3D-GIS HERITAGE CITY MODEL: Case study of the Historical City of Leiria

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Abstract

The use of 3D-GIS tools to model and support urban analysis has been increasing in the last decade, mainly because those tools can combine, in an efficient way, the spatial analysis capabilities of a traditional GIS with high 3D visualization performances, mandatory for sustainable decisions in urban planning activities. This paper presents results of the 3D-GIS model developed for the Historic Centre of Leiria City (HCL) in Portugal, where the integration of 3D BIM model in a 3D-GIS environment was tested. The application was developed to contribute both to the conservation of the heritage buildings and to the dissemination of tangible and intangible heritage of the historical city centre. The model has been enhanced with the application of textures and patterns and information about the conservation status of buildings has also been included. For more than 0.40 km2 of the city, 3D GIS building geometry and thematic information have been processed. The buildings have been represented at various levels of detail, including block-models (LOD-1), geometry-models (LOD-2), architectural models (LOD-3), and detailed indoor models (LOD-4). For some heritage buildings, historical details have been introduced in order to allow a virtual tour with access to historical information. This project has been carried out in a partnership between the Leiria Municipality and the Polytechnic Institute of Leiria.

Keywords: 3D-GIS, Three-Dimensional Modelling, Shape Grammar

1 Introduction

One of the huge challenges faced by the scientific community is related with the identification of solutions that allow the preservation of the tangible and intangible heritage historical city centres. Another issue is related with the management of architectural heritage information which faces significant challenges since architectural objects require an integrated representation of various types of information in order to develop appropriate conservation strategies [6]. As a consequence of urban sprawl and the construction of new modern residential areas, most of the historic urban areas in Portugal have been abandoned contributing to an increase of its degradation. The existence of updated information (historical, geographic, economic and others) along with the use of technological platforms management and information visualization, such as Geographic Information Systems (GIS), Building Information Model (BIM), City Information Modelling (CIM) decisively contribute to develop appropriate conservation strategies of the historical city centres, to make sustainable decisions of urban planning and also the regulation of urban sprawl.

Thus, the number of 3D city models which are being built by municipalities or other organizations is increasing and these models are needed for an increasing number of GIS applications, such as urban planning ([2]; [3]), noise emission simulation mapping [4] and disaster management [5]. However, moving towards 3D models from two dimensional (2D) drawings consists of not only the creation of volumetric objects to navigate through 3D Models but it is actually a more complex process, in particular when conservation professionals or planners need to perform spatial and multi-criteria queries in a virtual 3D environment to help taking decisions [6]. In addition, there is a growing interest in the integration of BIM models in a GIS environment, which creates new opportunities in the field of 3D-GIS models [1]. The integration of these two approaches allows BIM models to no longer be limited to the description of a building, but also to the interactions with its environment, contributing to the management of urban facilities (including buildings and urban elements) in an interoperable way [7]. On the other hand, GIS, which are computerized systems designed for the storage, retrieval and analysis of geo-spatial data, having proved their great potential in exploring spatial relationships of demographic, cultural, economic and geographic areas, have not yet revealed their potential in the management of architectural heritage information on a single building scale [7].

In this paper the authors present the development of a 3D-GIS model of the historical Leiria city centre in Portugal, where the integration of 3D-BIM models in a 3D-GIS environment was tested. Information about the non-structural pathologies of the buildings was associated with each building of the model to support the municipality decisions related with the

conservation of the historical city centre. A virtual tour through the alleyways of the Leiria historical centre was also created to further contribute to involving citizens in the preservation of heritage through the dissemination of the recorded information. For the three-dimensional modelling the ArchiCAD software is employed for the BIM approach and Esri CityEngine software for the 3D-GIS approach.

2 Case Study Area and Data set

The case-study area is the historical downtown centre of Leiria with an area of approximately 0.40 km2. The ancient downtown spreads from the slopes of the hill on which the castle is situated along the flat riverbanks and is occupied mainly by old buildings, some of which date from the 16th century to the 19th century, innumerable alleyways and some small squares (Figure 1).

Figure 1: Study area.

In this paper the main methodological steps implemented to develop the 3D-GIS model of the historical city centre are presented, in which 319 buildings have been modelled and a virtual city tour through the narrow alleyways of the city has also been built. The virtual tour consists of 727 metres and 110 buildings, some of which have important architectural elements and are connected to historical episodes of an important Portuguese writer, Eça de Queirós (figure 2).

Figure 2: Virtual tour (yellow line). Red spots refer to the location of buildings where a detailed indoor model has been developed (LOD-4).

For the development of the 3D-GIS city model, the following data sources have been used:

- Cartography information on a 1:10 000 scale;
- Architectural plans of the four historical buildings;
- A database with the information of the non-structural pathologies of buildings as well as the historical information. It provides the essential information about the level of conservation of each building.
- Digital orthorectified aerial image with a spatial resolution of 0.5 m to be linked to the virtual 3D city model.
- Façade images orthorectified with a spatial resolution of 0.012m

3 Methodology

The 3D-GIS city model developed uses three-dimensional (3D) spatial information and thematic attribute information together with a geographic database for the historical city center. Spatial and semantic properties are structured in five consecutive LODs (Level of Detail), where LOD0 defines the historical center model and the most detailed LOD4 comprises building interiors and indoor features.

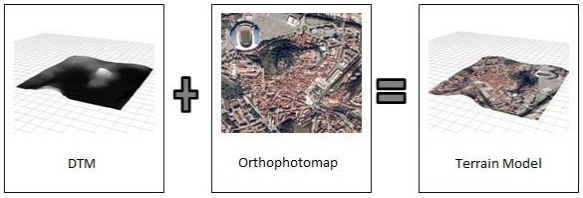
The 3D city model developed basically provides five different LODs, as follows: (1) the level LOD0 is essentially a two and a half dimensional Digital Terrain Model (DTM), over which an aerial image or a map may be draped; (2) LOD1 is the well-known blocks model, without any roof structures or textures; (3) in contrast, a building in LOD2 has differentiated roof structures and textures; (4) LOD3 denotes architectural models with detailed wall and roof structures as well as balconies, high-resolution textures were mapped onto these structures; (4) LOD4 completes a LOD3 model by adding interior structures like rooms, interior doors, stairs, and furniture.

The methodology developed includes the following steps: (1) data collection of information including non-structural pathologies of the buildings identified *in situ*; (2) development of the geodatabase in 2D GIS environment; (3) construction of a digital terrain model; (4) architectural modelling of four isolated historical buildings with BIM tools; (5) data integration of all information in the 3D GIS environment; (6) development of the virtual tour.

3.1 Terrain and Building Modelling

The development of the 3D-GIS model started with the construction of a DTM. For the whole urban area of approximately 0.40 km2, a DTM with 1 m spatial resolution was produced. The higher-resolution DTM is used for the core part of the virtual 3D city model and was built using the cartographic altimetry namely contour lines and elevation points. The digital orthorectified aerial image was then projected on top of the DTM (Figure 3), this level of detail corresponds to a LOD0. The DTM, built using ArcGIS tools, was then imported to the CityEngine software.

Figure 3: Digital Terrain Model of Leiria City.



The next sept was the modelling of buildings, which were represented with various levels of detail according the goals of the project. For the 319 buildings of the historical city centre, geometry-models and differentiated roof structures and textures (LOD-2) were created using CityEngine software (Figure 4). For the 110 buildings throughout the historical tour (Figure 1) orthorectified images were projected onto the facades as textures to allow a more realistic virtual tour (Figure 4). Architectural models and detailed indoors like rooms, interior doors, stairs (LOD-3 and LOD-4) were only developed for four historical buildings, connected to historical episodes of Eça de Queirós writer (Figure 5). This level of detail was necessary to create a model with information about its internal structure and the mutual relations between the architectonic elements, allowing a virtual visit to the interiors of these buildings with access to historical information. The location of these buildings is represented in figure 2 (red spots). Figure 6 shows the details of the model of one of the palaces. The three-dimensional buildings model related with indoor details and textures was made using the software ArchiCAD.

Figure 4: Buildings that were modelled, providing geometry models and differentiated roof structures and textures (LOD2).

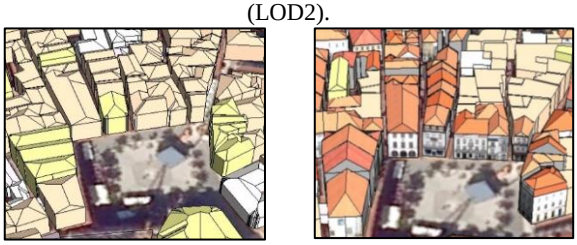
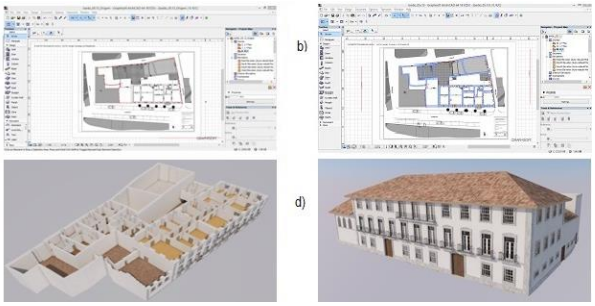


Figure 5: Buildings that were modelled providing architectural and indoor details (LOD-3, LOD-4).

Figure 6: 3D Model (LOD-4) of the Baron of Salgueiro Palace.



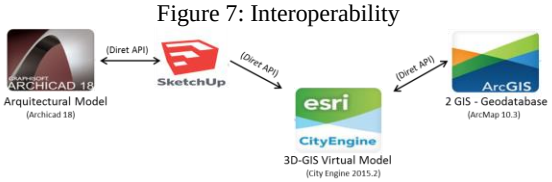
A geodatabase using ArcGIS software was created to introduce the information related with the history and the pathologies of each building. This information was subsequently integrated in the three dimensional model.

3.2 3D GIS: Leiria City Model

The development of the virtual city model was implemented with CityEngine (CE) software using a “Grammar-based" or "procedural" approach towards modelling. The Computer Generated Architecture (CGA) shape grammar of the CityEngine is a programming language specified to generate architectural 3D content. The idea of grammar-based modelling is to define rules, or CGA rules within CityEngine, that iteratively refine a design by creating more and more detail. The rules operate on shapes which consist of geometry in a locally oriented bounding-box.

The process started with the importation for the CE software of the MDT, the buildings shapefile and attributes of the non-structural pathologies, the four buildings modelled in BIM ArchiCAD software and the facade orthophotos of the buildings (Figure 2). The figure 7 shows the interoperability of all the process.

Figure 7: Interoperability



The CE software provides an interface for shape grammar programming. In addition, CityEngine's CGA shape grammar provides commands such as "extrude", "split" or "texture" allowing 3D complex architectural forms to be created. The final step was to apply high-resolution textures to the 3D building façade. All the attributes related with the pathologies information were combined with the 3D model. Figure 8 shows the implemented process and figure 9 shows an example of a building, consulting information throughout the virtual tour "Leiria: Ruas e Ruelas" such as type of usage, period of construction, facade coatings anomalies, cracks, type of moisture, global level of facade degradation, etc.. The access to this kind of information could be used by municipality technicians to support their decisions related with conservation of the historical city centre.

Figure 8: Methodology used to build the City Model Visualisation.

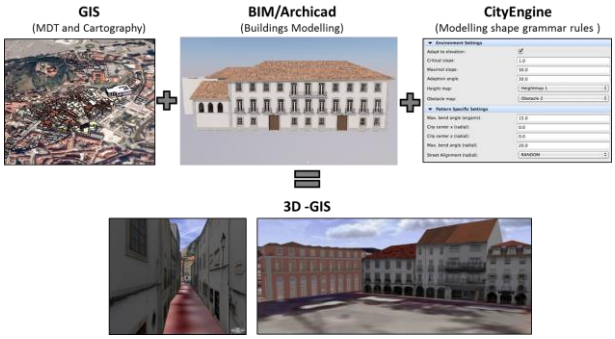
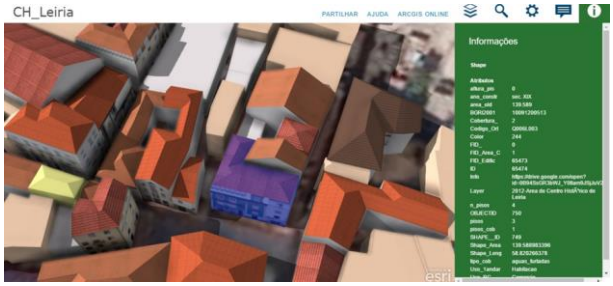


Figure 9: Example of information access throughout the virtual tour "Leiria: Ruas e Ruelas".



With respect to the data processing in a BIM environment, there exist several libraries of building elements in the ArchiCAD environment. However, one of the drawbacks is due to the fact that "historical" buildings are often composed of "non-standard" elements. Thus, historical buildings require the creation of new architectural elements, namely "new component families", which is extremely time-consuming.
Another limitation is the fact that Archicad and CityEngine sotware are not totally compatible. To integrate a BIM model developed in the ArchiCAD environment into the CityEngine environment, it was necessary to convert information using intermediate software and some information was lost.

4 Conclusions

This paper presents the methodological steps used to develop the 3D city model of the historical city center of Leiria. The model was enriched with a collection of pathologies information identified *in situ*. The final model allows an interactive system for the management, integration and presentation of historical urban geoinformation. Despite the high degree of CityEngine interoperability which promotes the application to new domains and improves the usability of the geoformation, some limitations still exist related with the integration of BIM models. As an essential component of the developed geodata infrastructure, the virtual 3D city model of the historical city centre seamlessly integrates key information of the pathologies database and the 3D geo-database as well as allowing the operation of updating processes.

Web-services for the model's contents are under development to further extend the ways the city model can be accessed by the municipality, technicians and others partners.

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