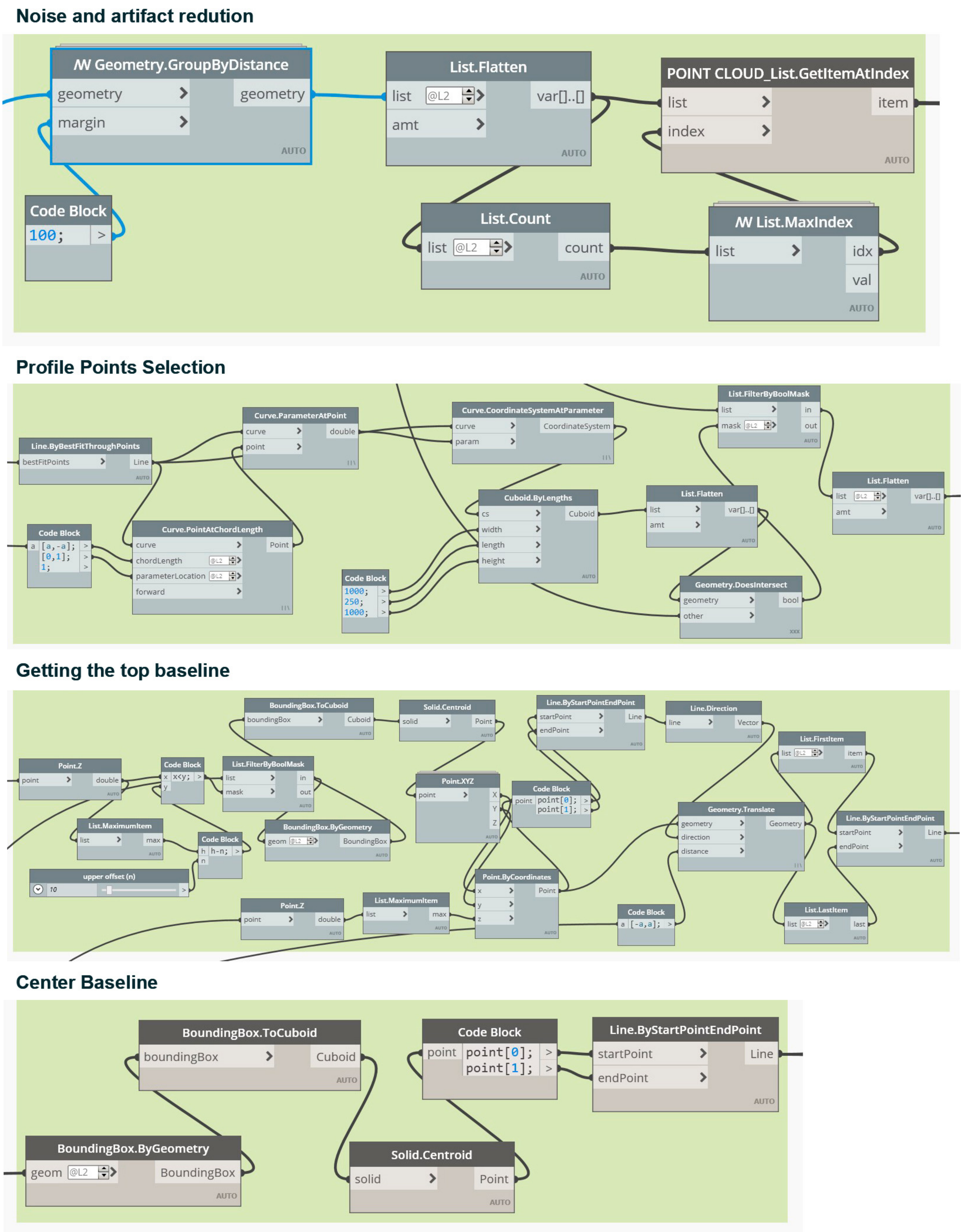

Figure A6. Structural beam modeling algorithm—part 2.

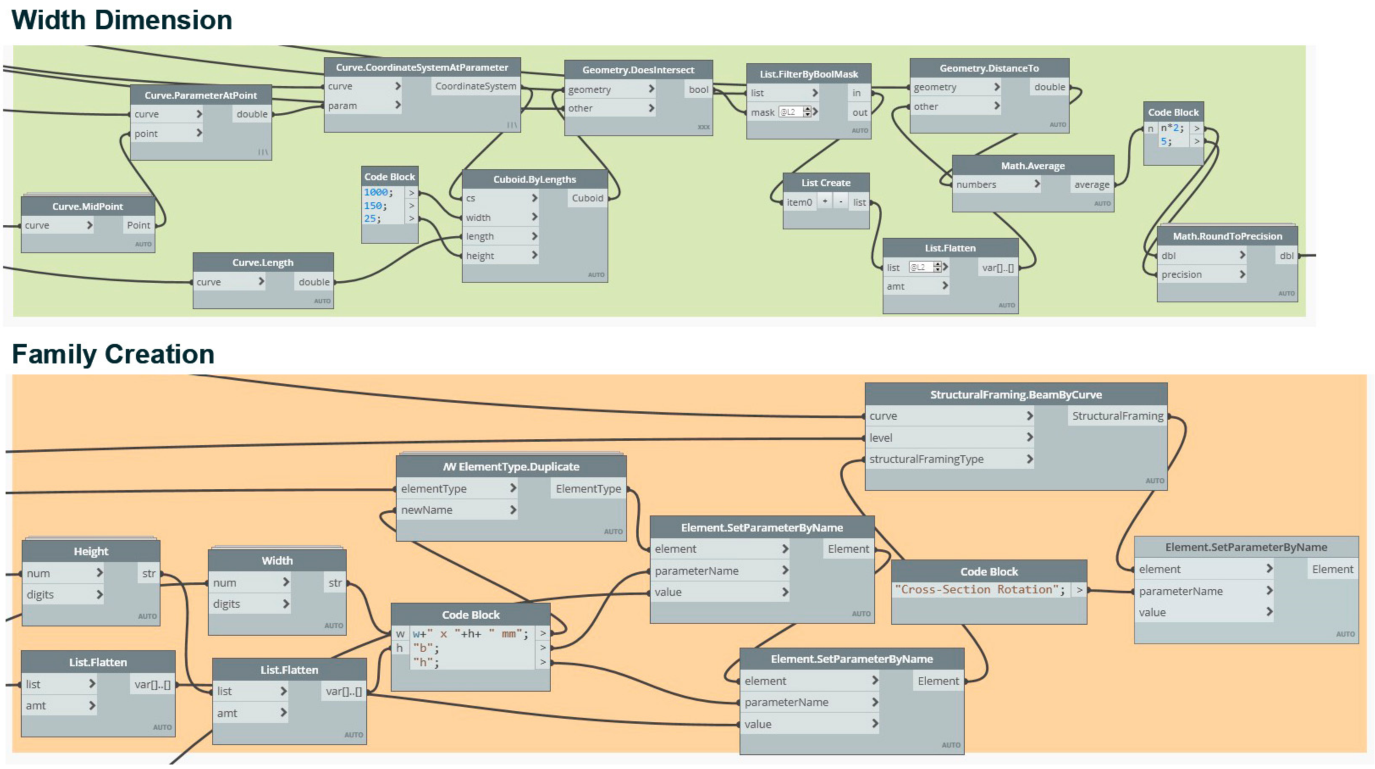

Figure A7. Structural beam modeling algorithm—part 3.

Appendix D

Detail of the algorithm for modeling walls.

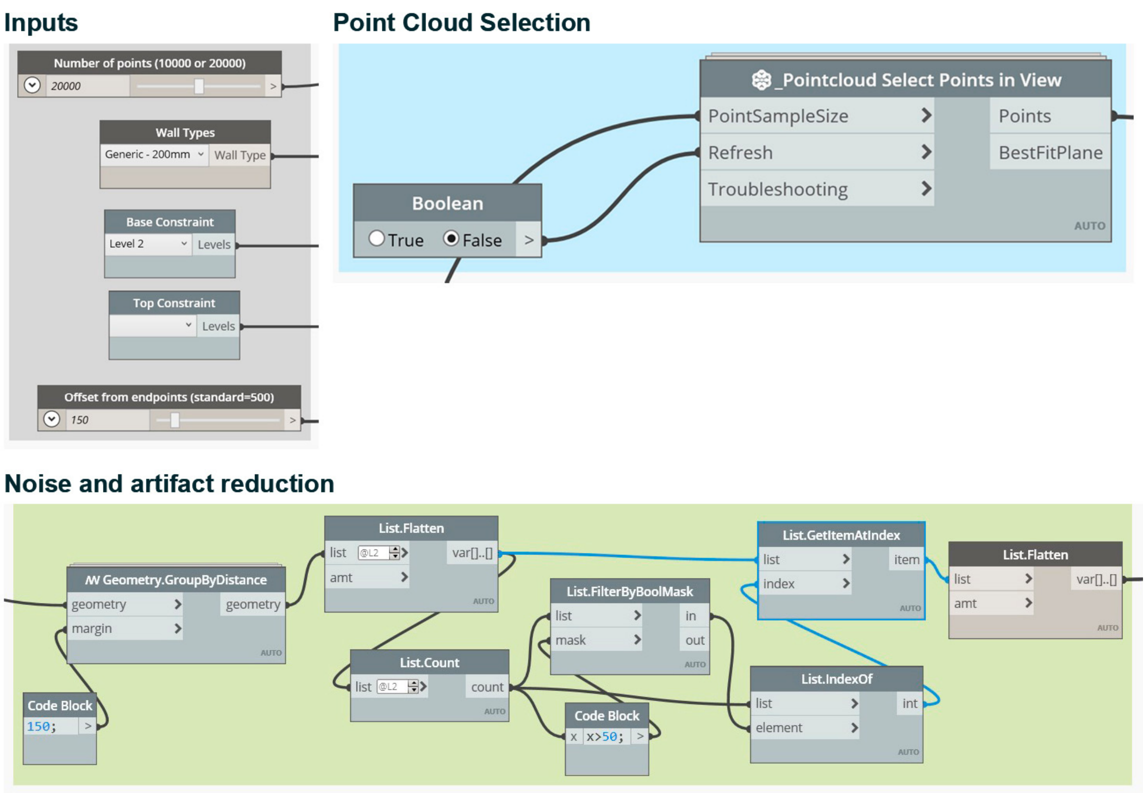

Figure A8. Wall modeling algorithm—part 1.

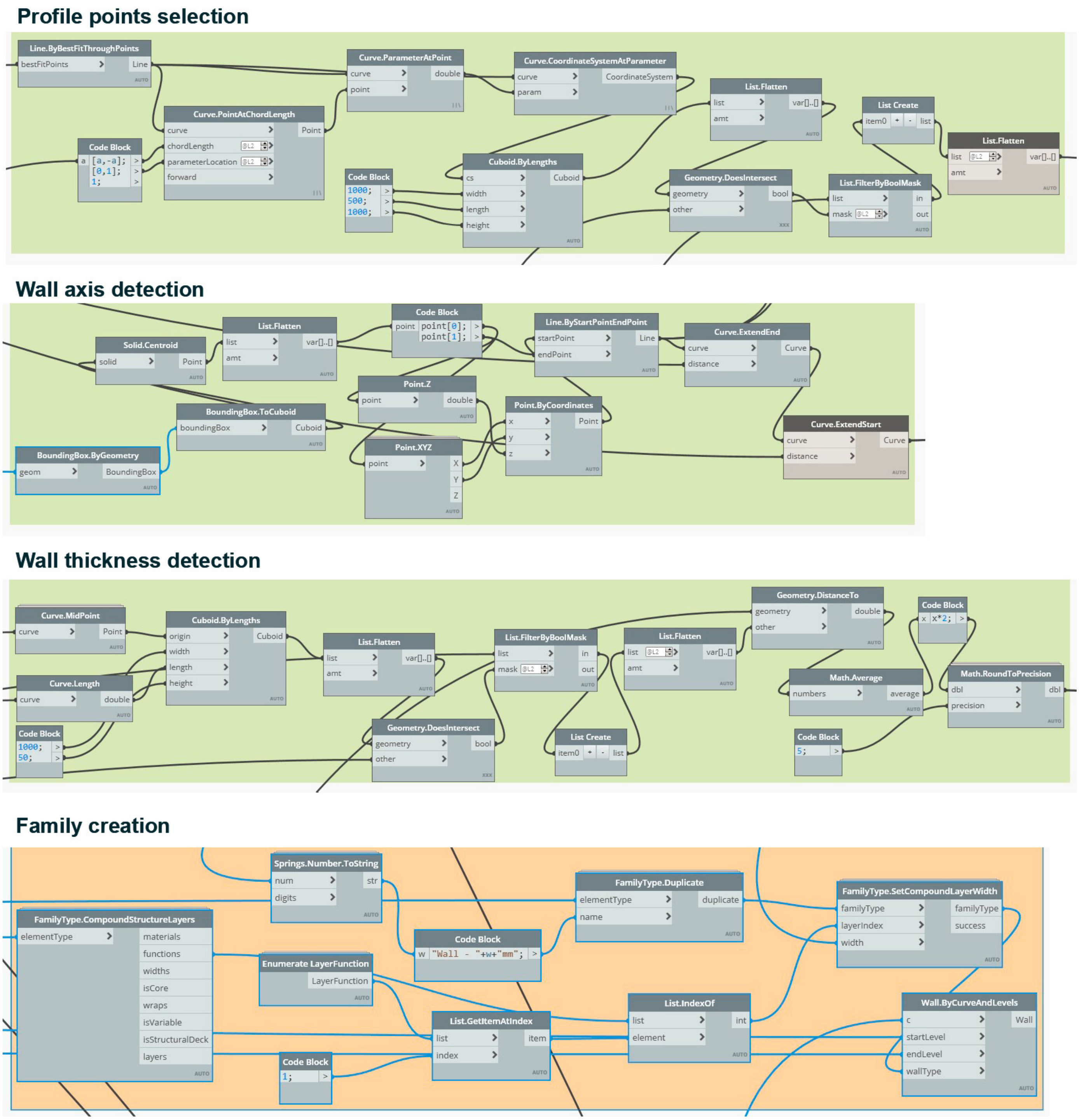

Figure A9. Wall modeling algorithm—part 2.

Appendix E

Detail of the algorithm for modeling floors.

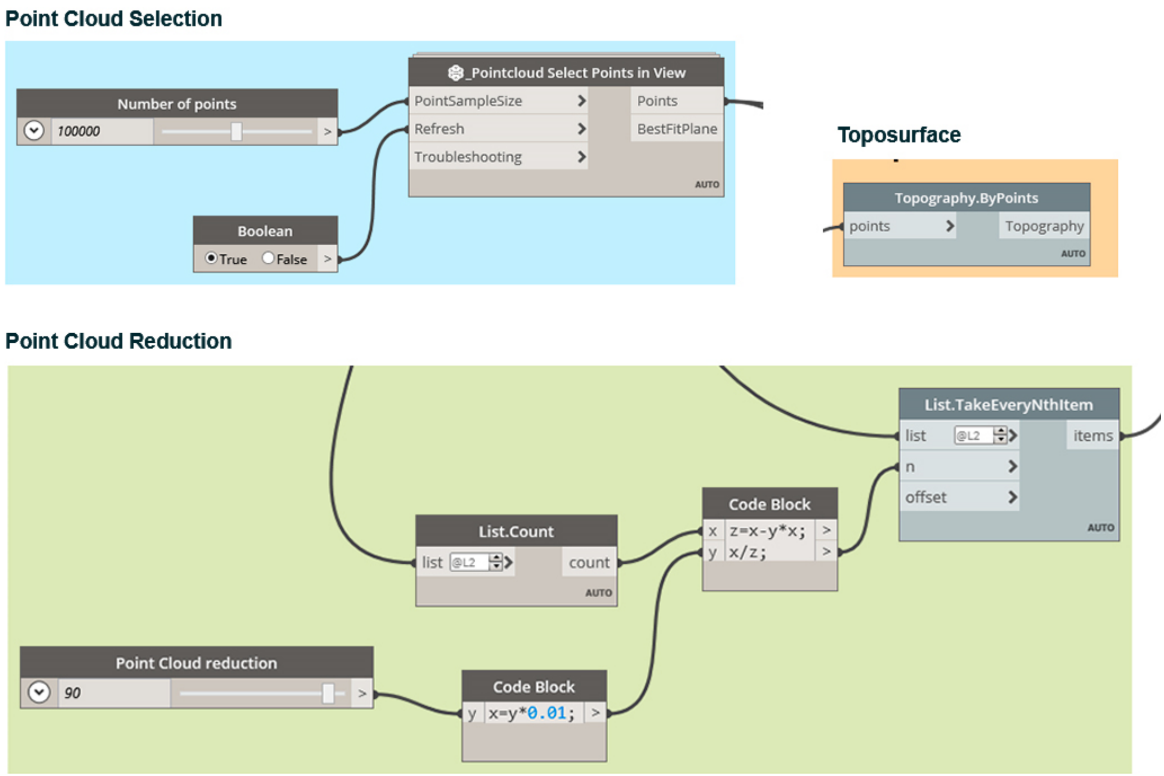

Figure A10. Floor modeling algorithm—part 1.

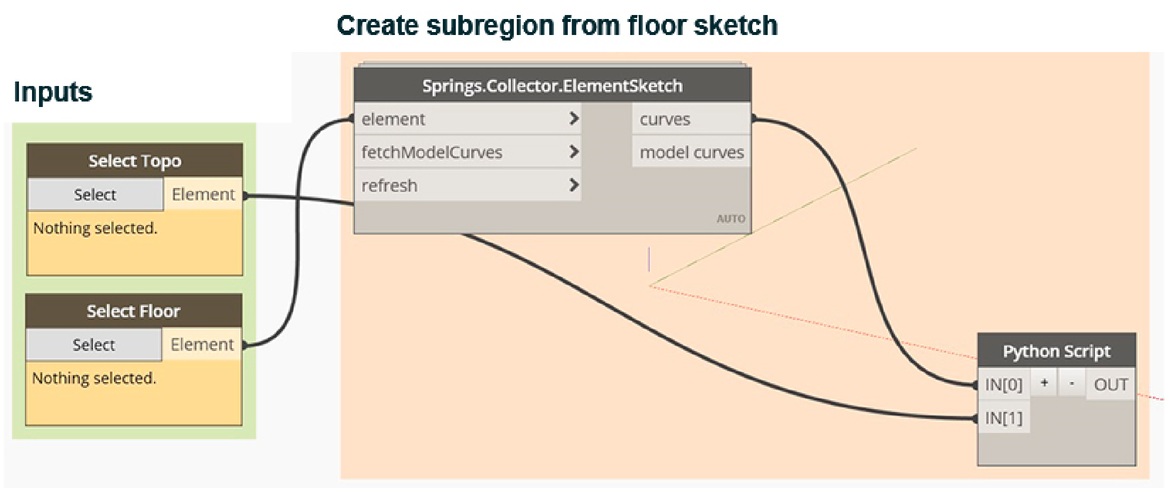

Figure A11. Floor modeling algorithm—part 2.

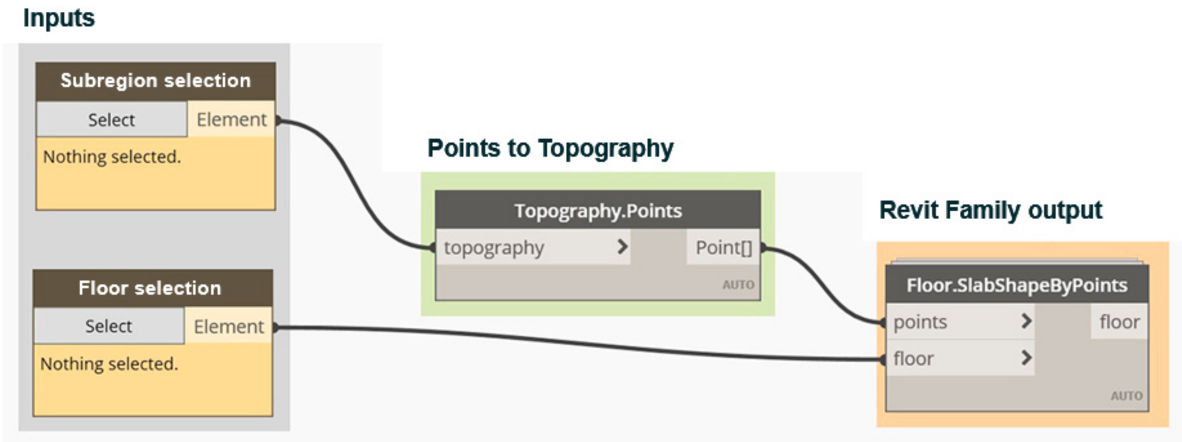

Figure A12. Floor modeling algorithm—part 3.

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