

Article

Point Cloud-Based Historical Building Information Modeling (H-BIM) in Urban Heritage Documentation Studies

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Abstract: Integrating building information modeling (BIM) technology into historical and cultural heritage structures has resulted in historic building information modeling (H-BIM), an effective method for managing and documenting invaluable historical artifacts. H-BIM has the potential to aid with the design, restoration, and maintenance activities of historical buildings by properly integrating parametric data and deliberately assessing semantic information, thus progressing the 3D model's performance. H-BIM also aims to conduct cultural heritage (CH) studies in a systematic manner by combining 3D modeling techniques and information management. The first step in this process is to conduct a suitable geomatic survey to build accurate 3D models. The most efficient modeling method is to employ 3D point cloud data that are acquired using the terrestrial laser scanning method. This study proposes a manual modeling strategy for urban historical buildings that falls within the scope of the H-BIM methodology. The proposed modeling strategy follows a workflow that inserts point cloud data into the BIM environment in order to create a 3D urban cultural heritage model using ontologies applied with the H-BIM methodology. With this objective in mind, the H-BIM model development platform Revit was used to model the object elements of the inheritance structure in 3D and save them in the BIM library. It is very important to model building elements separately in 3D modeling studies. The resulting BIM product sheds light on fundamental data for the future planning, design, operation, and maintenance processes of the building. Users can obtain data suitable for H-BIM by adding graphical and non-graphical data.



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Keywords: architectural heritage; BIM; H-BIM; construction documentation stage; BIM-based drawings; urban heritage documentation; terrestrial laser scanning

1. Introduction

Historical and cultural heritage structures are significant masterpieces reflecting the fundamental architectural identities of communities. Such heritage structures, which offer immeasurable cultural value, require interventions targeted at conserving, improving, and renewing their structural integrity while considering the principal conditions of their constructed era. For these structures to survive and maintain their current form, targeted restoration and maintenance interventions must be planned rapidly and systematically [1–3]. In CH studies, contemporary measuring technologies and software offer new insights into the modeling and analysis of buildings by facilitating the acquisition of geometric data. In this sense, acquiring useful information for CH studies is achievable while obtaining precise 3D digital representation models of structures [4–7]. Currently, the BIM approach offers users the opportunity to work from different perspectives within the remit of the architecture, engineering, and construction (AEC) industry. Moreover, it delivers interdisciplinary work to the project stakeholders in a 3D setting at every stage, beginning with a construction project, followed by the completion and activity stages, as well as a process that facilitates the follow-up of retrospective data [8–12]. BIM offers the opportunity for collaboration, data sharing, data integration, and the ability to store

parametric objects from multiple disciplines in its library; it also facilitates the application of BIM methodology into architectural structures [13–15]. Integrating BIM methodology into historical heritage buildings reveals the H-BIM methodology. In general, H-BIM methodology is applied to historical architecture, and its primary objective is to conceive the potential of the BIM paradigm. Given its ability to associate with various disciplines, the methodology is a multidisciplinary process that delivers a promising approach for managing and documenting heritage structures. It further provides utility in terms of tracking changes in the buildings' surroundings and monitoring the aging process of the buildings of interest. However, the H-BIM restructuring procedures for historical buildings are rather complex. The heterogeneous and distinctive features of the entities in heritage structures consist of items unrepresented in current BIM software libraries [16–18]. Currently, 3D data are indispensable components in permanently conserving cultural heritage styles and passing them on to future generations; however, modeling a historical building as it remains requires both semantic information and technical information about the components of that building. The data obtained via research and application within the purview of the H-BIM methodology encompass semantic and geometric data [19]. Building-related research and observations lead to the acquisition of semantic data. These data include historical data, building material type, construction technique, physical property data, and archival information. The gathered semantic data make it easier to accurately interpret and analyze structures; this positively affects the decision-making procedure regarding the buildings in subsequent processes. An H-BIM is created by integrating these piled data into geometric data. In addition, metric measurements taken from structures allow us to obtain geometric data. The advancement of measurement techniques makes it possible to obtain geometric data with photogrammetry and terrestrial laser scanning (TLS) devices. Obtaining the 3D model also enables the provision of diverse views, floor plans, façades, and section drawings of the building in question [20]. Three-dimensional point cloud data acquired from terrestrial laser scanners are a data type that enable the provision of BIM-compatible studies [21–24]. The 3D laser scanning technique produces a series of digital data points in the global point cloud based on the principle that each data point is represented by a coordinate in 3D space. Laser scanners swiftly and precisely calculate the 3D geometry of a structure by using the back-reflection of laser beams focused on the construct or object. The key benefit of this approach is its ability to acquire a dense point cloud between 5 and 10 mm, thus allowing users to capture the intricate geometry of the structure with high accuracy. Therefore, the TLS approach has gained popularity in most prominent studies seeking higher accuracy and applicability [25–27]. In this context, 3D models and parametric objects are generated with H-BIM by analyzing the 3D point cloud data generated via TLS in BIM software. The model developed by the H-BIM model is also practical in terms of identifying the knowledge gaps in the historical structures in question and proposing a theoretical approach for the heritage site. Various studies have recently focused on managing the point cloud, creating parametric objects, and developing a compatible 3D model within the scope of BIM [26,27]. It may be possible to discuss the existence of this strategy over the past ten years by considering studies that were focused on conserving cultural heritage sites and conducted within the context of BIM and H-BIM. However, the number of scientific studies in this area has increased significantly since 2018. Some findings of the studies are as follows: [28] analytically criticized the latest technological state of the H-BIM methodology and [3] sought to identify structural deformities by developing a digital twin of 18th-century architecture. In this context, the studies compiled data using the TLS method and assessed the point cloud model using Revit 2022 software on the BIM platform, concluding that the structural deviation values were within the permissible limits of the sizes of the objects. In [10], point cloud data were utilized as part of restoration and reconstruction projects, thus simplifying the 3D modeling processes. They employed the point cloud data in their study and stayed within the parameters of the H-BIM methodology. They also developed semi-automatic solid modeling using TLS-generated cloud data and relevant software. Correspondingly, [29] used

terrestrial laser scanning equipment to gather data while conducting a selective analysis of the Church of Saint Barbara for 3D documentation processes in the CH analyses. The study further discussed the applicability of point cloud data within the scope of H-BIM methodology. In the context of H-BIM, a 3D model was created individually by modeling the components of the building. [30] executed a procedure to generate 3D models in a BIM setting. While acquiring the solid model directly from the point cloud of the 3D model in the Revit environment, they classified and modeled each architectural element in the object library. They also emphasized that BIM was parametrically competent to model historical architectures and complicated aspects in this way. [6] used TLS, UAV, and fisheye cameras to develop a BIM model and analyze the historical constructs of The Church of San Nicola in Montedoro and San Cono Bridge. The authors used all three techniques for measuring the church, whereas they collaboratively employed TLS and UAV approaches while measuring the bridge. Initially drawing the images in the Rhinoceros environment, they subsequently emphasized both the bridge and the church in the BIM environment in Revit 2022 software. Finally, structural analyses were performed by running additional software. This study built an H-BIM of the urban heritage structure under consideration using a manual modeling procedure. In line with this modeling process, individual entities of the studied architecture were modeled in a 3D format by applicable software and integrated into the research model. Therefore, this endeavor aimed to develop a novel approach to designing the structural components to be built from the point cloud data during the H-BIM model creation phase as objects compatible with the originality of the building.

1.1. Building Information Modeling (BIM)

Building Information Modeling (BIM) is the running process of a digital model representing a building's physical and functional features [8,22–24,31]. The primary intent of BIM technology is to enable better construction in light of science, technology, and innovation [8,22,31,32]. In addition, BIM technologies are also used in planning, design, operation, and maintenance processes. Especially for maintenance work, BIM provides the necessary information and documents to the project stakeholders [9,13,21,33,34]. BIM generates novel working perspectives and visual environments in architecture and restoration. The first step of this process, which refers to constructing a structure or an entity twice, is to create the building in the virtual background, while the second step covers building it physically on the site. The first stage comprises updating the 3D model of a construct with the relevant details and information and performing various analyses. Hence, this step addresses numerous potent issues through the virtual model, which provides practical convenience and advantages for the actual building construction on site [24,31]. BIM technology is a groundbreaking approach and improves the effectiveness of the process. It also sustains quality control, minimizes the time spent, and aims to avoid budget excess while constructing new buildings [16,34,35]. It is possible to employ diversified approaches and software to model structures within the scope of BIM. In the BIM technique, there are various item-based parametric models for constructions. These items usually include fundamental construction elements such as walls, floors, ceilings, windows, doors, and columns. Although the objects are predetermined, users are reluctant to modify, personalize, or use them directly. The items in question fall under the category of parametric functions. Such a categorization makes it simpler to supply the relevant standards and streamline application processes. Saving several object classes in libraries increases accessibility and facilitates application processes [33–37].

1.2. Level of Detail (LOD)

The concept of level of detail (LOD) refers to setting the standards and level of detail for BIM model elements from the design phase of the project to the construction phase. LOD levels contain information about the project, graphical data, and non-graphical data. Thus, it contributes to improving the level of communication among BIM users and ensuring consistency in application [12,38–40]. LOD is a reference corresponding elementarily to

the questions of the project stakeholders about BIM. The geometric information content of the building components is apprehended through LOD levels and is a way for disciplines to convey their provisions to each other. The main reason for applying the LOD concept is to clarify how the information will progress and deliver higher quality and competent projects by alleviating complexities. The LOD100 refers to the preliminary design universe. The model element can be represented graphically by a symbol or general representation whereas the LOD300, LOD400, and LOD500 levels derive from capturing data into the model Figure 1 [11,24,38–40]. It is also feasible to conduct more in-depth studies using the LOD250 and LOD350 levels depending on the conditions [11,38–40].



Figure 1. Level of detail.

LOD100: This level defines the initial state of the construction phase. It refers to the design and semantic stage. Details produced at this level ground on basic mass rendering, lines, and 3D geometry. This level typically provides information about how the structure of a building will scrutinize in principle. LOD100 retains no details such as doors or windows [11,17,24,38].

LOD200: This level signifies components graphically represented within the model, such as an available system, object, or assembly, with approximate qualities, quantities, sizes, shapes, positions, and orientations. The LOD200 level also represents spaces with limitations such as walls, height, and columns. Any conclusions drawn from LOD200 items should be deemed approximate. This level stands for the creation of an introductory presentation model. The level also provides initial attributes about doors, window shapes, sizes, rudimentary and overall furniture arrangements, etc. For instance, this level displays door and window locations. LOD200 models are a critical aspect of architectural BIM services that begin with models for design purposes and potentially diversify for several additional functions [17,38–41].

LOD300: The other model phases begin with LOD300. The model phase is more than just a representation, displaying the 3D geometry created. LOD300 is the level where model detailing will retain proper quantity, size, location, and orientation, along with manufacturing, assembly, and installation details. This model phase may use both general and parametric Revit library items [17,41].

LOD400: It denotes LOD300's upper level. Apart from the items displayed in the LOD300, all other components, including columns, beams, crosses, gusset plates, joints, reinforcement plates, angles, casting plugs, metal grates, seismic or secondary supports, and beam transitions, are situated at this level. The model also includes non-graphical data that properly relate each element to its assembly sequence and illustrates the size of the structural components [17,38–41].

LOD500: This level stands as the final phase of BIM modeling. The model designed at this level is saved for subsequent use in facility management and building renovation. It is also attainable to utilize this model for the effectiveness analysis of building efficiency.

This level of the model will have all the necessary geometry and data to support building lifecycle operations and maintenance [17,41].

1.3. Historical Building Information Modeling (H-BIM)

H-BIM technologies are tools using point clouds to create BIM geometry while modeling historical buildings. These technologies utilize information from laser scanning devices or photogrammetry [3,42–45]. H-BIM enables the management of historical building geometry and, in particular, the planning of the restoration process. Working in the H-BIM environment aims to build more complex models from 2D drawings [9,46–49]. The H-BIM approach manages building attraction and deterioration data or information analysis to sustain material and structure characterization and protection response measures in diverse scenarios [31,42,50]. From the standpoint of building conservancy, the H-BIM model may exclusively be regarded as a building catalog, assisting in determining affordable and reasonable maintenance and keeping track of the potential modifications over time. For instance, it serves as a database that enables suitable restoration and replacement in case of an earthquake event or artificially caused (human-driven) demolition [51–53]. There has been substantial progress in proper conservation, restoration, and reconstruction procedures for historical heritage, thanks to the numerous advantages H-BIM offers [54–56]. Historic England published the bulletin of ‘BIM for Heritage’ to guide the development of the H-BIM methodology in 2017. Additionally, it proposed a lifecycle policy for H-BIM implementations depicted in Figure 2 [17,20,22,47].

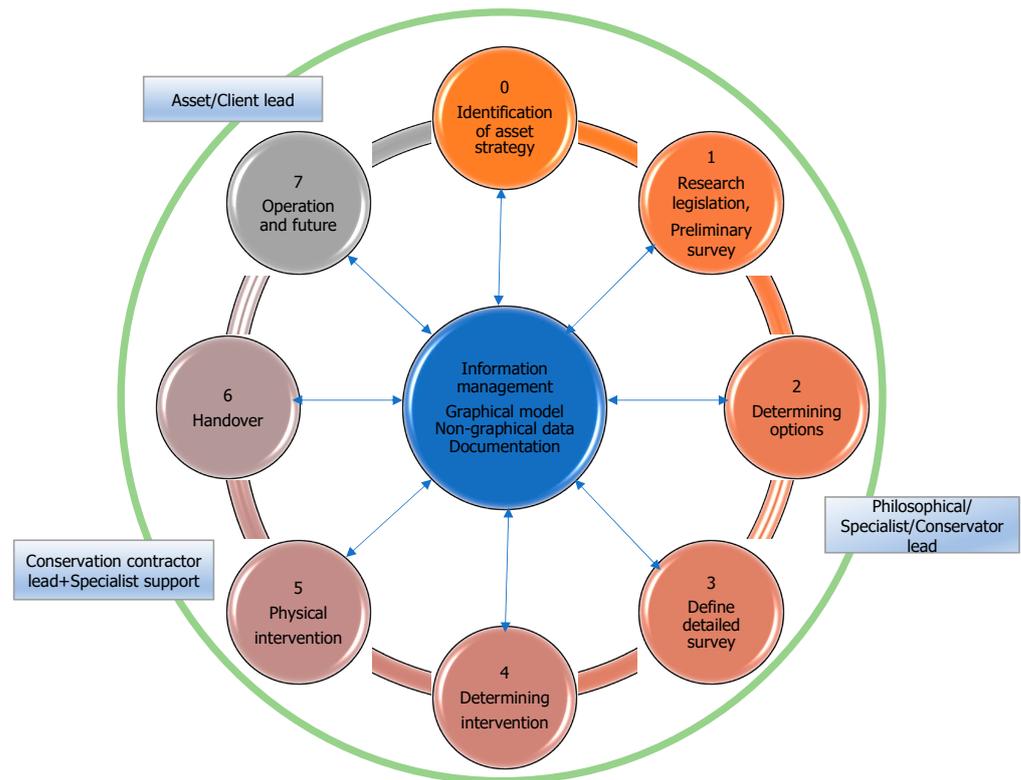


Figure 2. The process of the H-BIM lifecycle policy.

After the decision-making process on the study area and the relevant geometric data collection technique, the initial process begins with compiling information on graphical, semantic, morphological, and typological data within the scope of H-BIM. Utilizing 3D laser scanning and photogrammetry techniques is the method for gathering graphic data. Object surfaces scanned by these technologies are transferred to the geometric plane using point clouds; however, the semantic, morphological, and typological information is accessed through textual and historical sources. This information provides details

about the materials and construction techniques of the building, its architectural features, and the transformations it has undergone from the past to the present [10,52,53]. The utilization of all gathered data in a database constitutes the foundation of the second stage of the study methodology. Preferentially, the generated point clouds are modeled best parametrically using automatic or manual techniques. The auto method derives from automatic segmentation and parametric-object creation by point clouds via utilizing specific algorithms and software plugins available for level surfaces or primitive geometries. However, the manual method involves directly integrating filtered point clouds into BIM environments to generate objects [43,54].

2. Materials and Method

2.1. Study Area

The historical education building constructed in 1929 is still active for educational purposes in Konya. The school building consists of a basement and two floors. Smooth-cut stone was used in its construction, and it was built with the masonry technique. The first-floor windows are round and the second-floor windows are pointed arches. Figure 3 displays the location map of the school building, which serves as the study area, and Figure 4 illustrates a current photograph of the building exterior (outside).

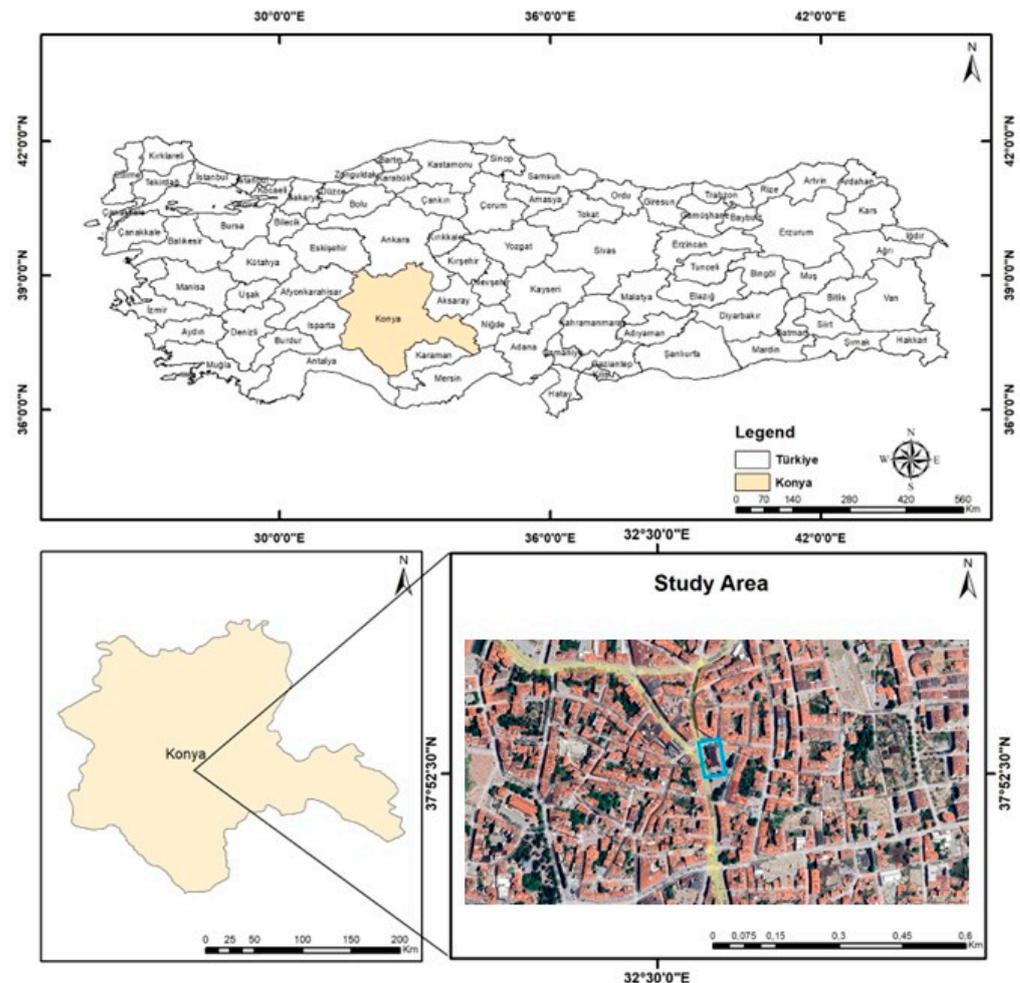


Figure 3. Study area: Google Earth image of the historical education building of İsmetpaşa Primary School.



Figure 4. The outside view of İsmetpaşa Primary School.

2.2. Terrestrial Laser Scanning and Working Principles

One of the most functional and cutting-edge measuring technology items is undoubtedly the TLS method. Laser scanners, which allow architectural documentation studies to be carried out vigorously and by the required standards, are frequently used for documentation studies nationally and globally [20,55–57]. This study employed a terrestrial laser called ‘Faro Laser Scanner X-330 HDR’. The FARO Laser Scanner Focus3D X 330 is a precision measuring tool that creates photorealistic 3D images. The Faro Laser Scanner X-330 HDR device is also suitable for 3D documentation studies and field surveys. It is a top-tier German-patented terrestrial scanner and can complete post-measurement operations with minimum effort owing to its improved range and scanning capacity [58–60]. Table 1 displays the primary technical specifications of the Faro Laser Scanner X-330.

Table 1. Technical specifications of the FARO Focus3D X 330 laser scanner.

Scan Distance	0.6–330 m
Size	240 × 200 × 100 mm
Weight	5.2 kg
Measuring Speed	976,000 points/s
Accuracy	±2 mm
Camera	70 megapixels
Resolution	1/1, 1/2, 1/4, 1/5, 1/8, 1/10, 1/16, 1/20, 1/32

Focus3D X-330 offers an operating principle based on sending an infrared laser beam to the center of a rotating mirror. It also employs phase change technology to measure distance. This technology enables the modulation of the laser beam through fixed waves of various lengths. By measuring the phase alteration in infrared light waves, it is possible to calculate the precise distance between the scanner and the object. Subsequently, each point X, Y, and Z coordinate is computed using angle encoders to measure the horizontal and mirror rotations of the Focus3D X-330. These angles are encoded simultaneously with the distance measurement. The distance, vertical angle, and horizontal angle create a polar coordinate (δ , α , and β), which is converted to a Cartesian coordinate henceforward (x , y , and z). It scans at 360 degrees horizontally and 300 degrees vertically [58–61]. Also, Figure 5 includes the workflow diagram followed throughout the study for the H-BIM process.

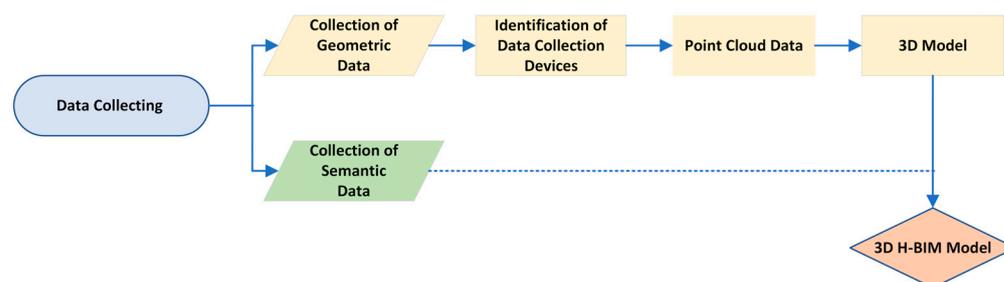


Figure 5. H-BIM workflow, adapted from Ref. [23].

2.3. Software Used: Autodesk Revit 2022 and As-Built for Revit 2021

Revit 2022 software is a 3D vector drawing program that allows functioning within the scope of H-BIM. It is a software allowing various users to create designs with parametric modeling and drawing elements. Revit 2022 software enables the generation of objects related to the building of interest, digitally modeling the structures by H-BIM and explicitly visualizing the depth of the objects [62]. In the context of conservation and restoration projects, architects have the potential to employ the 3D digital data class, which includes vector drawings produced by Revit 2022 software. Revit has no automatic object recognition tool; thus, object creation requires a manual process. Despite the studies on methods for creating object geometries in 3D format, these techniques are more practical for contemporary geometries nowadays [12,50,55]. Yet, they are not suited to the H-BIM technique since objects developed by automatic object creation fail to reflect historical architecture accurately. The primary reason to prefer Revit 2022 software in studies is that it employs real-life blocks and contains various templates while drawing, compared to other drawing programs. It is also achievable to acquire more detailed layouts and sheets (map section) from the building sections taken after running structural 3D modeling via Revit [62]. As-Built for Revit, on the other hand, is a Revit 2022 software plugin created by Faro. This program enables architects and engineers to efficiently create precisely completed data-driven building designs that are fully compatible with CAD and BIM systems. As-Built expedites the information extraction time from point cloud data and completes the job successfully [18,54]. Furthermore, this software program may extensively advance the effectiveness of the point cloud on the Revit program.

3. Results

This section covers modeling the scanning data of the historical education building, used as the study material, in the H-BIM environment via Autodesk Revit 2022 software.

3.1. Geometric Data Extraction from the Point Cloud into Revit

The building data were transferred to the Revit application using Autodesk Recap 2022 software, point cloud processing, and management software, as well as file conversion in the '.rcp' format (.rcp or .rcs). The 3D point cloud data of the building, used as the study material, were imported into the software. Figure 6 displays the visuals of the 3D point cloud.

3.2. Creating Level Plans (Floor Plans)

The study focused on creating the level plans via utilizing the point cloud based on the attic and floor walls of the building's existing floors. Each of the building's floor plans refers to a level. Accordingly, level 1, level 2, level 3, and level 4 represent the ground floor, first floor, second floor, and attic, respectively. The level plans for each floor's height were entered using the previously constructed level plans. Identifying the level plans is the initial step of the modeling process. Drawing the walls and designating the placements of items like doors and windows within and outside the building, within the range of detail levels, concludes the modeling at the LOD 200 level after setting the level measurements.

Figure 7 displays the overview of the level plans (floor plans) created upon the project's conclusion.



Figure 6. Point cloud data of the study area.

3.3. Creating the Wall and Floor Objects

Walls are the most critical constituent of a structure as they support the entire mass of a building. Every other object is somehow attached to the wall. Thus, the wall is the first and foremost object to consider for building construction. Accordingly, choosing a wall type is a priority. The family wall type possesses general characteristics of the wall, such as the wall thickness, the wall type properties to set the wall material, and the interior or exterior wall properties [29]. Initially, the drawings of the thin/thick walls were generated using a point cloud to determine the wall thicknesses. The most critical issue while building a model is to define distinct wall types with various thicknesses and geometrical characteristics. In this sense, modeling diverse types of walls based on their self-features will make them easier to classify and access [57]. This study employed a Basic Wall CW 102-50-100p family-type object. After defining the wall type, the wall-drawing phase begins, using the point cloud as reference data. Drawings are made on the cloud by separating the interior and exterior walls Figure 8. At this stage, the wall thickness was estimated at 550 mm. Then, in adhering to the uniqueness of the building, stone was selected as the material for the wall.

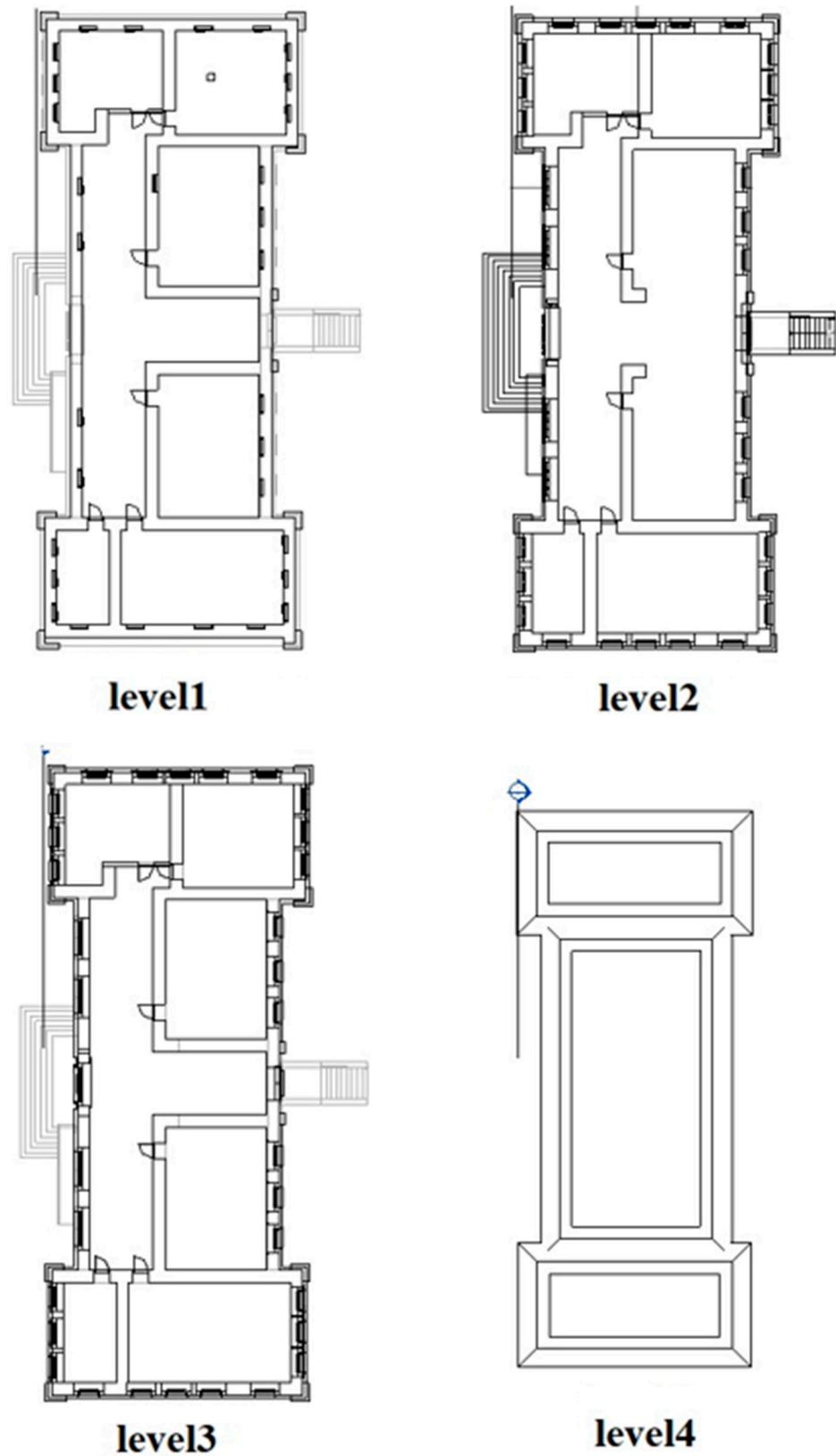


Figure 7. Floor plans: level 1, level 2, level 3, and level 4 represent the ground floor, first floor, second floor, and attic, respectively.

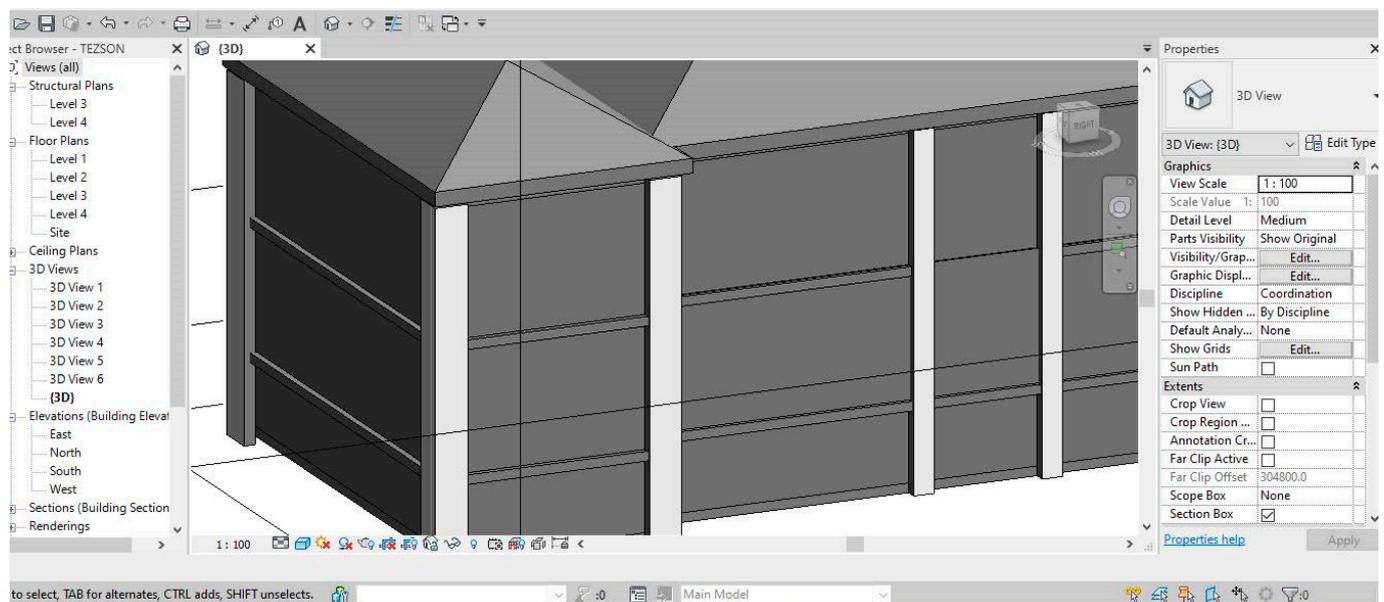


Figure 8. Creating the floor object in Revit.

Ground (floor) designing is the next crucial step in the process. A floor refers to the lower surface of the room. These floors, in other words, floor plans, may be attached to the groundwork. This study employed a floor generic 150 mm object type, and 330 mm thickness was found suitable. At this stage, wall and floor objects can be immediately created from the point cloud using As-Built 2022 software in an appropriate format. It can automatically select and generate the most accurate wall type according to the wall thickness settings. Furthermore, it may also intelligently assign the ground object to the model [62].

3.4. Creating Window and Door Objects

For the creation of door and window objects within the scope of the building, As-Built 2022 software generated orthophotos of the building façades; accordingly, adding two doors and four windows individually confined the building's door and window drawings. Subsequently, the 3D depth details were prepared from the point cloud. Thanks to Revit and As-Built 2022 software, the door and window objects were created and saved in the Revit family library. Thus, these objects were stored to be used again in case of need at later necessary stages. Therefore, this step finalized the creation of the LOD300-level design. As-Built 2022 software potentially enables the design of semi-automatic objects throughout the object construction process, and the program may also localize the position of the window or door objects. However, since the details of the building are unique to this structure and do not contain the object characteristics saved in the library, a window or door object could not be created automatically [35]. Therefore, this study utilized a manual method while designing the building-specific object details. Figure 9 displays orthophotos of the window and door objects acquired from the point cloud. However, the study created the drawing over the orthophoto of the window object in Figure 10 following applicable commands of the Revit program. Afterward, the depth was assigned referencing the point cloud. The building's vertical window object and the window on the ground floor both underwent identical procedures. Then, material preferences were made for the window and door objects by referencing the original designs of the building objects. They were attached to the model after saving it in the main library. Figure 11 displays the final versions of these items representing finalized and saved drawings and material assignments in the object library. Figure 12, however, depicts the appearance of the objects attached to the 3D model.

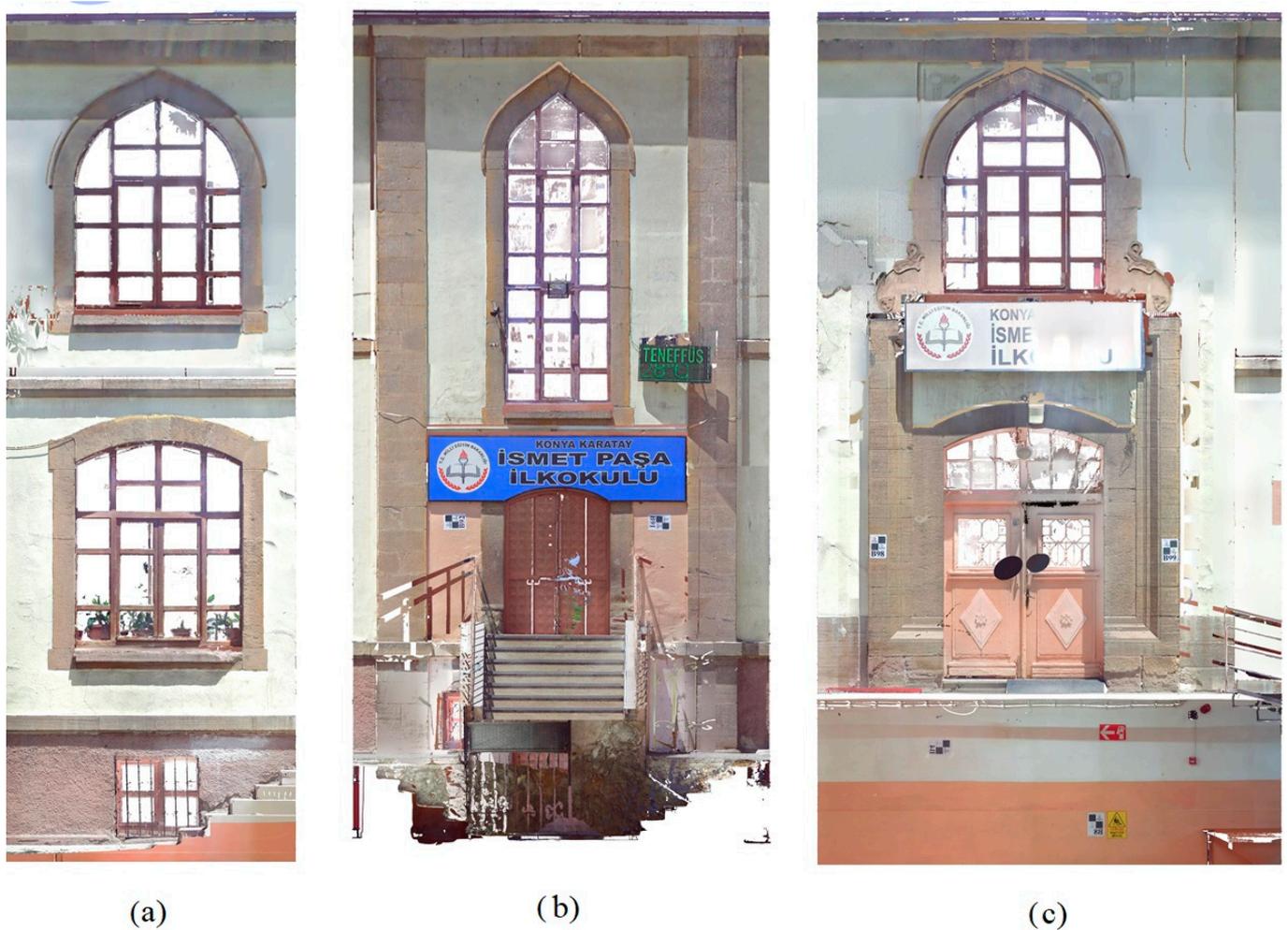


Figure 9. Orthophotos acquired from the point cloud with As-Built software: (a) windows; (b) back door and vertical window; and (c) front door and window.

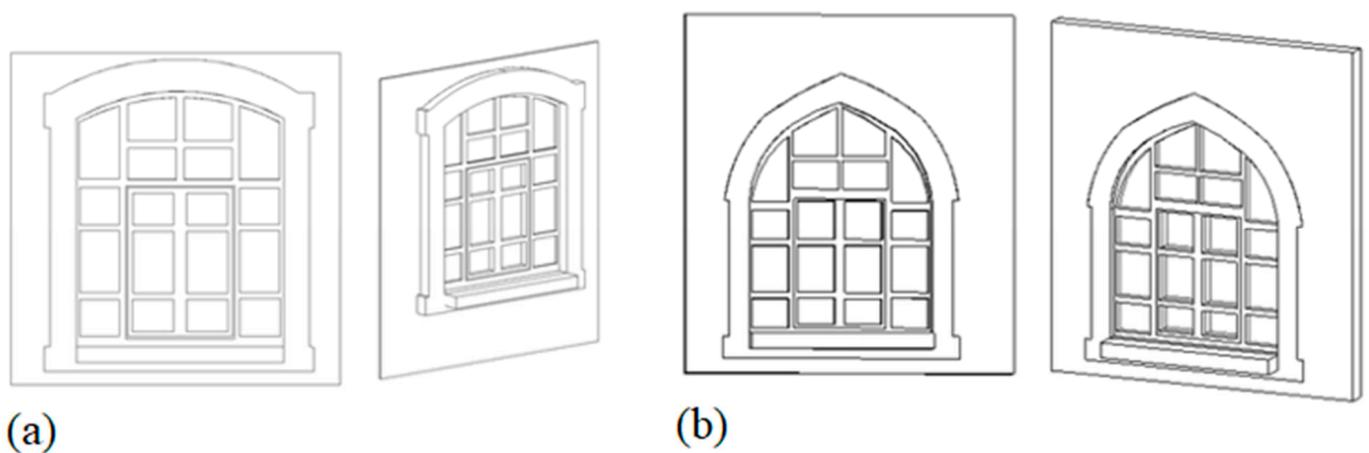


Figure 10. Manual drawings of the window objects over the orthophoto and point cloud: (a) level 2 drawing and (b) level 3 drawing.

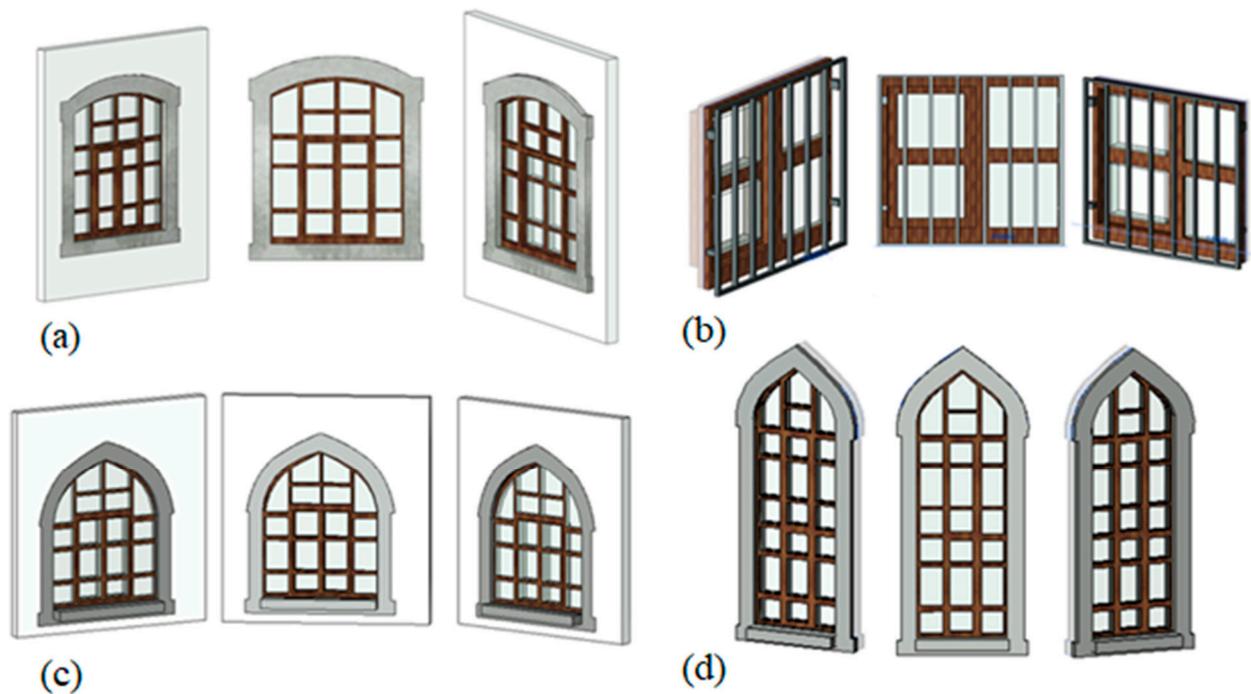


Figure 11. The final versions of the created window object saved in the family library. Window types for (a) level 2; (b) level 1; (c) level 3; and (d) level 2–level 3.

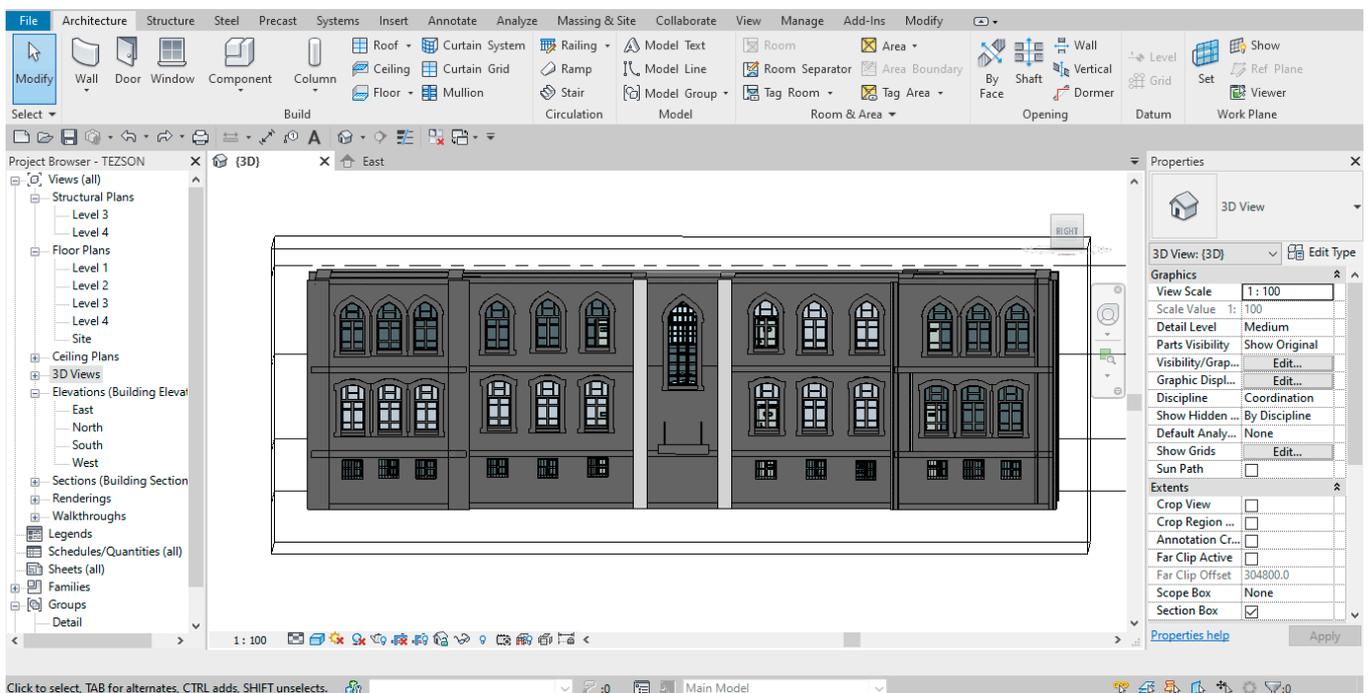


Figure 12. Attaching the created window objects to the 3D model.

The same commands were executed to generate door and window object drawings, except that the 'Metric Door' option was different when creating a new family class. Graphic generation was also materialized by calculating one-to-one twinning over the point cloud. Figure 13 illustrates the material assignments for two different door objects pertaining to the graphics of the front and the back doors. An orthophoto was used meticulously for the

detailed door drawings. Figure 14 depicts a shaded view of the model built by including the door object drawing in the 3D model.



Figure 13. The final version of the created door (front and back) object saved in the family library.

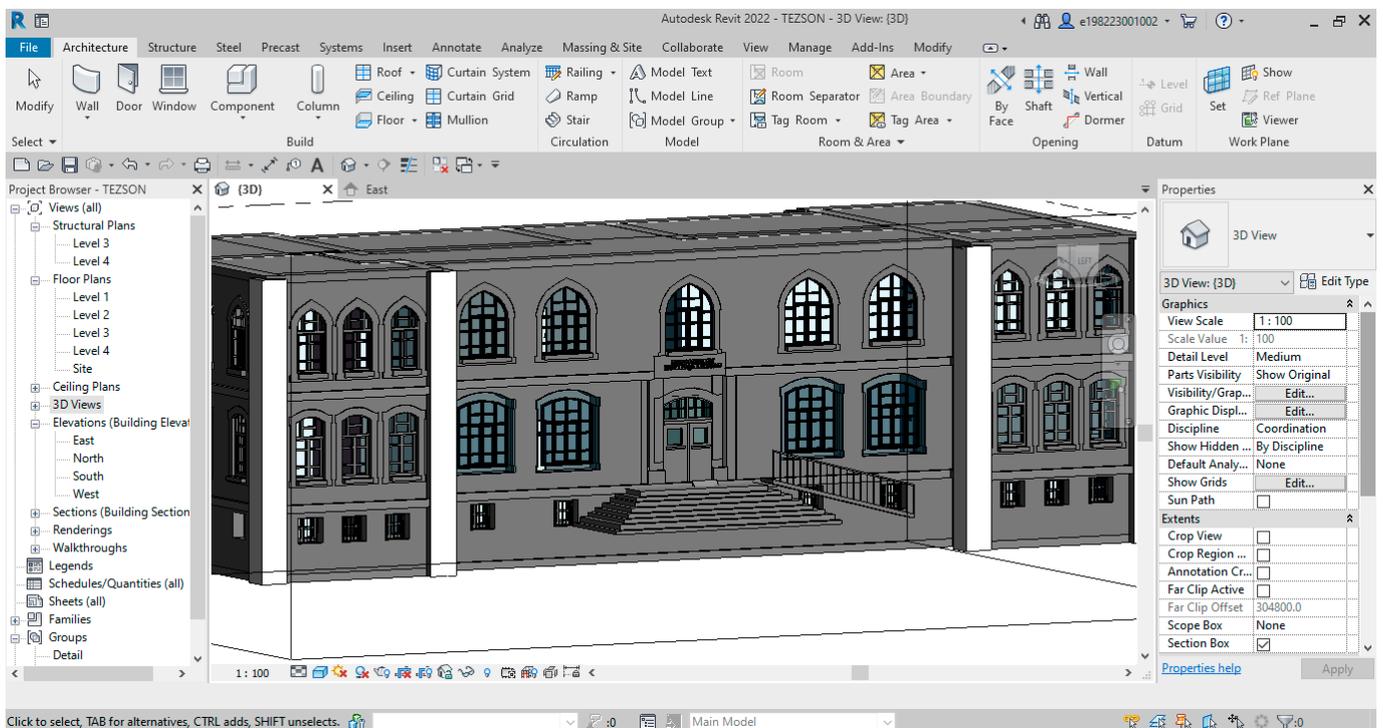


Figure 14. Attaching the created door objects to the 3D model.

3.5. Creating the Stairs and Ramp Object

The building's staircase objects were created by executing the stair instructions in the Revit software. For the ladder drawings, the graphic was made directly on the point cloud. The railing command for the railing detail and the ramp command for the school entry ramp created accurate images. Figure 15 displays the detailed perspectives attached to the 3D model.



Figure 15. Manual drawing of stairs, ramps, and railing objects. (a) stairs and railing details and (b) entry ramp and staircase object.

3.6. Creating the Roof Object

The building roof, one of the essential parts of a building, is composed of many physical roof kinds. The shape of the roof varies from region to region, depending on the construction style. Especially intricate structures may retain more than one roof. In essence, the roof structure in this study is in the traditional hip roof design. As a result, the Basic Roof Generic 400 mm family type object was selected as the building roof object (Figure 16). Figure 17 displays attaching the roof object to the model.

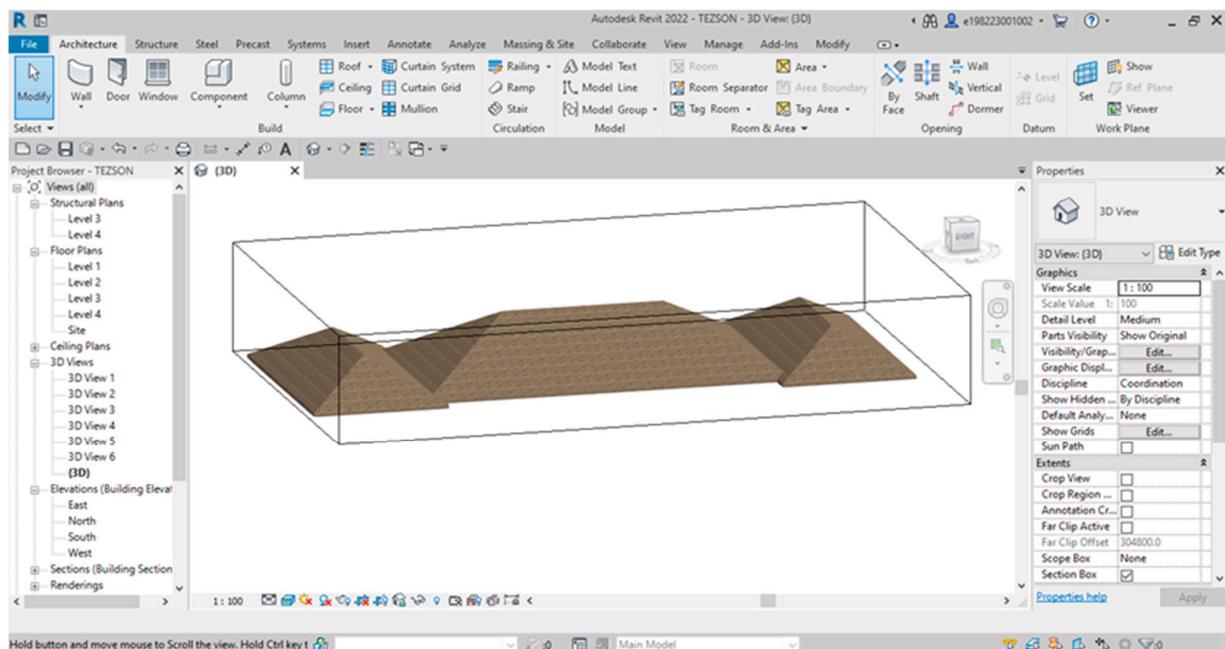


Figure 16. Creation of the traditional hip roof object.

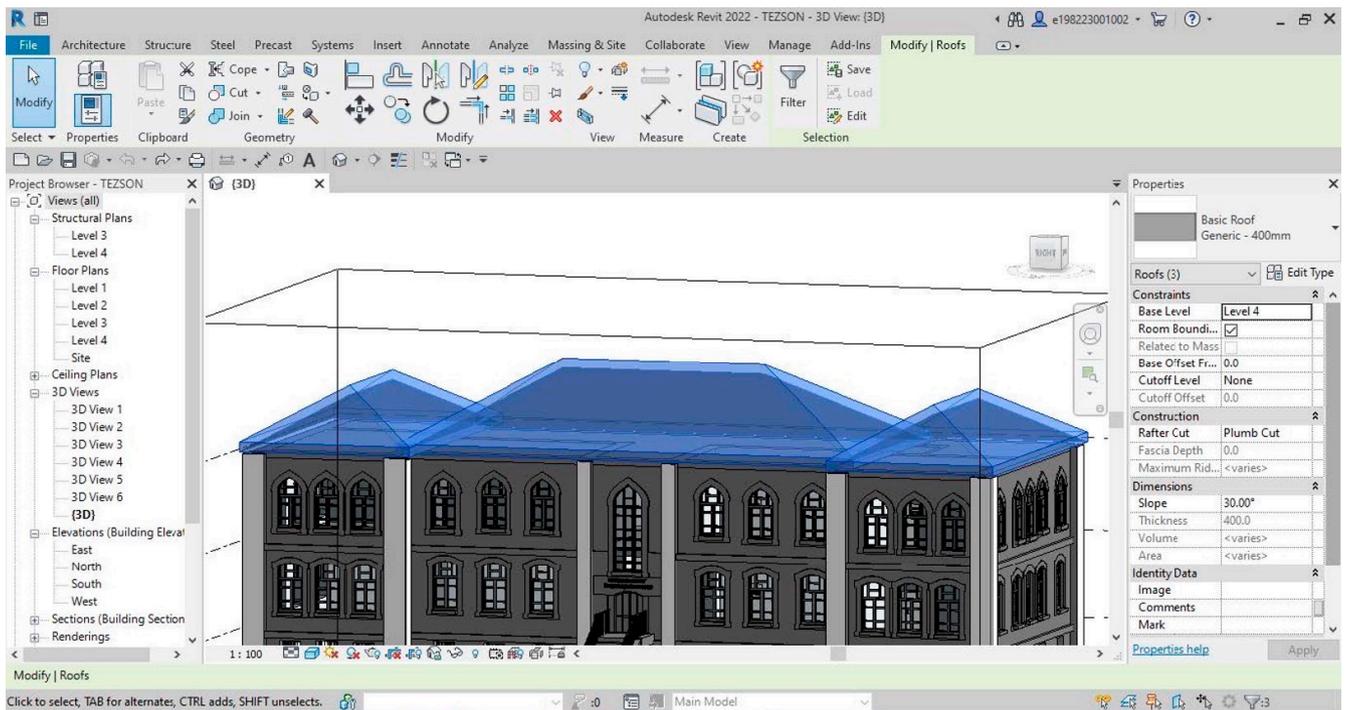


Figure 17. Attaching the roof object to the model.

Subsequently, the material selection process ensued for the model created among available databases in the Revit library. For this step, proper materials in the Revit library were used Figure 18. For instance, a wooden model was chosen for the window, a stone model was chosen for the wall, or an iron material was chosen for the railing object. The outcomes of all these steps led to the creation of floor plans, building details, façades, and 3D models of the building. Figure 19 represents the final version.

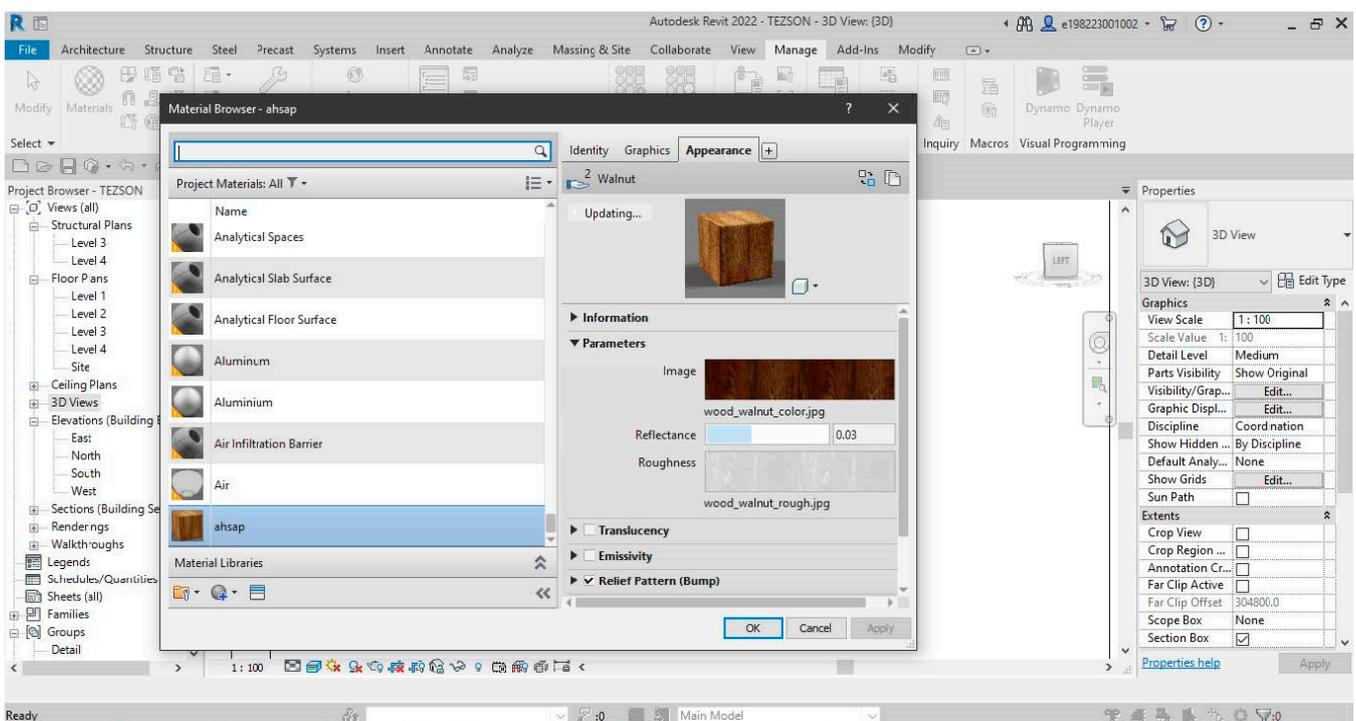


Figure 18. Material assignment to the modeled objects.



Figure 19. The appearance of material-added objects on the 3D model (realistic view).

3.7. Render Image Acquisition

The final stage of model creation involved a render acquisition in the study. Although the software operated during the design process delivers options such as necessary light coatings, colors, and objects, the users may still fail to acquire the desired final image. Accordingly, the designed image becomes final following the rendering process. While devising design and effects programs, light, objects, and color options do not retain the highest quality or coating. Yet, processing and rendering design options in real time may go beyond the capacity of many current computers at this stage. Rendering is, therefore, necessary to finalize a design by producing an output image with high quality and coatings. Such a process also eventuates in time-saving and reduces expenses for computerizing. Figure 20 demonstrates the rendered images of the four façade of the building acquired through Revit software.

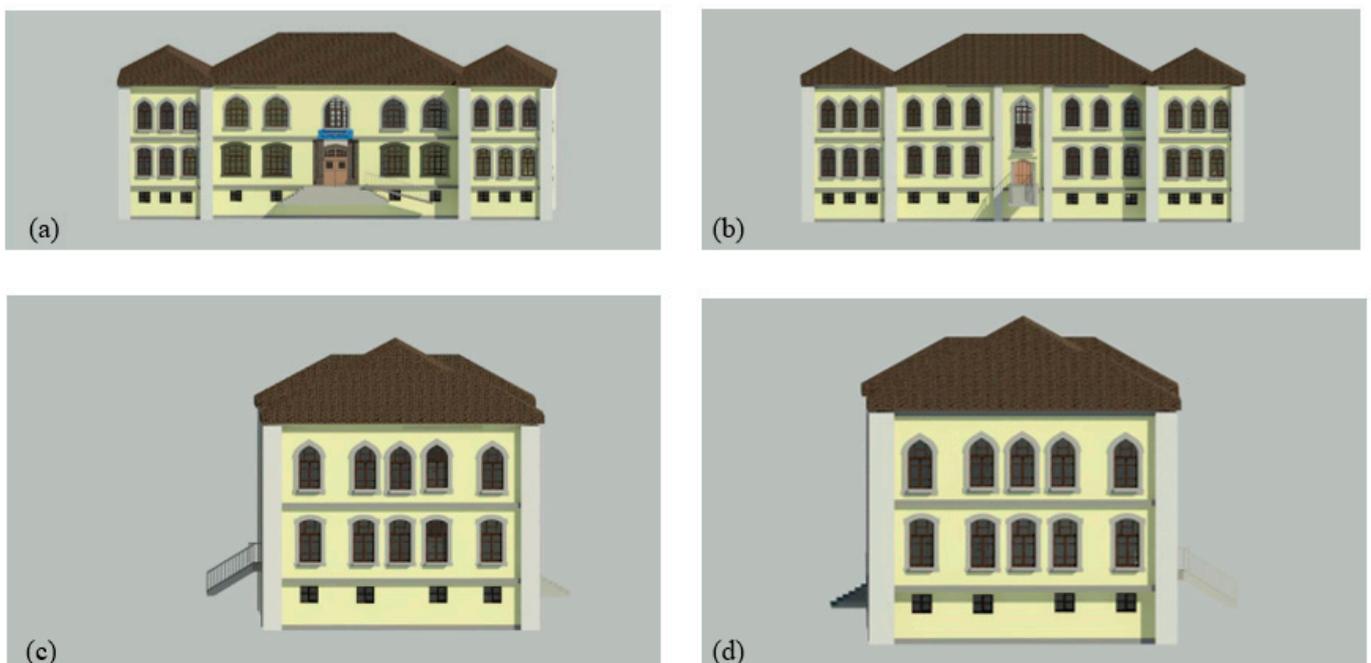


Figure 20. Rendered image model façades: (a) the frontage; (b) the rear front; (c) the right façade; and (d) the left façade.

4. Discussion

Acquiring and modeling the objects from the constructions under consideration is essential in the context of H-BIM since the primary objective is to depict the historical heritage structure and its artifacts. The creation of 2D drawings is also necessary for this goal, much like in the current study, employing orthophotos and subsequent software, such as As-Built, etc. The point cloud then enables the obtainment of 3D depth perception of the object. Additionally, the advantage of capturing the RGB color settings in the point cloud data, used as a modeling reference in the current study, played a critical role in achieving the building's realistic view (panorama), particularly in the assignment of materials and the selection of object kinds. In this regard, the scanning device's technical features bring forward its significance once again [29,50]. It is unattainable to automatically fetch geometric and semantic data directly from the point cloud since parametric objects of historical buildings are composed of excessively complex and unique object geometries. Hence, it would be wise to acquire items manually, as proposed in this study. Clip boxes are necessary to capture the demanded point in the point capture steps during modeling due to the size and complexity of the point cloud data within the scope of the study. In this manner, it is viable to acquire the demanded drawings by applying the necessary filters in the point cloud. Acquiring orthophotos from point cloud data to reflect architectural details and to be able to dominate objects during modeling delivers tangible model outcomes. In this context, when using H-BIM software, user competence is a critical issue in generating high-quality and operative models. In addition to architectural expertise and software experience, data management necessitates proper usage and point cloud interpretation during laser scanning and H-BIM model creation.

5. Conclusions

Studies on the conservancy of cultural heritage reside on the outcome of holistic and collective efforts. H-BIM is a multidisciplinary process that develops in line with user cooperation possessing various professional backgrounds [17,26,32,42]. H-BIM essentially serves as a database for geometric historical and archaeological data and a virtual prototype of an ancient building from a long-term perspective. In essence, this is a significant advantage as it considerably facilitates stakeholders to explore potential relationships underlying the vast amount of information associated with the architectural reference [37,45]. H-BIM is not a widely utilized technology due to its complex and demanding application procedures, expensiveness, and demanding skilled users. However, some theories in this field imply that the advancement of futuristic and technological tools boosting productivity and affordability will eventually make H-BIM a more popular and preferred methodology for historical documentation and management [16]. This article focuses on the use of point cloud data in H-BIM. The functional use of point cloud data for protection, renewal, maintenance, and other H-BIM processes is evident. In this context, it will be valuable for H-BIM studies that users can model para-metric objects manually and realistically in 3D modeling studies. There are no set criteria for the precision of point cloud modeling within the context of H-BIM. However, evaluation of the final product has revealed that it is an auxiliary for the survey data since the collected data are mostly in scaled format. Additionally, since the metrics used in this study refer to actual building measurements, it serves as a basis for architectural documentation studies for restitution and restoration. Since the final product is in the form of 3D numerical data, it poses the potential to take horizontal and vertical sections from preferred locations, floor plans, and façade views. It is also viable to assess the building life cycle from past to present and make attachments to it during the restitution phase owing to semantic data integration. As a result, the design process develops directly proportionate to the available data. This progress also allows for analysis and evaluation of the historical building's development process. Depending on the use of all this available data, on the other hand, the restoration phase may explicitly utilize the data acquired from the documenting procedure of the building in its original form.

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