

3D representation of the urban evolution of Braga using the CityEngine tool

Natália Botica¹, Manuela Martins¹, Maria do Carmo Ribeiro², Fernanda Magalhães¹

¹Unidade de Arqueologia da Universidade do Minho – Braga – Portugal

²Departamento de História da Universidade do Minho – Braga – Portugal

[SG1]

The morphological evolution of the city of Braga has been the subject of several studies focusing on different urban areas in different periods.

Using the accumulated knowledge provided by the available archaeological, historical and iconographic data of Braga, from the Roman times to the nineteenth century, we intend to present a working methodology for 3D representation of urban areas and its evolution, using the CityEngine ESRI tool.

Different types of graphic and cartographic data will be integrated in an archaeological information system for the characterization of urban buildings. Linking this information system to the rules of characterization of urban spaces through the CityEngine tool, we can create the 3D urban spaces and their changes. The building characterization rules include several parameters of architectural elements that can be dynamically changed according the latest information.

This methodology will be applied to the best known areas within of the city allowing the creation of different and dynamic layouts. Considerations about the concepts, challenges and constraints of using the CityEngine tool for recording and representing urban evolution knowledge will be discussed.

Keywords: *Urban Landscapes; Virtual Heritage Visualization; Procedural modelling* [SG2]; [Information System](#)

Introduction [SG3]

The morphological evolution of the city of Braga [SG4] (Portugal), has been the subject of several studies focusing on different urban areas and different periods. Using the accumulated knowledge provided by the available archaeological, historical and iconographic data of Braga, between the Roman period and the nineteenth century, the authors propose a working methodology for 3D representation of urban areas, using ESRI CityEngine procedural modeling tool.

[SG5] Metadata of urban spaces associated with different types of graphical and data are integrated in the archaeological information system. To create a virtual city, the information system is associated with a shape grammar to perform procedural modeling setups using CityEngine. Building characterization rules include several parameters of architectural elements that can be dynamically changed according to the current available information.

[SG6] This methodology was used in [SG7] two distinct periods of Braga city: the Roman medieval periods. For the Roman period, there are very accurate data on some studied areas. However, for the remaining areas several scenarios can be traced that result from interpretations according to current knowledge. To the post-medieval period, there are more detailed information on urban spaces and very specific details on the façades of most of the buildings.

Visualizing [SG8] the urban landscapes with CityEngine

CityEngine is a procedural generation tool that can be used for modeling an entire city in a semi-automatic way (Parish & Müller 2001: 301-308). Procedural modeling allows the creation of large-scale scenes, using a set of algorithms or rules. The rules that produce scenes can be parameterized, controlled by the user or set randomly. The level of detail can also change and be controlled by parameters that determine the number of polygons created for each element of the scenes (Ganster & Klein 2007: 123-130).

[SG9] This case study focuses on a methodology, using CityEngine, to represent the city Braga in two distinct periods: Roman and post-medieval. To represent the Roman virtual city our methodology combined procedural modelling with the already existing 3D models created with a constructive solid geometry modeling tool. For the second case the procedural modeling approach was based on the book “Mappa das Ruas de Braga”, from 1750 (Mappa das Ruas de Braga 1989/91). [SG10] These two periods require different approaches and methodologies, because they are based on different levels of information. For the period of 1750, there is a lot of cartographic information available to design the street network, the lots and the precise geometry of the buildings, and also detailed information about the building's appearances. In the case of the Roman city, the streets, lots and buildings are projected from the archeological information. There is detailed information about the structure of some Roman buildings, resulting from the studies of archaeological excavations (Martins 2004: 149-173), like the Public Baths of Cividade

(Martins 2005), *Carvalheiras Domus* (Martins 1997/98: 23-45), *Cavaliariças Domus* (Silva 2013), *Albergue Distrital and Escola Velha da Sé Domus* (Magalhães 2010[SG11]) and (Martins, Ribeiro & Magalhães 2006: 9-30). To other buildings we propose design hypotheses, based on some predefined set of construction rules (Haegler, Müller & Gool 2009).

[SG12] City [SG13] modeling based on *Mapa das ruas de Braga*

The book “*Mappa das Ruas de Braga*” (MRB) dating from 1750, represents the inventory of the houses, churches, monasteries and chapels belonging to the chapter of Braga’s cathedral. This book draws with remarkable detail and accuracy 4 064 façades of 70 streets of Braga.



Figure 1: [SG14] Rua Verde Street represented in the “*Mappa das Ruas de Braga*”

The information system records qualitative information associated with each building, including the tenants, number of floors and building height. Façade images were also associated with these items through a back-office [SG15] application created for this

Below is an example of the back-office [SG16] application form to register MRB data to MySQL database [SG17] (see fig. 2).

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Cidade Rua Quarteirão Parcela Ocupação Parcela Documentação Gestão Listagens

Designação: 14ca

Arendatário: André Carvalho

Estado Civil: C.C. Luisa da Costa

Profissão: Tratante

Renda: 200réis e 1Galinha

Tipo: Casa

Data contrato: 1719-03-11

Estado:

Nº policia:

Funcionalidade: Habitação

Funcionalidade: Comercial

Largura Fachada: 9,68

Interesse Arqueológico:

Nº de pisos: 3

Altura Fachada: 7,7

Nº de Águas: 2

Caves:

Nº de portas: 4

Atual (SIM):

Muralha_medieval:

Nº de janelas: 4j+5p

Observações: Escritura de Prazo

Muralha Romana:

* Campos obrigatórios

Gravar e Voltar Cancelar

Figure 2: Back-office application form [SG18]

Terrain creation

Braga's terrain was created from a height map that represents the Digital Elevation Model (DEM) of the area of interest. The height map was obtained using the *3D analyst* module of *ArcGIS (ESRI)* to export the Triangulated Irregular Network (TIN) to a raster file, created from contours dated from 1800 (Figure 3). These contours were used to estimate a terrain surface similar to the terrain of Braga in 1750.

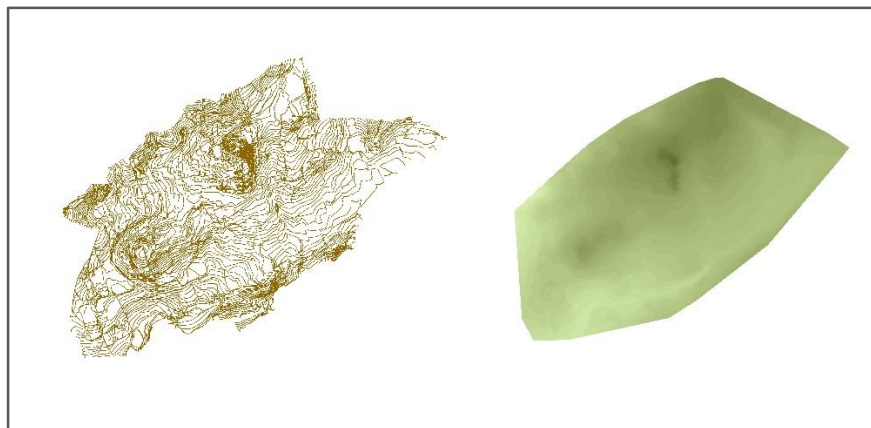


Figure 3: Contours of the terrain from 1800 (left) and height map (right)[SG19]

Urban building modelling

The MRB book represents the façades of the buildings in extremely accurate drawings (Figure 4 left). To obtain the building's footprints in a vector format[SG20], the topographic plan of *Garcez B. and M. Maciel* (Figure 4 center) and the *F. Goullard* map

of 1883-84 (Figure 4 right) are both combined with the MRB data (Martins & Ribeiro [SG21]2013: 11-44).



Figure 4: MRB (left), Mapa de B. Garcez (center) and Mapa Goullard (right)

[SG22] ~~Figure Figure~~ Figure 5 shows the Rua Verde vector footprint, subdivided into small (parcels) and grouped into blocks surrounded by streets. These footprints were committed to shape files to which the qualitative information of the information system, namely the height of the building and the *JPEG* file with façade image, is associated.



Figure 5: Footprints of Rua Verde

The first step of the 3D city model representation using CityEngine, began with the importation of the terrain high map, the colour and the footprints of the buildings to which the procedural modeling and texturing was applied. Figure 6 shows the layout obtained for the Rua Verde Street.

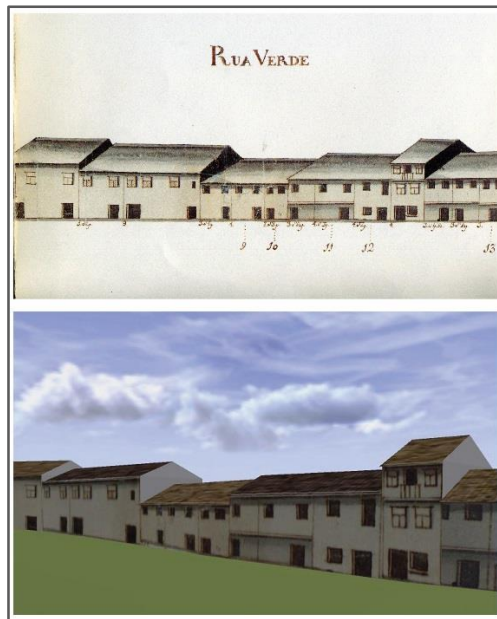


Figure 6: Design of the façades of the Rua Verde Street in MRB book (upper) [SG23][NB24] and the 3D produced in CityEngine (lower) [SG25][SG26]

The city model was further enriched with other elements like streets and public parks (Figure 7).



Figure 7: 3D models based on the MRB [SG27]

CityEngine also allows the comparison of different models enabling the observation of constructive actions of the façades over the years. Figure 8 compares two models of the same building, Largo do Paço, represented at two different periods of time. On the top is the present building represented using *SFM*, an Image-Based Modelling reconstitution

techniques and the bottom building model represents the same building in 1750, using MRB book.

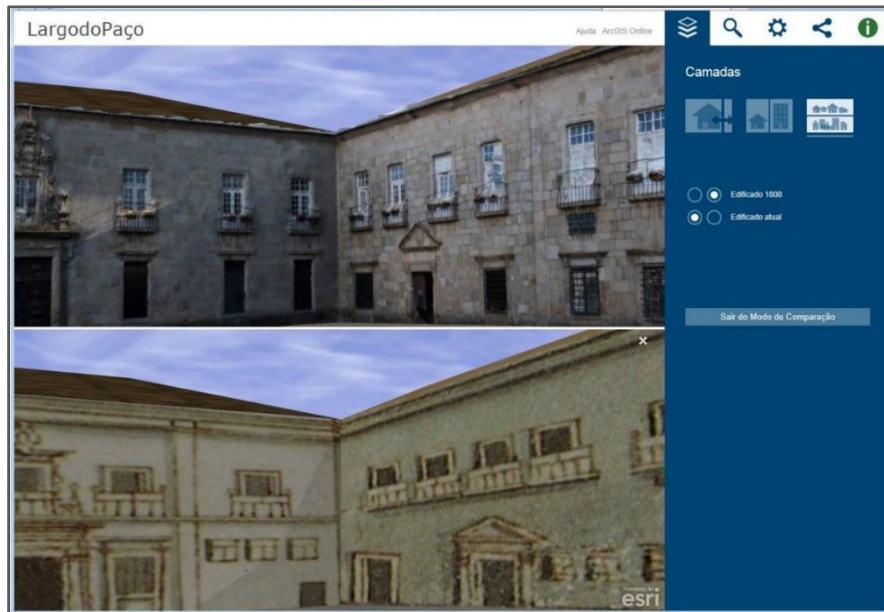


Figure 8: SfM 3D model (up) and CGA 3D model (down) in CityEngine's webviewer [SG28]

This kind of visualization widget, which can be easily and quickly implemented with CityEngine, enables the observation of construction activities and the evolution of urban heritage.

Representation of the Roman period - Bracara Augusta[SG29]

The first three-dimensional model of *Bracara Augusta* was created with computer-assisted drawing and modelling tools (Martins & Bernardes 2000: 347-357). For reconstructing the architectonic structures the UAUM team used commercial software such as *Microstation 95*, *AutoCAD Land Development Desktop R2* and *trueSpaceTM 4 V4.3* that enable the necessary constructive solid geometry (CSG) techniques for adequate modelling.



Figure 9: 3D model of Carvalheiras[SG30]

The archaeological excavations carried out over the last decades produced precious information regarding some buildings of the Roman period. This information was used to create some 3D models of these buildings which were imported to CityEngine, like the Public Baths of Cividade (Martins & Bernardes [SG31]2000), Carvalheiras *Domus* & Martins 2004), Cavalariças *Domus*, Albergue Distrital and Escola Velha da Sé *Domus* (Magalhães 2010) and Theater (Martins et al 2013: [SG32]41-76).

Terrain modelling

In the absence of known altimetry during Roman times, the current terrain was created based on the known elevation points associated to the Roman streets. The analysis of the variation between these points and the current surface elevation points led us to conclude that there were non-uniform changes of terrain elevation. So, we created some platforms where the changes were unvarying to interpolate the estimated Roman contour map. The surface model of the terrain will suffer successive enhancements as more Roman terrain elevation points are being identified.

To recreate the current terrain of Braga without human intervention we join elevation points and contour lines at the 1:1000 scale of modern maps (Figure 10). The estimated

TIN representation of the Roman terrain surface results from the subtraction between the elevations of this surface and the known elevation points of the Roman period.

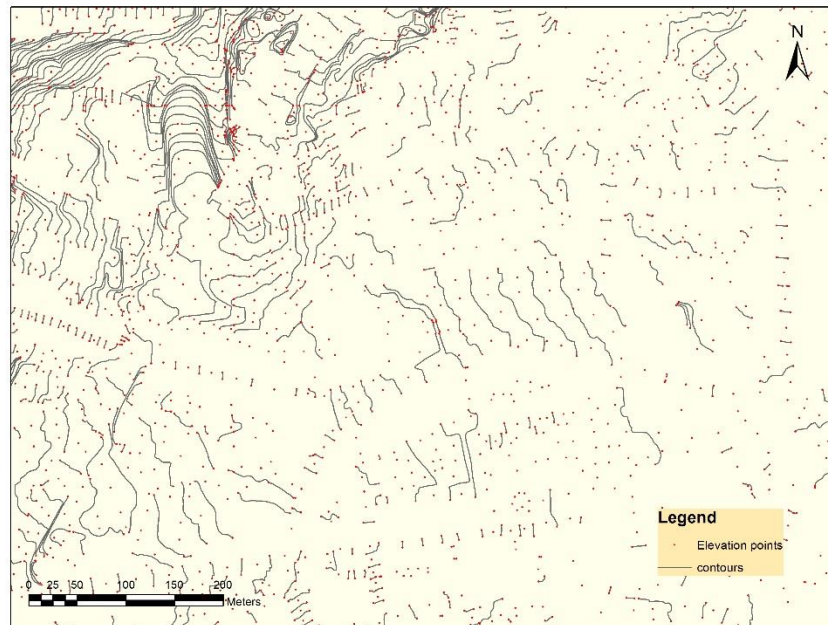


Figure 10: Contours and elevation points of the modern terrain

The obtained Roman terrain was further improved with CityEngine, by importing some georeferenced models with the exact quotas assessed by the archaeological excavations. Applying the operation "Align Terrain to Shapes", ensures that this representation of the terrain is approximated to the existing terrain in the Roman period (Figure 11).

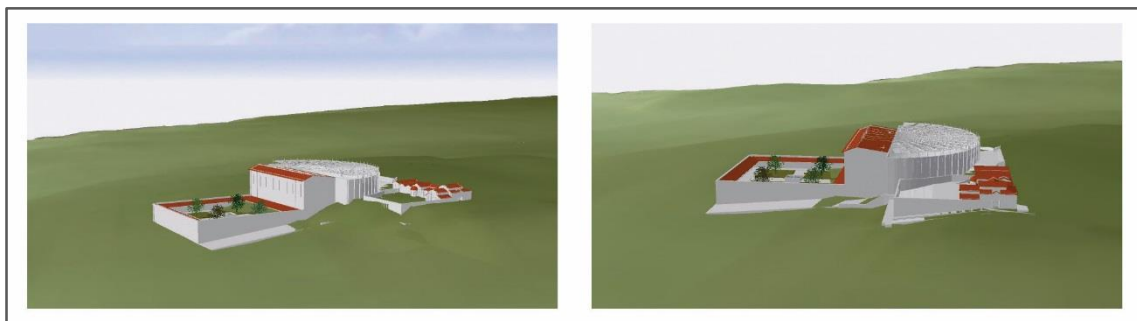


Figure 11: Roman terrain from height map (left) and after adjustment to building model (right)

[SG33] Urban building modeling

The urban planning of the city of *Bracara Augusta*, roads, water supply and sanitation, was made from scratch. As result, the road network of the city is very regular, weaving an urban map organized in orthogonal axes (Martins 2004).

The footprints of the Roman city are constituted by orthogonal road axes, limiting the lots where buildings were constructed (Figure 12).

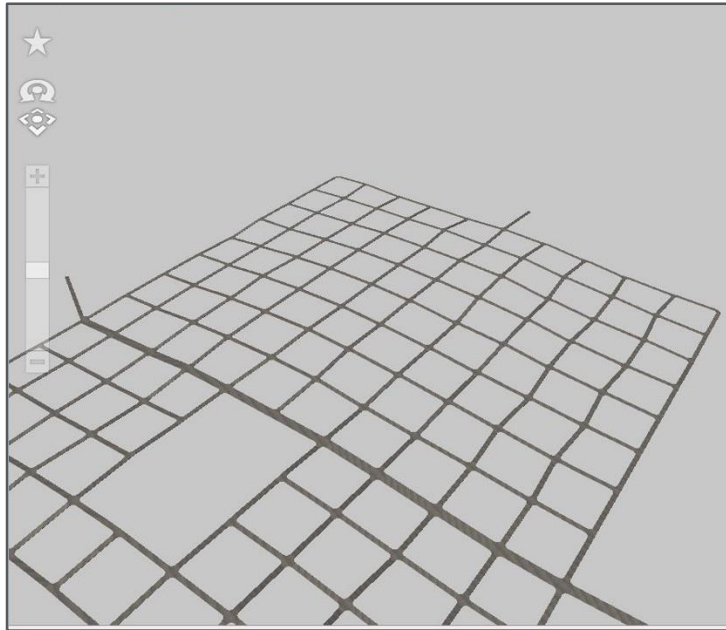


Figure 12: Footprints of Roman City

Each polygon corresponds to a lot with urban buildings, surrounded by streets (Martins & Ribeiro [SG34]2013: [SG35]11-44). The 3D models already developed for some buildings have been imported into CityEngine (Figure 13).

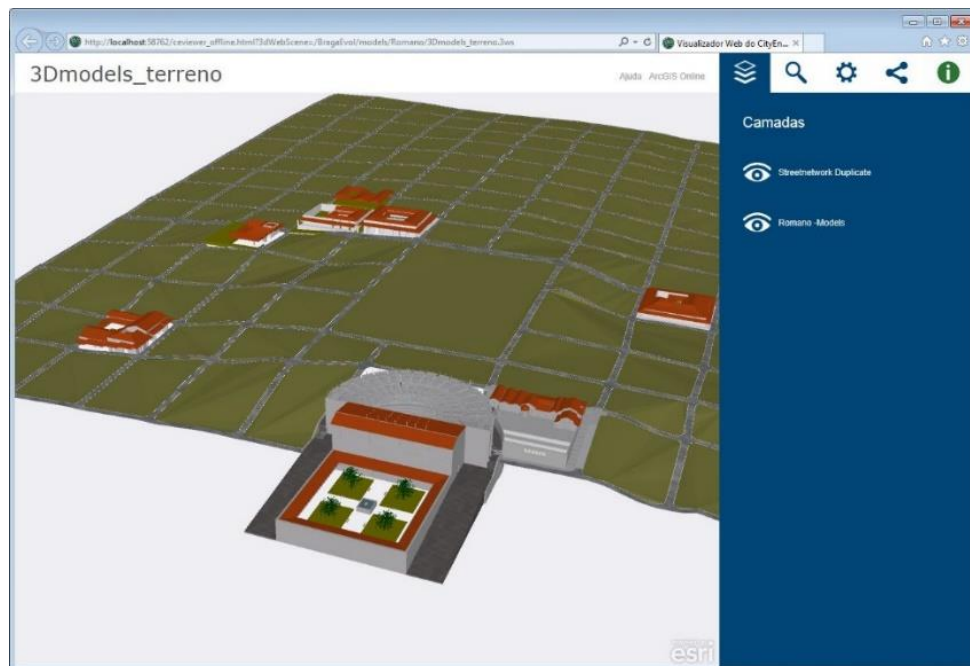


Figure 13: 3D models imported to CityEngine

[SG36]Procedural modeling without texturing, based on shape grammar (Müller et al 2005[SG37]: 287-298), was applied in a controlled and documented way, to fill areas where the archaeological information has not yet been acquired (Figure 14).



Figure 14: 3D imported models and procedural modelling

[SG38] In this way it is possible to have a clear distinction between archaeologically data and hypotheses that have to be validated through archaeological procedures. It is also possible to have multiple layout hypotheses of the virtual city by changing some parameter settings. Future layouts can incorporate archaeological knowledge about the sites to adapt the model with more detailed information.

Conclusions[SG39]

CityEngine has the advantage of being an extremely versatile tool, with particular 3D modelling procedures and interaction techniques. Therefore, it has been chosen to recreate the city of Braga in some remarkable periods of its history. This software allows the development of large scale virtual environments, requires less time and expertise than traditional tools, enables real-time interaction, easily combines data from heterogeneous sources and it is a powerful 3D visualization WEB platform.

The Roman city of *Bracara Augusta* was only known from partial archaeological and historical sources. The use CityEngine allows us to test different reconstruction hypotheses of the city layout in a virtual environment, where 3D models can be changed in a controlled and quick mode. It is possible to recreate a city plan that can be quickly changed as more information is known.

The recreation of a post-medieval model of the city, as a living model of the book “Livro das Ruas de Braga”, highlights the preserved buildings and can be a base model for activities in areas such as architecture, archeology and regional culture.

Bibliography

AUTODESK. Autodesk 123D - 123D Catch turn photos into 3D models. n.d. <http://www.123dapp.com/catch> [SG40](accessed August 2014).

BERNARDES, P. & MARTINS, M., (2004). *Computer Graphics and Urban Archaeology Bracara Augusta's Case Study*. Portuguese Journal of Computer Graphics: Advances of Computer Graphics in Portugal. Lisboa.

GANSTER, B. & KLEIN, R. (2007). *An integrated framework for procedural modeling*. Proceedings of the 23rd Spring Conference on Computer Graphics (Pages 123-130). New York: ACM.

HAEGLER, S., Pascal, M., & Gool, L. V. (2009). *Procedural Modeling for Digital Cultural Heritage*. EURASIP Journal on Image and Video Processing.

MAGALHÃES, F. (2010). *Arquitetura doméstica em Bracara Augusta*. MasterThesis. Universidade do Minho.

Mappa das Ruas de Braga. 2 vols. vols. I e II ADB/UM/IBM-Port., 1989/91.

MARTINS, M. (1997/98). *A zona arqueológica das Carvalheiras: balanço das escavações e interpretação do conjunto*. Cadernos de Arqueologia. Universidade do Minho - Unidade de Arqueologia. Braga.

MARTINS, M. (2004). *Urbanismo e Arquitectura em Bracara Augusta. Balanço dos contributos da Arqueologia Urbana*. Simulacra Romae. Roma y las Capitales Provinciales del Occidente Europeo. Estudios Arqueológicos. Tarragona.

MARTINS, M. (2005). *As termas romanas do Alto da Cidade: um exemplo de arquitectura pública de Bracara Augusta*. Escavações Arqueológicas 1. UAUM/NARQ. Braga.

MARTINS, M., RIBEIRO, J. & MAGALHÃES, F. (2006). *A Arqueologia urbana em Braga e a descoberta do teatro de Bracara Augusta*. Forum, 40. Braga.

MARTINS, M. & BERNARDES, P. (2000). *A Multi-disciplinary Approach for Research and Presentation of Bracara Augusta's Archaeological Heritage*. Archeologia e Calcolatori 11: 347-357.

MARTINS, M. et al. (2013). *A construção do teatro romano de Bracara Augusta*. História da construção, arquiteturas e técnicas construtivas. Braga: CITCEM/LAMOP/UAUM.

MARTINS, M. & RIBEIRO, M. C. (2013). *Em Torno da Rua Verde. A Evolução Urbana de Braga na Longa Duração*. Evolução da Paisagem Urbana: Transformação Morfológica dos Tecidos Históricos. CITCEM, IEM.

MÜLLER, P. et al. (2005). *Automatic reconstruction of Roman housing architecture*. Proceedings of the International Workshop on Recording, Modeling and Visualization of Cultural Heritage. Balkema Publishers (Taylor & Francis group). Ascona, Switzerland.

PARISH, Y.I. & MÜLLER, P. (2001). *Procedural Modeling of Cities*. Proceedings of the 28th annual conference on Computer graphics and interactive techniques (Pages 301-308). New York: ACM.

RIBEIRO, J. & MARTINS, M. (2013). *Os processos construtivos da edilícia privada em Bracara Augusta : o caso da domus das Carvalheira*. CITCEM, IEM.

SILVA, J.F. (2013). *A domus da zona arqueológica das antigas cavaliças de Braga : contributo para o estudo da arquitetura doméstica de Bracara Augusta*. MasterThesis. Instituto de Ciências Sociais, Universidade do Minho. Braga.