Digital Models – Proposal for the Interactive Representation of Urban Centres

The downtown Lisbon City Engine model

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Abstract. The idea of ‘city’ has now surpassed its physical concept. The emergence of the Internet and the growing development of information and communication technologies (ICT) have changed the behaviour of our society in the past decade and revolutionised the traditional ways of representing space. The classic 2D (floor plans, sections and elevations) and 3D representations have been gradually replaced by 3D digital models that can reproduce buildings and places in a virtual environment.

3D digital models are tools that enable a wide range of applications in urban planning and management, especially in architectural and data documentation where they allow the analysis of theoretical scenarios such as: 1) representation of the past, considering the procedures needed to restore the heritage; 2) visualisation of the present, to enable dissemination and communication of the city as it is; and, 3) simulation of the future, with the model being used to visualise and experiment with architectural objects, even those at a design stage. The main contribution of this work is to present an urban application developed into a GeoBIM tool, ESRI City Engine Software (CE), that integrates GIS (Geographic Information Systems) and BIM (Building Information Modelling) concepts. Finally, to enhance its potential, three spatial analyses were conducted.

Keywords. 3D model; GIS – Geographic Information System; BIM – Building Information Modelling; shape grammars; spatial analysis.

INTRODUCTION

Background
The traditional way of representing objects in architecture is based on physical 2D and 3D models. Usually these models are used at a design stage as a tool for communication or at a final stage as a tool for documentation, but are only accurate at one architectural stage. Digital 3D models, generated by graphical software from the early stages of conception to construction of a building, accurately reproduce the object at each of these stages. Based on digital design, objects can be modelled in CAD systems or using new parametric modelling processes, both generative and associative. While the first use digital representation as a communication
tool, the second use the model as a foundation to support data records and management (according to Nardelli (2007), it is able to deal with fragmented and scattered data). Yet, these systems allow the reliable use of fast procedures based on automation, which gives an electronic version of the manual model (Santos, 2009).

CAD modelling supported by primitive elements linked to a geographical reference position has proved to be a graphical tool suitable for the management of large amounts of data. For this it is important to understand the basic concepts of geographic information systems (GISs) and building information modelling (BIM), as well the potential of their assimilation.

**GIS and BIM**

GIS systems are suitable to model geographic phenomena since they can integrate spatial data acquired from different sources (maps, census data, land registration records, satellite imagery, etc.) and perform spatial analysis. To ensure the correct relation between entities, data are hierarchically organised, georeferenced, and placed in the real world. GIS features can be represented by several types of data models, but the vector and raster format are most widely used. Several difficulties may arise since data can come from distinct sources in varying detail, or be collected at different times by a variety of surveying methods (Groger at al., 2012).

BIM-related tools, meanwhile, can create 3D AEC (architecture, engineering and construction) design projects in a digital environment. The primitive elements are the constructive components such as spaces, walls, windows and beams. Parameters and annotations are linked to the 3D model. Rather than a series of drawings, BIM is based on creating and managing construction-related information in an integrated and automated way (Cowen, 1988).

Although GIS and BIM are different at a conceptual level, they both act as centres for data storage and management: BIM is focused on each constructive component that makes up the building and GIS is focused on its integration into a geographical space, where all the elements are represented. The integration of BIM and GIS contents to give a Geo-BIM — which CityGML (quite appropriately) called GeoBIM but whose scope completely transcends the brand that created it — system is of utmost importance in urban and land management. CityEngine (CE) software is one example of GeoBIM modelling software and was used in our work (Figure 1). However, the interoperability between GIS and BIM software is still looking for a solution (Hijazi et al., 2009).

**Objective**

The main purpose of this paper is to present a semi-automatic method for producing digital city models.
in a GeoBIM environment, which may become a useful tool for urban planning and heritage preservation analysis. The area that we modelled and studied is a part of downtown Lisbon (Portugal) (Figure 2), one of the most important heritage areas of the city, which was rebuilt in 1755 after being destroyed by an earthquake. The main goals of this work are to:

- develop a single database including all the building types for the study area;
- build a virtual model capable of supporting hypothetical scenario studies;
- identify the constraints of representation methods, both traditional and digital;
- illustrate the potential of the method by considering three practical applications.

METHOD

The proposed method for creating digital models is based on four key steps:

- data collection: gathering the available data from the different sources;
- data processing: combining the collected data;
- 3D modelling: this depends on the main elements, such as the terrain and buildings; at this stage parametric modelling software that combines BIM and GIS concepts can be used;
- spatial analysis: various spatial analyses can be conducted to fulfil the objectives of the work.

THE CASE STUDY

Historical environment

The set of urban blocks demarcated transversely by Rua do Comércio and Rua da Betesga and by Rua do Crucifixo and Rua da Madalena longitudinally (Figure 2). The criteria used to select the study area were:

- framing and modularity characteristics of the downtown reconstruction plan by Manuel da Maia, which gives it a natural unity;
- zone of national interest, target of several studies (Tostões et al., 2008), from which we select-
ed the historical hypothesis of José Augusto França.
Focused on the timeless nature of the model, two important historical moments of downtown Lisbon were represented: before and after the 1755 earthquake.

Data Collection
Data were collected from a number of sources in order to build an accurate model. Military maps with a 1:25,000 scale and maps from the local authority with a 1:1,000 scale were used along with orthophotomaps, technical drawings from the Manuel da Maia plan published in the Cartulário Pombalino (Viegas, 1999), written documents (França, 1989a,b), images, and photography of a physical model representing downtown Lisbon before the 1755 earthquake, made by Ticiano Violante and Gustavo de Matos Sequeira, provided by the Lisbon City Museum.

Data Processing
Two approaches were adopted when constructing the model: a simplified representation of Lisbon prior to the 1755 earthquake and a detailed representation of the city at the present. In the first case all buildings were modelled with simplified shapes and volumes, due to the lack of reliable data. For today’s Lisbon a more detailed representation was used that better represents the real shape of the buildings and the detailed architectural elements of the façades.

This phase was developed in three main stages: topographic, cartographic and architectural. In the topographic stage a digital terrain model was built based on 1:1000 scale maps (provided by Lisbon local authority), using GIS tools implemented in ArcGIS Desktop 10.

The urban network was the focus of attention in the cartographic stage. To this end, two datasets were used, one related to each period: a street dataset, where the attribute table included street name and building address; and a building block dataset, generated from CAD files. The two datasets were superimposed to optimise the final model generation. Regarding the lack of data prior to the 1755 Lisbon earthquake, the urban network was built up based on the overlay of the current mesh with an image of Manuel da Maia Lisbon Plan – available at Lisboa 1978: O Plano da Baixa Hoje, by Tostões et al. (2008). The georeferencing considered the coordinates of control points.

The architectural stage involved an exhaustive survey to collect a wide range of data. The information for the prior to 1755 Lisbon earthquake scenario included types of use, height / number of floors, façade textures, and types of roof (Figure 3).

For current downtown Lisbon, several analyses were carried out for the whole urban case study zone, including types of façade, textures, and building types (Figure 4).

Assuming the thesis proposed by José Augusto França (1989), the standardised façades (3 to
5 floors) had three types of decoration – A, B or C – ranked according to the importance of the street (the more important the street, the more showy the decoration). The difference in the sizes of the blocks was attenuated by the modularity of the façades, which kept the rhythm and continuity of the urban complex as a unit. Its careful analysis allowed decaying their composition in repeated modules (by floors), which is an important remark for the next work stage. A library of textures, coating materials, exterior components (such as types of doors and windows), related to the buildings has been created so that the 3D modelling, is as real as possible.

**3D Modelling**
The 3D model was implemented in CityEngine, provided by ESRI Portugal. This program integrates BIM tools in a GIS environment, suitable for a 3D model in urban scenarios. This software works with shape grammars (CGA programming language) which, by setting rules, automates the generation of a large number of buildings in extensive areas. However, shortcomings in the data conversion to other formats made it necessary to create compatible files.

This modelling followed three fundamental guidelines: terrain model, urban network model, and building model. In the terrain modelling a triangular irregular network (TIN) was imported. In CityEngine this operation automatically produces a layer named ‘Terrain’ that enables users to control its visualization. Regarding data scarcity, especially the topographical data prior to 1755, the same digital terrain model was used with a different texture applied to it (Figure 5).

CityEngine is a relatively easy and intuitive tool for urban network modelling. Comprising basic software elements – shapes and streets – the grid was obtained by importing the data (in shapefile format) collected in the cartographic stage. The model was automatically georeferenced by using the CityEngine functions Align Shapes to terrains and Align Graph to terrains.

Buildings were built using CGA instructions. The rules were defined according to the façade type, as shown in Table 1. The existing buildings have been defined according to the variation of the façade type (A, B or C), and the position (building-front-block or building-corner-block).

The buildings prior to 1755 were defined simply, according to their type of use: current buildings or churches.

Rules were created within the parameters defined by the users by means of shape grammars, enabling design variations of these buildings. Functions were invoked when rules were ascribed to the model so as to allow BIM features to be integrated into it. The final result is a 3D model linked to a single database, where parameter values such as surface area, roof area, glazed wall area, number of floors and number of windows, were automatically updated according to model edition. Once the rules are defined, they can be used to generate the model.
according to the specificity of the reality.

Outside the study area, building blocks were modelled in a less detailed representation to allow the contextualization of the model. Those models are presented in Figure 6.

Spatial Analysis

Finally, in order to use the model for tool management, integrating BIM data into a GIS environment, it was decided to establish three issues of academic relevance, which allow information to be collected

<table>
<thead>
<tr>
<th>Parameters used in model building (Prior to 1755 and current downtown).</th>
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<tbody>
<tr>
<td>Number of floors (n_pisos)</td>
</tr>
<tr>
<td>Type of roof (cobertura)</td>
</tr>
<tr>
<td>Texture (revestimento)</td>
</tr>
<tr>
<td>Building height (Min_altura)</td>
</tr>
<tr>
<td>Orientation of the main façade (orientação)</td>
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<tr>
<td>Building types (edifício)</td>
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<tr>
<td>Types of main façade (f_principal)</td>
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<tr>
<td>Types of lateral façade (f_lateral)</td>
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<tr>
<td>Floors with balconies (v_principa)</td>
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<tr>
<td>Floors with balconies on the lateral façade (v_lateral)</td>
</tr>
<tr>
<td>Wall cladding (revestimento)</td>
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<tr>
<td>Lot size – area of the shape of the lot, in m²</td>
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</table>
from different scales of the model, from the building to the urban level:

1st question – What is the shortest route enabling all the tile façade buildings in downtown Lisbon to be visited?

2nd question – In today’s downtown zone, which buildings have a glazed area of over 630 m²?

3rd question – Is there any relationship between the pre 1755 and current layouts, comparing current churches with those prior to the 1755 earthquake? Are any still on the same sites?

To answer the first question, we find the shortest path to visit all the tile buildings as a friendly plug-in of CE in ArcGIS. With Network Analyst extension, a path of 2183.4 meters connecting all the 48 buildings was obtained (Figure 7a). There was no other way to find it automatically.

For the second question, which was to find the area of glazing in current buildings, FileGeodatabase was used, created by exporting the model. It was then possible to identify in the GIS environment the BIM attribute generated in CityEngine that refers to the glazed area of each model building, allowing grouping by interval sets. Using the ‘Select by Attributes’ function it was possible to highlight the buildings for which glazing area was larger than 630 m². The result was the identification of 18 buildings (Figure 7b).

An analysis of the siting of the churches in the area revealed some overlap, which might help us to
appreciate how comprehensive the downtown plan of Manuel da Maia was, for example. We used the FileGeodatabase created by exporting the model for this (Figure 7c).

By consulting the attribute table linked to the imported polygons we can automatically compare the percentage of overlap of the sites of the churches from the two eras (BIM attributes,) created in CityEngine. Using the Intersect command, it was possible to calculate the value of the overlap area: about 15% for Nossa Senhora da Vitória church, and about 50% for S. Julião church. Even though these results have a certain subjectivity, as presented, since they depend on the data used, it was the first time that it has been possible to correlate two different historical periods. This was what we wanted to prove.

CONCLUSIONS AND FUTURE DEVELOPMENTS

Digital modelling tools have proven to be able to file, view and store a large amount of data relating to cities. However, when huge quantities of information are involved modelling becomes slow and needs constant updating.

The integration of GIS and BIM software to create city models, as proposed in this paper, can create a tool capable of performing an extensive range of analyses that relate the two levels of content. Its parametric features allow data to be added and modified to prevent the model from becoming obsolete.

Models can be automated by defining rules of grammar and the use of forms, which significantly reduces modelling time - certainly an asset when modelling cities.

Making the management operations, visualization and data analysis of buildings and urban centres available on a single database has potential for use in many areas; municipalities would be the most obvious, where projects are assessed for compliance with current legislation. Tourism-cultural companies would also find it useful to help working out routes linked to heritage and the experiences of places in the past, and also to provide information on the internet. And finally, it is a potential research tool for ascertaining the sustainability of constructions by identifying environmental imbalances, therefore paving the way for proposing measures to overcome this.

As for future developments, we should mention the wide use by experts from Lisbon municipality of the management, visualization and analysis of buildings and urban complex tools, now available in the same database.

We can conclude that this type of model has the potential for application in a variety of areas related to spatial analysis: it can define routes for tourism and cultural activity purposes; support investigations related to the persistence of a site, and enhance sustainability analyses related to buildings’ features and its geographical location, so that corrective measures can be devised.

This approach can be extended to other city models characterized by the same urban grid features.

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