Developing a three-dimensional city modeling with the absence of elevation data

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ABSTRACT

The past few decades have witnessed steady innovations in remote sensing technologies; however, elevation data needed for creating 3D city models are not reachable for several regions in all over the world. Many developed states still without proper nationwide elevation measurements dataset for developing sufficient 3D city models. The current paper addresses the possibility of producing 3D models for areas without elevation data but with footprints, measurements collected from government departments and volunteered individuals. The study aims to investigate and evaluate a different approach to create three-dimensional city models based on data that existed in open-source maps when elevation measurements are not available. The proposed approach can be divided into two stages: footprint and shadow data collection, and height estimation. At first, the footprint information and shadow area are manually gathered from satellite images, then the building height is predicted based on rooftop and shadow data. SketchUp, a 3D design software, is employed as an efficient tool for creating the 3D virtual city model. To develop such a model, the software utilizes procedural modeling in addition to an image-based approach. The developed model can produce a satisfactory and realistic virtual scene within a short time and for a large area. The 3D city modeling resulted from estimated heights is considered as a rational provisional solution at areas where elevation data are not available or are out-dated.

Keywords: Building height, Shadow detection, 3D city model, Footprint, SketchUp

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1. Introduction

Urban models such as city models are usually developed using computer-aided simulation software. These models are employed to examine theories related to spatial location and possible interference between land uses and the spatially dispersed human activities. Additionally, they present the built environment in digitized form to interrogate the outcomes of physical planning policies and action plans on the future shape and nature of the cities. As a result, 3D models for urban areas are essential to several diverse applications related to urban planning, virtual tourism, facility management, and 3D GIS. The three-dimensional city models also play a significant role in the process of planning and in simulating disasters including earthquakes, flooding, and tsunamis [1]. The provision of 3D urban structure models with relevant data can effectively aid in understanding the spatial feature capacities of the cities. Buildings are so vital features in any 3D city model, other modeled features may involve other urban infrastructure, terrain, and plants [2]. Therefore, many studies have considered the objective of acquiring 3D building information due to the importance of such geospatial information in various 3D applications such as simulation, navigation, mapping, urban planning, and terrain analysis [3],[4].
The developed 3D city models can generally reflect the overall urban structure of the existing city and hence these models are informative for decision-makers. The visual representation of the adopted development plan can be attained by overlaying on the existing city models, this let urban planners capable of simulating and making effective decisions [1], examples include the analysis and visualization of an adjacent environment in a building's design, the planning for new constructions and renewal the aged ones, the growth in the communication sector, adopting proactive emergency plans for unexpected catastrophic incidents and also the modeling of major environmental variables such as solar radiation, heat demand, urban noise, air pollution, and shadows predictions. These findings are quite difficult to be accomplished with the common survey methods as they would entail considerable time and effort to survey and analyze big urban regions like cities; hence leading

to a noticeable rise in the final 3D model cost [5]. It is useful to highlight that the typical data sources required for a 3D city model are digital terrain models, cadastral data, building models, green space models, in addition to street-space models [1]. 3D virtual city models are the resourceful technique to gather, combine, and manage diverse geoinformation. It exhibits activities, layouts, and functionalities of real communities and provides users with better visualization of their places. These applications demand various types of measurements usually obtained from a plethora of data sources. For ensuring efficiency, the adopted data have to be as accurate as possible and regularly updated [5, 6]. The city models vary in their goodness based on their geometrical accuracy, semantic quality, and their appearance realism [2]. Recent technological advancements such as high-speed computation, computer vision, and high accuracy sensory data acquisition in geomatics have effectively contributed to constructing good virtual 3D city models like geographical information system, photogrammetry, global positioning system, remote sensing, radargrammetry, and laser scanning [7]. Building a representative and accurate 3D city model requires the investigation of two chief issues. First, the exact reconstruction of precise 3D geometric models; second, the accurate texture mapping of model surfaces [8]. The appearance of the city depends on two parameters; characteristics of the city like street network geometry, building type, and density, the other factor is the city components distribution like roads, water, and vegetation [9]. Cost, time, texturing, and accuracy is essential parameters in 3D city establishing that largely s subject to the user requirements [7]. At present, to yield accurate and detailed 3D city models, traditional authoritative production processes are employed. They regularly depend on costly and advanced technologies such as laser scanning and aerial photogrammetry, which are usually expensive, lengthy, and demand the field participation of experts. Recently, there has been a rising awareness regarding the utilization of the Web to build, collect, and publicize user-generated geographic data supplied by volunteered citizens. This mapping scheme allows individuals to develop public domain universal maps that are accessible anytime anywhere by anyone [4]. Having that said, footprint data for buildings have lately become broadly obtainable through global geoinformation sharing tools like Google Map, OpenStreetMap, and Microsoft Bing Map. These spatial measurements lead to reduce the time, effort, and highly technical process required for building boundary extraction, enabling chances to create cost-effective and large-scale 3D city models. Footprint data can be combined with surface elevation measurements to yield 3D virtual building models [10, 11]. The purpose of the current research is to investigate and assess alternative approaches to create 3D city models when there are no elevation data. This is achieved by firstly examining the available alternative approaches. Having that the key feature in city models is the buildings, the approach we have commonly found is to predict buildings height based on rooftop measurements and building shadow which can give acceptable estimation for building height. Moreover, whereas this approach in estimating building heights has been widely used worldwide, it was never adopted for 3D virtual city modeling in Iraq – which is the significance of the current paper. It is true and understood that developing a 3D building model based on such estimation would not be the most accurate technique; however, it is an acceptable provisional solution when no elevation measurements are available. In addition, the proposed approach can be beneficial to implement other spatial analyses.

2. Background and related work

The construction of 3D urban models is of unlimited importance for developing countries where urbanization processes are dynamic, noticeable, and in continuous rise [12]. The typically needed measurements to develop 3D city models have been based on footprints and elevation dataset, the last one is usually gotten from lidar and photogrammetry survey. Footprint measurements are usually available as open data from relevant government departments or volunteered geoinformation. Elevation information, in contrast, still time-consuming and costly to collect, restricting the wide availability of 3D city models. Furthermore, existed elevation datasets are not always appropriate to create 3D models due to two reasons. First, the measurements might be outdated and hence producing smaller completeness as compared to footprints that are quite straightforward to be updated in comparison with point clouds and are as well generally formed under more recurrent intervals. Secondly, their quality and resolution are not continuously appropriately passable to make 3D city models. For instance, a common Shuttle Radar Topography Mission (SRTM) provides elevation datasets that are free and with global coverage; nevertheless, like these datasets are not adequate for creating 3D city models mainly as a consequence of their coarse resolution and low accuracy [13].
Building extracting has considered as one of a key techniques employed in GIS databases updating and digital maps updating. It has been recently a thriving research topic in remote sensing and computer vision. Nevertheless, the fully automatic systems for this topic aren't operational yet and can't be carried out in a solitary

step. These difficulties are because buildings have homogeneous spectral characteristics with other built environment objects like streets and squares. Buildings are available within satellite images of high spatial resolution. The major issue with this kind of data is a purchase cost and repeatability particularly when the study is multi-temporal. To overcome this financial issue, the alternatives presented by Google Earth were examined. Google Earth along with its rising acceptance between general users, has been gaining continuing interests in academia [14, 15]. The collection of height information and its accuracy can directly affect its use, especially in developing terrain analysis, topographic maps, infrastructure development, and several other engineering studies. Various approaches existed for extracting height information. The common approaches stand for ground surveys (direct measurements from the field) and satellite data by adopting various methods such as interferometric methods, stereo data of optical data, and LiDAR data systems. However, such data have been usually expensive and demand advanced processing software and professional staff. As a result, a simple method of getting building height data is needed to handle such problems. In the proposed method, buildings height data were obtained based on the shadow utilizing remote sensing satellite data. Shadow can be seen in the satellite image of high resolution and is described as "an area in which direct light from the light source can't reach attributable to obstructing by an object" [16]. A building shadow can be utilized for predicting its height and structure. This information is essential in a variety of remote sensing uses like urban change detection, disaster monitoring, reconstruction of an urban scene, and cartography update. To attain an efficient satellite image investigation and a building height estimation, a spectral heterogeneity and complexity that usually found in urban landscape scenes should be dealt with correctly and buildings shadows have to be identified and separated appropriately. Shadows are typically cast when objects partially or entirely obstruct direct light rays from the illumination source. According to many remote sensing studies, numerous methods were employed by numerous researchers for shadow delineation by means of satellite images. These methods are usually grouped into dual main classifications; property-based and model-based approaches. In property-based approaches, both spatial and spectral characteristics of shadow regions are employed. Model-based methods, in contrast, benefit from supplementary metadata or scene information like light source direction, sensor localization data, as well as object geometry as prior information [17]. Several studies have analyzed shadow to obtain building height from shadow properties, image metadata, angle of sunray, and sensor orientation. Following is a summary of some of these studies.

Over et al. (2010) examined the scenarios for generating interactive 3D City Models according to spatial geoinformation extracted from the Open Street Map project and height measurements supplied by the Shuttle Radar Topography Mission [18]. Izadi and Saeedi (2012) examined an approach for 3D Polygonal Building Model based on Single Satellite Images. They presented a system procedure for automatic detection and height predictions for buildings with roofs of polygonal shape based on single satellite images. Their developed system consisted of dual focal measures: two-dimensional Rooftop Detection and three-dimensional Building Estimation. They reported that the efficiency of their proposed system was with total mean shape accuracy of 94% and with a mean building height error of 0.53 m on QuickBird satellite (0.6 m/pixel) imageries [19]. Comber et al. (2012) presented a rule-based approach to obtain buildings' heights depending on their shadows. They classified the building shadow depending on their relative density within spatial context and scene features. Their proposed method was adequate for the analysis that demands a rough measure of building height [20]. Benarchid et al. (2013) developed the automatic building extracting technique by means of object-based classification and shadow data in huge resolution multispectral images for Tetouan city [21]. Peeters (2016) introduced a GIS-based approach for building three-dimensional geodatabases of urban structure from shadows and examining structural factors for urban-climate analysis. His study revealed that the developed approach can provide a dependable and cost-effective process for creating 3D geodatabases that used for investigating urban-climate parameters in less urbanized areas, where expensive required data and advanced processing practices have been less manageable [12]. A novel automated method for determining the shadows for buildings was produced by Liasis and Stavrou (2016). The estimated building heights using the length of shadow as well as the calculated or estimated solar elevation angle [17]. In their work, Biljecki et al. (2017) examined the viability of developing 3D city models based only on 2D spatial information without measuring for elevation data. Their analysis proved that there is a possibility to estimate buildings heights based on 2D data including their footprints and other properties have taken form volunteered geoinformation and cadastral survey, and subsequently extruding the footprints for obtaining three-dimensional models adequate for a wide range of uses [13]. Bshouty et al. (2020) employed a single contributed photograph in addition to Open Street Map (OSM) vector data to yield accurate snapped building height and then providing this data to the OSM map to create open-source three-dimensional city models. They developed a framework to improve the preset 2D OSM map infrastructure to the 3D domain [4].

3. Objective

The overall objective of the current paper is for supporting the systematic investigation of climate in developing urban areas. The developed approach utilizes building shadow lengths to build a 3D geoinformation related to urban morphology. In so doing, for constructing the 3D modeling of buildings the following sub-objectives should be attained:

- building footprints are obtained from open-source spatial data tools like OpenStreetMap and Google map.
- building height is predicted based on its shadow using Google Sketchup software.
- the goodness of the projected technique in detecting shadow and estimating building height is evaluated using related qualitative and quantitative methods.

3.1. Study area

This research article is based on an area in University of Baghdad campus which is located in the central part of Baghdad city, capital of Iraq as illustrated in Figure 1. This area consists of multiple colleges and departments with buildings having distinct differences in heights, which adds to the diversity of the analyzed structures. This area of study was chosen for the ease of extraction of urban building footprints and their shadows as well as the variation of the height helps in assessing the accuracy of the 3D city model.

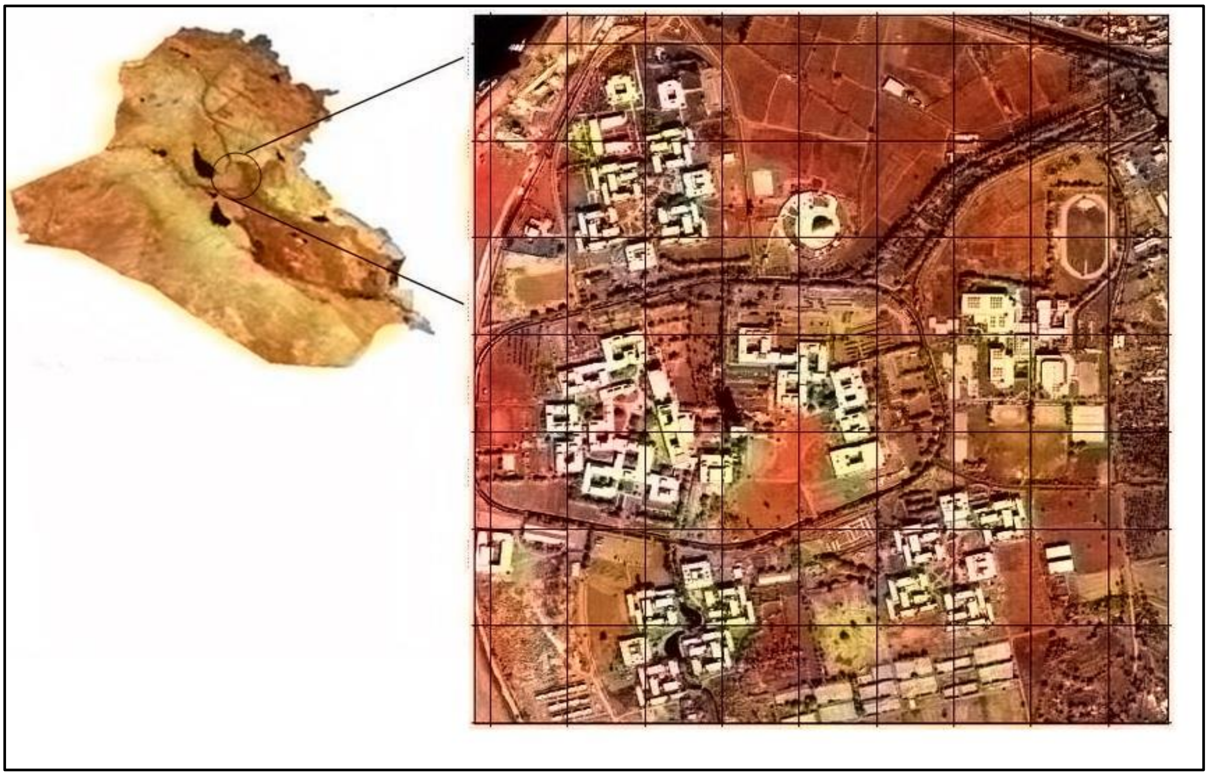

Figure 1. Study area

3.2. Methodology

The features of geoinformation maps and characteristics of city models should be carefully investigated. Various details are quantified for 3D virtual city models and several depictions are suggested for real-time 3D city model scaling, for simplifying 2D spatial maps and 3D building model depictions in multiple scales. Nevertheless, the majority of the 3D modeling techniques are based on geometry, which usually explains the foremost data volume of a three-dimensional model [22]. As highlighted previously, buildings represent the most focal stage of a 3D city model for several applications. The creation of a 3D city model designates the overlay of features in the 3D setting by overlapping the needed features on the surface of elevation data. If additional supplementary data, such as manual digitizing and field surveying becomes accessible later then the dataset can be modified and broadened as needed. Buildings heights should be identified for determining factors related to urban form, the latter is widely utilized for defining urban sites quantitatively. The key challenge in the automated designation of urban objects based on two-dimensional images is that vertical remotely sensed imaginings involves only 2D footprints of urban characteristics, with no information regarding heights. One opportunity to overcome this challenge is to consider the shadows generated from objects when restricting a light path. This shadow-driven technique is assessed as an effective procedure for estimating the heights of buildings based on a 2D image [12]. Image-based modeling software is considered a proper analysis tool for 3D city modeling. It is true, however, that analytic methods and computer programs have their own favorable and unfavorable attributes. The objective is then to determine the adequate software and the effective method based on the demands of the 3D city modeling project. Level of Details is also an essential issue for any 3D city modeling project [23]. The current paper uses a 3D city model as a correspondent to 3D building models taking into account that the key feature in three-dimensional city models is the buildings. Several 3D city models have been created manually and automatically with 3D modeling and designing software like Google SketchUp. The overall flowchart of the research methodology is depicted in Fig. 2.

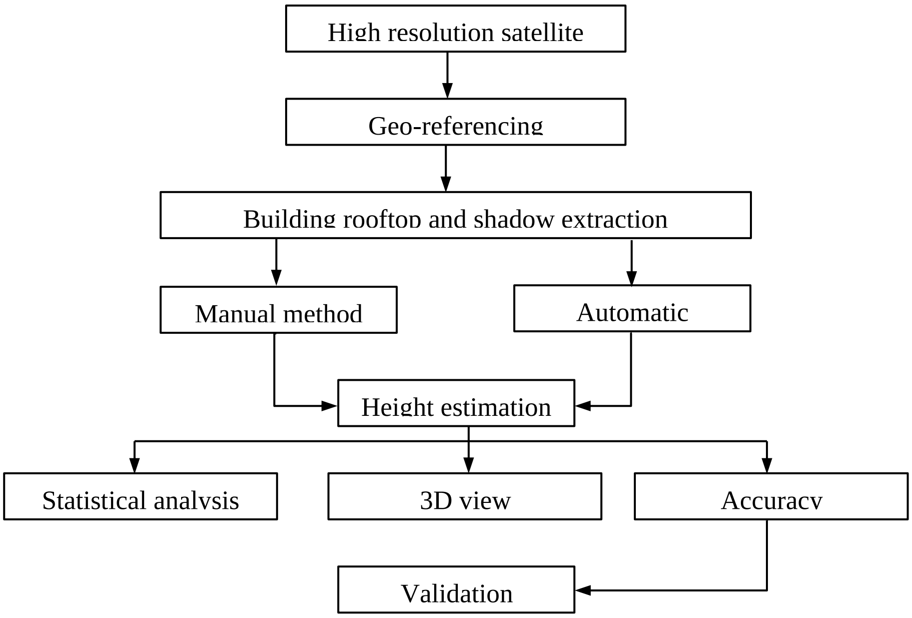

Figure 2. Overall flowchart of methodology

3.3. Shadow detection and height estimation

Shadows appeared in high-resolution imagery are usually straightforward to be identified through visual inspection, often depending upon information about nearby buildings or texture. Nevertheless, defining their boundaries automatically is difficult. That is primarily because the spectral attributes of shadows are quite similar to those of other surface objects like water and other land-cover types (e.g. burned area, road, roof, forest cover) that look dark on images [24]. Analyzing a tall building shadow requires taking into consideration that there are dual shadows; the part of cast shadow on the ground in addition to the self-shadow which is the non-illuminated part of the object, i.e., the building facade. The cast shadow that appeared in satellite images can be utilized to estimate the building height [16]. The current paper methodology involves the prediction of building height depending on analyzing the shadow shape in the satellite images. After defining a building shadow, the following step is to determine building height based on the shadow length which can be computed by dividing the shadow zone area by zone length. The true heights for buildings can be found by developing 3D building wireframes as well as building shadows in a three-dimensional object space for a proposed building height, then projecting them back to the two-dimensional image space. Next, altering the height by selecting multiple proposed values until achieving an acceptable harmony between the developed building shadows and planned building wireframes and the real ones in the image. The performance largely depends on the height adjustment and the degree of harmony. The process begins by choosing building roof corners which can be accomplished manually. Upon completion of roof determination, an initial arbitrary height is assumed and both 3D building wireframes along with its shadow in a three-dimensional space are developed. Thereafter, the 3D building frames and the developed shadow are projected back onto the 2D image space. These steps are repeated by gradually increasing the building height until an agreement is reached between both the projected building frame and shadow and their real figures in the image. The height value that achieved this matching is considered as the true building height. When the process of selecting building height is performed adequately, this technique is considered effective in extracting building in low-density urban regions with plenty of occluded building footprints and shadows. In the case of manual adjustment, any observable part of the building footprints and shadows can be chosen as guidance to govern the finest match. Figures 3 and 4 exhibit both building extraction and height prediction.

4. Results and discussion

The proposed technique for extracting buildings has been applied on a real case - the campus of the University of Baghdad. University courtyards, their surrounding buildings along their shadows were all identified and characterized as polygons based on the procedure explained in in Figure 3 and Figure 4. The identified features of the polygons were then ordered in a specific geo-database by spatially linking characteristics to each other to associate every courtyard with its wall and cast a shadow. Fig. 5 demonstrates the developed 3D city model depending on the deduced heights from the shadow. The obtained results reveal that the proposed procedure can effectively distinguish nearly all the building shadows, even when buildings are with non-uniform shapes or interact with other nearby objects. The proposed methodology for estimating building heights has the power of discarding a great amount of the non-building shadows with similar attributes in addition to any confusing objects. The proposed method was assessed by choosing several buildings in the study area with a known actual height to compare them with the estimated height. Table 1 lists a the attained results for actual buildings.

Table 1. Predictable building height evaluating for identified buildings

Name	Actual building height (m)	Estimated height (m)	Variation (%)
University Tower	79.45	82.60	+3.96
The central library	20.6	21.64	+5.06
Al-Hakim hall	20.7	21.61	+4.39

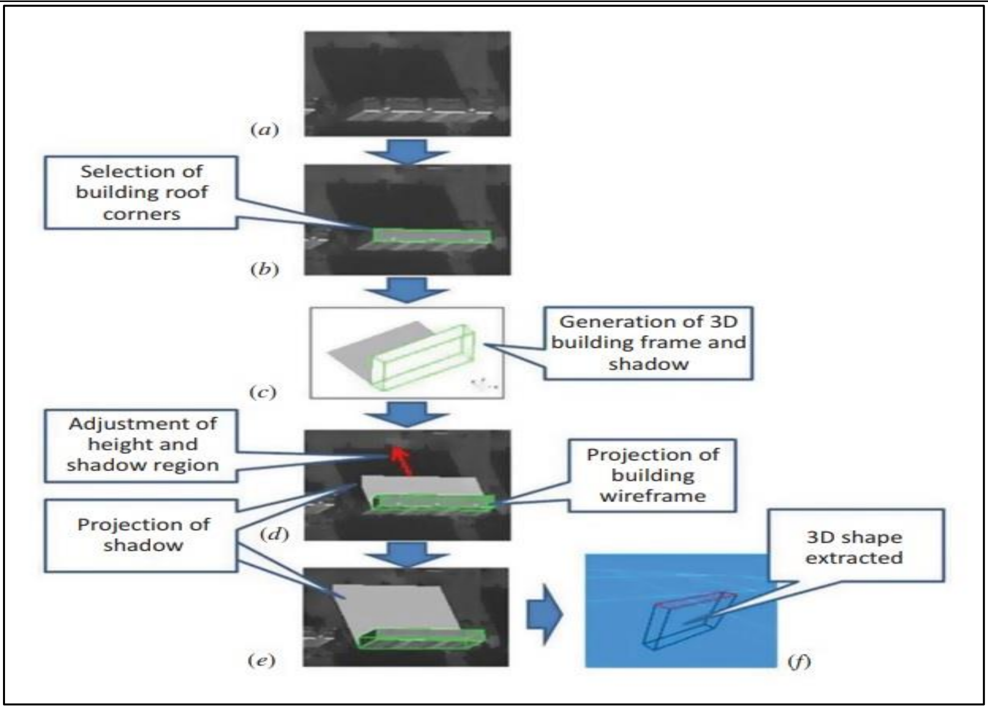

Figure 3. Building extraction and height estimation [3]

Figure 5. 3D modelling of the Baghdad university campus

5. Conclusions

The creation of a three-dimensional city model has not become a commonly used practice yet, mainly due to the high cost associated. The adoption of geomatic techniques therefore is a promising alternative that even allows the dependence on available digital data not specially developed for creating 3D city models. The current study primarily aims to investigate and evaluate the applicability of image-based 3D city models and to propose an alternative non-complicated and economical image-driven photogrammetric approach. The current study adopted the campus of the University of Baghdad as a case study with the developed 3D model works as big city prototype. The analysis reveals that adequate 3D city models can be directly developed without the need for elevation data; three related key reasons can be highlighted:

1. The accomplished accuracy is quite similar to those achieved in relevant studies and practice. In specific, for many of the developed models, most of the estimated heights were with less than 1m error; that is more accurate than several relevant 3D models adopted traditional techniques,
2. The developed models can be employed as an effective tool for carrying out several spatial analyses, and
3. The developed method also is applicable in enhancing available 3D models by updating newer buildings as long as their footprints are accessible but a LiDAR survey hasn’t implemented yet.

It is worthwhile emphasizing that the contextual association between buildings and shadows can enhance the performance, maximize the accuracy ratios, and discarding those objects mistakenly recognized as buildings. The achieved findings confirm a total percentage for building detection of 86.70%. The proposed approach can aid in recognizing different buildings needed for updating GIS databases and in detecting a transformation.

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