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Analysis of Remotely Sensed Imagery and Architecture Environment for Modelling 3D Detailed Buildings Using Geospatial Techniques

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Abstract

The use of three-dimensional maps is more effective than two-dimensional maps in representing the Earth's surface. However, the traditional methods used to create digital surface models are not efficient for capturing the details of Earth's features. This is because they represent only three-dimensional objects in a single texture and do not provide a realistic representation of the real world. Additionally, there is a growing demand for up-to-date and accurate geo-information, particularly in urban areas. To address this challenge, a new technique is proposed in this study that involves integrating remote sensing, Geographic Information System, and Architecture Environment software to generate a highly-detailed three-dimensional model. The method described in this study includes several steps such as acquiring high-resolution satellite imagery, gathering ground truth data, performing radiometric and geometric corrections during image preprocessing, producing a 2D map of the region of interest, constructing a digital surface model by extending the building outlines, and transforming the model into multi-patch layers to create a 3D model for each object individually. The research findings indicate that the digital surface model obtained with comprehensive information is suitable for different purposes, such as environmental research, urban development and expansion planning, and shape recognition tasks.

Keywords

Satellite Image, SketchUp Environment, Digital Surface Model, 3D Detailed Buildings

1. Introduction

The use of high-resolution satellite imagery to create three-dimensional models of buildings has become increasingly popular in geospatial technology [1] [2] [3] [4]. This involves using geospatial algorithms and software tools like Sketch-Up to extract the necessary information from the images and construct 3D models of the buildings [5] [6] [7] [8]. The results of incorporating high-resolution satellite imagery have been promising, allowing for more accurate and detailed representations of buildings and their surrounding environments. This advanced technology provides valuable insights for planners, architects, and engineers to analyze a building's structural features, evaluate its environmental impact, and plan more effectively for future development [9] [10] [11] [12]. This integration also enables 3D models to be integrated into urban planning and decision-making processes, enhancing communication and visualization of complex spatial information. Overall, the incorporation of high-resolution satellite imagery for creating 3D models of buildings is a powerful tool for developing sustainable and efficient urban environments [13] [14].

1.1. Generating Digital Surface Models

For many years, traditional techniques such as photogrammetry and LiDAR have been used to extract Digital Surface Model (DSM) in remote sensing and geospatial analysis [15] [16] [17] [18]. These methods involve using a series of aerial photographs or lasers to create a 3D representation of the terrain, which can be further processed to create DSM. While these techniques have proven to be effective in creating accurate and detailed DSM, they require significant time and resources [8] [9]. However, traditional methods remain important in areas with limited access to satellite imagery or other remote sensing data sources. The biggest challenge for studying any area is the lack of geospatial data, and digital elevation models (DEMs) may not show all of the features in the area of interest [19]. DSM generated through traditional methods often only show solid objects without any details of the objects within the area of interest [15] [16].

The advent of high-resolution satellite imagery, such as QuickBird, has ushered in a new era of earth monitoring and observation, offering images with high spatial, temporal, and spectral resolution [17] [18]. The Sketch-Up software, when combined with GIS functions, is a powerful tool for creating highly detailed 3D models [20]. To enhance data management, 3D spatial analysis using GIS was employed to integrate the spatial data of a university campus, demonstrating the efficacy of 3D GIS models in supporting specific applications for design and planning [21]. The generation of DSM requires essential processing steps, such as sensor operation, modeling, stereo matching, and editing and interpolation [22] [23] [24]. Stereo matching is critical to the accuracy and completeness of DSM, and the automatic generation of DSM from satellite images is still considered difficult, if not impossible [25]. It takes several hours to compute a DEM, and longer time is necessary to manually rectify errors, which are unfortunately frequent.

1.2. DSM with Computer Vision

The utilization of computer vision techniques for the generation of Digital Surface Model (DSM) has gained significant attention in the domains of remote sensing and geospatial analysis [22] [23] [24] [25]. Computer vision algorithms provide an automatic means for DSM extraction from diverse remote sensing data sources, including aerial photographs and satellite images [26]. The technique involves image processing to extract terrain elevation, building heights, and vegetation coverage, culminating in a highly detailed and precise representation of the terrain. The employment of computer vision techniques for DSM extraction presents diverse applications in urban planning, environmental monitoring, and natural resource management, as the resultant models provide crucial information for infrastructure planning, flood mapping, and terrain analysis [27].

Overall, the application of computer vision techniques for DSM extraction is a potent tool in the comprehension and administration of intricate spatial data inherent in remote sensing data [28]. Despite the adequacy of two-dimensional maps in charting building structures, roads, or other features, the demand for three-dimensional charting is on the rise in diverse mapping-related areas [19]. The advancement in technology has enhanced data collection, interaction, and visualization techniques, such as remote sensing, GIS, and computer systems, which has facilitated the creation of 3D models [29].

In the geospatial field, most 3D models are obtained by applying diverse algorithms, techniques, and approaches in Arc Map and Arc Scene software [27]. The primary objective of this research is to create an accurate, detailed 3D campus that is close to reality, while the secondary objective is to evaluate the efficacy of incorporating ArcGIS and SketchUp models in developing a site-linked 3D Faculty campus.

2. Methodology

The study utilized a methodology to generate highly detailed 3D models of the Engineering Faculty campus. The methodology consisted of several steps: 1) obtaining high-resolution satellite imagery, 2) collecting ground control points (GCPs) through fieldwork, 3) performing geometric and radiometric corrections using the collected datasets, 4) geo-referencing the satellite imagery using the GCPs, 5) creating a geodatabase in Arc Map 10.3v, 6) digitizing all the study area features to create a shapefile of the Buildings, including additional data on building names and heights to create attribute data, 7) generating the DSM of the study area in Arc Scene using the shapefile, and 8) creating 3D models of each object in the study area using Google Sketch Up, with the DSM and captured photos of the campus used as reference. The methodology is illustrated in **Figure 1** and was deemed effective in creating accurate and realistic 3D models of the campus. **Figure 1** illustrated adopted methodology to perform this study.

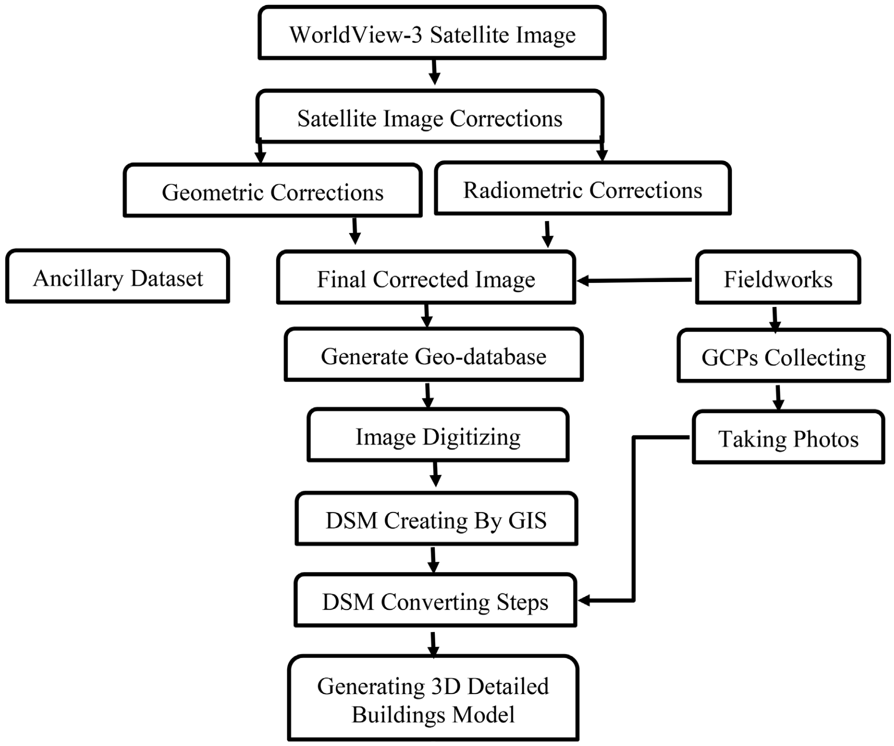

Figure 1. The flow chart of 3D mode and DSM methodology.

2.1. Study Area Description

The study area is Engineering Faculty campus one of the faculties of Al-Qasim Green University. The location of the Engineering Faculty is located in Al-Qasim city, in Babylon Province, it located in longitude 44˚41'8.91"E with latitude about of 32˚18'17.33"N. College of Engineering is one of the scientific colleges at Al-Qasim Green University. It specializes in teaching scientific and engineering subjects related to Engineering, methods of increasing civil engineering and water resources managing, and addressing production problems. It also teaches soil science and water resources from physical, chemical, and biological perspectives. The college was founded in 2014. It is area approximately 2 km^2, as shown in **Figure 2**.

2.2. The Used Datasets

For this study, data from multiple sources was gathered, including the WorldView-3 satellite image, ancillary data of the study area, and data collected from fieldwork. The study area covers an area of 2 km^2, which is visualized in **Figure 3**. The National Oceanic and Atmospheric Administration (NOAA) provided the license for the WorldView-3 satellite sensor, which captures panchromatic and multispectral bands, eight-band short-wave infrared (SWIR), and 12 CAVIS imagery. The sensor operates at an altitude of 617 km, providing high-resolution data, such as a 31 cm panchromatic spatial resolution, a 1.24 m multispectral resolution, a 3.7 m short-wave infrared resolution, and a 30 m CAVIS resolution. The satellite can capture up to 680,000 km^2 of data per day and has an average revisit time of less than one day. Launched on October 8,

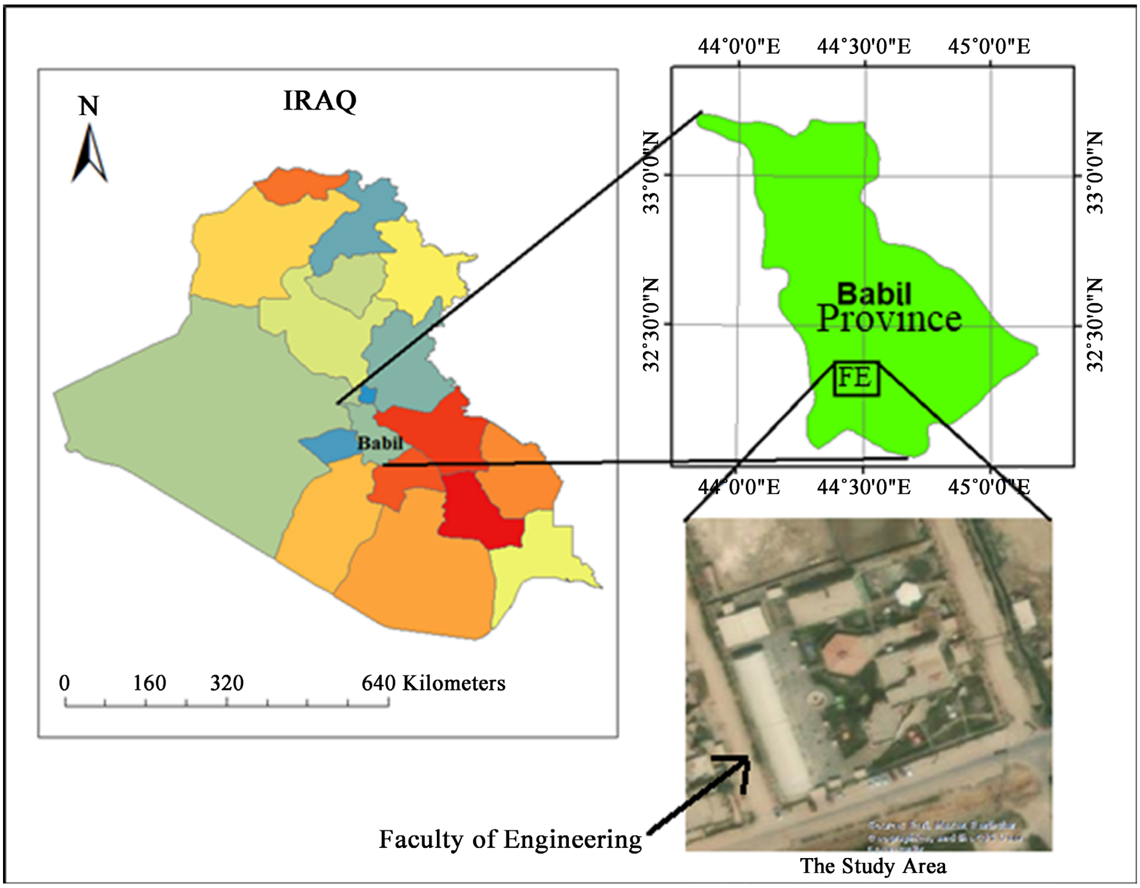

Figure 2. Faculty of engineering location.

Figure 3. The faculty of engineering's worldview-3 satellite image.

2009, the WorldView-3 satellite is similar to WorldView-2 in terms of its performance characteristics but offers improvements such as cost savings, risk reduction, and faster delivery for customers. The captured satellite image was taken on October 15, 2022, over AL-Hilla city, Babil province, Iraq, and underwent radiometric and geometric correction to remove noise. The WorldView-3 image and the study area are shown in Figure 3.

2.3. Fieldwork

At this stage of the research, an important step was taken to collect ground reference points, which is crucial for performing the geometric correction in subsequent steps. The ground reference points were collected through fieldwork using a handheld GPSMAP device of Garmin Csx76 type to record the coordinates of several features located in the study area, as shown in Figure 4. The fieldwork was conducted on January 19, 2022, and a total of eight GCPs surrounding the Engineering College were recorded and are presented in Table 1. Additionally, during the fieldwork, photographs of the College campus were captured for use in the subsequent steps of creating the 3D model of the area of interest.

Figure 4. Location of the Collected GCPs.

Table 1. The coordinates of ground truth points.

No.	points	Northing	Easting
1	A	32˚18'14.41"N	44˚41'12.87"E
2	B	32˚18'13.31"N	44˚41'09.70"E
3	C	32˚18'17.13"N	44˚41'11.86"E
4	D	32˚18'16.03"N	44˚41'08.49"E
5	E	32˚18'15.40"N	44˚41'10.57"E
6	F	32˚18'19.02"N	44˚41'07.24"E
7	G	32˚18'20.05"N	44˚41'10.57"E
8	H	32˚18'14.15"N	44˚41'11.04"E

3. Satellite Image Corrections

Geometric and radiometric noises are two types of errors that can affect remotely sensed images. Geometric errors refer to inaccuracies in the spatial positioning and orientation of the image, while radiometric errors refer to inaccuracies in the brightness and color values of the image. Here are some techniques to remove these types of noises:

Geometric correction: Geometric correction involves using ground control points (GCPs) to align and rectify the image. GCPs are physical features on the ground with known coordinates that can be identified on both the satellite image and a reference map. By using GCPs, the image can be transformed to its correct position and orientation, thereby removing geometric errors.

Radiometric correction: Radiometric correction involves adjusting the brightness and color values of the image to remove radiometric errors. This can be done using a variety of techniques such as histogram equalization, contrast stretching, and normalization. These techniques adjust the pixel values of the image to ensure that they are consistent and accurate.

Altering: Filtering techniques can be used to remove both geometric and radiometric noise from the image. Filters such as median, mean, and Gaussian can be applied to the image to remove noise and improve image quality.

Image fusion: Image fusion techniques can be used to combine multiple images of the same scene, acquired by different sensors or at different times, to create a single image with improved spatial and spectral resolution. This can help to reduce both geometric and radiometric noise in the final image. Overall, a combination of these techniques can be used to remove geometric and radiometric noise from remotely sensed images and improve their quality for analysis and interpretation [1] [2] [3].

Verify the accuracy of the corrected image: Once the image has been rectified, it is important to verify the accuracy of the corrected image by comparing it with reference maps and other ground truth data to ensure that the geometric errors have been successfully removed [2] [3] [4] [5]. The geometric correction of this study was done using the GCPs with use the first order polynomial transformation, the ENVI environment was used to remove the noises from the WorldView-3 satellite image. In the study area, the radiometric correction was performed using the Quick Atmospheric Correction (QAC), the collected GCPs and final and corrected satellite image shown in **Figure 5** below.

4. Result and Discussion

In this study, the research process consisted of three stages, as described in section 2. The first stage, pre-processing, involved the download of high-resolution satellite images of the study area from the WorldView-3 satellite. The pre-processing step included radiometric and geometric corrections to reduce image noise, following the approach described in reference [30] [31]. In the second stage, processing, the researchers geo-referenced the WorldView-3 satellite images by matching the coordinates of ground control points (GCPs) collected during fieldwork to their corresponding locations in the satellite image. **Figure 5** shows the image of the study area after applying radiometric and geometric corrections. To generate the DSM, the researchers digitized the satellite image, creating five layers with distinct information, including buildings, gardens, streets, boundaries, and trees. **Figure 6** illustrates the digitized satellite imagery and the layers of the Faculty campus, including the main building layer highlighted in red. In addition, **Figure 7** shows the 3D map of the Engineering Faculty. To create the geodatabase and attribute tables for each digitized feature, the researchers used ancillary data to expand the attributes by adding a new field to the feature attribute. The attribute tables were established for each layer, and the height field was found to be crucial in generating the university campus DSM and creating a 3D model. The final output shapefile of the study area is shown in **Figure 7**. The research demonstrated that the traditional 2D map is

Figure 5. The corrected satellite image.

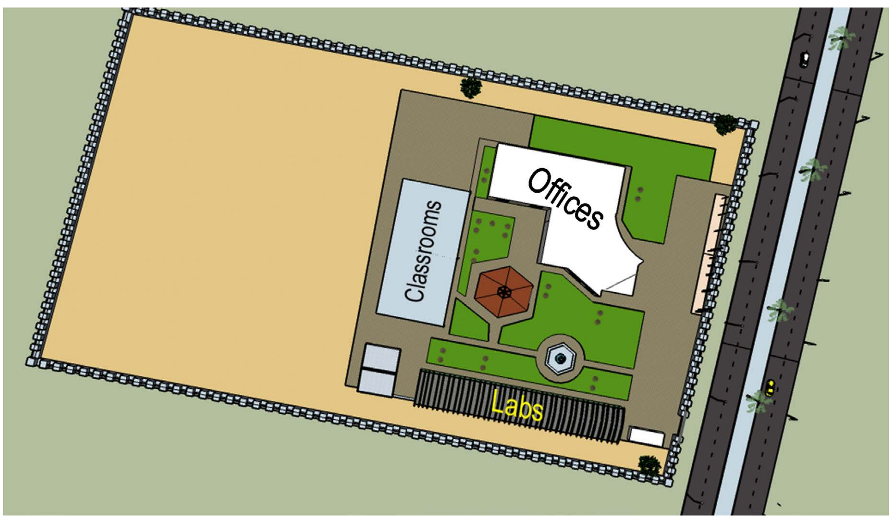

Figure 6. Faculty of engineering digitizing processing.

limited in its effectiveness for shape understanding and individual building data extraction because it is flat and has only two dimensions (X and Y). Nevertheless, it remains a useful base map for future research, as noted in reference [32]. Overall, the research process involved pre-processing, processing, and digitization, resulting in accurate and reliable data for further analysis.

The third and final stage of this research is post-processing, aimed at obtaining a detailed 3D model of the Faculty campus. To achieve this goal, the first step involves creating a DSM of the study area using the Arc Scene environment and the shapefile generated in the previous stage. The next step involves adding the third dimension, height, based on the features' attributes. The DSM is then generated using the Arc Scene environment. **Figure 7** displays the resulting DSM of the university campus.

The study conducted experiments that demonstrated the superior accuracy and detailed information provided by the final 3D model compared to the DSM [33] [34]. This final 3D model can be integrated into both Google SketchUp and Arc Scene environments, with the geometry file in Arc Scene being replaced with the SketchUp file [29]. The combination of GIS and SketchUp provides improved accessibility to vital geographic data concerning all structures and elements situated in and around the university campus. The created attributes offer users the necessary information for any future work geared towards developing the study area [35]. Moreover, this integration enhances the performance of the campus model by permitting models to be seamlessly transferred between different software applications [29]. Therefore, it is essential for facility management to effectively link the building model to the site model, facilitating realistic visualizations for visitors, accommodating changes as they occur, and enabling better visualization and analysis of current buildings [36]. The 3D model of the study area in the Engineering Faculty at AL-Qasim Green University, with detailed information, is presented in **Figure 8**.

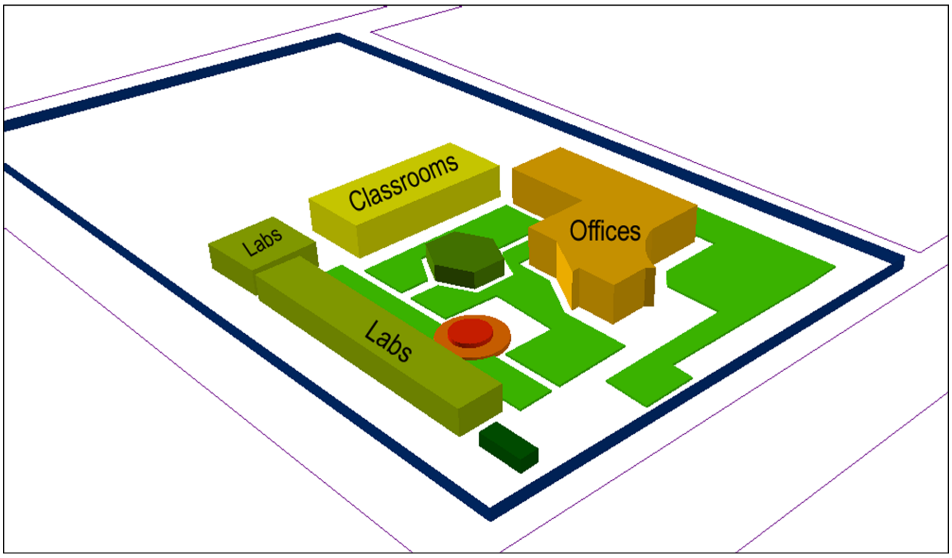

Figure 7. The DSM Faculty of engineering.

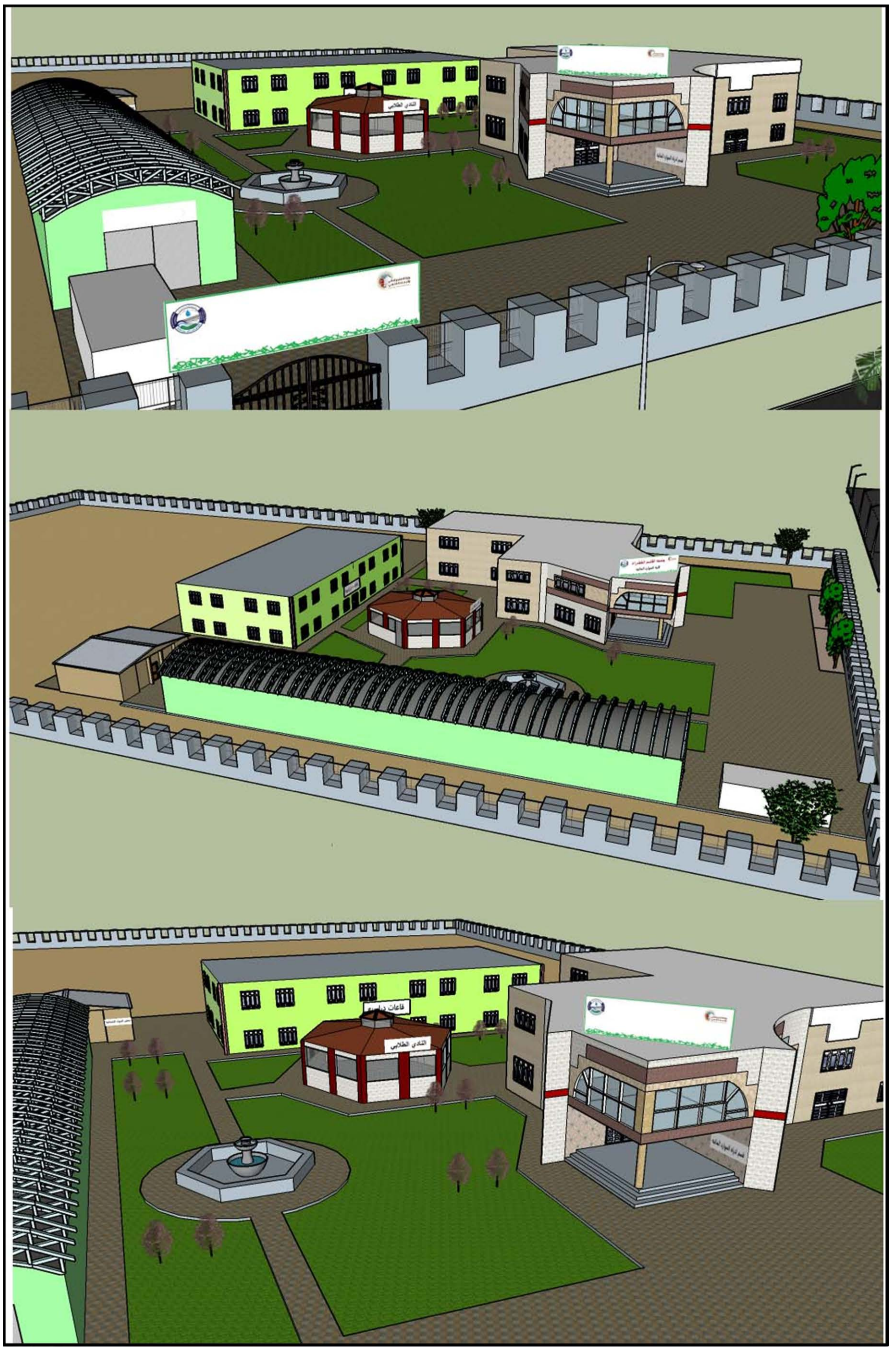

Figure 8. The detailed 3D buildings model of engineering faculty.

As demonstrated in **Figure 8**, SketchUp is a powerful tool that allows users to create detailed 3D models that accurately reflect their designs. One of the main benefits of SketchUp is its user-friendly interface, which makes it accessible for designers of all levels to create complex 3D building models. With a range of tools and features, designers can easily manipulate shapes and objects to achieve their desired outcomes, regardless of whether they are creating a simple box structure or a more intricate multi-level building. Furthermore, SketchUp offers the added advantage of being able to import and export a variety of file formats, making it a flexible option for working with other software programs [36] [37].

5. Conclusion

Currently, a Digital Surface Model or Digital Elevation Model that is represented by a single color and texture is no longer sufficient to meet the geospatial needs of today. To address this issue, our research proposes a new method involving three key steps. Firstly, we begin with pre-processing by inputting satellite imagery and then performing radiometric and geometric corrections to reduce image noise. Secondly, we move on to processing, which involves utilizing ancillary and fieldwork datasets to geo-reference the satellite image of the study area, establish a geodatabase, and digitize the image to obtain a 2D map of the university campus. Throughout the pre-processing and processing steps, we leverage various software, such as ENVI software, ArcMap, and ArcScene environments, to generate a Digital Surface Model. Lastly, in the post-processing step, we convert the extension file of our Digital Surface Model to a compatible format with Google SketchUp to create a 3D model based on the Digital Surface Model. The resulting 3D model provides a more detailed and realistic view compared to the Digital Surface Model. Our research demonstrates that the 3D model offers valuable information for various applications, such as environmental studies, urban development and expansion planning, and shape understanding tasks. Our study shows a detailed 3D model of the study area and emphasizes the effectiveness of obtaining a 3D model over the Digital Surface Model.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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