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Technical Note

Digital surface model based on aerial image stereo pairs for 3D building

Abdelkader El Garouani [a,*], Abdalla Alobeid [b], Said El Garouani [c]

[a] Sidi Mohamed Ben Abdellah University, Faculty of Sciences and Techiques, Route d'Imouzzer, BP. 2202, Fez 300 60, Morocco
[b] Institute of Photogrammetry and GeoInformation, Leibniz University, Hannover, Germany
[c] Abdelmalek Essaadi University, Faculty of Sciences, Tetouan, Morocco

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Abstract

There is an increasing demand for 3D city models for many applications and users worldwide. Fez is one of the most important tourism locations in Morocco and is a challenge for 3D city modeling due to its complex buildings and road structure. Due to its importance this Historic Medina of Fez was added to the UNESCO World Heritage List in 1981. It is located in the northern part of Morocco. In this work, we discuss the construction of a digital surface model based on aerial image stereo pairs using matching method and the use of this DSM for 3D city planning. We used aerial photographs with high accuracy (1/4000) covering the study area acquired in 2007 and additional cartographic data from Fez. 3D land use zoning allowed building volumes, usage, and density. They are the main tools defining the image of a city and bring into focus the model of best practice of the rehabilitation and conservation of the historic Medina.

Keywords: DSM; Matching; 3D building; Fez; Morocco

1. Introduction

Three dimensional models consisting of the geometry and texture of urban surfaces could aid applications such as urban planning and heritage conservation. A standard technique used to create large-scale city models automatically or semi-automatically is to apply stereo vision on aerial or satellite imagery. 3D city models are digital representations of the Earth's surface and related objects belonging to urban areas (like cities, factories, buildings etc.). Several disciplines like urban planning, architecture, telecommunication, tourism, environmental protection and many others have an increasing demand for digital 3D building, in order to use such complex data for planning, analyses, visualization and simulation in different applications.

Additionally, the open geospatial viewers (e.g. Google Earth, Virtual Earth, etc.) increase the demand on 3D city models (Remondino et al., 2006). 3D building and its update require the development of automatic methods for acquisition of Digital Surface Models (DSM) (Toutin and Gray, 2000). Digital photogrammetry, both airborne and spatial, is an efficient modern technique for DSM acquisition as a base for 3D building.

A digital surface model represents the elevation associated with the surface of the earth including topography and all natural or human-made features located on the surface of the earth. There is a variety of DSM source data available for developed areas and the suitability of these

* Corresponding author. Tel.: +212 6 63 82 90 46.
E-mail address: el_garouani@yahoo.fr (A. El Garouani).
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available data depends on the project specifications. In remote regions around the World, where little or no source data are available, the DSM can be produced automatically from stereo satellite scenes, from satellite sensors such as IKONOS, SPOT-5 and Terra-ASTER (Baltsavias and Stallmann, 1993; Gruen et al., 2007; Jacobsen, 2004). The DSM can also be provided from stereo digital aerial photography at various resolutions, depending on the quality and scale of the aerial photography.

This study concerns the historic city of Fez which is one of the most important tourist locations in Morocco. Due to its importance this historic Medina of Fez was added to the UNESCO World Heritage List in 1981. It is located in the northern part of Morocco (Fig. 1).

In this work, we discuss the construction of a digital surface model based on aerial image stereo pairs using the matching method and the use of this DSM in 3D building. A 3D-GIS (Geographic Information Systems) application was used to visualize the existing state of the city and to perform simulations of district development plan.

2. Material and method

2.1. Study region and used test data

Fez is the most ancient of the imperial cities of Morocco. The urban community of Fez accounts for one million inhabitants and the city has about 95 km^2. Founded in 789 by Moulay Idriss 1st and home to the oldest university in the world (Quaraouiyne university built in 857), Fez reached its height in the 13th–14th centuries under the Marinids, when it replaced Marrakesh as the capital of the kingdom. The urban fabric and the principal monuments in the medina – *madrasas* (*traditional school*), *fondouks* (*traditional hotels*), palaces, residences, mosques and fountains – date from this period (El Garouani et al., 2012). Although the political capital of Morocco was transferred to Rabat in 1912, Fez has retained its status as the country's cultural and spiritual center. Fez is a religious, touristic and academic center. The figure below presents some historic landscapes of Fez Medina (Fig. 2).

The 3D city model of Fez can be used in many applications:

- To visualize the city for various purposes (tourism, virtual tours, etc.),
- In urban planning,
- In navigation systems,
- In intelligent transportation systems,
- In urban risk modeling;
- In architectural visualization;
- In telecoms – positioning of mobile phone transmitters;
- In flood risk mapping.

The surveying flight 2007 of Fez was carried out by the *CABINET BELMLIH* (*GeoData*) by order of the *Agence Urbaine et de Sauvegarde de Fez*. The whole city area of Fez was recorded in 7 north–south strips. For the camera, we were used the Zeiss RMK-A 15/23 with a focal length 152 mm.

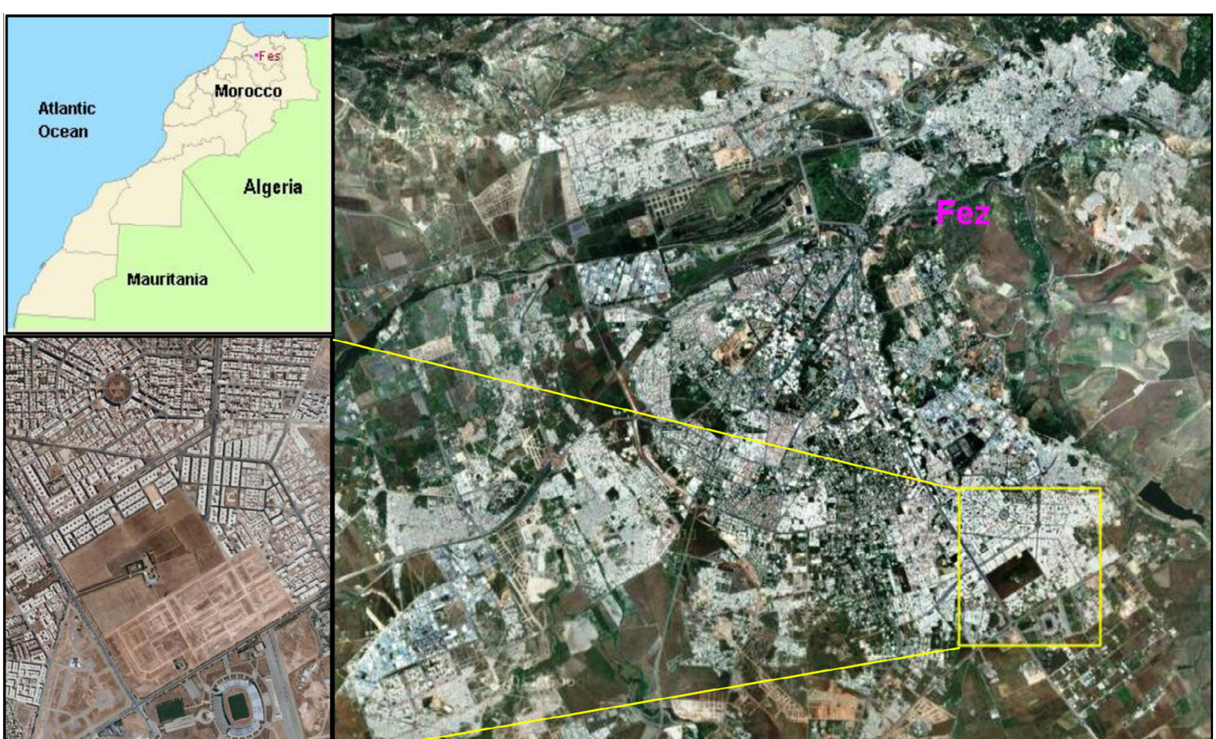

Figure 1. Location of the study area (yellow box: 2.0 km × 1.5 km).

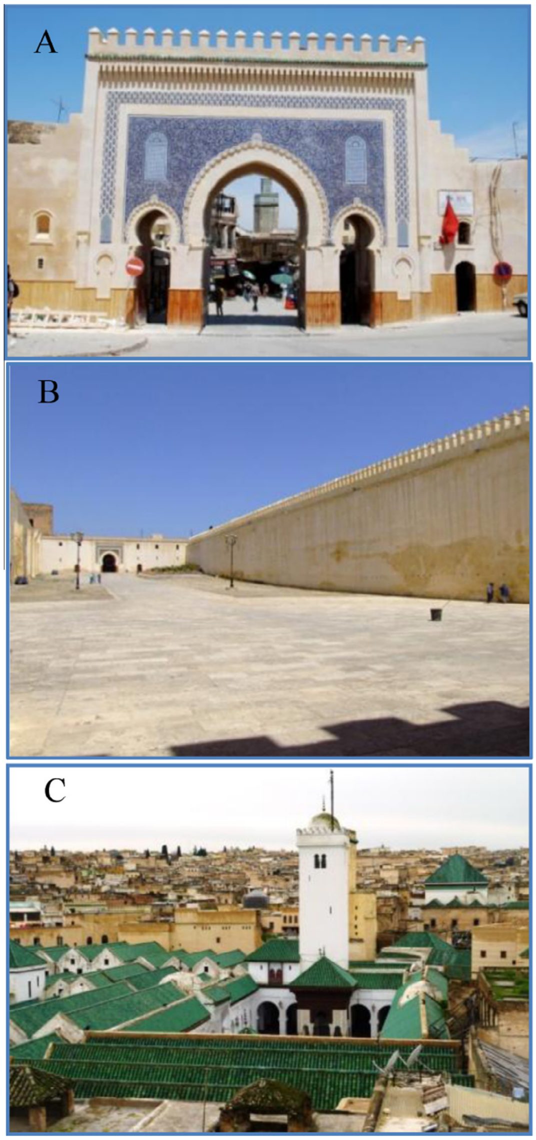

Figure 2. Boujloud door (A), the historic wall that surrounds the city (B), University Quaraouiyne (C).

This surface area is covered by 350 aerial photographs that have been flown with a long-track overlaps at 60% and across-track at 30% with a ground sampling distance (GSD) of 10 cm. Large scale normal angle photos scanned with 8 μm pixel size (panchromatic) and 20 μm (multispectral), from August 2007 are available with a scale 1:7500.

In this first stage of the project, we started with a test area covered by two pairs of photos see Fig. 1.

2.2. Geo-referencing images

Before the image analysis can be performed, the camera data have to be geometrically rectified (Geo-referenced) with respect to a map projection system. The geo-referencing of the GPS/IMU-supported camera data of the surveying flight Fez 2007 was carried out at the *CABINET BELMLIH* (*GeoData*) in Fez.

The GPS/IMU-data were available at a rate of 50 Hz. For further use these data were transformed into the national object coordinate system of North-Morocco (Lambert North-Morocco, Datum Merchich) by applying regional transformation parameters.

Geo-referencing operation concerns the sensor orientation that include the determination of the exterior orientation along the flight trajectory of each flight strip and the resampling of the scanner data into the object coordinate system (Ecker et al., 1993). With the help of some control points the GPS/IMU-model can be shifted and rotated for correcting the datum definition. This model is defined for each flight strip and with control and ties points and transformed into the object coordinate system (Heipke et al., 2002; Ries et al., 2002).

2.3. DSM generation

A variety of approaches have been suggested for the reconstruction of DSM from aerial images. Since manual 3D processing of aerial images is time-consuming, the development of automatic or, at least, semi-automatic techniques becomes a necessity.

This work investigates the topic of automatic image matching with a focus on the generation of DSMs using imagery acquired from airborne or space sensors. There is a variety of algorithms that have been developed for DSM generation from satellite images and aerial photography (Büyüksalih and Jacobsen, 2007). One of the methods is to use two images at a time for the reconstruction of a three dimensional stereo model in which the altimetric information can be extracted (Toutin, 1995).

3D models can be achieved from very high resolution (VHR) satellite image stereo pairs from satellites like Ikonos, QuickBird or GeoEye (Alobeid et al., 2010; Zhang et al., 2002). An image matching approach, which in principle is applicable to any type of linear array imagery, is developed for DSM generation and feature extraction from high resolution satellite images. Fig. 3 shows the main work flows of the research work. The work flow is mainly designed to develop a DSM which will take aerial image stereo pairs data and other additional information as input and will produce desired surface model as output (El Garouani, 2012).

2.3.1. Ground point coordinate determination

This method generally contains three basic steps: set up sensor mathematical model to reflect the relationship between points on the ground and pixels on the image, do image matching to get a disparity map, and finally calculate each point's altitude. In this study, we can use the procedure of DSM generation developed by Kwoh et al. (2004). This process can be broken down into the following steps:

The point measurement tool is designed to collect Ground Control Points (GCPs) and tie points that are common to two images so that the images can be correlated. In the case

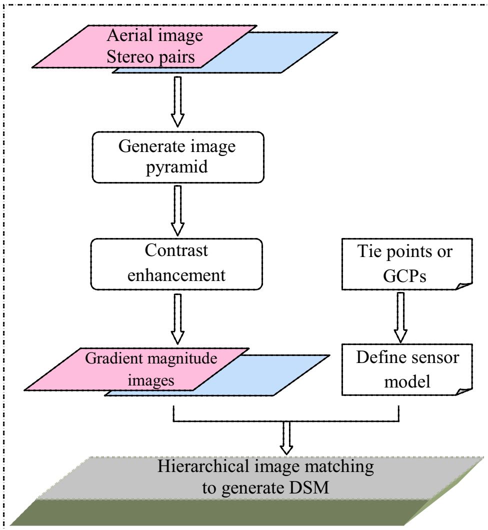

Figure 3. Working process of DSM generation.

of IKONOS imagery, the RPC file that comes with the images contains valuable information that lessens the need to collect large numbers of control points. In this step we can see how choosing GCPs and generating automatic tie points can considerably improve the results of the orthorectification (Rottensteiner et al., 2008).

2.3.2. Digital image matching for DSM

Ground points appearing within the overlap portion of the left and right images associated with a DSM are identified. This is referred to as digital image matching. The resulting output consists of the image location of ground points appearing within a DSM.

2.3.3. DSM construction

The automatically extracted and calculated mass points are used as a basis for constructing a DSM. DSMs are constructed differently depending on the specified DSM output type. The use of *LPS* software of *Leica Geosystems* to extract DSM from aerial photography includes (ERDAS, 2010):

- *Create/open a block file*

This operation concerns the selection of the sensor model and the definition of block properties, addition of imagery to the block file, collection of GCPs, generation of tie points and refining of the model.

- *DSM Extraction Process*

In this step, we set the DSM extraction properties, we check the advanced extraction properties and we generate and view the DSM from aerial image stereo pairs. In the end we check the Contour Map.

The quality of DSM products are measured by how accurate the elevation is at each pixel and how accurately the morphology is presented. Several factors are important for the quality of DSM derived products:

- Terrain roughness
- Sampling density (elevation data collection method)
- Grid resolution or pixel size
- Interpolation algorithm
- Vertical resolution
- Terrain analysis algorithm

In order to check the geometric accuracy of the obtained results, building heights and points on the ground have been measured manually. These measurements have been compared with the generated height models. We selected points in the center of the building tops and on the ground at a sufficient distance from the facades. The root mean square (RMS) difference between the manually measured heights and the automatic results turned out to be ±22 cm.

In general it can thus be stated, that for the height accuracy is in the range of two pixels GSD. This value includes not only the matching accuracy, but also the accuracy of manual measurement.

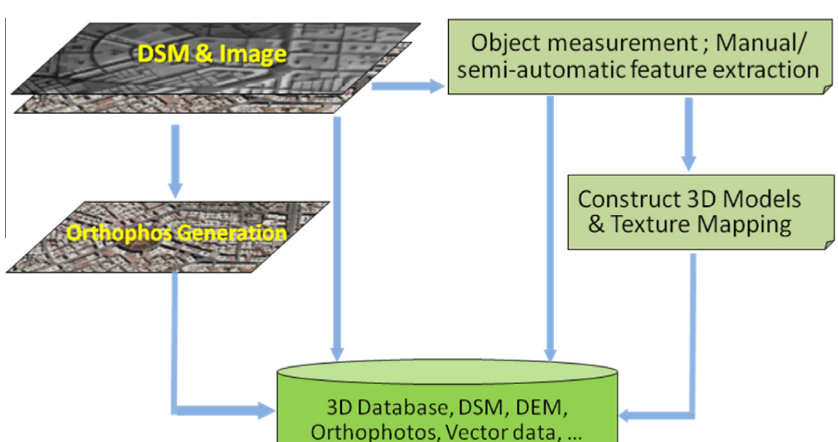

Figure 4. Workflow of the 3D building generation.

2.4. 3D building

Many GIS problems can only be solved in 3D, particularly in the area of urban development, with capabilities for generating high-quality 3D building using the same GIS data.

Modeling objects for 3D descriptions of the real world have been useful for many urban applications such as planning, construction and representation of the urban sceneries. Buildings, roads, trees and terrain are considered as the most important objects in producing a 3D city model particularly for the creation of virtual environments. 3D city model is basically a computerized model or digital model of a city. This work considers important stages involved in creation of 3D city models, which includes reconstruction of buildings, landscape and urban settings that are relevant in urban and environmental planning. The platform used in the creation of a virtual 3D city model has been provided by the GIS environment and assisted by CityEngine; a 3D modeling software. The emphasis is placed on the use of aerial and terrestrial photographic techniques and the existing topographical map data (El Garouani and Alobeid, 2013; Suveg and Vosselman, 2000).

This work considers important stages involved in creation of 3D city models, which includes reconstruction of buildings, landscape and urban settings (Fig. 4). The manual and semi-automatic feature extraction capability provides a good basis for 3D city modeling applications (Tuan, 2013; Yin et al., 2009).

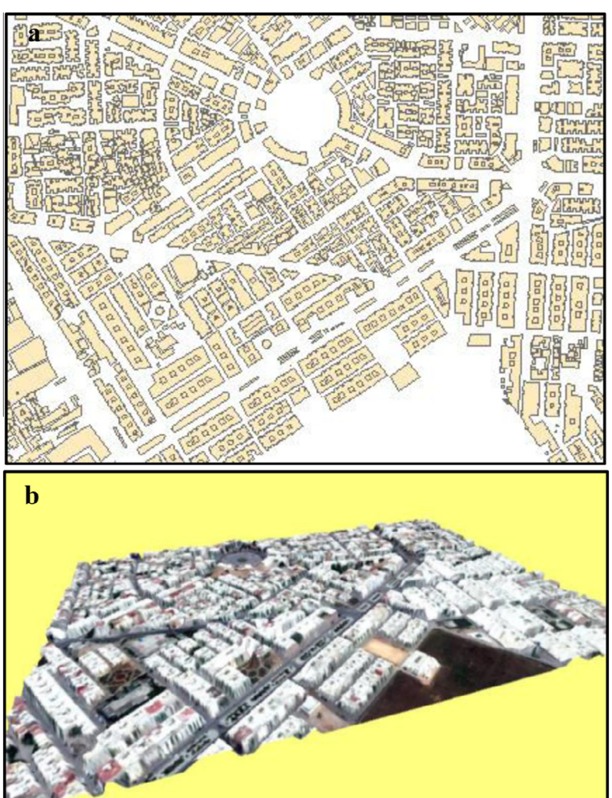

Figure 5. 2D Building footprints (a), Orthophoto drape onto DSM (b).

In this work, to generate the 3D model, we followed several steps:

- Geodatabase/2D Information.
- 3D Streets, Blocks, and Parcels (import or creation).
- 3D Extrusion, Roof Generation, and Street Furniture.
- Texturing and Façade Creation.
- Finished 3D City and Updation in the Geodatabase.

CityEngine software delivers a full suite of tools to aggregate geospatial data, layout and edit street networks, generate and modify buildings. The essential tasks performed are:

- Turn the 2D feature into 3D based on an elevation surface.
- Create 3D urban scenes based on standard GIS data.
- Semi-automatic and manual extraction of 3D features.

Information about the ground plan of the building contained in the GIS map is used to delineate a building in an image. The GIS map used is a two-dimensional digital map

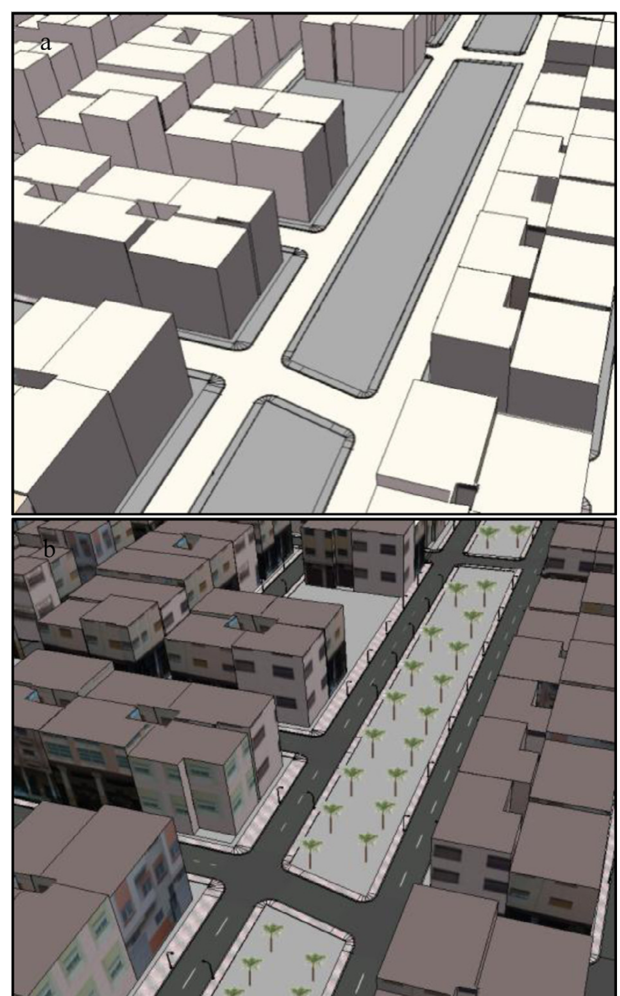

Figure 6. Foundation or initial model (a), the final building model (b).

representing the ground plans of buildings. Orthophoto and topographic map are used to derive building footprints (Fig. 5a). The next step is the overlying or draping process, a 2D representation of topographic features, e.g. roads, rivers & land use information from orthophoto is draped onto a DSM. Fig. 5b shows orthophoto draped onto DSM.

Building footprints map are extruded according to height derived from DSM to produce the foundation or initial model (Fig. 6a). In other developments, multiple view point of terrestrial images is used to reconstruct photo-textured building models. The building models are created using simple primitives of constructive solid geometry such as a box, roof, and rectangle.

The final process in the developing model is to integrate both foundation of the initial city model with the photorealistic building models and adding-on facades and extra accessories (landscape objects) such as trees, lamp post, sign board etc. (Fig. 6b).

3. Results and discussion

The starting point of any 3D city models is the data source. The main data source is a topographic map and aerial photographs. Topographic map provides a geographic reference which stores the positional information of terrain features such as buildings, roads, rivers, contours, land use, administrative boundaries etc. A stereo pair of aerial photography is therefore used to generate DSM and orthophoto image. Orthophoto and topographic map are used to derive building footprints. Terrestrial photographs of every single building from multiple view points are needed to construct photorealistic 3D model of buildings. These terrestrial photographs were captured using a conventional photographic technique using a digital camera.

To illustrate how the proposed workflow is realized in real applications, many aerial stereo images covering area for experimental purposes are chosen and demonstrated in Fig. 7.

Aerial photographies have been used to generate terrain surface elevation models and assist to create a model and visualize the urban space in three dimensions. 3D models can be used as a user-friendly interface for querying the urban environment as a GIS for hyper-linking Web-based information, for visualizing model results, and for accessing functional simulation models.

A general classification of 3D city models, based on their operational purposes, might be organized around four main types:

- 3D CAD (computer aided design) models of cities.
- Static 3D GIS models of cities.
- Navigable 3D GIS models of cities.
- 3D urban simulation model.

If a 3D building modeling and visualization application requires good detail pertaining to the building features and terrain slopes for critical project decisions, an accurate digital terrain model (DTM) and digital surface model (DSM) must be available.

The results of the process of 3D building is presented in Fig. 8.

Virtual 3D city models are improving the practice of urban environmental planning and design. The visual display capabilities illustrated in this work enable the explanation of the development plans or alternatives to the public. Public interest and understanding can be raised by using both graphic and image files that show the relationship between the proposed project and individual properties, neighborhoods, local landmarks, community services, and other features.

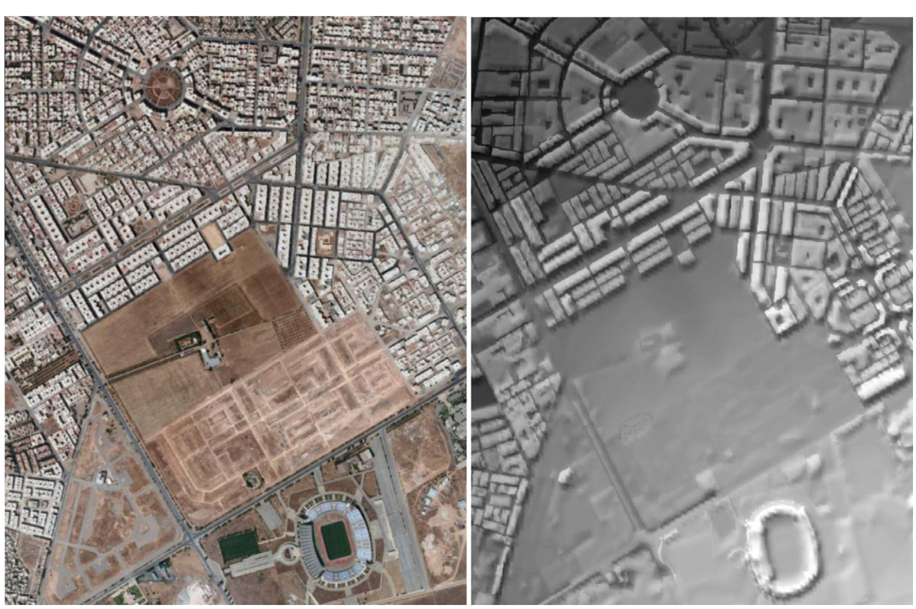

Figure 7. Orthophoto (in the left) and DSM generated from aerial photographs (in the right).

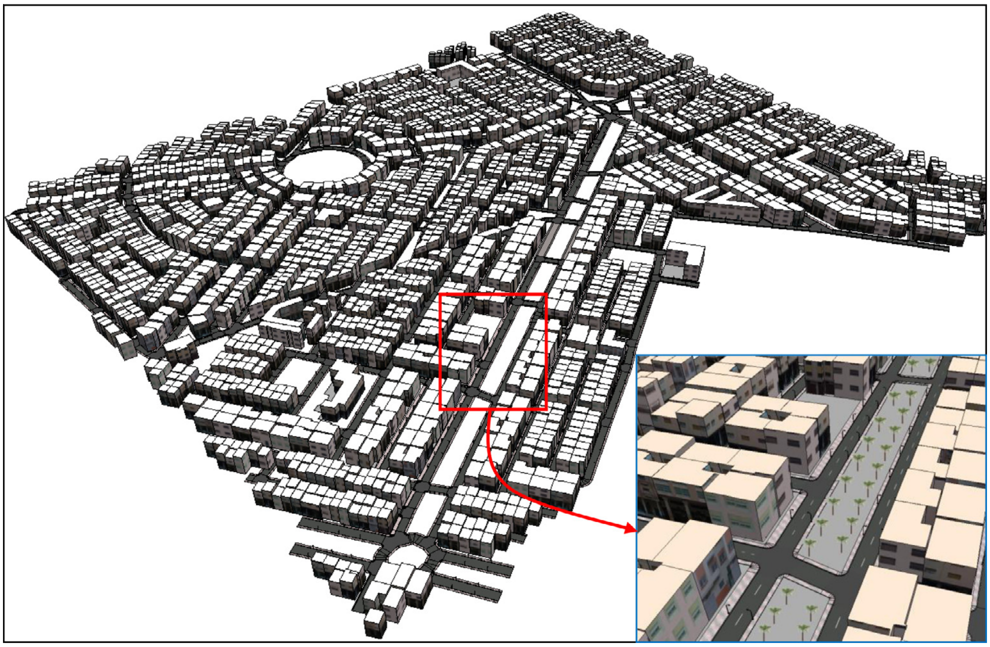

Figure 8. Example of 3D building.

4. Conclusion

This paper investigates the necessity of detailed surface representation in order to generate a feasible platform for the detailed simulation of urban modeling. In this first step of the project, we generated a digital surface model based on aerial image stereo pairs using the matching method. Methods to generate the 3D city structures have been investigated and possible solutions are tested and discussed. Features and 3D models extracted from these data can provide benefits in various GIS applications, where the building is necessary. For example, 3D surface objects extracted from aerial photographs can represent a significant layer of GIS databases for the simulation of natural disasters, telecommunications planning (i.e., positioning of antennas). 3D land use zoning allowed building volumes, usage, and density. They are the main tools defining the image of a city and brings into focus the model of best practice of the rehabilitation and conservation of the historic Medina.

The GIS provides a close monitoring of the repartition of interventions in the medina, which helps in understanding and guiding the mechanisms of rehabilitations. The GIS of Fez is an edge management tool for the conservation data and supervision of projected and implemented projects.

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