VALORIZATION OF URBAN HERITAGE: MODELING UAV 3D DATA FOR MOBILE PLATFORMS

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Key words: Heritage, 3D Modeling, UAV, Mobile Platforms

Abstract

The valorisation of the urban heritage is presently one of main topics discussed, mostly in the theme related conferences, treaties, conventions and programs. Mobile platforms (especially smartphones and tablets) may be very useful technological means for the agents in the territory. Admitting these assumptions, we created an information model for a mobile application (app) development, with a specific theme (water and city) that represents and describes architectural

elements of a city. The selected architectural elements are those related with the water supply system in Lisbon built from XVIII to the XIX century.

The inclusion of these elements in a mobile platform requires 3D modelling, improving the visualization and alphanumeric information access (e.g. historical) very useful to the agents (in particular to the city visitors). 3D models were created based on terrestrial and UAV surveys, considering rapid and authentic data acquisition. The stages of building the models were: i) Data acquisition (UAV - flight planning and image acquisition); ii) Data processing; iii) Data visualization (App/AR). The created models are very realistic. However, the results may differ when processing the data in different software, especially concerning the level of detail. The technical challenge is to simplify the models to use in mobile platforms and maintain the level of realism. The Communication will present a case study of 3D modelling with UAV data and their representation in an Augmented Reality environment through mobile platforms.

Introduction

The comprehension of an individual's mental images of the urban systems and their elements (which may change if the circumstances of observation are different); the level of those images and their quality; and the development and inter-relations, all contribute to build a wider satisfactory physical environment for everyone. Modelling, or remodelling, should be accompanied by a definition of a "Visual Plan" for the city or metropolitan area: embracing a set of recommendations and controls that would be concerned with the visual scale in urban form, illustrating the relevant public images, basic visual problems, opportunities, critical elements of the images, interrelationships of elements with their detailed qualities and possibilities for transformation (Lynch, 1960). According to Golledge (1997) if we are aware of people's preferences, perceptions and attitudes, better matches can be made between planning and policy making, addressing the population's needs (for whom plans are made). Knowing something about people's perceptions, preferences and images, provides fundamental information that complements planners' and managers' intuition guidelines and legal restrictions (Gärling and Golledge in Golledge, 1997).

The effectiveness of external representation is influenced by how it supports cognitive perceptions (Hahn and Kim, 1999 in Khatri et al., 2006). Perceptions capture an extensive range of sensory variation having a huge epistemological importance, being at the very source of all human empirical knowledge. From a cognitive point of view, the structure of geographic information and cartography can provide auspicious premises to approach how humans perceive, represent and interact with their spatial environment, regarding the valuable evidence to the properties of the underlying mental structures and processes for spatial cognition (Berendt et al., 1998).
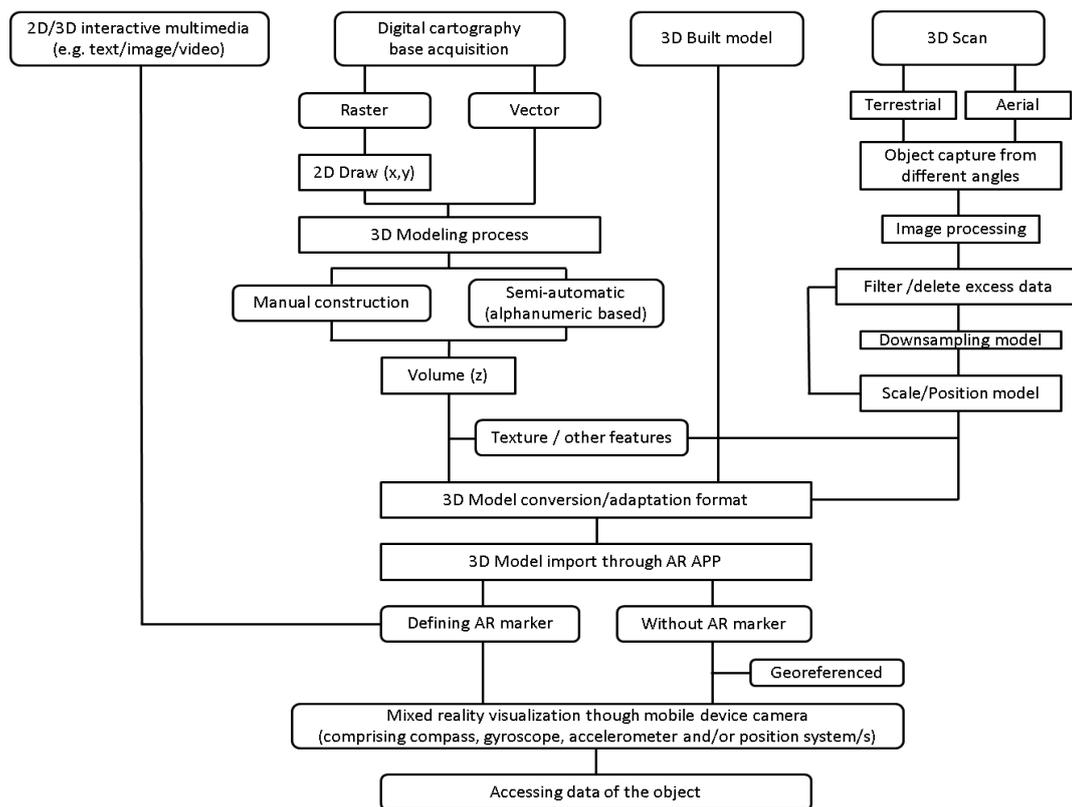
Zhang (1997, 2001) in Khatri et al., (2006) argues that "Most work in cognition assumes that the mind has mental representations analogous to computer data structures". As in cognitive mapping, in Geographic Information Systems (GIS), physical objects are usually associated with

geometry and position. Computers allow us to conduct reproducible experiments, introduce or modify variables and change conditions in a way that is not possible in the physical world itself. Technological advances, especially regarding the ability to extend (represent) the physical world and computer modelling capabilities, have led to the creation of an increasing number of models of objects and environments (Koller et al., 2009). The use of Digital Representations (DR) in research offers a number of advantages, especially the ability to create detailed models of possible pasts and futures. By modelling a number of different variables, we can test and change them to explore different hypothetical situations. This is, of course, impossible in the real world, as circumstances on site are unpredictable and constantly changing (Eve, 2012).

Schematic approach to model, represent and visualise 3D objects in an AR environment

The "Águas Livres" Aqueduct System, deactivated for approximately 50 years, is presently an important historical and cultural heritage structure in Lisbon. The existence of this system for water distributing (through gravity) is not obvious in the city, especially because it is not visible (mostly underground), even if having contributed to define, in part, the evolution of the territory (concerning water supply and especially the structure impact as contributing to define the city morphology). The use of technology applied to cultural heritage has enormous advantages to better visualise and comprehend the importance of such elements, and recognise the connection between the structural elements (visible) and areas (supplied, known by its path). The use of technology applied to CH has enormous advantages to better visualise and comprehend the importance of such elements. The figure 1 schematically synthesises the methodology, procedures and fluxes of data carried out for several experiments developed concerning the visualization of 3D models, gathered (internet catalogues) or produced, using 3D modelling software or 3D scanning (terrestrial or aerial - UAV) to be visualised in an AR environment.

Figure 1. Schematic approach to gather/model and visualise 3D objects in an AR environment

2D/3D interactive multimedia (e.g. text/image/video)	Digital cartography base acquisition	3D Built model	3D Scan

Raster — Vector

Terrestrial — Aerial

2D Draw (x,y)

Object capture from different angles

3D Modeling process

Image processing

Manual construction — Semi-automatic (alphanumeric based)

Filter /delete excess data

Downsampling model

Volume (z)

Scale/Position model

Texture / other features

3D Model conversion/adaptation format

3D Model import through AR APP

Defining AR marker — Without AR marker

Georeferenced

Mixed reality visualization though mobile device camera (comprising compass, gyroscope, accelerometer and/or position system/s)

Accessing data of the object

Source: Authors. 2016

Considering the fluxes of data, based on digital cartography, in the case of the 2D vector, the volume associated with alphanumerical "z" values can been created (in the case of a building having, for example, the number of floors, the user can assign a medium height and multiply to calculate an estimation of the building's volume), while on raster documents (e.g. satellite imagery or ancient cartography) the process requires 2D/3D drawing and eventually adding texture (e.g. building façades) or other features (e.g. audio or video). In the case of a built 3D model (e.g. internet catalogues), it may be necessary to convert or adapt to other formats, compatible with the AR application to be used in the mobile device. A 3D scan can be carried out using several techniques, geomatics, sensors and terrestrial or aerial platforms, taking into consideration scale and object availability. The UAV point cloud extraction by image-matching overlapped images produces rapid data acquisition and processing results. In view of the high Level of Detail and the large amounts of data retrieved in the models produced, it is frequently necessary to filter and down sample to further improve the performance of the model, especially in mobile platforms (considering the graphics and processor capacity). The models produced required some adjustments regarding graphic correction, scale and positioning. Once the 3D model has been imported to the AR application, a marker can be defined (e.g. satellite imagery, ancient map or a touristic map, as in previously to examples) or visualised over a certain chosen surface. However, in the case of not using AR markers, the visualisation in the field may

be associated with real coordinates (a georeferenced 3D model) and eventually enable the possibility to access more information about the object.

The experiments permit verifying the potential of this technology as parts of an ongoing mobile application development. It is intended to integrate the most adequate solutions for the mobile application and therefore understand the potential of these technologies when applied for heritage valuation. It is planned to direct specific interviews and/or inquiries to validate these assumptions not only to common users but also specialised technicians, opinion/decision makers, promoters and other stakeholders.

3D data acquisition and modelling

The most prominent manifestation of humans' pattern recognition capabilities concerns visualisation, revolutionising our behaviour and way of communicating, travelling, organizing and even managing space (Portugali, 1996). 3D representations generate more intuitive methods of interaction between the user and the represented data. 3D environments can increase the engagement of the user, making it much easier to understand, interact and participate by visualizing interactively, for example, volumes, textures, shadows, sights and their relation. This principally occurs because of its high level of similarity to reality, congregating detailed information (Level of Detail - LoD) and volume property, stimulating more enthusiasm and simplifying creative solutions for detected problems after a walk-drive-fly-through re-presentation (embodying the user in that environment or presence), improving comprehension and communication (adapted from Geertman, 2002; Crampton, 2001; Neves and Camara, 1999; Jacobson, 1992 in Zhang, 2004). Thus, 3D representations and analysis tools are more adequate for volume variation and enrich the spatial representations (Zhang, 2004).

The technical-scientific advances of measuring the physical world and computer modelling capabilities, have led to the creation of an increasing number of high quality 3D models of existing cultural heritage objects and environments. These are often supplemented by additional metadata information, as well as synthetic reconstructions of missing data. Heritage representations depend on efficient access, interoperability and scientific endorsement of the 3D models.

Progress in geographic information acquisition and development (hardware and software), allows innovative perspectives for territorial management using third dimension, enabling advanced possibilities of visualisation and analysis in virtual, immersive, or mixed environments (Valencia et al., 2015). The association of 3D modelling and cultural heritage has been growing in interest, partly due to the broader use of LiDAR (laser scanning) and photogrammetry. These technologies allow to record objects remotely, efficiently and accurately, often difficult to perform with previous survey methods (Dore et al., 2012).

There are obvious advantages in conventional airborne remote sensing and the very high-resolution satellite imagery. However, Unmanned Aerial Vehicles (UAV) photogrammetry introduces a flexible, low-cost and rapid response alternative to other traditional methods such as the ground acquisitions and manned vehicles, producing large-scale topography or detailed 3D models, as a main or complementary solution. The rapid and high frequency of data acquisition, and the spread of low-cost platforms combined with SRL cameras and GNSS

systems (e.g. GPS, GLONASS, BeiDou for navigation, point cloud coordinates and possibly geopositioning) constitutes some of the main characteristics for the success of this technology (Nex and Remondino, 2014).

3D point cloud data automatically generates 3D models, including: Digital Terrain Models (DTM - plain terrain), Digital Surface Models (DSM - including the elevations of objects above the ground), and 3D models (from isolated or collective objects). 3D point clouds are mostly generated directly from a laser scan or through stereo image matching, processing imagery algorithms by overlapping (terrestrial or airborne). This means that it is possible to acquire relevant urban parameters at low-cost, from 3D point cloud data acquisition to the extraction of parameters (Tenedório et al., 2014).

UAV 3D data acquisition

To conduct the UAV survey, the following steps in data acquisition were taken: Flight plan parameters (height, overlapping, time, focal distance, camera data, spatial resolution) and collecting data survey (concerning planning aspects such as safety, interferences and calibration).

The UAV survey was conducted in September of 2015 at a height of 50.3 meters and gathered 198 images with the following parameters:
- Resolution of 5456 x 3632 pixels;
- Focal length of 16 mm;
- Pixel size: 4.4 x 4.4 um;
- Overlapping: 75% and 65% (lateral).

Based in the information collected through UAV was conducted several experiments using different advanced processing software for to develop the 3D models of the Lisbon aqueduct structures. The workflow processes and results are quite dissimilar regarding Agisoft Photoscan and Bentley.
- i) Agisoft Photoscan

Figure 2 UAV data acquisition in *Mãe de Água* reservoir (Lisbon Aqueduct Structure): Setting the UAV flight plan (left) and camera locations (right).

Source: images from the authors. 11-09-2015.

Procedure workflow:

      A) Loading photos; inspecting loaded images and removing unnecessary images;

      B) Aligning photos;

      C) Building dense point cloud;

      D) Building mesh; 3D polygonal model;

      E) Texturing the 3D model;

      F) Calculating DEM and DTM;

      G) Ortho image;

      H) Export results.

Area: 298.000m x 309.000m

Dots: 105 million dots

Average density: 1747,104 point/m2

Size: 2,6GB

    ii)   Bentley ContextCapture

Procedure workflow:

      A) Loading photos (georeferenced);

      B) Aerotriagulation;

      C) Building mesh (47 tiles);

      D) Final product (texture automatic added);

      E) Export results.

Area: 298.000m x 309.000m

Dots: 680 million dots

Average density: 13829,761 point/m2

Size: 18,5GB

Considering the same base information the workflow is more extend in the Agisoft than in Bentley and for the same area and data (number / quality of images), the Bentley creates a tiling mesh superior in density and overall number of point cloud, however the size is also higher. The results can be visualised in the figures 3 and 4 with approximately the same angle permit to verify that they are quite dissimilar, especially when observed in detail and without texture.

Figure 3. 3D modelling form the *Mãe de Água* (Lisbon Aqueduct System) and detailed area results using Agisoft Photoscan software
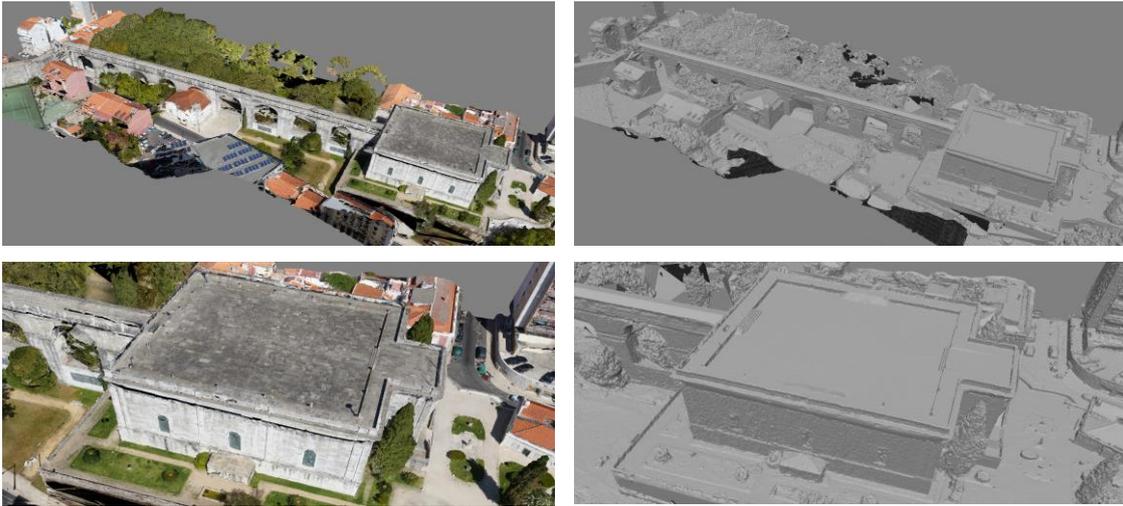
Source: images from the authors. 12-03-2016

Figure 4. 3D modelling form the *Mãe de Água* (Lisbon Aqueduct System) and detailed area results using Bentley software

Source: images from the authors. 12-03-2016.

When placed side by side and compared both models produced, there are substantial differences visible (figures 3 and 4) especially in the detailed area without texture (bottom down, right images). However, the size of the model produced and structure (tiled) can constitute a difficulty to represent in an Augmented Reality (AR) environment, especially when using mobile devices.

3D modelling and visualisation in an Augmented Reality environment

The visualisation of 3D models in an AR environment can be achieved by recognising features of an image such as a city map which is free and available. The existence of this structure in the city is not obvious, especially because it is not visible (mostly underground) and the main objective was to visualise the structure and 3D models of their elements using a mobile device and AR environment, enabling the possibility to access more information about the object. This procedure is carried out with the digitalisation of the city map and the definition of samples of image targets, which will then be detected by the AR software development kit allowing for the 3D objects rendering on top of it, by the recognition of key elements in the image target.

Figure 5. *Mãe de Água* reservoir 3D model and AR environments using the city map as a marker

Source: images from the authors. 17-10-2015.

Figure 6. 3D models (terrestrial and using UAV) from the main structural elements of the Lisbon *Águas Livres* Aqueduct

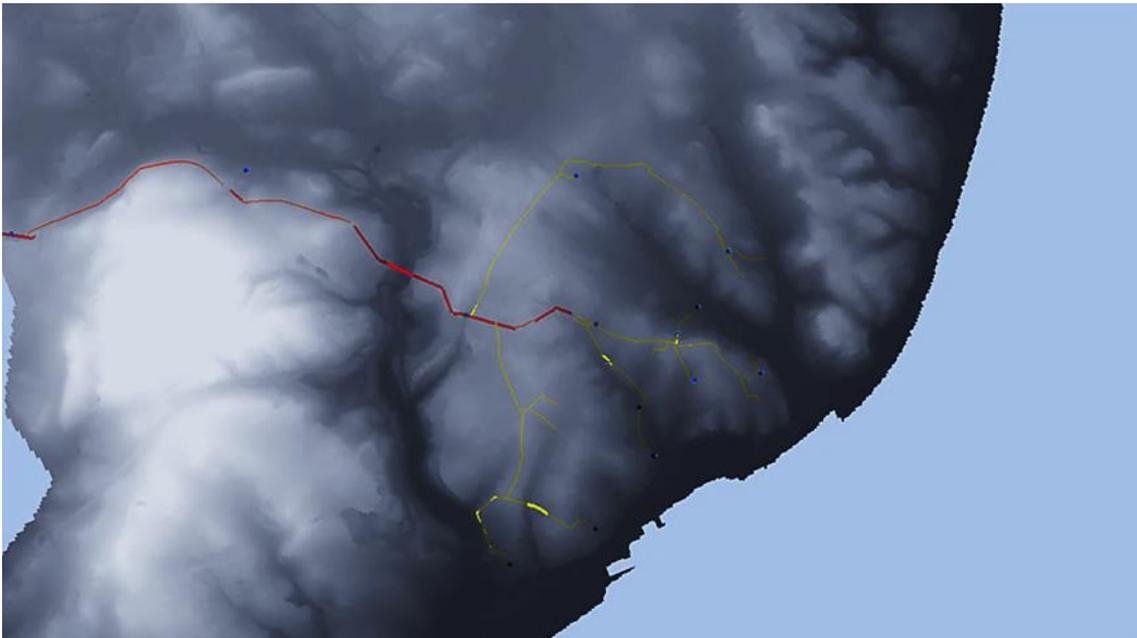**Source:** images from the authors. 17-10-2015.

This way, users are able to simply open the application (App), point the camera at the paper city map and visualise the 3D models that represent the different elements of the aqueduct system (e.g. main aqueduct, reservoirs and fountains) and access additional multimedia information related with each one of these elements (e.g. description, photos, historic cartography), as well as manipulate the 3D model (e.g. 3D rotation, zoom).

Figure 7. Ancient cartography georeferenced with the aqueduct path

Source: image from the authors. Cartography: Planta Geral da Cidade de Lisboa (1868), Câmara Municipal de Lisboa.

Figure 8 Detail of the 3D representation of the Lisbon Digital Terrain and the plan of the Lisbon *Águas Livres* Aqueduct.

Source: images from the authors. 17-10-2015.

Besides the visualisation of the 3D models of the aqueduct elements, the importance of identifying the heritage corridor and its configuration led to the use of the dataset with the representation of the entire system path, identifying sections which are both over and underground, and the ones which can be visited. This information was gathered using georeferenced ancient cartography (Figure 7). AR techniques were also used to overlay the Lisbon Digital Terrain Model (DTM) on the city map (distributed freely in paper) to evaluate the earth surface and recognise the parts which were over (+) and under (-) the ground (Figure 8).

Conclusion

The Geographic Information Technology advances are placing the world on a fast track to having knowledge of where all physical objects are located on the earth not only in present (and real) time, but also in the past or the future, especially regarding the interaction of web-based and mobile technologies (Sui and Goodchild, 2011).

The advantages of using 3D point cloud meshes and UAV systems consist of the ability to rapidly gather higher temporal and spatial resolution information, practically on demand (high frequency). In addition, the user can collect and process, very rapidly, authentic 3D data at a low cost, especially when compared with traditional methods. However, 3D scan technics cannot be applied to digitally recreate and represent past (disappeared) or future (planned) objects. The integration of 3D modelling with GIS permits the association between the high capacity of human perception and visualisation (3D) with the strong capability of spatial query and analysis of GIS. AR environments allow the user to combine the virtual data to the real world (in place), using mobile platforms. In this way they allow for a better understanding of the

elements of visible and non-visible cultural heritage, not only in the present, but also in the past and future (re-present).

The use of advanced processing software for 3D modelling available in the market may produce different results regarding the same base information. The most visible differences between the software used consist in higher level of detail, but also in size. To reproduce 3D models in and Augmented Reality environment, the model size constitutes an important advantage to the usability of the application when applied to mobile platforms. The technical challenge is to compact the information and maintain the level of quality.

These emerging representations of the physical (regarding external affordances at different moments) and even the mental world (through internal minds or imagined/simulated/synthetized) are also creating the opportunities for the development of virtual and real environments (mixing DR with the real world), not only on desktop computers, but growing also to people's daily using mobile devices (with the potential of being mobile and gradual increase in use).

Uncertainty remains to understand people's overall perceived added value attributed to cultural heritage, through technology resources and digital representations. The interaction between the human/device/mixed environments can be applied for the majority of users. However, this interaction is dissimilar and inapplicable, presently, to all devices (regarding their characteristics) and should be available to everyone as part of the democratic access to technology and information. Nevertheless, technology is in a constant state of change and this means becoming reachable in a geometric progression. These are the main topics currently under debate within the principal scientific events, which allow for the prediction of a nearly revolutionary combination between the real and VE, especially applied to cultural heritage (Tenedório et al., 2014).

References

BERENDT, B.; BARKOWSKY, T.; FREKSA, C.; and KELTER, S. *Spatial representation with aspect maps.* [online] Date of consultation: October 2012. In FRESKA C., HABEL C. and WENDER K. F. eds. Spatial Cognition and Interdisciplinary Approach to Representing and Processing Spatial Knowledge. Berlin: Springer, 1998. pp. 313-336. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0169204608002326> ISSN: 01692046.

DORE, C. and MURPHY M. *Integration of HBIM and 3D GIS for Digital Heritage Modelling* [online] Date of consultation: October 2015. In: Virtual Systems and Multimedia (VSMM), 2012 18th International Conference On Edinburg, Scotland, 2012. pp. 22-23. Available at: <http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6365947>.

EVE, S. *Augmenting Phenomenology: Using Augmented Reality to Aid Archaeological Phenomenology in the Landscape.* [online] Date of consultation: October 2015. In: Journal of Archaeological Method and Theory. 19, no.4. 6, July, 2012. pp. 582–600. Available at: <http://www.springerlink.com/index/10.1007/s10816-012-9142-7>   doi:10.1007/s10816-012-9142-7.

GOLLEDGE, R.G. *Spatial Behavoir: A Geographical Perspective.* Guilford Press. 1997. 619 p.

KHATRI, V.; RAM S. and SNODGRASS R.T. On Augmenting Database Design-support Environments to Capture the Geo-spatio-temporal Data Semantics. [online] Date of consultation: January 2012. In: Information Systems. N.31, (2) 2006. pp. 98–13. Available at: <http://www.sciencedirect.com/science/article/pii/S0306437904000961>.

KOLLER, D.; FRISCHER B.; HUMPHREYS G. *Research Challenges for Digital Archives of 3D Cultural Heritage Models.* [online] Date of consultation: January 2012. In: Journal on Computing and Cultural Heritage. 2 (3) (December 1), 2009. pp. 1–17. Available at: <http://portal.acm.org/citation.cfm?doid=1658346.1658347> doi:10.1145/1658346.1658347.

LYNCH, K. *The Image of the City*. MIT Press. 1960. 205 p.

MARQUES, L.; TENEDÓRIO, J. A., BURNS, M. C., ROMÃO, T.; BIRRA, F.; MARQUES, J.; PIRES, A. 2013. *Cultural Heritage 3d Modelling and Visualisation Within an Augmented Reality Environment, Based on Geographic Information Technologies and Mobile Platforms* in ACE Arquitectura, Ciudad y Entorno (Accepted to be published in 2016).

NEX, F. and REMONDINO, F. *UAV for 3D Mapping Applications: A Review.* [online] Date of consultation: October 2015. In: Applied Geomatics. 6, 2013. pp. 1-15. Available at: <http://dx.doi.org/10.1007/s12518-013-0120-x>.

PORTUGALI, J. *The Construction of Cognitive Maps*. Dordrecht; Boston: Kluwer Academic Publishers. 1996. 367 p.

SUI D. and GOODCHILD M. The convergence of GIS and social media: challenges for GIScience. [online] Date of consultation: July 2013. In: International Journal of Geographical Information Science. 25:11, 2011. pp. 1737-1748. Available at: <http://www.geog.ucsb.edu/~good/papers/516.pdf>.

TENEDÓRIO, J. A.; REBELO, C.; ESTANQUEIRO, R.; HENRIQUES, C.; MARQUES, L.**;** GONÇALVES, J. A. *Geographical Information Technologies in Urban and Spatial Planning: Process: methods and tools.* In: PINTO, N.; TENEDÓRIO, J.A.; ANTUNES, A.P.; ROCA, J., Eds. Technologies in Urban and Spatial Planning: Virtual Cities and Territories. Hershey/Pennsylvania, IGI Global, 2013. pp. 342. DOI: 10.4018/978-1-4666-4349-9.

VALENCIA, J.; MUÑOZ-NIETO A. and RODRÍGUEZ-GONZÁLVEZ , P. *Virtual modeling for cities of the future. State-of-the art and virtual modeling for cities of the future. State-of-the art an.* [online] Date of consultation: October 2015. In: ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL–5/W4. 18, February, 2015. pp. 179–85. Available at: <http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-5-W4/179/2015/> ISSN: 2194-9034.

ZHANG, X. *Designing a Geographic Visual Information System (GVIS) to Support Participation in Urban Planning*. [online] Date of consultation: July 2015. Phd, University of Salford, UK. 2004. Available at: <http://usir.salford.ac.uk/2178/>.