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Building 3D City model from painting: the case study of Old Town of Taranto, Italy

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***Abstract* – The aim of the work concerns the building of a three-dimensional model of the old town of Taranto (Italy) from a 1761 painting by English historian and geographer Thomas Salmon and published by Venetian printer Giambattista Albrizzi. To achieve this aim, a suitable and original methodology was developed. In addition, 3D modelling based on the use of Rhinoceros enabled the construction of a 3D city model. This model makes it possible to highlight the transformations and evolutions of the old town over time.**

I. INTRODUCTION

The construction of 3D models of urban centres plays a key role in the interpretation and analysis of the development of the urban fabric.

In the context of the representation of cities, the scale and quality of details of individual buildings require an adequate standard, such as the CityGML. The level of detail (LOD) concept of the OGC standard CityGML is intended to differentiate multi-scale representations of semantic 3D city models. The concept is in practice principally used to indicate the geometric detail of a model, primarily of buildings. According to Gröger et al. 2008 [1] five consecutive levels of well-defined detail can be achieved: LOD0-regional, landscape; LOD1-city, region; LOD2-city neighborhoods, projects; LOD3-architectural models (exterior), landmarks; and LOD4-architectural models (interior) [2]. CityGML 3.0 includes a revised concept of level of detail (LOD). LOD4, which is used to represent the interior of objects (such as interior modeling for buildings and tunnels) has been removed, only LODs 0-3 will remain. Instead, the interior of objects can now be expressed integrated with LODs 0-3 [3,4].

The 3D geometry of the city can be realized in several ways depending on the geomatics data available. Indeed, the 3D city model can be realized by old maps [5], cartography [6, 7], Airborne Laser scanning (ALS) data [8] and satellite images [9].

In this paper, the 3D model of the Old Town of Taranto in the year 1761, Italy, was built. The city of Taranto, at the centre of the gulf of the same name, stands on a strip of land between two seas: the outer one, Mar Grande, is bordered by the Cheradi Islands and is joined to the inner one, Mar Piccolo, by two canals, a natural one to the west of the island, on which the historic city stands, and an artificial one to the east.

The old city of Taranto is an island of approximately 30 hectares that is connected to the mainland by two bridges: the “Ponte di Porta Napoli” (or “Ponte di Pietra”) to the north, and the “Ponte Girevole” (swing bridge) to the south that connects it to the new city.

Based on a famous painting from 1761 by Thomas Salmon and published by the Venetian printer Giambattista Albrizzi, a 3D model was realised. Giambattista Albrizzi is considered to be one of the progenitors of modern journalism [10]. At the end of 1740, he was granted the privilege of printing a newspaper containing political and military news by the Reformers of the Study of Padua. It is therefore possible to attribute a military purpose to the 1761 depiction of the city of Taranto (coinciding with the city's current historic centre), which would set aside perspective accuracy and emphasise the city walls, the various towers, the bridges leading to the city and the coastline.

One aspect that should not be underestimated is that although different historical sources of the city can be found, it is difficult to find images representing the same places with the same views, in a specific reference period. Therefore, there are no related metadata to such images that can provide time-geolocation information [11]. Therefore, the process of investigating the historical urban fabric must start from assumptions that can consolidate the design choices when developing the 3D model. An innovative approach related to the implementation of a 3D City Model was used for the purposes of this research.

In particular, according to the CityGML standards established by the Open Geospatial Consortium, a LOD2 has been achieved in the 3D modelling where, compared to the previous LOD1 level (block model), roofs are modelled and the different surfaces are thematically differentiated with the possibility, in addition, to represent plant objects.

II. DATA

Two old cartographies were taken into consideration: an image depicting an engraving of the old town of Taranto in 1761 made by the English historian and geographer Thomas Salmon and published by the Venetian printer Giambattista Albrizzi (Figure 1) and one representing the view of the old town from above in 1860 (Figure 2).

Fig. 1. Map of the city of Taranto of 1761.

Fig. 2. 1860 map of the city of Taranto.

These two old maps represent the basic elements for the construction of the planimetric model; as for the height of the buildings, a numerical cartography, i.e. a cartography developed in computer-aided design (CAD) environment with the elevation of each building in scale 1:2000 was used. The declared accuracy of this (numerical) cartography is 0.60 m in planimetry and 0.40 m in altimetry. In addition, this cartography was used in order to georeference the 1860 map of the city of Taranto.

In addition, the historical evolution of the ancient city of Taranto was reconstructed by analysing various maps of the territory obtained from historical research conducted at state archives, municipalities, and consultation of historical books. In particular, the time span analysed starts from the early 19th century up to the 2000s. The maps and documents taken into consideration, for the validation of the 3D urban model, are reported below [12-16]:

- "Map of the city and port of Taranto" (scale and reference system are unknown) and is dated 1810. This map was extracted from a historical atlas of Apulia;
- Map drawn up by Tommaso Zampi in the second half of the 19th century, (scale and reference system are unknown);
- "Pipeline and drinking water distribution" (scale and reference system are unknown) and dated 1885 This type of map was used by engineer Giovanni Galeone for the design of the aqueduct in the old town of Taranto;
- "Map of the city of Taranto" dated 1910 (scale 1:5,000 and reference system unknown);
- "Map of the city of Taranto" dated 1938 (scale and reference system unknown);
- Cartography of Italian Geography Military Institute (I.G.M.I.) dated 1960 (scale 1:5,000; reference system Gauss-Boaga (Italy) East Zone, datum Roma40).

III. METHOD

In order to build a 3D model representing the urban shape of the city of Taranto in the 19th century, an appropriate methodological approach was developed.

Based on the georeferencing of the historical map of 1860, it was possible to reconstruct the urban agglomeration of the ancient city and subsequently, by comparing it with the painting of the 18th century, to identify its individual buildings. At this step, the visual interpretation and comparison of the two different datasets was important in order to correctly define not only the position of the individual buildings, but also their aggregation into districts. Once the characteristic elements (city walls, buildings, etc.) were vectorised, a 3D model was elaborated following the CityGML standard for the multiscale representation of semantic 3D city models, with the possibility of exporting and rendering the final 3D model for visualisation in different software. In particular, the method is shown in the following pipeline (Figure 3).

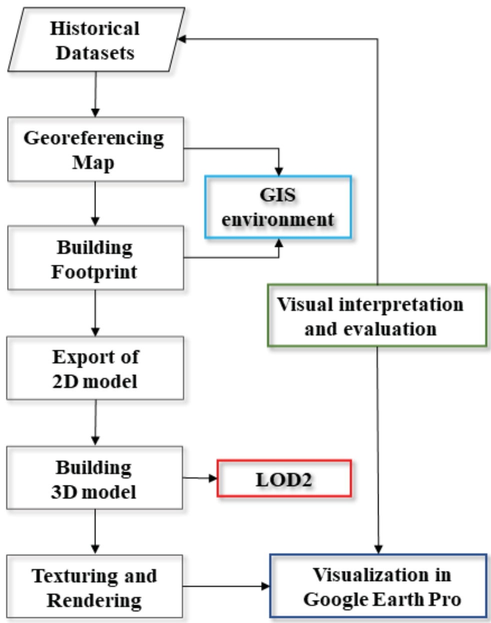

Fig. 3. Pipeline of methodological approach.

IV. CASE STUDY

A. Georeferencing of the map

Before proceeding with the georeferencing of the map, the map of 1860 was scanned with a resolution of 600 dpi.

The equations, used to perform the transformation model, is [17-18]:

$$X = \sum_{j=0}^{n} \sum_{i=0}^{j} a_{ji} \cdot x^{j-1} \cdot y^{i}$$
$$Y = \sum_{j=0}^{n} \sum_{i=0}^{j} b_{ji} \cdot x^{j-1} \cdot y^{i} \qquad (1)$$

where:

x, y coordinates of source system;
n degree of polynomial;
XY coordinates in the target system.

Using a second order polynomial function, the maps was georeferenced; this task was performed in Esri ArcMap (v.10.8) software. The GCPs was taken from the numerical cartography in UTM-33N WGS84 reference system (EPSG: 32633). Root Mean Square Error (RMSE) achieved on the map in the georeferencing step was 7 pixels.

In order to make a comparison on the historical evolution of the urban built-up area, using the procedure just described, the other maps and cartographies were also georeferenced.

B. Building 2D shape in GIS environment

The 1860 map was imported into the ArcMap software and with the creation of a layer called 'walls', the bases of the city walls and houses were represented, taking the historical image of 1761 as a reference for their layout, number and shape.

Using the polyline division layer, the map was divided into the five groups of housing conglomerates that can be inferred from the historical depiction. In this way, it was possible to make a comparison between the building blocks in the painting (Figure 5) and the georeferenced cartography (Figure 6).

Fig. 5. Identification of building blocks in the painting of 1761

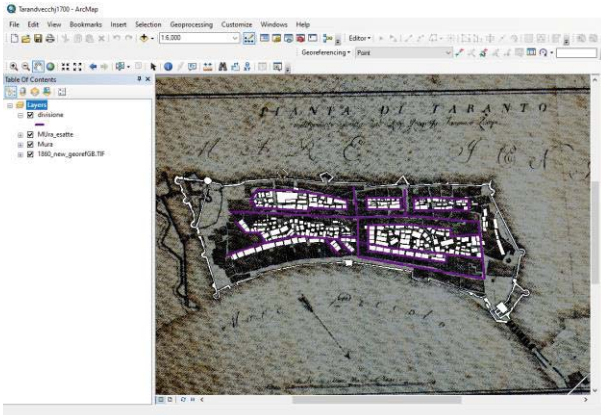

Fig. 6. Identification of building blocks in reference cartography of 1860 in ArcGIS environment (b).

C. Building 3D City Model

The shape of buildings and walls realized in GIS environment were imported in Rhinoceros software (v.7), developed by Robert McNeel & Associates, in *.dxf format (Drawing Interchange Format, o Drawing Exchange Format). Subsequently, it was possible to extrude the various buildings, construct roofs, model towers and bridges.

This task was achieved thanks to the tools developed in Rhinoceros, which enabled three-dimensional modelling of the individual structures, as shown below (Figure 7).

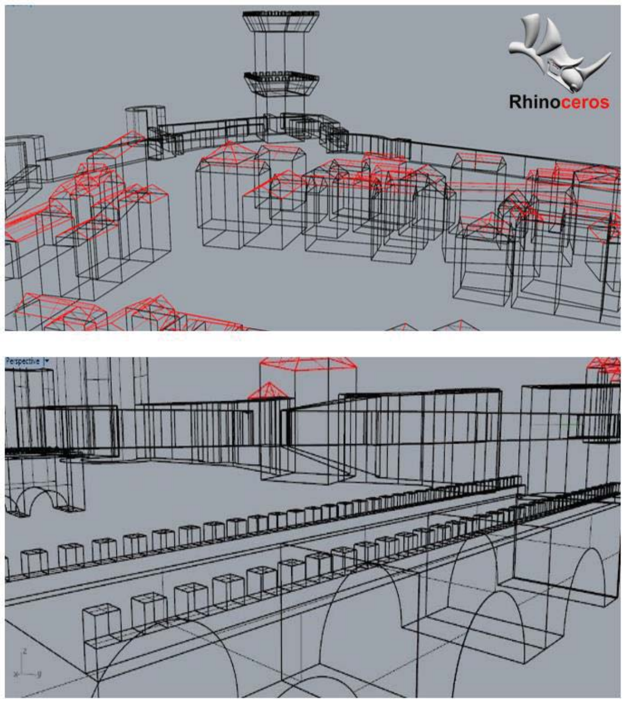

Fig. 7. Building the 3D city model in Rhinoceros software.

In addition, a terrain modelling was performed; in particular, starting from a series of elevation points and considering the ground heights of some historical buildings still existing and represented in the various historical cartographies, it was possible to obtain a mesh referable to the terrain modelling. Once the terrain elevation points had been entered, a three-dimensional digital terrain model could be constructed.

The final 3D model was subsequently texturized to distinguish the buildings, the elements related to the roofs of the buildings, the surrounding city walls and other characteristic structures of the model.

To achieve this aim, KeyShot [19, 20] software was used. KeyShot is a stand-alone real-time ray-tracing and global illumination programme used to create 3D renderings, animations and interactive images. Thanks to its CPU-based architecture, photorealistic real-time rendering can be achieved. A visualisation of the rendered model is shown in the Figure 8.

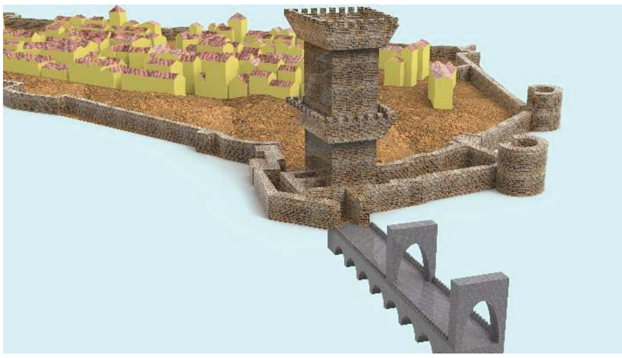

Fig. 8. Textured and rendered 3D model.

The 3D model obtained can be shared on web platforms, such as Google Earth Pro, to visualise the spatial context. For this reason, the 3D model was exported in the .KMZ format; however, to georeference the model correctly, it was first necessary to use the Anchor Point command and then to perform the export. For the georeferencing, the largest tower of the Aragonese Castle was taken as a reference point, obtaining its latitude and longitude values from Google Earth. The visualization of the 3D model on Google Earth Pro platform is shown in Figure 9.

Fig. 9. 3D City Model in Google Earth.

V. CONCLUSIONS

The methodology developed allowed the building of a 3D model of the city with high detail quality.

The geometry of the buildings was reconstructed from geomatics data (numerical cartography, orthophotos, metric maps, etc.) and compared with historical cartographic elements. However, it was not possible to precisely define the variation in height or the presence of certain buildings in relation to the historical dataset, as it did not comply with the perspective rules of representation, but the author of the painting intended to represent as many characteristic elements of the historical city in as much detail as possible. Furthermore, the reconstruction in height of geometric elements that are no longer present is based on further analysed historical sources.

The reconstruction of the author's point of view in the painting allows us to state that the depiction of some buildings was impossible from that point of view, i.e. that in order to depict part of the built-up area, the author most probably carried out a survey.

This is evident from the fact that pentagonal promontories are depicted in the northern area that are impossible to see from a distance, as well as a group of breakwaters in the north-western area.

Once the viewpoint of the painting is identified, there is a realistic visual perception of the changes that have occurred over the years (Figure 10).

(a)

(b)

Fig. 10. Hypothetical reconstruction of the viewpoint of the author of the painting (a) and panoramic view of the ancient city of Taranto from the same viewpoint (b).

The transition between the simple visual approach and an eventual automatic generation of the changes that have occurred can occur if historical information is combined with recent Computer Vision algorithms. Future research developments will involve new methodological approaches that, from historical images, use the latest innovations such as high-performance algorithms for automatic image rectification and segmentation, as well as of the production of 3D models with photorealistic content that highlights the historical characteristics of the objects represented.

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