



UNIVERSITAT POLITÈCNICA DE CATALUNYA - BARCELONATECH
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DEPARTAMENT DE TECNOLOGIA DE LA ARQUITECTURA

PhD thesis

Augmented Valuation of Cultural Heritage through Digital Representation based upon Geographic Information Technologies

The case study of Lisbon Aqueduct System within an Augmented Reality environment

PhD Candidate: **Luís Filipe do Espírito Santo Correia Marques**

Thesis Supervisor: **Professor Josep Roca** (UPC/ETSAB/DTA – Spain)

Thesis Supervisor: **Professor José António Tenedorio** (UNL/FCSH/DGPR – Portugal)

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¹ The IGEO (internet portal of geographic information for Portugal) is based in Web Services (WMS/WFS) served from the official institutions directly through internet. These services (constantly actualized from the producer to the user in near real time) are available through online resources (via portal igeo.pt), feeding online geographical viewers and three main mobile Apps. One of these App's was the SIPA iGeo-Património (Heritage), available for Android and IOS, which was based in the SIPA inventory and archives (texts, pictures and cartography) where the author worked from the year 2002 until 2014.

Acronyms and Abbreviations

| | |
|-----------|---|
| 2D/3D/4D | – 2/3/4 Dimensions |
| AdP | – Grupo Águas de Portugal |
| AGNSS | – Assisted Global Navigation Satellite Systems |
| App | – Mobile Application |
| AR | – Augmented Reality |
| AV | – Augmented Virtuality |
| BOOM | – Binocular Omni-Orientation Monitor |
| CAVE | – Cave Automatic Virtual Environment |
| CCD | – Charge-Coupled Devices |
| CH | – Cultural Heritage |
| CICS.NOVA | – Centro Interdisciplinar de Ciências Sociais |
| CIPA | – International Committee for Heritage Documentation |
| CPSV | – Centre de Política de Sòl i Valoracions |
| CS | – Catalogue Service |
| DEM | – Digital Elevation Model |
| DGPC | – Direção Geral do Património Cultural |
| DGT | – Direção Geral do Território |
| DK/NO | – Don't Know / No opinion |
| DR | – Digital Representations |
| DSM | – Digital Surface Model |
| DTM | – Digital Terrain Model |
| EC | – European Commission |
| EGNOS | – European Geostationary Navigation Overlay Service |
| EPAL | – Empresa Portuguesa de Águas Livres |
| ESA | – European Space Agency |
| ESRI | – Environmental Systems Research Institute |
| ETSAB | – Escola Tècnica Superior d'Arquitectura de Barcelona |
| FCSH | – Faculdade de Ciências Sociais e Humanas |
| FCT | – Faculdade de Ciências e Tecnologia |
| GIS | – Geographical Information Systems |
| GIT | – Geographic Information Technologies |
| GLONASS | – GLObalnaya NAVigatsionnaya Sputnikovaya Sistema |
| GML | – Geography Markup Language |
| GNSS | – Global Navigation Satellite Systems |
| GPRS | – General Packet Radio Service |
| GPS | – Global Positioning System |
| GTIDA | – Grupo de Trabalho para a Iniciativa Dados Abertos |

HMD – Head-Mounted Displays
HSPA - High-Speed Packet Access
ICNF – Instituto da Conservação da Natureza e Florestas
ICCROM – International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOM – International Council of Museums
ICOMOS – International Council on Monuments and Sites
ICT – Information and Communication Technologies
IHRU – Instituto da Habitação e Reabilitação Urbana
IM – Image Matching
INSPIRE – Infrastructure for Spatial Information in the European Community
IRNSS – Indian Regional Navigational Satellite System
ISO – International Organization for Standardization
ISPRS – International Society of Photogrammetry and Remote Sensing
ISRO – Indian Space Research Organization
JAXA – Japan Aerospace Exploration Agency
LAS – Lisbon Aqueduct System
LiDAR – Light Detection And Ranging
LoD – Level of Detail
Lx_W – Lisbon and Water App (integrates the related Apps: AqueductAR and AqueductGPS)
MEO – Medium Earth Orbit
MR – Mixed Reality
NASA – National Aeronautics and Space Administration
NAVSTAR – Navigation Satellite Timing and Ranging
NRC – Natural Resources (Council) Canada
NS/NR – Não Sabe / Não Responde
OGC – Open GIS Consortium
PC – Personal Computer
PIVC – Parieto-Insular Vestibular Cortex
PNT – Position, Navigation, and Timing
POI – Point Of Interest
PTAM – Parallel Tracking And Mapping
QZSS – Japanese Quasi-zenith Satellite System
RE – Real Environment
RNS – Regional Navigation Systems
ROA – Remotely Operated Aircraft
RPV – Remotely Piloted Vehicle
RS – Remote Sense(ing)
RTI – Reflectance Transformation Imaging
SDI – Spatial Data Infrastructure

SDK – Software Development Kit

SIPA – Sistema de Informação para o Património Arquitectónico

SLR - Single-Lens Reflex camera

UAV – Unmanned Aerial Vehicle

UNESCO - United Nations Educational, Scientific and Cultural Organization

UNL – Universidade NOVA de Lisboa

UVS – Unmanned Vehicle System

UPC – Universitat Politècnica de Catalunya – BarcelonaTech

USSR – Union of Soviet Socialist Republics

US(A) – United States of America

W3C – World Wide Web Consortium

WAAS – Wide Area Augmentation System

WCS – Web Coverage Service

WFS – Web Feature Services

WMS – Web Map Services

WP – Work Program (ICT Work Programs of the EC)

VE – Virtual Environments

VGI – Volunteered Geographic Information

VR – Virtual Reality

VST – Visualization Systems Technologies

VTC – Virtual Cities and Territories

VRML – Virtual Reality Modelling Language

VRS – Virtual Reality System

VTT – Virtual Time Travel

X3D – eXtensible 3D

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Keywords (Eng.): Geographic Information, Augmented Reality, Digital Representations, Cultural Heritage, Lisbon, Aqueduct

Abstract (English)

The thesis focus in the central idea of Digital Representations and the Valuation of Cultural Heritage, in the relation between Technology, Agents and several knowledge Domains, seeking to analyse the Augmented Valuation of Cultural Heritage, based on Geographic Information Technologies (GIT). It introduces the significance of (digital) representations through the concepts of the individual's spatial cognition (internal/mental representations) and physical (external representations) perceptions and their epistemological importance, revealing what are the GIT contributing to these representations: Global Navigation Satellite Systems (GNSS), Remote Sensing (RS), Geographical Information Systems (GIS), 3D data Acquisition, Modelling and Visualisation and Virtual/Mixed Environments.

The methodology involves of point clouds (x,y,z) data acquisition using terrestrial and Unmanned Aerial Vehicles (UAV), 3D modelling procedures, integration between 3D-GIS and virtual environments applied to cultural heritage systems and elements in urban areas. The results consist of geographical information products and 3D acquisition and modelling processes to be visualised in an Augmented Reality environment, through mobiles platforms. It was discussed experiments using mobile applications (App) available in the market that have enabled the adjustment of core solutions for further development of the App Lx_W, consisting in the related Apps: AqueductAR and AqueductGPS.

Selecting the ancient Lisbon (Aqueduct) water supply system (classified as a national monument in 1910) as a case study and considering the fact that most of the structure is unnoticeable, due to the large extent of underground galleries, these types of synthetized enhanced environments enable onsite visualisation and the perception of the relation between the system and the city. The prototype of Lx_W App was evaluate during the workshop with the purpose of analysing the application that had been developed using the answers obtained in survey, relating this App and some experiments carried out with other Apps available in the market. A second survey was conduct supported by a video where the heritage system and the Lx_W App were introduced, showing the App's features and capabilities applied to this specific case study.

The methods used aimed to strengthen the idea of the potential application of this technology for heritage valuation, introducing the concept of Augmented Valuation of Cultural Heritage, associating the use of geographic information to fields commonly related to a strong visual perception of space, providing essential data to the Agents, not only for occasional users (public), but also for specialised technicians, opinion/decision makers, promoters and other stakeholders, addressing solutions (or contributions) to the existing problems in the several technical-scientific, socio-economic, political-administrative, ideological-symbolic-religious Domains.

Palabras clave (ES): Información Geográfica, Realidad Aumentada, Representaciones Digitales, Patrimonio Cultural, Lisboa, Acueducto

Resumen (Español)

La tesis se centra en la idea de las Representaciones Digitales y la Valoración del Patrimonio Cultural, en la relación entre Tecnología, Agentes y los Dominios del conocimiento, procurando identificar y analizar la Valoración Aumentada del Patrimonio Cultural mediante las Tecnologías de Información Geográfica (TIG). Introduce la importancia de las representaciones (digitales), a través de conceptos cognición espacial (representaciones internas/mentales) y la relevancia epistemológica de las percepciones individuales del ambiente físico (representaciones externas), revelando as TIG que contribuyen a las construcciones de estas representaciones: Sistemas Globales de Navegación por Satélite, Detección Remota, Sistemas de Información Geográfica, adquisición de datos/modelado en 3D y la visualización de los Ambientes Virtuales.

La metodología consiste en la adquisición de nubes de puntos (x, y, z) obtenidos en el suelo o por medio de vehículos aéreos no tripulados (UAV) para el modelado 3D, integración en ambientes 3D-SIG y la creación de ambientes virtuales aplicados a los elementos y conjuntos patrimoniales en áreas urbanas. Los resultados incluyen productos y procesos de adquisición y modelación 3D de información geográfica para ser vistos en ambientes de Realidad Aumentada a través de plataformas móviles. Se discuten varios experimentos utilizando aplicaciones móviles (App) disponibles en el mercado que han permitido el ajuste de soluciones para el desarrollo de la App Lx_W, que consiste en la asociación de las aplicaciones: AqueductAR y AqueductGPS. Seleccionando el antiguo sistema de abastecimiento de agua de Lisboa (Acueducto de Águas Livres, clasificado como monumento nacional en 1910) como estudio de caso y teniendo en cuenta que la mayor parte de la estructura es imperceptible, debido a la gran extensión de las galerías subterráneas, estos tipos de ambientes sintetizados permiten la visualización y la percepción, *in situ*, de la relación entre el sistema y la ciudad. El prototipo de la App Lx_W se evaluó recurriendo a un *workshop* con el objetivo de analizar la aplicación desarrollada a través de las respuestas obtenidas en cuestionario que tevé como intuito comparar esta aplicación y algunos experimentos realizados con otras App disponibles en el mercado. Se realizó un segundo cuestionario de evaluación con soporte en un video donde se introdujeron la estructura edificada y la App Lx_W, demostrando algunas principales características y capacidades.

Los métodos utilizados apuntan a reforzar la idea de la potencial aplicación de esta tecnología para la valoración del patrimonio, introduciendo el concepto de Valoración Aumentada del Patrimonio Cultural, asociando el uso de la información geográfica a campos comúnmente relacionados con una fuerte percepción visual del espacio, providenciando información a los Agentes, no únicamente para los usuarios ocasionales (público), como también para los técnicos especializados, decisores, promotores y otras interesados, criando soluciones (o contribuciones) a los problemas existentes en los diversos Dominios Técnico-científico, Político-Administrativo y Ideológico-Simbólico-Religioso.

Palavras-chave (PT): Informação Geográfica, Realidade Aumentada, Representações Digitais, Património Cultural,
Lisboa, Aqueduto

Resumo (Português)

A tese centra-se na ideia das Representações Digitais e Valorização do Património Cultural, na relação entre a Tecnologia, os Agentes e os diversos Domínios do conhecimento, procurando identificar e analisar a Valorização Aumentada do Património Cultural, com base em Tecnologias de Informação Geográfica (GIT). Introduce a importância das representações (digitais), usando conceitos de cognição espacial (representações internas/mentais) e a relevância epistemológica das percepções individuais do meio físico (representações externas), revelando quais as TIG que contribuem para a construção das referidas representações: Sistemas Globais de Navegação por Satélite (GNSS), Deteção Remota (RS), Sistemas de Informação Geográfica (SIG), aquisição/modelação de dados 3D e a visualização em Ambientes Virtuais/Mistos.

A metodologia consiste na aquisição de nuvens de pontos (x,y,z) obtidos no solo ou através de veículos aéreos não tripulados (UAV) para a modelação 3D, a integração em ambientes 3D-GIS e a criação de ambientes virtuais aplicados a elementos e conjuntos patrimoniais em áreas urbanas. Os resultados incluem produtos de informação geográfica e processos de aquisição e modelação 3D para serem visualizados em ambientes de Realidade Aumentada, através plataformas móveis. São discutidas várias experiências utilizando aplicações móveis (App) disponíveis no mercado que possibilitaram o ajuste de soluções para o desenvolvimento da App Lx_W, que consiste na associação entre as Apps: AqueductAR e AqueductGPS. Selecionando o antigo sistema de abastecimento de água de Lisboa (Aqueduto das Águas Livres, classificado como monumento nacional em 1910) como caso de estudo e considerando que a maior parte da estrutura é impercetível, devido à enorme extensão das galerias subterrâneas, esses tipos de ambientes sintetizados possibilitam a visualização e a perceção, no local, da relação entre o sistema e a cidade. O protótipo da App Lx_W foi avaliado recorrendo a um *workshop*, com o objetivo de analisar a aplicação desenvolvida, através das respostas obtidas em inquérito, que teve o intuito de comparar a App Lx_W e as experiências previamente realizadas com outras Apps disponíveis no mercado. Foi realizado um segundo questionário para efeitos de avaliação com suporte em vídeo onde são apresentados a estrutura construída e a App Lx_W, demonstrando algumas das principais características e potencialidades.

Os métodos utilizados visam reforçar a ideia da potencial aplicação desta tecnologia na valorização do património cultural, introduzindo o conceito de Valorização Aumentada do Património Cultural, associando o uso da informação geográfica a campos comumente relacionados a uma forte perceção visual do espaço, fornecendo dados essenciais aos Agentes no território, não apenas no que concerne a utilizadores ocasionais (público), mas também para técnicos especializados, decisores, promotores e outros interessados, criando soluções (ou contribuições) para os problemas existentes nos vários Domínios Técnico-Científico, Socioeconómico, Político-Administrativo e Ideológico-simbólico-religioso.

Introduction

The increasing use, interest and heterogeneity of Geographic Information Technologies (GIT), especially Remote Sensing, Geographical Information Systems, Global Positioning System, Digital Cartography, and Point Clouds (XYZ), available for Cultural Heritage² studies has led to a vast number of international initiatives, reflected mostly in conferences, treaties, conventions and programs (some of them with a considerable financial support). However, there is a growing need to understand the main usability of this technology applied to the area of cultural heritage and analyse the potential augmented value³ for the main Agents and Domains.

This thesis focuses on the valuation of cultural heritage representations in the combined actions of different Technologies, the Domains of their applications, and the potential benefits to the existing Agents in the territory. In this context, the following operations are considered: identifying sources of pertinent information; evaluating the quality, concerning reliability, accuracy, coherency, efficiency, periodicity and compatibility; structuring the information in databases and datasets; developing several approaches to represent cultural heritage; identifying and researching the agents and their perspective on the augmented valuation of cultural heritage based on digital representations; gathering the advantages of digital representations applied to the technical-scientific, social-economic, political-administrative, ideological-religious domains within the cultural heritage concept. This topic will contribute to increase scientific knowledge providing adequate solutions for the enhancement of cultural heritage through representations with the support of GIT, regarding the perceptions and needs of the agents, making available informational,

² For a discussion of the concept of Cultural Heritage, see pages 87 to 93 and 187 to 215.

³ The value attributed to any object or place can vary with the perception of different groups of people, interests or cultures. The terms “economic value” and “cultural value” have been used in an effort to capture the difference between the types of value a given cultural asset might have. Economic value is ultimately used in terms of money (Throsby, 2003). This type of value can be understood as the “money the potential consumer is willing to pay” (Navrud & Ready, 2002), however when we think of the value that a certain object or place has for a specific culture or group of individuals, it might be priceless as part of a process, symbolic or historical fact. Cultural value is multi-dimensional, unstable, questioned; it lacks a common unit of reason and may contain elements that cannot be easily expressed according to any quantitative or qualitative measurement (Throsby, 2003). The value of Cultural Heritage signifies the rareness, importance or symbolic representation of one or more specific events, milestones, achievements or historical significances. According to Feilde *in* Stendebakken *et al.* (2015), cultural heritage might have architectural, aesthetic, historic, documentary, archaeological, economic, social, political, spiritual and/or symbolic value. Silva & Roders *in* Stendebakken *et al.* (2015) propose the following values in heritage (impact) assessments: social, economic, political, historic, aesthetic, scientific, age and ecological. Enhancing these aspects are not heritage values themselves, but they indicate the relative importance of different heritage values. Enhancing aspects include uniqueness, authenticity, representativeness and pedagogical value (Stendebakken *et al.*, 2015). Thus, this value must be understood, assimilated and disseminated. On the other hand, considering that for the great majority of heritage buildings the intention is to continue using them, it is relevant to find practical solutions to make the necessary renovations while retaining their historical value. Making decisions about approaches to upgrade or repurpose these buildings should be based on a comprehensive assessment of the consequences of and the possibilities for different approaches to upgrading and management (Stendebakken *et al.*, 2015). Digital representations of cultural heritage are highly valuable for scientific study, conservation, and educational purposes (Zlot *et al.*, 2014).

documentary and assessment processes to support architectonic, urban and land use management.

The schematic approach (Fig. 1) seeks to reveal the structure of the thesis centring the discussion on the topic of cultural heritage valuation through digital representations, intersecting the different domains of interest (Political-Administrative, Social-Economic, Technical-Scientific, Symbolic-Ideological-Religious); their main agents (Opinion/Decision Makers, Public, Technicians, Promoters, and other Stakeholders), who provide intelligence

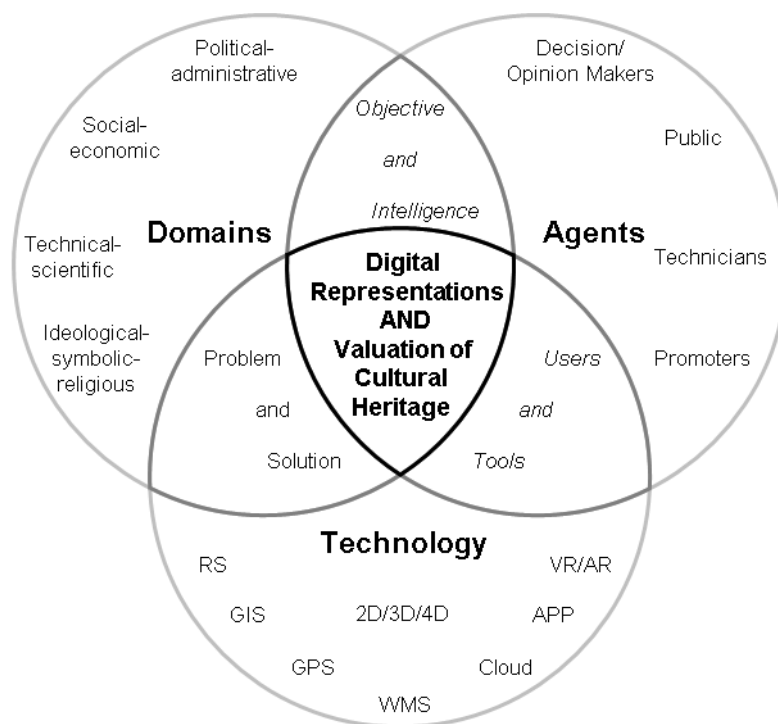


Fig. 1 – Thesis schematic approach (source: the author).

for the processes of developing, conserving, managing, promoting and using information for their proposes; through the use of tools such as Geographic Information Technologies (particularly Remote Sensing, Geographical Information Systems, Global Positioning System, and Digital Cartography at 2D/3D/4D; regarding also notions of Virtual Reality, Augmented Reality, Mobile APPlications, Web Map Services, and Cloud Computing) in terms of gathering, storing, managing, modelling, disseminating and using heritage information, thus dynamically increasing the value of the object represented.

Research Objectives

This thesis seeks to demonstrate that digital representations distinctively augment the valuation of cultural heritage through technological resources, the perspectives of agents, and the contributions from the different domains. The congregation of main technological applications and the basic methods for heritage preservation, conservation and restoration will contribute to recognize fast acquisition techniques and methods of heritage representation, considering their advantages and disadvantages, and comparing them with traditional methods. Thus, there will be the need to identify multi-sources of pertinent information and designing structures of information datasets and databases, recognizing the potential to disseminate and use dematerialized cultural heritage (digital/virtual). After determining the main technological resources to represent cultural heritage digitally (e.g. Remote sensing, GIS, GPS, 3D + time), several approaches to the virtual representation of cultural heritage will be developed. Subsequently, it is essential to involve the main agents associated with cultural heritage (e.g. public, technicians and opinion/decision makers) and diagnose the value recognized by those agents in the case of the examples of heritage representations developed. Therefore, it is fundamental to understand the main areas/domains in the role of cultural heritage (e.g. conservation, documentation, promotion, research, and dissemination), and the usability/applicability of these technologies, analysing the potential increased value through the digital representation.

Initial Hypothesis

The main question of the thesis is whether digital representations distinctively augment the value of cultural heritage, considering Technology, Agents, and related Domains. Originating from this main question, there are three other related topics.

- i) Which technological means make the valuation of cultural heritage viable from the point of view of data acquisition, processing, visualization and dissemination? Remote Sensing, GIS, GPS, 3D, Mobile Apps, Augmented Reality, other...?

The culture of a society is often represented by the entire corpus of material signs that can be either artistic or symbolic. The term heritage reflects the idea of legacy as a constituent part of the affirmation and enrichment and the unique human experience belonging to all mankind (UNESCO, 1989). Each region or community often uses their heritage to distinguish their culture and what they have accomplished, expressing it with signs, symbols or other means of representation. Technology has played an important role in this process, using scientific knowledge, methods, materials, and devices to capture and disseminate the representations of cultural heritage. With the evolution in terms of geometric progression of technological resources, more accurate and detailed models have been developed. However, it is still not clear which are the most adequate technologies to add value to the cultural heritage, considering the available resources, type of object and scale, data acquisition and specifications, interoperability and compatibility, quality of information (concerning also reliability, accuracy, and coherency), efficiency, periodicity, economic viability, contribution to scientific knowledge and end-users and for which proposes, among many other doubts. This thesis purposes to research the technological solutions and develop multiple experiments using GIT to verify the associated (potential) increase of the intrinsic value of cultural heritage.

ii) What are the Agents in the territory and how do they value the digital representations of their associated cultural heritage? Technicians, general public, opinion/decision makers?

Representations of cultural heritage involve several agents, i.e., technicians (e.g. architects, artists, conservators, engineers, historians, geographers, and urban planners), who are mostly concerned with preservation, conservation, planning, and providing detailed, accurate and reliable information; decision/opinion makers (e.g. politicians, managers, ecclesiastics, and other institutional representatives), who are commonly concerned with economic viability, proposals, end-users, efficiency and symbolic values; promoters (e.g. travel agents, hospitality and commerce), who are usually preoccupied with the benefits commonly associated with the type and frequency of costumers and business valorisation; general public (e.g. tourists, visitors, users), who frequently regard aspects such as individual perceptions (internal versus external representations), symbolism and value (importance), sensations through observation, gathering the fundamental issues and

understanding of history and the main particularities of an object. This thesis intends to identify the principal agents involved and the value of digital representations for the main stakeholders recognised. Through survey, it was intended to detect and typify identical (collective) answers and acknowledged solutions adapted to their perspectives for possible/adequate applications.

iii) What are the different Domains of valuation concerning digitally represented cultural heritage? Technical-scientific, social-economic, political-administrative, ideological-symbolic-religious?

The agents are closely related with the main contributions to the different domains. This thesis proposes to recognise the valuation of cultural heritage through digital representations, using GIT within the scope of technical-scientific, social-economic, political-administrative and ideological-symbolic repercussions, encompassing the main problems and solutions.

Thus, this thesis posit the hypothesis that *digital representations distinctively augment the valuation of cultural heritage through technological resources, the perspectives of agents and the contributions to the different domains.*

Methodology

The convergence between cultural heritage and the increasing use, interest and heterogeneity of Geographic Information Technologies (GIT), especially Remote Sensing, Geographical Information Systems, Global Positioning System, Digital Cartography, Point Clouds (XYZ), and data visualization through Digital Representations, particularly using mobile devices capabilities, allowing to merge the real and virtual environments (e.g. through Augmented Reality technology) has led to a vast number of international initiatives (conferences, conventions, directives, standards and others) to gather, store, manipulate and disseminate information. The congregation of these main technological applications, techniques and methods for preservation,

conservation and restoration has contributed to recognize heritage representations, considering their advantages and disadvantages and comparing them with traditional methods.

To accomplish the main objectives, the following research tasks and fluxes of information were developed using qualitative (case studies or actions research and defining the variables involved) and quantitative (how many/how much, and survey and experimentation) research.

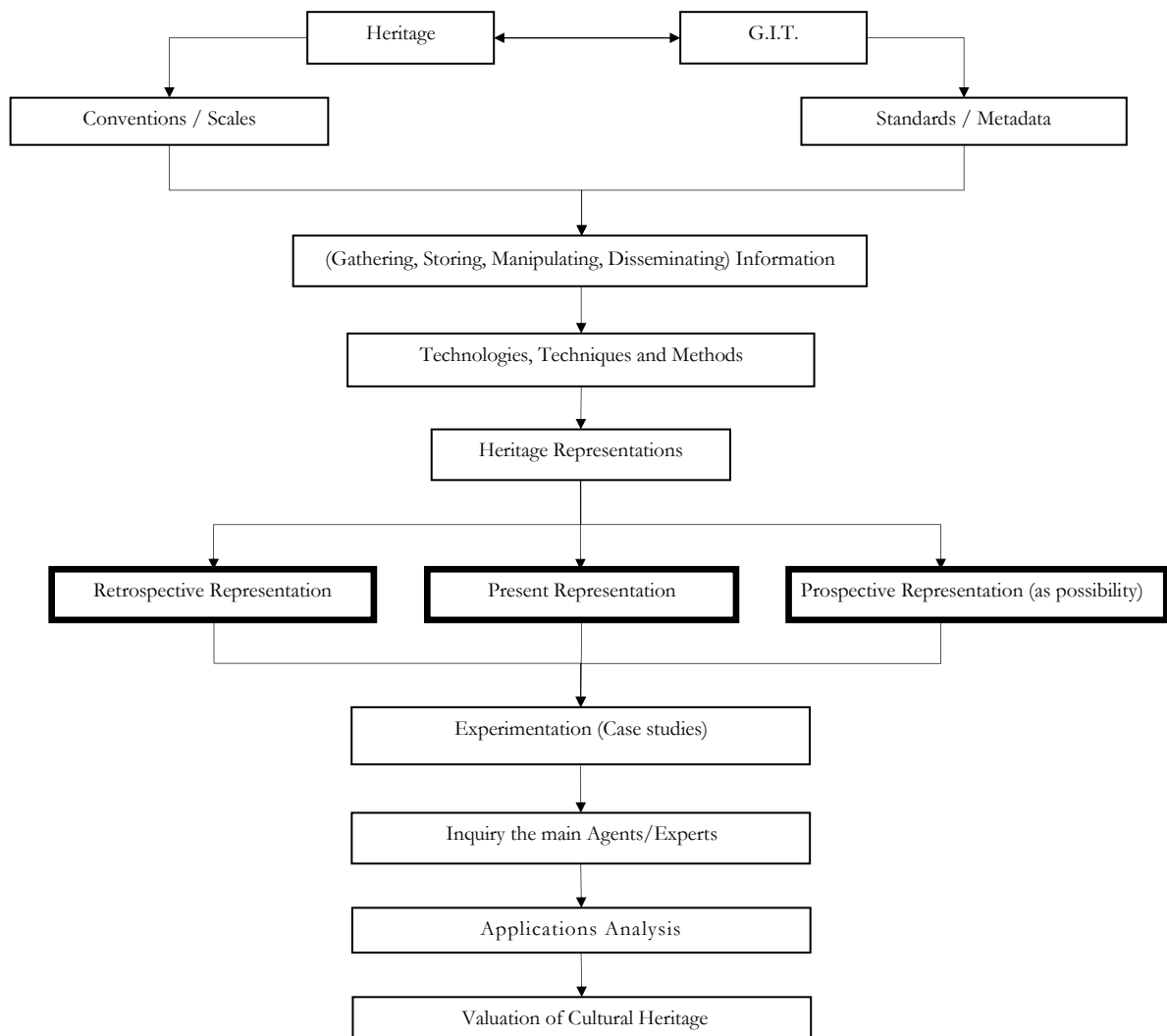


Fig. 2 – Thesis general workflow.

The methodology was supported by 2D/3D and 4D case studies implemented using digital representations of cultural heritage.

| | Heritage Representations | 2D | 3D | 4D |
|---|--|--|---|---|
| ↑ Primary Sources / Secondary Sources ↓ | GIS (producing, processing, managing, storing, visualising) | 2D Cartography Raster/Vector (point, line, polygon) | Raster/Vector (Modelling) 3D Cartography | Historical/ Ancient Cartography Present Cartography Project Cartography |
| | Geobrowser (Visualising GI) | 2D Cartography | 3D Cartography | Historical/ Ancient Cartography Present Cartography Project Cartography |
| | GPS (gathering GI or searching, requesting, identifying objects) | X/Y | X/Y/Z | X/Y/Z + T |
| | WMS (researching/ Visualising/ disseminating GI) | 2D Cartography Raster/Vector (point, line, polygon) | Raster/Vector (Modelling) 3D Cartography | Historical/ Ancient Cartography Present Cartography Project Cartography |
| | Remote Sensing (gathering, visualising GI) | Satellite Imagery UAV | 3D point clouds (terrestrial, aerial, satellite) LiDAR | 2D/3D data at different moments |
| | Mobile APP (Virtual / Augmented Reality: visualising, searching, identifying from GI) | 2D Cartography Raster/Vector | Raster/Vector (Modelling) 3D Cartography | Historical/ Ancient Objects/Cartography Present Objects/Cartography Project Objects/Cartography |

Table 1 – Heritage Representations in 2D, 3D, 4D.

Heritage Representations in 2D, 3D, 4D

After developing the case study experimentations and creating a survey oriented to the main interested agent/expert groups identified (technicians, general public, opinion/decision makers, promoters, stakeholders, others), it is intended to detect and typify groups of identical (collective) answers and analyse their perspectives on the digital heritage representations and possible/adequate applications. Considering the case study experimentations, the perspectives of the agents/experts and the contributions to the different domains, our intention was to recognize the valuation of cultural heritage through digital representations based on GIT.

Chapter I

Digital Representations

Chapter I – Digital Representations

1. Representations

1.1. Awareness of the Concept of Representation

The etymological origins of the term “representation” indicates making present again (re-presentation). Generally, it means making something present which is not (Pitkin, 1967); or, to be more precise, to make something present which presently is absent (Ankersmit, 2012). A representation is a likeness or simulation of a certain idea, concept, or purpose. It can be considered as a sign or configuration of signs, characters or objects that can stand for something else (to symbolize, provide an idea or to represent). Some representations may be more detailed and express meaning in a very direct way, while others can be more abstract (Rapp & Kurby, 2008).

According to Plato’s “Allegory of the Cave”, representations create worlds of illusion⁴ leading one away from the “real things”. For Aristotle, representation becomes Man’s way of being in the world and his method of learning. Unlike Plato, Aristotle seems to view representation as a medium or channel through which Man gets to “the real”. To Stuart Hall (1997), representation involves understanding how language and systems of knowledge production work together to create and disseminate meanings. Representation becomes the process or channel or medium through which these meanings are both

⁴ Illusions occur when something is unlike how we perceive it to be. As well as being prey to illusions, we can also have hallucinations in which there is nothing actually there to perceive at all. (O’Brien, 2007, Available at URL: <http://www.iep.utm.edu/perc-obj/>, February, 2016).

created and reified⁵. Piaget (1951) *in* Golledge (1999) made a distinction between “representation” in the sense of knowledge (conceptual representation or cognitive representation) and in the sense of re-presentation of absent realities (symbolic representation).

Representations of the past and future only make sense while placed in the present (Ethington, 2007). However, Johnson & Sherman (1990) problematize the categories of time *past*, *present* and *future* by opposition to *before* and *after*, discussing the assumption that if there is a present, how long is it. These authors also refer that there are important differences about the past and future considering construction, reconstruction, and constraints. It would appear that the future can only be constructed and shaped rather than reconstructed, considering that, the future is still to occur. The past can be either constructed and shaped in the present without distortion or, on the contrary, it can be distorted or reconstructed. A veridical representation of the past or future intent to depict the entire universe of possibilities, appropriately weighted for corresponding probabilities. Nevertheless, the already-happened past, as remembered, consists only of possibilities because of the uncertainty of the past. Thus, it is tempting to perceive the future as open as the past.

Zhang & Norman (1994) *in* Khatri *et al.* (2006:6) propose that “distributed cognition that asserts that tasks require processing of information distributed across internal minds and external representation”. *Internal representations* are associated with the mind, while *external representations* with the physical environment (Khatri *et al.*, 2006). To provide inputs and stimuli to the internal mind, external representations determine cognitive behaviour. The external representations are the shapes and location of the signs, the spatial relations (among others), which can be perceived from the environment (Zhang & Norman, 1995 *in*

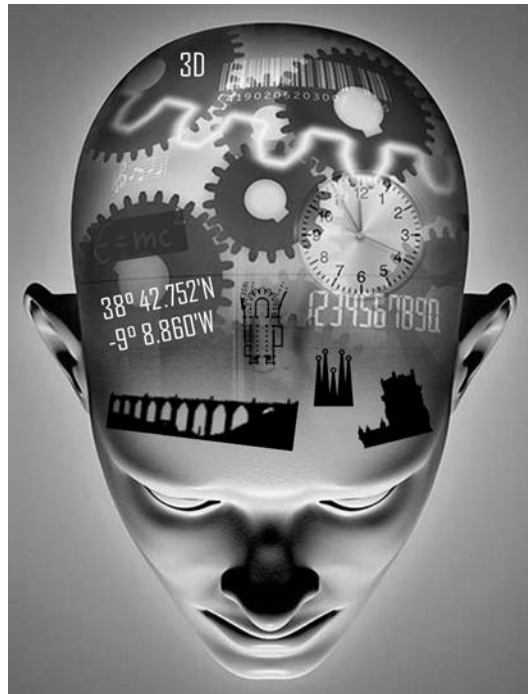


Fig. 3 – Internal representations of the physical environment.

⁵ Available at URL: <http://csmt.uchicago.edu/glossary2004/representation.htm> (June, 2013).

Zhang, 2000). To perform this operation, individuals need to process external representations interlinked with information retrieved from internal representations in a dynamic way (Zhang, 2000). The effectiveness of external representation is influenced by how it supports cognitive perceptions (Hahn & Kim, 1999 *in* Khatri *et al.*, 2006).

Perceptions capture an extensive range of sensory variations having a huge epistemological importance and being at the very source of all human empirical knowledge. Our thoughts, especially those that express or involve propositions, are considered and distinguished from one another depending on various facts that involve concepts and our understating of them. Those concepts can be understood by different agents, so it seems that the very same principle can be represented in many different minds at once (Earl, 2007⁶).

The concept of representation has an important place in scientific theorizing about the mind (Roth, 2010). Zhang (2000:1) refers that “knowledge representation is a fundamental issue in cognitive science. It is impossible to imagine a cognitive system in which representations do not play a central role”. A wide variety of cognitive and perceptual capacities is clarified in terms of the occurrence and processing of mental representations (Roth, 2010). However, representations have a huge diversity of different, nonetheless identifiable, meanings depending on the circumstances, applications, and contexts (Pitkin, 1967; Scaife & Rogers, 1996).

The following terms are examples of these complex systems of representation, related theories and concepts⁷:

- Perceptions, which lie at the base of all our empirical knowledge, acquire much of what we know about the world through testimony using our five senses: sight, hearing, touch, taste, and smell. This is true even if originally such knowledge relies on the world having been perceived by others, through representations;
- Illusions, that occur when the world is not how we perceive it⁸;
- Concepts, as they are immanent in the mind as particular mental representations of some category or other;

⁶ available at URL: <http://www.iep.utm.edu/epis-per/> (February, 2016).

⁷ *In* Berendt *et al.* (1998).

⁸ E.g., when a stick is partially submerged in water, it looks bent when it is actually straight.

- Consciousness, similarly a mental state is conscious by virtue of standing in a representational relation to a higher-order thought, or in other words, it is not intrinsic to their nature⁹;
- Intelligence, which might shape the capacity to think extensively and well, involving suitable conceptions centrally, true representations and correct reasoning;
- Description, which triggers the experience of mental imagery, is some sort of representation that is explanatory or linguistic;
- Language, as a discourse representation language: usually our thoughts are structured just like as sentences, following the same sorts of grammatical rules that spoken languages;
- Symbolic, as while it is a standing for something and not the same as descriptive representation;
- Imaginary, as our representations underlying the experience of imagery in mental cognition;
- Pictorial, which underlies the experience of mental imagery, is some sort of representation.

The previous list could continue, considering the notions of the related subjects, such as: Exemplify, Express, Serve, Comprise, Constitute, Typify, Correspond, Describe, Demonstrate, Present, Act, and Interpret. In this approach and regarding a branch of the broader sense of the representation concept, spatial representations can also include an assortment of terms, such as¹⁰: Abstract Maps (Hernandez, 1991); Cognitive Maps, Representations, Configurations, Images, Schemata, Space, and Systems (Tolman, 1948; Downs & Stea, 1973; Golledge, 1978; Lloyd, 1982; Lee, 1968; Montello, 1989; Canter, 1977); Conceptual Representations (Stea, 1969); Configural or Layout Representations (Golledge, 1969; Kirasic, 1991); Environmental Images (Lynch, 1960); Imaginary Maps (Trowbridge, 1913); Mental Images, Maps, and Representations (Pocock, 1973; Gould, 1966; Gale, 1982); Orientating and Place Schemata (Neisser, 1976; Lee, 1968); Survey Representations (Downs & Stea, 1973); Topological Representations, and Schemata

⁹ For example, if someone began to address you using a nickname, no intrinsic feature of who you are would change, but you would now be represented in a new way (Droege, 2005, available at URL: <http://www.iep.utm.edu/consc-hi/>, February 2016).

¹⁰ In Berendt *et al.* (1998).

(Shemyakin, 1962; Griffin, 1948); World Graphs and Cognitive Atlases (Lieblich & Arbib, 1982). These expressions can be found in the literature that discusses spatial cognition and spatial representations. 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 provided by the properties of the underlying mental structures and processes for spatial cognition (Berendt *et al.*, 1998). For example, the classification and cartographic representations of the evolution of land use and occupation are very relevant for the quantitative analysis and studies of urban and peri-urban growth (Tenedório, 1998).

Concerning images, Gubern (1996) refers that the uniqueness of the iconic image is that it is a representation that is presented to the viewer in two simultaneous ways, transitive and reflexive: transitive because it represents something with its shapes and colours, and reflective because it represents itself signifying something, which is what semioticians have recently denominate as the double reality of images. The iconic image is a perceptual and cognitive (representational) category that conveys information about the world perceived visually in a way that is encoded by each human culture as iconic expression. Therefore, iconic image is a visual communication form that represents a physical environment or a fragment, or a mental reproduction, or a combination of both (in space and time)¹¹.

1.2. (Internal/External) Representations and Spatial Processes

Nadel, 1999 (*in* Golledge, 1999) suggests that the brain structure is the core of an extensive neural system sub-serving the representation and the use of information about the spatial environment. The *hippocampus* is the part of the brain responsible for spatial memory/navigation and therefore critical for mapping, forming and storing information on the external environment. The hippocampal system depends on exploration as its means of gathering critical information to the formation of specific spatial representations. The existence of an area in the PIVC – *Parieto-Insular Vestibular Cortex* (involved in the processing of multisensory and particularly vestibular cues about head motion in space) is

¹¹ Gubern (1996).

probably the essential station in the transition of *vestibular information*¹² from the nuclei (vestibular), over the sensory *thalamus*¹³, to the cortical areas involved in the elaboration of spatial cues. This data (i.e. head direction) reaches the hippocampus, after receiving visual environmental information from the *parietal cortex*¹⁴, contributing to the reconstruction at this level of spatial localization and orientation. The brain has at least two main pathways that seem to carry vestibular information: the PIVC route, which codes angular head rotation in many planes; and the head direction system, which codes static head route in all horizontal directions. A specific discrepancy of head direction leads to a deficit in the ability to store direction and lead, in the absence of vision or in the presence of conflicting visual cues, to an insufficient evaluation of direction. Although the hippocampus is not necessarily the only area involved in spatial memory, damages to the hippocampus system invariably impairs the ability of humans and animals to learn, remember, represent and navigate through environments, while neurons in this system organize data for location, direction and distance, thereby providing elements needed for mapping system (Berthoz *et al.*, 1999 in Golledge, 1999). However, these disorders can also be attenuated after active rehabilitation (e.g. through optokinetic stimulation).

Cognition includes mental (internal) structures and processes involved in perception, attention, thinking and reasoning, learning, memory, linguistic and non-linguistic communication (and the role of emotion as a growing research field). However, it also contains external symbolic structures and processes (such as maps or the written procedures for carrying out a formal spatial analysis), which assist internal cognition (Montello, 2009). Mental or cognitive representations are not directly observable and often do not represent space exhaustively. Like external maps (or any kind of representation), internal maps only represent some aspects of the represented space and sometimes are distorted or even inconsistent (Berendt *et al.*, 1998).

Spatial cognition is essential to an extensive variety of human daily activities, such as reaching for an object or finding the way home. To accomplish such tasks successfully, our cognitive system registers and integrates relevant aspects of the available spatial

¹² The vestibular system contributes to a wide range of functions, from postural and oculomotor reflexes to spatial representation and cognition. Vestibular signals are important to maintain an internal, updated representation of the body position and movement in space (Péruch *et al.*, 2011, available at URL: <http://www.sciencedirect.com/science/article/pii/S0028393211003617> April, 2014).

¹³ Its function includes relaying sensation, spatial sense and motor signals to the cerebral cortex, along with the regulation of consciousness, sleep and alertness (available at Princeton University at URL: <https://www.princeton.edu/~achaney/tmve/wiki100k/docs/Thalamus.html> , April, 2014).

¹⁴ It consists of several prominent anatomical regions in the posterior part of the human brain; although very heterogeneous stimuli and tasks activate parietal brain regions, a large body of empirical evidence shows a particular role of the posterior parietal cortex in spatial cognition (Sack, 2009, available at URL: <http://www.sciencedirect.com/science/article/pii/S0166432809001582> April, 2014).

information, while also retrieving previously acquired and stored information from short-term and long-term memory (Gehrke & Hommel, 1998 *in* Freksa *et al.*, 1998). The notion of representation is central in Spatial Cognition studies. Understanding and modelling people's representations and construction of the world is a difficult challenge for cognitive science (Lovett *et al.*, 2008 *in* Freksa *et al.*, 2008). A number of perceptual and cognitive processes are involved in establishing mental representations, such as maps (Tversky *in* Freksa *et al.*, 2008).

Tolman (1948) introduced the notion of *Cognitive Map*, showing (in a set of experiments conducted during the 1930s and 1940s) that animals and humans have the capability to construct in their minds a representation of the external extended environment they experience (Portugali, 1996 and 2011). The term cognitive map is used to refer to the internal spatial representation of environmental information, while spatial representation might be regarded as the organization of components of spatial knowledge, metaphorically involving an “as if” quality, particularly when referring to purported *Maplike* properties of representation (Golledge, 1999). According to Kaplan (1973) *in* O'Keefe & Nadel (1978), Cognitive Map is a concept that has been proposed to explain how individuals recognize the physical world. It assumes that people store information about their surroundings in a simplified form and in relation to other information they already possess. The information is coded in a structure in the mind and corresponds to the environment it represents, as if an individual carried a map or model of the environment in his head. Thus, instead of a picture or image similar to what represents, a Cognitive Map is an information structure from which map-like images can be reconstructed and from which behaviour dependent on place information can be generated (O'Keefe & Nadel, 1978). Thinus-Blanc and Gaunet, 1999 (*in* Golledge, 1999) denote that “cognitive” refers to a dynamic processes and “map” to a static picture of the real world, considering that the term *Cognitive Mapping* is functionally more correct. The simplest definition of a map is the representation of a part of space. Thus, if the components of space are places, an alternative definition of a map is the representation of a set of connected places, which are systematically related to each other by a group of spatial transformation rules (O'Keefe & Nadel, 1978). Eric Chown, 1999 (*in* Golledge, 1999) indicates that the world is a complex system, which induces a necessity of higher simplicity at the internal representations level (extremely accurate is improbable). If our internal representations of space were as detailed

as the real world, their usage would be unfeasible, especially given the need to keep the amount of information at a manageable level; therefore, cognitive mapping cannot be a perfect reproduction of the real environment. Qualitative representations might ultimately be more useful and efficient than metric representations, considering frequent changes in space, and requiring less maintenance than precise ones, even if humans have the capacity to learn in detail (although much information is still possible to be missed). Allen, 1999 (*in* Golledge, 1999) reinforces this idea stating that the objective of a cognitive map is to represent a great deal of information in a flexible format with a maximum economy of effort. From a cognitive point of view, exploring the structure of maps can provide a promising access to the approach to how humans perceive, represent and interact with their spatial environment (Berendt *et al.*, 1998 *in* Freksa *et al.*, 1998).

It has been suggested that the map-like representations that support human spatial memory are fragmented into sub-maps with local reference structures, rather than existing as a global unit. However, the principles underlying the organization of these “cognitive maps” are still not well-understood (Madl, 2016). Fragmentation into separate parts of an environment has also been observed in electrophysiological recordings of grid cells (Derdikman, 2010; Frank, 2000 & Moser, 2008 *in* Madl, 2016), which suggests that instead of a single “cognitive map”, there is a variety of sub-maps represented in brains (Derdikman, 2010 *in* Madl, 2016).

The cognitive mapping system allows humans and animals to define a place and locate themselves in space, remember where an object is, and define how to get from one point to another (Nadel, 1999 *in* Golledge, 1999). Spatial representations are fundamental for orientation in a given environment, contributing to the organization of gathering new incoming spatial information while exploring a familiar/new environment. Navigation involves planning travels through the environment, updating position and orientation during travel and in the event of becoming lost, reorienting and re-establishing travel toward the destination. Spatial orientation naturally requires cognitive maps (Etienne, 1999 *in* Golledge, 1999). Human navigation and wayfinding require multiple spatial representations. Long-term representations allow individuals to plan future movements, recognize previously experienced environments and identify remembered locations, even when those are obscured from view. The sensorimotor representation is thought to be used when performing body-defined actions, such as transverse obstacles and navigate

toward intermediary goal places, like landmarks, which can function as beacons. Because these behaviours typically rely on egocentrically organized actions, the navigator must be able to identify outstanding features of the surrounding environment and match those features to the same features in long-term spatial memory, which is particularly evident when attempting to reorient after becoming lost (Kelly & McNamara, 2008 *in* Fesksa *et al.* 2008).

Self-movement occurs in different ways that result in different types of (1) *afferent* (arrival) and (2) *efferent* (exit) information: the first concerns the feedback from a recently produced act and the second concerns the feed-forward from intended and soon-to-be-produced act. According to Gibson, 1958; Lee, 1978 (Rieser *in* Golledge, 1999), *exteroception* is known as the perception of the surrounding features and relations among them (including spatial relations); *proprioception* signifies the perception of the position of the individual in relation to another individual, as well as changes in their relative positions; and *exproprioception* means the perception of the individual position in relation to the surrounding environment, as well as changes in position. The awareness of dynamic spatial orientation is exproprioceptive; however, the regular performance changes when access to the environmental information is null. When traveling without multisensory data, individuals integrate their knowledge of the surroundings with the afferent (proprioceptive) or efferent motor information associated to their perception of self-movement. When walking or swimming without vision, people typically have their immediate surroundings in mind, and thus can calibrate their position in relation to their remembered surroundings. Visual inputs specify environmental flows with more precision and across a wider range of distances than other senses, constituting the primary source (visual system) of spatial information in humans (adapted from Rieser & Chown, 1999 *in* Golledge, 1999).

People perceive differently the distances between themselves and/or objects. When the observer perceives the distance between himself and one location in the environment, distances originating from the observer are known as *egocentric distances*. *Exocentric distances* are associated between two objects. While egocentric distances are judged quite accurately, observers produce substantial errors in the comparison of exocentric distances. The estimation of distances from memory is made using the mental representation of spatial information (Rothkegel *et al.*, 19998 *in* Freksa *et al.*, 1998).

There are several ways in which spatial information can be learned, where perhaps, the most natural way (by opposition to learning spatial information from texts / maps, or present spatial stimuli like photographs, multimedia and more recently: virtual or mixed environments) is by navigating through the environment (e.g. walking, driving). It is conceivable that different modes of navigation may result in different mental representations (adapted from Rothkegel *et al.*, 1998 in Freksa *et al.*, 1998).

When traveling through an environment, an individual will need to define certain types of decisions and choices. Making an incorrect judgment might result in being lost and suffer the associated psychological and physiological discomforts. Thus, the greatest amount and highest accuracy of information may be concentrated at points where choices or decisions have to be made or at locations where prime or signal-specific activities have to take place (Golledge, 1999).

The internal information of a route contains information on several path segments and turns. The representation of underlying *Path Integration* is constantly updated where the traveller is continuously evaluating his current position and orientation based on travel velocity and prior estimated and stored representations of the path (Loomis, 1999 in Golledge, 1999). Path Integration (continuous integration of movement cues) or *Dead Reckoning* (deduced reckoning) is the process by which a body continuously monitors the route taken from a particular reference position so that the individual always knows the distance and direction from the reference point, which constitutes an important component of spatial wayfinding (Etienne in Golledge, 1999). Path integration or dead reckoning is the constant update of the Egocentric coordinates of the initial position based on instant displacement and rotation data, involving the memory of the current home-vector (initial coordinates) and not the entire path (Mallot *et al.*, 1998 in Freksa *et al.*, 1998). Even in the absence of environmental cues, humans can maintain a sense of spatial orientation through path integration, updating perceived self-location and orientation using internal motion cues, such as Vestibular and Proprioceptive, and external motion cues, such as optic flow, integrating those motion signals over time to estimate self-location and



Fig. 4 – Spatial cognition decision process.

orientation (Kelly & McNamara, 2008 *in* Fesksa *et al.* 2008). Navigation in a spatial environment requires the brain to update information stored in spatial memory about orientation and position (Berthoz, 1999 *in* Golledge, 1999). Familiar landmarks that are associated with specific places are most appropriate to help the individual return to particular locations (the association Landmark-place may be based in Dead Reckoning). The recognition of landmarks near the destination through *image matching* allows the establishment of an accurate retinotopic correspondence between the actually perceived landmarks and their memorized snapshot. Once accurate image matching is achieved, the subject only needs to turn or advance in order to reach the goal. The learning process for identifying particular landmarks automatically implies the association of these landmarks with specific places (Etienne, 1999 *in* Golledge, 1999).

Etienne, Mauer, Georgakopoulos, Griffin & Loomis, 1999 (*in* Golledge, 1999) suggest that dead reckoning (which does not involve learning an environment) seems more prevailing in nonhumans, whereas landmark-guided movement may be more dominant in humans. According to Etienne, 1999 (*in* Golledge, 1999), some animals may have a simple cognitive map that helps their memory in terms of routes and places (sources of food). Insects reveal an important association with landmarks in their movement behaviour, which must therefore be represented in their memory. Wiltschko, 1999 (*in* Golledge, 1999) indicates that compass orientation is the basic element in avian navigation and orientation. Birds face orientation in the following behavioural contexts: returning home, nesting, and migration. Birds must establish contact with their goal indirectly via external references in their long travels: such as magnetic compass (geomagnetic fields) and celestial cues (sun and other stars). When such birds were displaced in a distorted magnetic field, they were no longer orientated (Golledge, 1999). Some similarities in storing and processing information give credit to the existence of different types of routes and grid cognitive maps in birds as in humans. The process of dead reckoning plays a significant role in spatial representation and wayfinding across the entire animal kingdom. However, whereas spatial representation may be universal, cognitive maps may develop only in a limited number of species.

Some individuals within their kind have better orientation than others. A successful wayfinding is reflected in the traveller's ability to achieve a specific destination within the confines of pertinent spatial or temporal constraints and despite uncertainty. The examination of the main differences focuses on the attributes and abilities exhibited by

humans and other species, adapted to environmental demands. Individuals may differ in their success over an orientation task because they use different means, for example Path Integration versus landmark-based navigation, or differ in their ability to apply a particularly resource (Allen, 1999 *in* Golledge, 1999). The recognition of objects in different perspectives and orientations appears intact in amnesic patients though it is disturbed by parietal lesions. The correlation between generalized memory defects and deficits in geographic orientation is an indication of the form of spatial representation we assign to the hippocampus (O'Keefe & Nadel, 1978). The lack of early visual experience affects the representation of spatial environment. Early blind individuals were less successful than late blind or blindfolded subjects performing tasks that require a mental manipulation or reorganization of spatial information (such as shortcuts), being unable to construct an accurate spatial representation as non-visually impaired people would be able to do. Vision is recognized to be the spatial sense *par excellence*; however, blind or visually impaired humans can become competent independent travellers using simple cognitive processes (Golledge, 1999). Infants learn about their dynamic spatial orientation while walking or moving without vision, which indicates that the navigational basic system comes early in life. The increasing precision in orientation with growing age indicates that the system is updated to take growth into account (Rieser, 1999 *in* Golledge, 1999).

Locomotion and wayfinding constitute fundamental tasks of the human existence, where a momentary disorientation and lack of recognition of immediate surrounds generate an uncomfortable sensation of being lost. This state occurs when the wayfinding process that is used to guide travel fails (Golledge, 1999). Spatial cognition research frequently decomposes navigation into locomotion (perceptually guided movement through one's immediate surrounds - walking through and avoiding obstacles) and wayfinding (route selection between distant locations). When attempting to understand how an individual uses and remembers a city, wayfinding behaviour is of particular interest (Dara-Abrams, 2008 *in* Freksa *et al.*, 2008). Internal spatial representations in humans are imperfect and susceptible to error, providing distortions or fragmentations (Baird *et al.*, 1992; Casey, 1978, Garling *et al.*, 1979, 1981, 1984, 1985, 1986; Golledge, 1987, Lloyd & Heivly, 1987; Presson *et al.*, 1989; Tversky, 1981; Warren & Scott, 1993 *in* Golledge, 1999). Wayfinding errors can take a large variety of forms, including temporary or permanent damage of multisensory system; incorrect sense of velocity, time or distance (under- or over-estimation); encoding

and decoding errors (due to incorrect perception or implementation of spatial relations); or improper internal manipulation (such as perspective changes or incorrectly integrating routes to produce configurational information). Navigation is one of the most important requirements for human existence, even if their cognitive mapping is imprecise, incomplete, inaccurate, and based on fragments or sketches of the external environment. However, internal representations are usually sufficient for anthropological needs (adapted from Golledge, 1999). The majority of human navigation is made in familiar (or partly familiar) environments, so humans tend to use cognitively stored and recalled information, although a variety of guidance instruments and materials are available. When individuals are in a new environment they will tend to use information provided by other individuals and tools that aid in wayfinding (such as descriptions, images, signs, maps or 2D/3D models). The use of external references greatly enhances the accuracy of the measurement and estimation of direction and distance. This process involves the ability to match these instruments and understand the symbols commonly used to represent real world features. Human self-guiding competence is frequently good in terms of interpretation and wayfinding ability in space. The majority of spatial knowledge of individuals and societies is represented in map form, especially when dealing with wayfinding, which appears to be a fundamental component of explanatory schemas (Golledge, 1999). The knowledge gained from maps frequently differs from similar information gained through locomotor experience (Allen, 1999 *in* Golledge, 1999). *Route knowledge* is characterized by the information of sequential locations without the awareness of general interrelationships and is acquired by navigating through the environment. *Configurational knowledge* is characterized by the ability to generalize beyond learned routes and locate objects within a general frame of reference. *Survey knowledge* is easy to obtain when looking at a map, which provides an overview of a space that normally is too large to be seen at once (Mecklenbräuker *et al.*, 1998 *in* Freksa *et al.*, 1998).

Cartography embraces the absolute and relative locations of places, features and spatial relations, summarizing the physical reality (containing the fundamental references for interpretation, such as representation reference, orientation, scale, symbols, and legend). *Semiotics* is the general theory of representation and it can be defined as a theory of signs and signification that examines communication by means of organized signification systems. To use maps as communication media, the components are linked by the semiotic

code shared by the people that have generated it and the ones that use the map (Berendt *et al.*, 1998 in Freksa *et al.*, 1998). An *aspect map* is a spatial organization structure that represents one or more characteristics of geographic entities (properties and relations between elements). Thus, any cartographic representation can be considered an aspect map, even if it includes only a few aspects and which restrict interpretations (Berendt *et al.*, 1998 in Freksa *et al.*, 1998). *Strip maps* are segments of a route (that does not need scale, orientation or reference), considered perhaps as the simplest way for humans to represent an itinerary internally or externally and together with *sketch maps* and verbal descriptions have existed for thousands of years (Bell, 1995; MacEachren, 1986 in Golledge, 1999).

A traveller's unfamiliar background (e.g. visiting a city for the first time) is usually learned by navigating through the new environment. This implies that the spatial awareness will not be seen as a whole, but as different objects or landmarks learned in a certain order. The knowledge of a new place acquired from a map, on the other hand, allows the direct retrieval of spatial relations between objects (without reference to the routes connecting them). As the acquisition of data and the information itself are different in the case of route learning or map learning, there are different sequences of learning objects in a spatial configuration. As one travels becomes more familiar with the place and intersection points, multiple routes may be identified (Rothkegel *et al.*, in Freksa *et al.*, 1998). Urban areas are more frequently visited by individuals who are there for the first time or occasional self-driving travellers in a strange place, guiding deliberation processes involved in making decisions under uncertainty. In most cases, the trip has been pre-planned, and deviations from the previously planned routes of non-recurring obstacles are very common or gaps between the cognitive network and the faced situation, which encourages the subject to look for strengthening cues, usually by matching elements in the mind to elements in the environment¹⁵ (Stern & Portugali, 1999 in Golledge, 1999). Urban navigation includes a wider level of information and cues available in the sequential process of decision making concerning route choice (behaviour), matching internal to external information while moving between a predefined origin and destination. To become completely lost is perhaps a rather rare experience for most people in the modern city. Individuals are supported by the presence of others and by special wayfinding devices: maps, street numbers, route signs, or information placards (Lynch, 1960).

¹⁵ In other words, Landmarks.

Lynch (1960) focuses on the image of that city which is held by its citizens, concentrating especially on one particular visual quality: the apparent clarity or “*legibility*” of the urban systems. Environmental images are the result of a two-way process between observers and their environment, with great adaptability and in light of their own purposes, selecting, organizing and endowing with meaning to what they perceive. An environmental image may be analysed into three components: *identity* (implies its distinction from other things, with the meaning of individuality), *structure* (must include the spatial or pattern relation of the object with the observer and with other objects), and *meaning* (must have some meaning for the observer, whether practical or emotional). The map (or representation), whether accurate or not, must be good enough for navigation, being sufficiently clear and well integrated to minimize mental effort (the map must be readable). The relation between the physical qualities and the identity and structure attributes in the mental image lead to the definition of what might be called *imageability*: that quality in a physical object which gives it a high probability of evoking a strong image in any given observer.

Through the individual’s perception or cognitive mapping of the spatial structure of the urban systems, the author identified five key elements:

- Districts are “medium-to-large sections of the city”. They are typically held together by some commonality (the individuals often enter or pass through and recognize something common and identifiable). According to Lynch, most people use this concept to define the broader structure of their city.

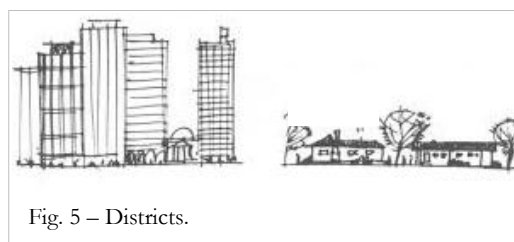


Fig. 5 – Districts.

- Edges provide the boundaries that separate one region from another, the seams that join two regions together, or the barriers that close one region from another. They are linear elements, but are not the paths along which the individual experiences the built environment. They

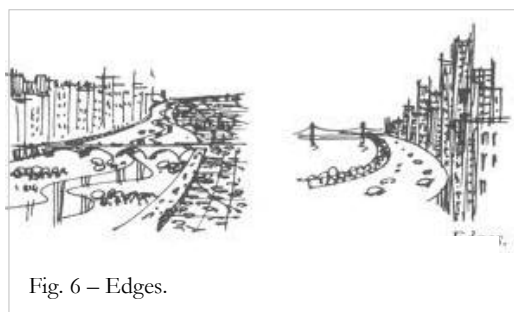


Fig. 6 – Edges.

can be physical edges such as shorelines, walls, railroad cuts, linear interruptions in continuity, or edges of development. Edges can be less well-defined barriers that keep regions isolated from other regions or connection fronts, where regions communicate and meet.

- Paths consist of the “channels along which the observer customarily, occasionally, or potentially moves”. These can include streets, paths, transit routes, or any other defined path of movement. It is important to note that

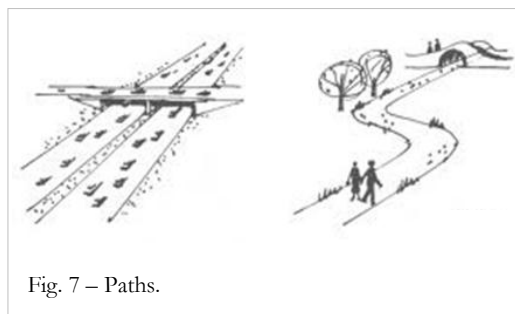


Fig. 7 – Paths.

the paths an individual identifies may not correspond to a traditional street network. These are often the most predominant items in an individual’s mental map as this is main mechanism to experience a city.

- Nodes are strategic points within the city in which the individual enters (constituting often the main focal point where the subject is traveling to/from). They are essentially junctions (crossing or converging paths), transport

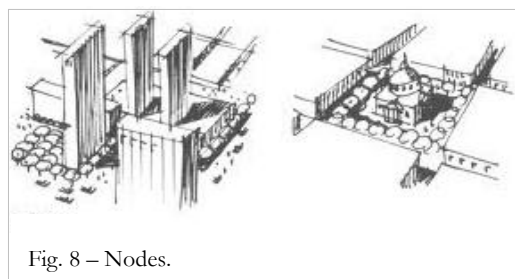


Fig. 8 – Nodes.

interruptions or changes in urban structure, serving an important physical function (e.g. agglomeration, dispersion) and individual perception (e.g. awareness and decision). In many cases, the nodes are the centres of the district (e.g. plaza area) and are often a popular meeting point.

- Landmarks are also a point-reference (similar to nodes). However, unlike nodes, which the individual enters during his travels, landmarks remain external features to the individual. They are often

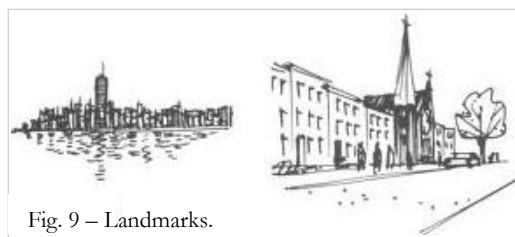


Fig. 9 – Landmarks.

distinct or evident physical structures such as a building (e.g. tower, dome,

church), geographic features (e.g. mountain) or a sign. The range of landmarks is extensive (they can be distant), but the commonality is that they are used by the individual to better understand and navigate in that environment.

Lynch (1960) refers that none of these type-elements exists isolated from reality and they constantly stand out and interconnect. The districts contain nodes in their structure, which is limited by edges, crossed by pathways, and includes landmarks. Chown, 1999 (*in* Golledge, 1999) indicates that landmarks are unique objects that are worth learning about, because they are not easily confused with other elements of the environment. Landmarks are so important for navigation and spatial cognition, that humans have developed a highly efficient object recognition system that comprises visual pathways. Distinguishing a familiar landmark is sufficient to make the difference between being lost and knowing where we are.

Understanding the 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 of inter-relations, all these contribute to build a wider satisfactory physical environment for everyone (Lynch, 1960). According to Golledge & Stimson (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' intuitive guidelines and legal restrictions (Gärling & Golledge, 1997 *in* Golledge & Stimson, 1997). 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).

Portugali (2011) states that Lynch's (1960) relation to cognitive mapping studies has been neglected, focusing and forging a link to Lynch's original study, considering the role of external representations in the overall process of cognitive mapping. Lynch's elements (landmarks, paths, edges, districts, and nodes) have geometry, however what makes such

elements is not their geometry and external appearance, but the meaning attached to them or their semantic form. The author approached the study of the city from three perspectives: Shannon's information theory¹⁶ (Shannon & Weaver, 1949); Haken's (1988/2000) study on Information and Self-Organization¹⁷ with his notion of semantic information¹⁸; and introduced SIRN (Synergetic Inter-Representation Networks)¹⁹, which emphasize the role of external representations in the process of cognitive mapping. Considering cities, the author includes, in addition to Lynch's elements, all the buildings, roads, parks, as well as their various configurations (piazzas, neighbourhoods or the city as a whole), also arguing that some elements transmit more information than others and are therefore more significant in making the city legible. In a landscape (or any set of geographical objects) where all objects are different, it is possible to compress information by means of categorization and indices, so such objects then become elements in Lynch's sense. While in social theory representation refers to external representation (e.g. society or economy), in studies of cognitive science and mapping it refers to internal representation. According to this view, a cognitive map of a city is an internal representation in the mind of individuals' experiences in the city, the information they have accumulated on it by means of these experiences, as well as by other means. Portugali suggest between information theory and processes of categorization in the city to issues such as systematic distortions in cognitive mapping, spatial learning and wayfinding behaviour; the relationship between our theorization of the face of the city and urban dynamics or the possibility of integrating information measures into Geographical Information Systems (GIS).

The inherent mobility of humans and the fact that objects are necessary distributed over space may argue that the primary purpose of a cognitive map is to facilitate place recognition and wayfinding; however, a second purpose is to act as an organizer of spatial experiences (if not more). The configurational properties of cognitive maps can consist in combinations of places and locations (points); routes, paths, and tracks (lines); regions and districts (areas). Places and locations form spatial distributions; paths, tracks, and roadways

¹⁶ The relevant entities in the process are the sender, the message, the channel, and the receiver(s) or processing operations of compressing, reliably storing and communicating data. Shannonian's information is independent from meaning.

¹⁷ As self-organizing systems, the author refers complex urban dynamics, which makes its impact on the city as a whole unpredictable and uncontrollable and its parts are so numerous that there is no technical way to determine causal relations between them and form a complex network of interaction, with feed-forward and feedback loops, which makes the determination of causal relations in essence impossible.

¹⁸ Semantic information refers to meaning and is thus dependent on the receiver.

¹⁹ As presented, it suggests that many cognitive processes and tasks evolve as an interaction between internal and external representations that emerge in the process.

form networks; landmarks and nodes form hierarchies. These, combined, represent the structure of spatial knowledge (Golledge, 1999). These associations resemble the five elements referred by Lynch organized into three categories: points (nodes and landmarks), lines (paths, edges) and polygons (districts), especially if represented in a cartographic map. These facts allow us to understand and develop, in computer science, new approaches concerning simulations or representations of the real world in a digital format.

2. Digital Representations Approach

Technology plays an important role in the operationalization of the concept of digital representations. 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).

Zhang (1997, 2001) *in* Khatri *et al.*, (2006:6) argues that “Most work in cognition assumes that the mind has mental representations analogous to computer data structures”. As in cognitive mapping, in GIS, physical objects are usually associated with geometry and position. Geometry represents the shape and size of an object, usually represented by a *point*, a *line*, or a *polygon*. (David, Herrewegen & Salge, 1996 *in* Khatri *et al.*, 2006). The position in space is based on coordinates (x, y, z) in a defined reference system (e.g. Cartesian or Geographic). In geography, space is commonly associated with time (Parkes & Thrift, 1996 *in* Khatri *et al.*, 2006), which increases the interest in adding a temporal dimension to geographic information (Goodchild, 1997 *in* Khatri *et al.*, 2006).

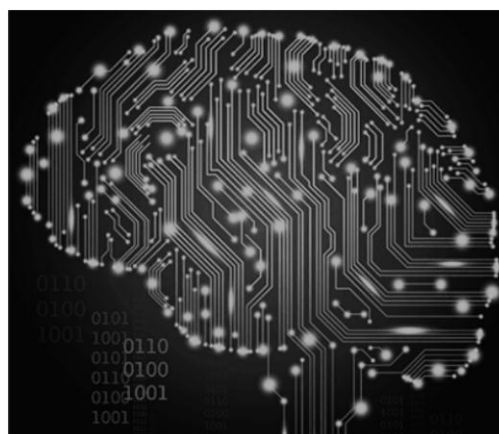


Fig. 10 – Digital Representations.

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. We can add natural or cultural features and structural changes to the topography and lighting conditions. Once we have created our model, we can run any number of experiments with empirical results that can be measured, compared, and recreated by the scientific community (adapted from Eve, 2012). Thus, geographic information has the ability to add the spatial reference to a certain part of the earth surface or nearby, in other words, to represent the spatial environment, in a certain way digitally augmenting the real world.

According to Engel *et al.* (2005:182), “the construction of mental images and mental image-based reasoning can be seen as rather extreme cases in which a plethora of analogies between mental and external representations can be drawn”. These authors refer that these analogies created intense discussions in the scientific community about the representational format of the mental representations. Moreover, the introduction of metaphors has led to an increase in knowledge in various lines of research. Metaphor and analogy are among the challenging problems posed in the field of knowledge representation (Way, 1991). They are so pervasive in everyday dialogue that we are rarely aware of their existence. Analogy can be considered as mapping or isomorphism between entities and relationships of systems. Metaphor is important in moving away from known and familiar concepts or ideas to new and unknown ones. It is a method frequently used for assimilating new knowledge. Carroll & Mack *in* Way (1991:8) claim “Metaphors can facilitate active learning in this situation by providing clues for abductive and adductive inferences through which learners construct procedural knowledge of the computer”. The importance of metaphor for learning justifies the seriousness that the field of *Artificial Intelligence* has dedicated to the subject. Metaphor goes far beyond the scope of single words, and does not always involve similarities between two things (Way, 1991).

Barkowsky (2001, 2002) & Engel *et al.* (2005) present some metaphors and their respective authors for spatial mental knowledge processing: Cognitive Maps (Tolman, 1948); Spatial Images (Lynch, 1960); Spatial Schemata (Lee, 1968); Environmental Images (Appleyard, 1970); Cognitive Atlases (Kuipers, 1982; Hirtle, 1998); Cognitive Collages (Tversky, 1993); Interrepresentation Networks (Portugali, 1996); and Geographic Information Systems – GIS (Hirtle, 1998). Montello & Freundschuh (1995) *in* Barkowsky (2002:22) present a list of “common cognitive and spatial terms that allow for a

combination of more than 200 metaphorical notions for mental spatial knowledge representations”. These metaphors induce theoretical approaches, helping to build models and guiding the development of hypotheses for empirical investigations (Barkowsky, 2002). Thus, it seems reasonable to seek the most appropriate metaphor when any of these questions is explored. However, different metaphors reveal diverse aspects of mental spatial knowledge representation. “None of these metaphors must be taken literally, for example, mental knowledge about geographic spaces is found to be frequently distorted, fragmentary, and incomplete” (Tversky, 1993:183). In addition, “mental representations of spatial knowledge are often organized hierarchically (Stevens & Coupe, 1978) or chunked together to form more complex structures (e.g. as visual chunks, Kosslyn & Pomerantz, 1977)”²⁰. The mental representation of spatial environment diverges from reality, eliminating from and/or adding entities (some of them inexistent) to the real world, inducing distortions and artificial structures (Engel *et al.*, 2005). Occasionally, spatial information is associated with mental representations of non-spatial information. Nevertheless, mental representations typically preserve the topological or semantic relationships (Barkowsky, 2002).

As an example of one of these metaphors, Hirtle (1998) *in* Barkowsky (2002) emphasizes specific technical representation and processing characteristics found in GIS that can be applied to the explanation of mental representations of spatial knowledge. These characteristics comprise the use of raster vs. vector-based representations in GIS, and changes of accuracy when altering representational formats. Scale and resolution techniques of data overlays used in GIS representations to account for partial representations can be refined on demand, as well as the application of the problem of data integrity in GIS to representations of spatial knowledge in the human mind. GIS can be considered as a collection of digital maps where the term map (in GIS context) should be taken as a metaphor for digital representations of geographic entities and/or environments (Berendt *et al.*, 1998 *in* Freksa *et al.* 1998). Golledge (1992) stated the common characteristics of acquiring, storing, and processing geographic knowledge in GIS and in the human mind. The cognitive map should be viewed as internalised GIS, where data are symbolized, coded, and further decoded (in both systems)²¹.

²⁰ *In* Engel *et al.* (2005:183).

²¹ *In* Golledge & Stimson (1997).

Virtual Environments (VEs), as representational reproductions of the spatial knowledge with which users can interact, are particularly valuable and frequently used in research on wayfinding. The main advantage of using VEs in research is that they allow easier changes than are possible in real, built environments (Skorupka *in* Haq *et al.*, 2008). In the last decade, the main objectives of urban studies (laboratories, research centres, public and private organizations) have been focused on artificial environment issues, with special emphasis on:

- The reliance on cognitive models as a source for agent’s behaviour and decision making;
- The intensive use of Geographical Information Technologies (GIT);
- or Virtual Environments to visualize three dimensional urban environments and simulate their evolution.

This emergent interest is strongly related to globalization and to the very rapid process of urban sprawl, also associated with the tendency to growth in high axis. The number of high-rises structures has been increasing and with them a whole complexity of urban processes has emerged and taken place in the third dimension of buildings and urban areas. Humans have a strong tendency to perceive the territory at two dimensions, and thus the third dimension has been neglected when compared to the greater importance of the first two dimensions. This 2D approach was fully justified by the need for information level reduction. In fact, the abstraction of the information about the volume has become problematic and questionable, considering the growing importance of the third dimension in cities (adapted from Portugali, 2010).

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, 2010). Steadman & Yichum Xie *in* Portugali (2010) define three forms and purposes of model visualization: *pedagogic visualization* (explicit and explicable); *exploratory visualization* (which enables the individuals to explore unanticipated outcomes); and *predictive visualization* (enabling users such as planners to engage in using the models for simulation, prediction, prescription, and control). Planning is the ability to think ahead to the future and to act ahead and Cognitive Planning is a research domain that studies planning as a basic cognitive capability of humans

(Portugali, 2011). Modelling is assumed to enable planners to understand patterns, experiment upcoming scenarios, represent current trends, and envision the impact of various plans and policies. A digital model might be a beautiful mathematical construction, or visually realistic and still constitute an incorrect representation. The principles of model building state that the more parameters you add, the less we can understand what the model is actually for and why. A good simulation model should be based on as few parameters as possible (controllable and understandable)²². Regarding modelling, GIS gives the user the option to acquire, manage and observe different data configurations, while Virtual, Augmented and Mixed Reality create Virtual Environments, within which individuals can virtually walk, drive, fly and see the world in real, past or future time (Virtual Time Travel) and/or even communicate, meet and work (creating new forms of human interaction and locational settlements, thus reducing the needs for transportation, which is represented in the virtual environment)²³.

Geographic Information Technologies (GIT) and Visualization Systems Technologies (VST) provide databases and means to perceive and understand the outcomes in a continuously growing level of high realism: global navigation satellite systems allow us to navigate with electronic aids and function as gateways between the virtual and the real world as mobile gadgets recognize their position; Remote Sensing acquires spatial information in real time or near real-time, observations, and classifications (through systematic chronological series of data); GIS stores, processes, and manages spatial data in the form of points, lines, and polygons, within a growing 3D software solution; and Virtual Environments create a parallel world within which it is possible to virtually navigate and simulate scenarios, or mixed it with the real world (in 4D). Fully integrating GIT and VST-based simulations into the visioning process makes it possible for agents in several domains to fundament their decisions (and understand them) at policy and experimental levels, achieving a faster and wider consensus (adapted from Portugali, 2010).

²² Portugali (2010).

²³ Adapted from Portugali (2010).

Chapter II

Geographic Information Technologies for Digital Representations

Chapter II - Geographic Information Technologies for Digital Representations

1. Satellite Navigation

According to Golledge (1999), the act of locomotion helps an entity to explore and exploit an environment in an adaptive manner as to satisfy their needs. A traveller must be able to “plan and perform a goal-directed act of path selection by deducing an itinerary from the memorized spatial relationships between the goal and the traveller’s current position”²⁴. The individual engaged in a wayfinding task must be able to define and choose the best alternatives according to his objective when facing unfamiliar environments. To interact successfully in the physical environment, humans need to attend selectively to items in the extra-personal world (external representations) and to those stored in their mind or internal/mental representations (Griffin & Nobre, 2003²⁵).

The position in space/time is a fundamental perceptual and inerrant task for digital representations. Perceiving the location requires information about several dimensions in space/time and the relations between objects. The position given by coordinates x, y, z (or latitude, longitude, and altitude) are the bases to measure, refer, identify, detect, locate and represent information. Thus, while representations and time can answer the essential questions “*what?*” and “*when?*” respectively, the use of coordinates as a basic and fundamental component of spatial cognition and representations answers the question “*where?*”, especially when their insertion in space is desired for both real and virtual environments and internal/external representations.

²⁴ Golledge (1999:xv).

²⁵ Available at URL: <http://cognitrn.psych.indiana.edu/busey/cegseminar/pdfs/FromAshley/internalrep.pdf> (June, 2013).

Satellite navigation systems have become an integral part of every positioning request, especially where mobility plays an important role. The principal advantage of satellite navigation is the real time positioning and time synchronization. For that reason, location services directed to wide virtual and augmented reality systems must be highlighted, considering the possibility of significant improvement of accuracy and integrity performance of (mobile) on-site digital representations²⁶. The idea that led to the development of satellite navigation systems started with the Sputnik (Satellite in Russian) artificial satellites program implemented by the former Soviet Union, more precisely with the launch of Sputnik 1 on October 4, 1957. Scientists at the Applied Physics Laboratory of Johns Hopkins University (Maryland, USA)²⁷ were monitoring the famous beeps transmitted by the passing satellite, when they noticed that the transmitted radio frequency had a characteristic curve when plotted into a graph (Doppler²⁸). The changes in the radio frequency as the satellite moved permitted them to determine the orbit of the satellite. Considering this idea in reverse, if the satellite orbit was known, Doppler shift measurements could be used to determine a certain position on Earth (Lammertsma, 2005).

Satellite-based navigation systems use triangulation to locate the user, through calculations made using information from a number of satellites. Each satellite transmits coded signals at precise intervals. Using this information, any receiver on or near the earth's surface can calculate the position of the transmitting satellite and the distance (from the transmission time delay) between the satellite and the receiver. Coordinating current signal data from four or more satellites enables the receiver to determine the position (latitude, longitude, and altitude).

²⁶ In Princeton University, available at URL: <http://www.princeton.edu/~alaink/Orf467F07/GNSS.pdf> (June, 2013).

²⁷ Available at URL: <http://www.jhuapl.edu/newscenter/pressreleases/1998/980414.asp> (June, 2013).

²⁸ *Der Doppler-Effect or Doppler Shift*, first described by the Austrian physicist Christian Doppler in 1842, explains theoretically how the relative motion of the source and the detector affects the observed frequency of light and sound waves. For example, suppose a stationary radar source emits a signal: if the target is moving toward the radar source, the number of reflected pulses received per time unit is correspondingly higher than the number of pulses emitted. Conversely, if the target is moving away from the source, the frequency of the reflected signal is lower than the frequency emitted. (Lowrie, 2007 and URL: <http://www.britannica.com/EBchecked/topic/169325/Christian-Doppler> June, 2013).

1.1. Global Navigation Satellite System (GNSS)

Global Navigation Satellite Systems (GNSS) is the generic term for space-based systems that transmit signals, which can be used to provide three services: Position, Navigation, and Timing – known collectively as PNT (The Royal Academy of Engineering, 2011). GNSS consist of four main (global) satellite technologies: GPS (North American), GLONASS (Russian Federation), Galileo (Europe), and Compass (China). The free availability and accuracy of GNSS signals, combined with the low cost receiver chipsets, have been creating abundant solutions for a very wide and growing range of applications. These include not only transport and mobility (in aviation, nautical, rail, road, cycle, walk), but also telecommunications, cartography, safety, environmental, economic and scientific surveying, monitoring, managing, and research. GNSS can be classified into different core segments/components: Space (consists in a constellation of several satellites in certain orbital planes); Ground/Control (uploading data to the satellites, synchronizing time, and tracking satellites); and User (consists in receivers and associated antennas used to decode the signal and provide PNT information). However, according to Hofmann-Wellenhoof *et al.* (2008²⁹), apart from the quality or transmission, the signal may be affected by errors at different sources and segments, such as: satellite (due to the timing of the on-board atomic clocks, an error in the transmitted location/orbit of the satellite, and/or geometry/shadow); atmospheric (in particular, the ionosphere and troposphere, which affect the signals); receiver noise (intrinsic noise within the receiver which causes uncertainty of the signal); multipath (reflection of satellite signals from the ground and other objects, causing multiple copies of the signal or expansion of the signal); or intentional degradation of satellite signals (safety purposes).

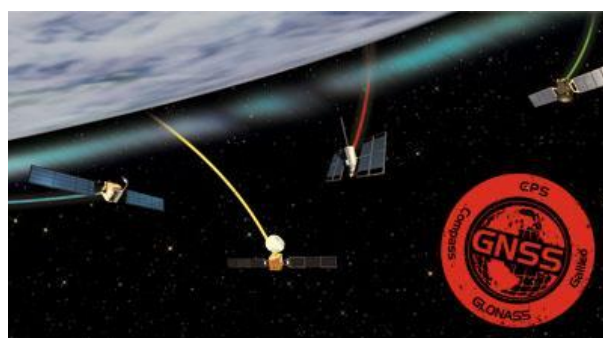


Fig. 11 – Global Navigation Satellite System (GNSS).

²⁹ Available at URL:

http://books.google.pt/books?id=Np7y43HU_m8C&pg=PA436&dq=Sources+of+error+in+GNSS&hl=en&sa=X&ei=Y1CzUe-INej17AbB1IDgBQ&ved=0CFcQ6AEwBQ#v=snippet&q=%20error%20GNSS&f=false (June, 2013).

The increasing investment and recent developments in navigation systems can be justified by several arguments (i.e. military or civilian) or the confluence of the whole, including the importance of position for different applications involving virtual and mixed environments and representations (2D, 3D, or 4D). Nevertheless, there are also increasing requirements for the acquisition of tri-dimensional information as well as the fast growing necessities of technology that relies on position systems (such as mobile system navigation, LiDAR, and other applications and systems).

1.1.1. Global Position System (GPS)

Originally called NAVSTAR (the acronym for Navigation Satellite Timing and Ranging), the Global Positioning System (GPS) was developed to provide navigation capabilities, initially as a military application (by the Department of Defence). This system consisted of a space segment of 24 satellites moving at velocities of approximately 11 300 km/h, orbiting at an approximate altitude of 20 000 km, which enables the system to circle the globe every 12 hours. The first GPS satellites were launched into space in 1978 and the system was completed in 1994 (officially becoming operational in 1995). The incorporation of solar panels into the system has allowed it to capture the sun's energy for its operation, although, alternatively, the energy may come from a battery to keep operating. These satellites also have small rockets embedded for the maintenance and correction of their orbits. Each satellite sends coded radio signals that enable receivers to determine their position (Marques, 2009). GPS is not a static system and has been updating its capacity through several generations of equipment. In June 2011, the U.S. Air Force successfully completed the system expansion known as the *Expandable 24* configuration. From the 24 slots, three were expanded and six satellites were repositioned (the extra satellites became part of the constellation baseline). As a result, GPS now operates effectively as a 27-slot constellation with improved coverage in most parts of the world³⁰.

In the 1990s decade, GPS employed a feature called Selective Availability that degraded its accuracy for civilians on a global basis and was terminated in 2000 in order to make GPS more responsive to civilian and commercial users worldwide. The accuracy of the GPS signal in space is actually the same for both civilians and the military. However,

³⁰ U.S. Government, available at URL: <http://www.gps.gov/systems/gps/space/> (June, 2013).

civil broadcasts use only one frequency, while the military uses two. This means that military users can perform *ionosphere correction*, a technique that reduces radio degradation caused by the Earth's atmosphere, providing a better accuracy³¹.

A GPS Augmentation³² is any system that benefits GPS by providing accuracy or any other improvement to positioning, navigation, and timing, which is external to the GPS itself. Some examples are: Differential GPS - widely used to improve GPS precisions, consisting in the compensation of system errors through corrections in the position of coordinates or other variables of interest; Wide Area Augmentation System (WAAS) – uses a network of ground-based reference stations to monitor GPS satellite signals, and geostationary satellites to transmit information to users; or European Geostationary Navigation Overlay Service (EGNOS) – aiming at supplementing GPS and potentially GLONASS and Galileo by providing integrity messages, corrections, and additional ranging signals (The Royal Academy of Engineering, 2011).

GPS constitutes the most used and reliable navigation system worldwide. It is presently essential to not only to locate and guide users, but also to place digital representations.

1.1.2. GLONASS

The GLONASS (*GLO*bal*N*avigation *S*atellite System), currently operated by the Russian government, complements and provides an alternative to the GPS (Marques, 2009). The development of GLONASS began in the USSR in 1976, with the full constellation completed in 1995. After the system restoration during the 2000s, it achieved full coverage of the Russian territory in 2010 and one year later of the entire globe. The space segment is composed of 24 satellites in three orbital planes. These satellites operate in circular 19 100 km orbits at an inclination of 64.8°, and each satellite completes the orbit in approximately 11 hours and 15 minutes. The location of the satellites provides continuous and global coverage of the terrestrial surface and the near-earth space. User equipment consists of receivers and processors that collect and process the GLONASS navigation signals, which allows the operative system to

³¹ U.S. Government, available at URL: <http://www.gps.gov/systems/gps/performance/accuracy/> (June, 2013).

³² U.S. Government, available at URL: <http://www.gps.gov/systems/augmentations/> (June, 2013).

calculate the coordinates, velocity, and time³³. These systems have started to be gradually integrated into current devices that need spatial positioning and acquiring x, y, z coordinates, especially as a complement to the North American GPS, both cumulatively increasing signal and precision.

1.1.3. Galileo

The Galileo³⁴ system of the European Union and ESA (still in development) is intended to interoperate with GPS and GLONASS, having launched its first experimental satellite (GIOVE-A) in 2005. The first two operational satellites from the Galileo constellation were launched in 2011 and with the additional satellites they will form a space segment constellation of 27 operational satellites plus 3 active spares (to ensure that the loss of one satellite has no discernible effect on the user). This system is expected to be fully operational by 2019 (Marques, 2009 and ESA, 2013³⁵). The Galileo constellation will be positioned in three circular Medium Earth Orbit (MEO) planes at an altitude of 23 222 km above the Earth, and at an inclination of the orbital planes of 56° to the equator. This system will provide coverage even at latitudes around 75° north, which corresponds approximately to Norway's North Cape (the northernmost part of Europe).

The Galileo Control Centres will be responsible for satellite management and perform the navigation mission's organization, using data from the sensor stations (via a redundant communication network), computing the integrity of the information, and synchronising the time signal of all the satellites with the ground station clocks. As an additional feature, these satellites are also being equipped with a transponder, which is able to transfer distress signals from the user receivers to regional rescue co-ordination centres, which will then initiate the rescue operation (and send a response signal to the user, for example, informing them that their situation has been detected and that help is on the way). This system will use the user feedback feature for the first time, which is considered a major upgrade compared with the existing systems (ESA, 2013). Thus, Galileo intends to be more focused on civilian usage, providing essential information for digital positioning

³³ Russian Institute of Space Device Engineering, 2008 (available at URL: <http://gauss.gge.unb.ca/GLONASS.ICD.pdf> June, 2013).

³⁴ In a nod to the Italian astronomer Galileo Galilei.

³⁵ European Space Agency (ESA) website at URL: http://www.esa.int/Our_Activities/Navigation/The_future_-_Galileo/What_is_Galileo (June 2013).

and contributing to the development of the acquisition and placing of digital representations in the real world.

1.1.4. BeiDou/COMPASS

BeiDou navigation system from China consists of two separate satellite constellations. The first is BeiDou-1 is composed of one experimental regional navigation system (for the Asia-Pacific area). The deployment of an experimental satellite navigation system based on the twin-satellite navigation systems started in 1994. Two satellites, BeiDou 1A and BeiDou 1B, were launched in 2000, providing position services one year later. The successful launch of BeiDou-1C (in 2003), intended to establish the BeiDou-1 system, has made it available to civilian users since 2004 (accuracy of 100m, enhanced up to 10m with differential methods)³⁶. The BeiDou-2 (or Compass) is the second-generation satellite navigation system that will be capable of providing positioning, navigation, and timing services to users worldwide. Although the upgrade of its regional navigation system towards a global solution started in 1997, it is expected to provide global navigation services only by 2020. Currently under construction, it is planned to contain 5 geostationary and 30 non-geostationary orbit satellites (27 in Medium Earth Orbit and 3 in Inclined Geosynchronous Orbit). This system was officially announced in 2011, to provide initial operational services (positioning, navigation, and timing services) for the whole Asia-Pacific region with a constellation of 10 satellites. During 2012, 5 additional satellites were launched increasing to 15 the number of satellites of the constellation³⁷.

The ground section consists of a certain number of stations, including the main control stations, the injection stations, and the monitoring stations. The user section includes terminators of the BeiDou system and some compatible with other navigation satellite system³⁸. This program has developed quite fast, revealing the importance given by the Chinese government to technology applied to mapping and positioning, with substantial investments until their full operationalization.

³⁶ ESA, available at URL: http://www.navipedia.net/index.php/Other_Regional_Systems#BeiDou-2_Phase_1 (June, 2013).

³⁷ ESA, available at URL: http://www.navipedia.net/index.php/COMPASS_General_Introduction (June, 2013).

³⁸ BeiDou, available at URL: <http://www.beidou.gov.cn/2012/12/14/201212142e8f29c30e0d464c9b34d6828706f81a.html> (June, 2013).

1.2. Regional Navigation Systems (RNS)

Beside the GNSS, several countries have shown the intention to develop their own Regional Navigation Systems (RNS). Examples of RNS are briefly described below.

The Chinese BeiDou 1 regional network will be developed to the global Compass Navigation System as referred before.

The Indian Regional Navigational Satellite System (IRNSS) is an autonomous regional satellite navigation system that is being developed by the Indian Space Research Organization (ISRO). Approved in 2006, this system consisting in Space, Ground, and User segments was completed and implemented by 2016 (with the launch of the seventh satellite 1G). The space segment will consist of a constellation of seven navigational satellites, three of which will be placed in the geostationary equatorial orbit; two satellites will be placed in the geosynchronous orbit with an inclination of 29 degrees; and two spare satellites jointly provide 7 meter-position accuracy throughout India³⁹.

The Japanese Quasi-zenith Satellite System (QZSS) space segment consisted initially of one satellite and ultimately three (or more) satellites for regional time transfer system and enhancement for GPS covering in Japan (guided to expand the positioning service provision in mountainous and urban regions in Japan⁴⁰). The satellites are in the traditional equatorial geostationary; however, they have a large orbital inclination so they do not remain in the equatorial plane. Several Tracking Control Stations are strategically positioned at locations that enable continuous monitoring and control of the QZSS (JAXA, 2013⁴¹).

The investment made in positioning systems not only in the most developed countries, but also in emerging countries, attests to the importance of relying in accurate location and the belief in their prominence in the near future applied to military or civilian purposes, constituting a useful tool for the acquisition and display of geographical information for digital representations.

³⁹ Indian Space Research Organization (ISRO), available at URL: <http://www.isro.gov.in/newsletters/contents/spaccindia/jan2012-jun2012/article5.htm> (June, 2013) and URL: <http://www.isro.gov.in/spacecraft/list-of-navigation-satellites> (May, 2017).

⁴⁰ Japan Aerospace eXploration Agency (JAXA), available at URL: http://www.jaxa.jp/projects/sat/qzss/index_e.html (June, 2013).

⁴¹ Available at URL: http://qz-vision.jaxa.jp/USE/is-qzss/DOCS/IS-QZSS_15_RH_E.pdf (June, 2013).

1.3. Cellular Networks (Assisted GNSS)

According to Hofmann-Wellenhoof *et al.* (2008), the concept of assisted GNSS (AGNSS) was conceived in the early 1980s and consists in a navigation module that interacts with a communication module (cellular networks). Depending on the availability of these different data sets, the receiver is assisted in its operation in by one or the other. Since communication channels usually have a much higher transmission rate than GNSS signals, the channel of information is conducted in a shorten period of time and consecutively consuming less time to identify and fix the user location (time needed for a GNSS receiver between power on and providing the first position information). Thus, Cellular Networks are essential for faster acquisition and accurate positioning of user location and positioning digital representations, especially concerning mobility and (in particular) devices such as smartphones (considering the communications network).

2. Remote Sensing

According to Lillesand & Kiefer (1994) *in* Marques (2009), Remote Sensing (RS) can be defined as the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a sensor that is not in contact with any of these entities being considered. Digital image processing was fundamentally initiated in the 1960s⁴², with the analysis of images obtained (mainly) from airplanes or satellites. However, it was only after the mid-1980s (with the advance of computer hardware) that there was a significant development (Jensen, 1996; Lillesand & Kiefer, 2000 *in* Marques, 2009). Remote sensing uses instruments/sensors that allow us to measure the electromagnetic radiation reflected by or emitted from the Earth's surface (Jensen, 2005 *in* Marques, 2009). The registration of multiple spectral bands (some of which are outside the visible spectrum) enable the possibility to overtake the capabilities of the human eye to distinguish objects by their spectral signature and therefore creating an improved usage of

⁴² Before, the term RS was used. The first photograph was taken in 1827 by Joseph Niepse. Daguerre continued Niepse's work and in 1839 took one photograph in the top of a tall building in Paris; in 1858, Gaspard Tournachon (Nadar) captured the first aerial photograph from a balloon over Bievre Valley (Baumann, 2001 available at URL: <http://www.oneonta.edu/faculty/baumanpr/geosat2/RS%20History%20I/RS-History-Part-1.htm> July, 2013).

the detected information (Richards, 1986, Richards & Jia, 1998; Eastman, 2001 *in* Marques, 2009).

Electromagnetic energy, i.e. electromagnetic radiation, constitutes the support of RS science (Tenedório, 2008 *in* Marques, 2009⁴³). The electromagnetic wave has patterns that can be acquired considering their wavelength and frequency. Usually these waves propagate in a straight line on open space; however, in the presence of objects, the propagation direction can be altered by reflection or diffraction (Oliveira *et al.*, ND *in* Marques, 2009). From the incident energy three types of interaction may occur: absorption, reflection, and transmission, depending on the physical characteristics of the entity, angle of incidence, and wavelength. Sensor systems in RS can be categorized into the following types of resolutions (Tenedório, 2008 *in* Marques, 2009):

- Spectral resolution, which refers to the amount (number) and the amplitude of the bands (wavelength range) recorded by the sensor;
- Spatial resolution, which is the sensor's ability to distinguish objects on the planet surface or the pixel size variation of the image (depending on the spatial resolution);
- Radiometric resolution, defined as the sensitivity of the sensor to receive energy, determining the number of values that can be recorded by the sensor;
- Temporal resolution, which refers to the frequency in which a sensor observes the same point (nadir) on land or the regularity of data collection in the same area.

The analysis of the acquired data is performed remotely using a variety of image processing techniques⁴⁴. The analysis of the acquired data seeks to detect and identify occurrences, objects or areas, which are generally measured and used for several problem solutions (Lillesand & Kiefer, 1994; These *et al.*, 1983; Haack *et al.*, 1997; Jensen, 2005 *in* Marques, 2009). According to Corns and Shaw (adapted, 2010)⁴⁵, digital data and representations, collected by RS, may be applied in several domains, and constitute a powerful tool in systematically accessing fundamental information, simultaneously

⁴³ Translated from Portuguese.

⁴⁴ Such as Assisted Classifiers, Non-Assisted Classifiers, Artificial Neural Networks or Object Oriented (Marques, 2009).

⁴⁵ Available at URL: http://www.earsel.org/symposia/2010-symposium-Paris/Proceedings/EARSeL-Symposium-2010_1-01.pdf (July, 2013).

eliminating barriers, such as institutional (regarding protectionist attitudes, and a reluctance to share resources), semantic (different techniques and methods to describe or represent spatial information), and geographical (regarding different strategies for accessing data internationally and depending on information type/format, scale, quality, frequency, and temporal needs). The increasingly larger archives of satellite imagery and the progressively higher spatial resolution of the sensors allow RS to be applied in many different domains and solutions. Dore *et al.* (2010)⁴⁶ mention that RS is a non-invasive technique for monitoring cultural heritage in remote areas and/or difficult access or dangerous areas, constituting a great support, even where political constraints or other characteristic/event create difficulties to the surveys *in situ*. Sand *et al.* (2010:38) state that

“management and monitoring both depend on reliable access to current information so that the tools and methods of intervention remain pertinent to existing conditions. However, the multitude of actors intervening on these protected areas, from local managers to international organizations, passing through researchers and non-governmental organizations, produce and use a wide body of disparate information. Lack of knowledge of the information resources available can even lead to the redundant collection of similar data causing a costly loss of efficiency”.

The authors consider the advantages of using RS for monitoring and managing cultural heritage, more specifically applied to world heritage sites.

Using RS, agents can detect systematic variations and patterns in objects, groups of objects, areas and occurrences, which allows them to qualify and quantify progressive evolution rates, performing valuations and creating conditions (with other GIT tools), collecting essential information to understand the past and present, beside modelling, simulating and predicting the future through digital representations. Stubbs & McKee (2007) give the example of how RS can be used as the baseline dataset in documenting and analysing the historical and contemporary effects of human activities at cultural heritage sites. The integrated use of RS and other Geographic Information Technologies (GIT) allows Agents to catalogue, analyse, and manage the cultural heritage, which besides mapping, can be applied to graphic representations of space-time data. These technologies are currently common in cultural heritage conservation and dissemination, constituting a great advantage for planning and management (Xiaoqian, 2010).

⁴⁶ Available at URL: <http://www.earsel.org/symposia/2010-symposium-Paris/Abstract-Book.pdf> (July, 2013).

2.1. Operation Mode Platforms

Platforms are the structures or vehicles on which remote sensing instruments are mounted. There are three main categories of remote sensing platforms: Spaceborne, Airborne and Ground-based.

2.1.1. Spaceborne platforms

The most stable RS spaceborne platforms are the satellite and the Space Shuttle⁴⁷, both orbiting the planet. The first RS satellite was launched in 1960 for meteorology purposes growing into a nowadays constellations of multinational earth observations programs and systems, launching every year more satellites to perform multi-tasks (NASA, 2003⁴⁸). The satellites can be classified by their orbital geometry and timing consisting in three main classes of orbit (NASA⁴⁹):

- High Earth Orbits, which include Geostationary⁵⁰ orbits, have a period of rotation equal to the Earth's, remaining over the same location in the planet (commonly used for communications and weather purposes);
- Medium Earth Orbits⁵¹, as the satellite moves the Earth rotates underneath crossing over the same two locations on the equator. This orbit is consistent and highly predictable (it is the orbit used by GPS satellites);
- Low Earth Orbits, where the most scientific satellites are located, constituting, for the most part, in the world Earth Observing Systems (EOS). In nearly polar orbit (highly inclined), the satellite circulates the planet from pole to pole⁵², in

⁴⁷ In its operating period, the Space Shuttle also functioned as a RS platform and be reused for several missions and purposes. The most famous project is the Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth (North American Space Agency - NASA, available at URL: <http://www2.jpl.nasa.gov/srtm/> July, 2013).

⁴⁸ Available at URL: <http://www.ccpo.edu/~lizsmith/SEES/> (July, 2013).

⁴⁹ Available at URL: <http://earthobservatory.nasa.gov/Features/OrbitsCatalog/page2.php> (July, 2013).

⁵⁰ At the altitude of 42,164 kilometers from the center of the Earth (about 36,000 kilometers from the Earth's surface), the satellite orbits at the same speed the Earth is turning, so the satellite seems to stay in place over a single longitude, although it may drift north to south (geosynchronous). A satellite in a circular geosynchronous orbit directly over the equator (eccentricity and inclination at zero) will have a geostationary orbit that does not move at all in relation to the ground. It is always directly over the same place on the Earth's surface (NASA, available at URL: <http://earthobservatory.nasa.gov/Features/OrbitsCatalog/page2.php> July, 2013).

⁵¹ For example, the semi-synchronous orbit is a near-circular orbit at 26,560 kilometers from the center of the Earth (about 20,200 kilometers above the surface).

⁵² Taking approximately 99 minutes.

which the Sun-Synchronous Orbit is included, which means that the satellite crosses the equator at the same local sun time, maintaining the same relative position from the sun for all of its orbits⁵³ (many RS satellites are Sun Synchronous which ensures constant sun illumination conditions during specific seasons).

RS satellites typically maintain higher orbits ranging from 600 to 1000 km, while the Space Shuttle used to have a low orbital altitude of 300 km. In terms of spatial resolution, the satellite imaging systems can be classified as (CRISP, 2013⁵⁴): Low resolution (approx. 1 km or more); Medium resolution (approx. 100 m to 1 km); High resolution (approx. 5 m to 100 m); Very high resolution (approx. 5 m or less). The data retrieved for RS satellites can include Photographic systems, Electro-Optical Sensors, Synthetic Aperture Radar (SAR) imaging, or LiDAR systems. The Optical/thermal imaging systems can be classified according to the number of spectral bands used (CRISP, 2013): Monospectral or panchromatic (single wavelength band, "black-and-white", grey-scale image); Multispectral (several spectral bands); Superspectral (tens of spectral bands); Hyperspectral (hundreds of spectral bands). The information collected by spaceborne satellites currently constitutes the most notable development in the systematic representation of several aspects of the planet, especially at a global level.

2.1.2. Aerial

2.1.2.1. Airborne Manned Vehicles

In airborne RS, downward or sideward looking sensors are mounted on an aircraft in order to obtain images of the Earth's surface. When compared to spaceborne RS, airborne RS offers the capability to gather very high-resolution spatial images albeit with the disadvantage of a small coverage area and high costs per unit area of ground covered (especially for large areas and using a common manned aircraft). Airborne RS missions are

⁵³ However, because a Sun Synchronous orbit passes nearly over the Poles and not directly, it is not always possible to acquire data for the extreme Polar Regions.

⁵⁴ Centre for Remote Imaging, Sensing and Processing, available at URL: <http://www.crisp.nus.edu.sg/> July, 2013).

often carried out as one-time operations, whereas Earth observation satellites offer the possibility of continuous monitoring of the Earth (Adapted from CRISP, 2013).

2.1.2.2. Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicle refers to a class of aircrafts that can fly without the presence of a pilot (on-board), often controlled at a Ground Control Station or directly from the ground beneath. However, there are other expressions adopted to indicate these types of vehicles, such as Drone, Remotely Piloted Vehicle (RPV), Remotely Operated Aircraft (ROA), and Unmanned Vehicle System (UVS).

The development of UAVs started in the 1950s (during the Cold War) for military purposes in many different countries, when different projects were started with the goal of producing vehicles that were able to carry out missions without an on-board pilot (with evident multiple advantages). The success in the military field (where the market for UAVs has been rapidly growing) has offered valid stimuli for the development of these systems for civilian applications. Nowadays, UAV-systems are quickly increasing in photogrammetric applications (including LiDAR systems, *in* Lin, 2011⁵⁵), considering the reduction of costs, especially due to the development of navigation systems and other geographic information technologies. Based on low-cost platforms, it is subsequently possible to set up affordable projects for civilian usage (Bendea *et al.*, 2007⁵⁶). Also due to its widespread use in civilian and commercial applications, it is fundamental to develop guidelines and regulations that allow aeronautic authorities to include UAVs in the civilian airspace (Doherty & Rudol, 2007⁵⁷).

For both military and civilian applications, there is a desire to develop more sophisticated UAV platforms where the emphasis is placed on the development of intelligent capabilities to interact with human operators and additional robotic or other UAV platforms. The emerging area of Intelligent UAV research has shown rapid development in recent years and offers a great number of research challenges for Artificial

⁵⁵ Available at URL:

http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5624563&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxppls%2Fabs_all.jsp%3Farnumber%3D5624563 (July, 2013).

⁵⁶ Available at URL: http://www.researchgate.net/publication/228372201_Mapping_of_archaeological_areas_using_a_low-cost_UAV_the_Augusta_Bagiennorum_Test_site/file/9fcfd510f703c855e5.pdf (July, 2013).

⁵⁷ Available at URL: http://link.springer.com/chapter/10.1007/978-3-540-76928-6_1# (July, 2013).

Intelligence (AI) and knowledge representation (Doherty, 2004⁵⁸). The development of integrated hardware/software has been supporting fully autonomous UAV missions (especially regarding UAV's independent flight from one waypoint to another, rounding or covering an area). It's deployment in applications, such as monitoring and surveillance (e.g. security, emergency assistance, traffic, environmental issues), photogrammetry and geospatial data acquisition has been growing in interest. Presently, UAV can support the survey of multispectral 3D geographic information in real-time (or catalogue information, both on demand) through on-line distribution to the user's multi-device application (e.g. desktop/laptop computers, tablets, or smartphones).

There are obvious advantages in conventional airborne remote sensing and the very high-resolution satellite imagery. However, Unmanned Aerial Vehicles (UAV) data survey introduces a flexible, low-cost and rapid response alternative to other traditional methods such as ground acquisitions and manned vehicles, producing large-scale topography, imagery or detailed 3D models as the main or complementary solution. The rapid and high frequency of data acquisition, and the spread of low-cost platforms combined with SLR⁵⁹ cameras and GNSS systems (e.g. GPS, GLONASS, BeiDou for navigation, point cloud coordinates, and possibly geopositioning) constitute some of the main reasons for the success of this technology⁶⁰ (Nex and Remondino, 2013).

2.1.3. Terrestrial or Ground-Based Platforms

Wide varieties of ground-based platforms are used in remote sensing. Some of the most common ones are handheld devices, tripods, towers, and cranes. Permanent ground platforms are typically used to monitor real world occurrences and long-term terrestrial features. Towers and cranes are often used to support research projects where a reasonably stable long-term platform is necessary. Towers can be built on site and can be tall enough to project through a forest or urban cover so that a range of measurements can be taken from the floor level, through and above the coverage (CRISP, 2013). Field instruments are also largely used for research purposes, often hand-held or mounted on a tripod or other

⁵⁸ Available at URL: <http://www.aaai.org/Papers/KR/2004/KR04-076.pdf> (July, 2013).

⁵⁹ Single-Lens Reflex camera.

⁶⁰ Example of that is the amazing growth (e.g. sales, offices, employees) of DJI Systems (drones and software: Apps) and their successful partnership with Apple in using their iPhone and iPad devices. Available at URL: <http://www.dji.com/company> (May, 2017).

similar support (NASA, 2003⁶¹). Ground-based platforms can also be classified according to their operational range (Muriuki *et al.*, 2009)⁶²:

- Long range systems, can measure at distances of up to 1km and are frequently used in open-pit mining and topographic survey applications.
- Medium range systems, operate at 150-250m, also achieving millimetre accuracies in high definition surveying in 3D modelling applications (e.g. large structures and buildings monitoring);
- Short range systems, operate at 50-100m with panoramic scanning and are often used to map building interiors or small objects;

2.2. Sensors Systems Technology

Simultaneous coverage by different sensors beneficiates multiple applications, considering more than one sensing system mounted on a single platform. In addition to sensor systems, there are often devices for recording, pre-processing, and transmitting the data. The Space-Aerial-Ground platforms associated with the sensors systems technology, constitute the fundamental infrastructure of tools to acquire vital digital spatial data and representations at two and three dimensions in several periods of time (4D).

The advances on Information and Communication Technologies (ICT) regarding the dissemination and access to information and the “process of democratization” of RS information have been affecting how people perceive the planet at different levels and different domains (such as research, technical-scientific, socio-economic, or political-administrative) regarding various issues related with the people’s needs and concerns (such as basic everyday weather forecasts or essential support tools for environment and cultural heritage knowledge, monitoring, and modelling). Nowadays, most humans can have access to fundamental information such as Earth’s imagery and data (2/3/4 D) collected by RS, available for example through geo-browsers or virtual globes⁶³ (such as Google Earth, Yahoo Maps, or Bing Maps), connected via the Internet. Considering both passive and

⁶¹ Available at URL: http://www.ccpo.odu.edu/~lizsmith/SEES/veget/class/Chap_5/5_3.htm (July, 2013).

⁶² Available at URL: http://meteorology.uonbi.ac.ke/sites/default/files/cbps/sps/meteorology/space_platforms.pdf (July, 2013).

⁶³ Mostly without costs for the software acquisition of basic available versions.

active sensors, there is an enormous potential growth for multiple solutions in these multiple Domains, applied to multiple Agents in the territory. Regarding the capability of monitoring cultural heritage, concerning landscapes, sites, urban settlements and monuments, RS can be a fundamental tool for acquiring and representing essential information. The numerous assignments, research projects, events, and entities that associate the cultural heritage to RS can be referred as examples of that.

2.2.1. Passive Sensors

Passive sensors measure light reflected or emitted naturally from surfaces and objects. Such instruments merely observe, and depend primarily on solar energy as the ultimate radiation source, illuminating surfaces and objects (NASA, 2003). They do not emit their own radiation, but receive natural light and thermal radiation from the Earth's surface. Most passive sensors make use of a scanner for imaging (such as LANDSAT). Equipped with spectrometers, these measure signals on several spectral bands simultaneously, resulting in the so-called multispectral images, which allow for numerous interpretations (Albertz, 2007; Löffler *et al.*, 2005 *in* SEOS, 2009⁶⁴). Built only to receive energy, passive sensor systems are generally simpler in design.

A major limitation of the passive systems is that they mostly require sunlight in order to acquire valid and useful data. Consequently, deployment of or data acquisition by passive sensors is very dependent on light (period of day or year/season and latitude) and weather conditions, considering that the atmosphere (e.g. clouds) can interfere with the path of solar radiation from the sun to the Earth's surface and then to the sensor. The signals detected by passive sensors can be greatly altered, especially in the

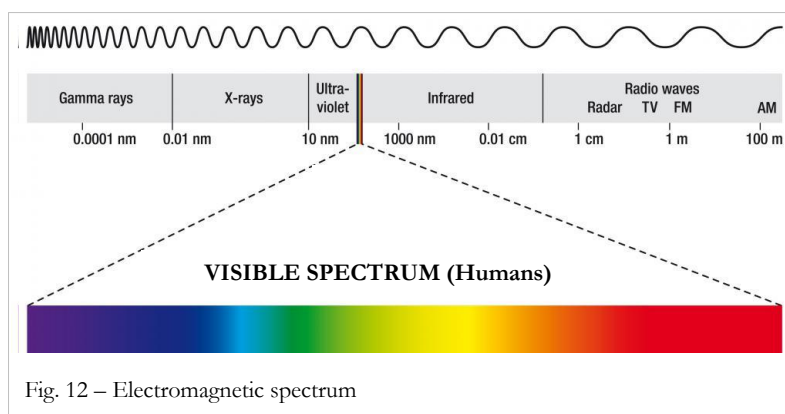


Fig. 12 – Electromagnetic spectrum

⁶⁴ Science Education through Earth Observation (SEOS), available at URL: <http://www.seos-project.eu/modules/remotesensing/remotesensing-c00-p02.html> (July, 2013).

shorter wavelengths of the electromagnetic spectrum. These effects can be minimized (but not eliminated) by collecting data only under very clear and dry atmospheric conditions. There are several atmospheric correction routines to remove these effects from data acquired by passive sensors (NASA, 2003).

The most common sensor system is the photographic camera and its basic element systems, consisting fundamentally in optics⁶⁵, film⁶⁶/CCD⁶⁷, and filters⁶⁸. Cameras can be used on nearly every platform (Space, Aerial and Ground-based) and consist in one of the most common practices of (re)presenting the real world. In most aerial photographs, the coverage depends on several factors, including optic (lens), platform altitude, and format. At high altitudes, a camera will register a larger area on the ground than at lower altitudes, but with reduced detail. Usually, these photographs are classified as either oblique or vertical, depending on the orientation of the camera in relation to the ground during acquisition. Oblique aerial photographs are taken with the camera pointed to the side of the aircraft and because of distortions in scale from foreground to background, they are not widely used for mapping although they can be applied to measurements of distance, area, and elevation. Vertical photographs limit geometric distortion and therefore they are the most common elements of aerial photography for RS and mapping purposes. Another characteristic is the possibility of overlapping the photograph thus facilitating stereoscopic observation to see a three-dimensional view of the area (NRC⁶⁹).

Electro-optic radiometers are similar in design to a camera in that they have an opening for the light to enter, lenses and mirrors for the light to pass through, recording the intensity of electromagnetic energy. As energy hits the detector, a signal proportional to the incoming irradiance is processed to either a digital or an analogue output that can be

⁶⁵ Optics refers to lenses and the geometry of light retrieval in a camera. The lenses in a camera are responsible for focusing and zooming.

⁶⁶ Photographic films are sensitive to light from 0.3 μm to 0.9 μm in wavelength covering the ultraviolet (UV), visible, and near-infrared (NIR) spectrums. Panchromatic films are sensitive to the UV and the visible portions of the spectrum, producing black and white images. Colour and false colour (or colour infrared, CIR) photography involves the use of a three layer film with each layer sensitive to different ranges of light (Natural Resources Canada – NRC, available at URL: <http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1815> July, 2013).

⁶⁷ Instead of using film in digital cameras, Charge-Coupled Devices (CCD) respond individually to electromagnetic radiation. Energy reaching the surface of the CCDs causes the generation of an electronic charge, in which based on magnitude, a digital number for each spectral band is assigned to each pixel. The digital format of the output image is amenable to digital analysis and archiving in a computer environment, as well as output as a hardcopy product similar to regular photos. Digital cameras also provide quicker turnaround for acquisition and retrieval of data and allow greater control of the spectral resolution (Natural Resources Canada – NRC, available at URL: <http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1815> July, 2013).

⁶⁸ In many remote sensing applications the use of filters can be applied to restrict the light entering the camera, working by absorbing a range of wavelengths while allowing others to pass through, or instead altering the spectral composition of light, reducing the amount of light of all wavelengths that pass through (Natural Resources Canada – NRC, available at URL: <http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1815> July, 2013).

⁶⁹ Natural Resources Canada – NRC, available at URL: <http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1815> (July, 2013).

recorded. The radiometer measures the intensity of electromagnetic radiation in a set of wavebands ranging not only from the visible bands of the electromagnetic spectrum, but also to the ultraviolet and microwave wavelengths, overcoming the natural human capability to visualize and (re)present the world (e.g. the use of thermal or infra-red images for multiple proposes).

Researchers have recently turned to digital representations based on local features that can be reliably identified and detected, being also invariant to the transformations likely to occur across images, such as geometric or radiometric transformations. Comparing images in order to obtain a measure of their similarity or Image Matching (IM) and feature-based matching are important digital methods with a variety of applications, such as content-based image retrieval, object and scene recognition, texture classification, and video data mining. Recognizing similar objects and scenes within a database of images remains challenging due to viewpoint or deformations, lighting, colour and partial occlusions that may exist. Global image statistics such as colour histograms or responses to filter banks have limited utility in these real-world scenarios, and often cannot give adequate descriptions of an image's local structures and discriminating features (Grauman & Darrel, 2005)⁷⁰. Forstner (1986)⁷¹ refers that the Feature Based Matching (FBM) procedures consists in three major steps:

- Selecting distinct points in the images separately (through Distinctness, Invariance, Stability, Seldomness, and Interpretability);
- Building up a preliminary list of candidate pairs of corresponding points assuming similarity measure (Through Invariance, Seldomness, Heuristics, Metric);
- Deriving the final list of consistent point pairs.

IM is a key component in almost any image analysis process, and is crucial to a wide range of applications (e.g. navigation, guidance, automatic surveillance, robot vision, and mapping sciences)⁷². Regarding the real and virtual environment interchanges, IM can

⁷⁰ Available at URL: http://www.cs.utexas.edu/~grauman/papers/grauman_darrell_cvpr2005.pdf (July, 2013).

⁷¹ Available at URL: http://www.ipb.uni-bonn.de/uploads/tx_ikgpublication/foerstner86.feature_gesamt.pdf (July, 2013).

⁷² Gruen, 1985 available at URL: http://www.idb.arch.ethz.ch/files/alsm_awgruen.pdf (July, 2013).

contribute to recognize the characteristic features from the real world and match them with the synthetic (virtual) world⁷³, creating opportunities for an enhanced mixed environment.

2.2.2. Active Sensors

Active systems supply their own light energy, which can be controlled. Some advantages that active systems have over passive sensors are that they do not require solar illumination of surfaces or perfect weather conditions to collect useful data. Consequently, they can be employed at night or in conditions of haze, clouds, or light rain (depending on the wavelength of the system)⁷⁴. There are two main types of active sensors, RaDAR and LiDAR systems.

RaDAR (Radio Detection And Ranging) systems use microwave wavelengths (ranging from 1 millimetre to 1 meter). Microwave pulses are transmitted to a target or surface, and the timing and intensity of the return signal is recorded. Factors determining the strength of a radar return signal are complex and varied, however the most important are geometric and electrical properties of the surface or object that reflects the signal. Information about the structure and composition of objects and surfaces can be detected with radar. Radar has been used in a number of fields, including military, meteorology, oceanography, geology, and cultural heritage, especially in archaeological studies for the visualization of underground ruins (adapted from NASA, 2003).

LiDAR (Light Detecting And Ranging) systems use laser light as an illumination source. A short pulse of light is emitted from a laser and a detector receives the light energy (photons) after it has been reflected, or absorbed and remitted by an object or surface. LiDAR systems emit pulses at specific, narrow wavelengths that depend on the type of laser transmitter used. The possible wavelengths range from about 0.3 to 1.5 micrometres, which covers the ultraviolet through near-infrared spectral range. The simplest LiDAR system measure the round trip travel time of a laser pulse, which is directly related to the distance between the sensor and the target. Basic distance measuring LiDAR are often referred to as rangefinders or laser altimeters if deployed on an aircraft or spacecraft. These systems typically measure elevation, slope, and roughness of land, ice, or water surfaces

⁷³ Modelled.

⁷⁴ NASA (2003).

(NASA, 2003). However, multiple assignments of LiDAR technology are being applied to collect three dimensional point clouds of cities and buildings.

According to Heritage *et al.*, (2009:x) “never has our need to understand the physical world been greater, and we are beholden to use the best technologies to help us in our research”, referring especially to LiDAR technology. Capturing real-world properties in digital computing produces spectacular and faithful results, constituting perhaps the most important and successful representation of the physical environment (Roussou & Drettakis, 2003). The principle advantages of laser scanning are the provision of precise x, y, z and the high level of automation (Heritage *et al.*, 2009), increasing data acquisition in a short period of time, and avoiding the common mistakes generated by traditional surveying (Castillo & Almirall, 2006). In this sense, LiDAR systems have established a new era in terms of the three-dimensional (Gambino *et al.*, 2005) to register, measure, and model, even if the application of this technology in architectural survey does not replace the widely accepted methods to register architectural heritage (Castillo & Almirall, 2006). Paraizo (2004) recognize the necessity to consider the proper scale for each survey regarding the difficulty for ordinary computers to manipulate models with some complexity versus the level of detail. Fuentes *et al.* (2007) present the results of several experiments performed using 3D Laser Scanning to assisting in restoration efforts and to evaluate damage in cultural heritage, stating that

“The recent incorporation of laser devices provides advanced tools for assisting the conservation and restoration of Cultural Heritage. It is necessary to have as complete as possible understanding of the object state before evaluating or defining the reach of the restoration process. Thus, a special effort is devoted to surveying, measuring and generating a high-resolution 3D model prior to restoration planning”⁷⁵.

The authors Mateus & Ferreira (2013) refer that they recognize 3D digitalization as a merge of Laser Scanning and Digital Photogrammetry, often linked to architectural (and archaeological) heritage documentation.

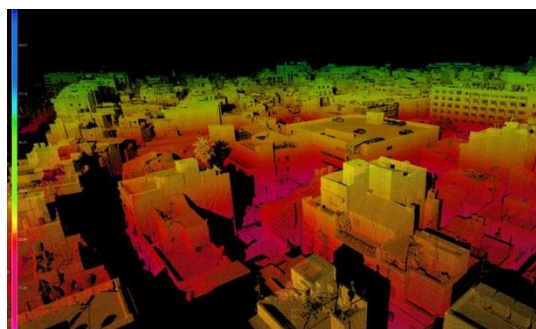


Fig. 13 – Laser Scan of Lloret de Mar containing 46,3 million points (X,Y,Z,i,R,G,B), using RIEGL LMS Z420i. Source: Marambio *et al.* 2011 (7VTC – Lisbon, Portugal).

⁷⁵ Fuentes *et al.* (2007:65).

Reflectance Transformation Imaging (RTI) is a digital acquisition process that captures a set of images of a subject from a single view under varying lighting conditions. This kind of technology has significant potential in the Cultural Heritage field. The characteristics of the material, reflectance behaviour, and texture offer major perceptual and cognitive hints for the study of these kinds of objects. Digital models encoding only 3D shapes are not able to capture every noteworthy and interesting aspect of the artwork. In many cases, the ability to interactively play with the light is often more useful than the manipulation of an accurately sampled 3D shape. Moreover, there is a wide difference in terms of cost and precision that can be achieved with current RTI technologies compared to 3D scanning techniques: RTI techniques use inexpensive and widely available hardware (in many cases, just a digital camera and light (Mudge *et al.*, 2006 *in* Palma, 2010)); scale well to both large (Dellepiane *et al.*, 2006 *in* Palma, 2010) and very small objects (Mudge *et al.*, 2005 *in* Palma, 2010); and are able to easily achieve a sampling density and a precision that most current 3D scanners are unable to reach, even under optimal acquisition conditions. For those reasons, RTI techniques are widely used in the Cultural Heritage field for documentation tools (Mudge *et al.*, 2008; Padfield *et al.*, 2005 *in* Palma, 2010) and to support detailed visual analysis (Freeth *et al.*, 2006 *in* Palma, 2010). While there is an increasing interest in RTI technologies, the study of advanced visual analysis methodologies for this kind of data is in its infancy, since few enhancement techniques have been proposed (Palma, 2010).

Cultural heritage is increasingly associated with imaging systems such as multispectral cameras and 3D scanners⁷⁶. Though these acquisition systems are often used independently, collecting complementary information (spectral vs. spatial) used to study, archive, and visualize cultural heritage. Recording 3D and multispectral data in a single coordinate system enhances the potential insights in data analysis. Cultural heritage is a favourite application of the image processing and computer graphics community (Chane, 2013).

⁷⁶ Not only using Remote Sensing sensors, but also terrestrial laser scanners with different resolutions are increasingly used in the field of cultural heritage, such as: Faro Focus systems, Leica geosystems, Konica Minolta Range7, Riegl systems or Trimble.

3. Geographic Information Systems (GIS)

The development of Geographic Information System (GIS) started in the mid-1960s and in the past years it has produced a vast collection of data models and structures. GIS science deal with the accurate processing of map contents, thinking about the process of representing and characterizing the world. Discovering methods to represent the infinite complexity of the real geographic environments, in the limited space and binary language of a computing system, is perhaps the greatest challenge that GIS research faces. Thus, the core of a GIS is a system of representation in which features of the real world are coded in the binary alphabet of the digital computer, including three aspects of real world features: their locations on the Earth's surface (using coordinates); their attributes; and relationships of importance between them (Goodchild, 2010).

GIS have been gathering massive interest worldwide. Their recent and fast development, commercial orientation and diversity of applications have made it difficult to produce a clear and unambiguous definition (Maguire, 1991⁷⁷). Although different definitions of geographic information and GIS can be found in the literature, they mostly focus on the concept of georeferencing⁷⁸. However, in the many proposed definitions⁷⁹, some authors believe that the core components of GIS are software, hardware, liveware, and data. Other authors argue that the most relevant features in GIS are information processing and applications (adapted from Maguire, 1991⁸⁰). According to Longley *et al.*, (1999, 2010) *in* Goodchild (2012:1)⁸¹, GIS “can be defined as a

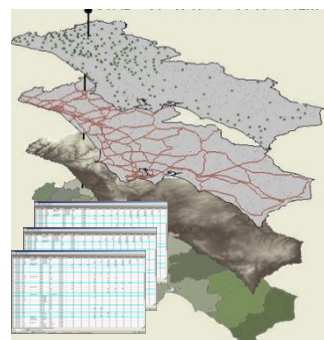


Fig. 14 – GIS (georeferenced layers and associated Data Bases).

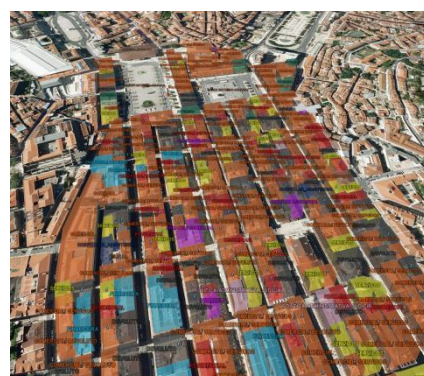


Fig. 15 – 3D modelling at urban scale, typology representation and alphanumeric data access. Lisbon, 2007. Image by the author.

⁷⁷ Available at URL: <http://www.journalism.wisc.edu/~gdowney/courses/lis-gis/PDF/Maguire%20D%201991.pdf> (June, 2013).

⁷⁸ The term Georeferencing means the process of connecting a dataset with spatial reference information (coordinates) *in* Neumann, 2005, available at URL:

<http://geodata.ethz.ch/geovite/tutorials/L3GeodataAndSpatialRelation/en/text/L3GeodataAndSpatialRelation.pdf> (June, 2013).

⁷⁹ Introduced and discussed by Maguire, 1991.

⁸⁰ Available at URL: <http://www.journalism.wisc.edu/~gdowney/courses/lis-gis/PDF/Maguire%20D%201991.pdf> (June, 2013).

⁸¹ Available at URL: <http://www.geog.ucsb.edu/~good/Goodchild-CV.html> or URL:

computer application capable of performing virtually any conceivable operation on geographic information⁸², from acquisition and compilation through visualization, query, and analysis to modelling, sharing, and archiving”. Other authors define GIS as designed to capture, store, manipulate, analyse, manage, and present all types of geographically referenced data, built in a computer-based digital system (Foote & Lynch 2000; Burrough & McDonnell 1998; Bernhardsen 2008 *in* Schatz *et al.*, 2013)⁸³.

Conventional GIS employ two-dimensional (2D) digital maps as a user interface to display geographic information. Layers of data are usually built on a digital map to establish links between geographic information from various sources. To construct a digital map, many methods have been developed (Lin, 2008). The integration of the processes with geospatial technologies, mainly GIS, has already shown that it can simplify procedures in multiple ways. Many authors have demonstrated the importance of using conventional two-dimensional (2D) GIS technologies applied to urban scenarios, understanding the territory by visualising and analysing fundamental geospatial data and then contributing to decision-making processes (Hanzl 2007, Batty 1998 *in* St-Aubin *et al.*, 2010). Hamilton *et al.*, 2001 (*in* Zhang, 2004) also argued that interpreting 2D plans to form mental pictures of physical entities, like buildings, is a skill that has to be learnt. Yu *et al.* (2012) refer that traditional 2D GIS analysis has been an excellent tool for planners (Chapin 2003; Ramsey 2009; Riveira & Maseda 2006; Riveira, Maseda & Barros 2008 *in* Yu *et al.*, 2012)⁸⁴. However, traditional 2D GIS mapping is not able to meet the visualization needs of various agents, especially for citizens who are non-experts (Yu *et al.*, 2012). Zhang (2004) showed in his research⁸⁵ that 2D maps might not be as good as three-dimensional (3D) virtual models to present detailed information on a small area. Technological developments in 3D visualization allow the generation of a 3D virtual world from the GIS dataset, which improves communication between technicians, the general public, and decision makers (Yu *et al.*, 2012). 3D representation increases the engagement of the user and it becomes easier to understand and interact, considering its similarity with reality (Zhang, 2004). 3D

<http://www.geog.ucsb.edu/~good/papers/515.pdf> (June, 2013).

⁸² Geographic Information is defined as information linking locations on or near the Earth’s surface to the properties, characteristics, and phenomena found at those locations (Goodchild, 2012). Eighty-five per cent or more of all information could be regarded as geographic data because it can be spatially referenced (Stillwell *et al.*, 1999).

⁸³ Available at URL: http://link.springer.com/chapter/10.1007/978-3-642-37030-4_2#page-1 (June, 2013).

⁸⁴ Available at URL: <http://www.questia.com/library/1G1-303450150/a-hybrid-system-of-expanding-2d-gis-into-3d-space#articleDetails> (June, 2013).

⁸⁵ PhD thesis (School of Construction and Property Management, University of Salford, UK) that presents a theoretical framework based on the Learning System Theory, integrating GIS, Virtual Reality, and Internet technologies thus facilitating participation in the planning activity. This work was based on a local urban renovation project in Salford, UK.

visualization is currently used in many applications; nevertheless it is still separated from 2D GIS. While 2D GIS is applied to data management and analysis, 3D visualization is only used to present the results. Several common analytic functions in 2D GIS are still unavailable in 3D visualization. Thus, a true 3D GIS besides providing realistic representations should enable other GIS capabilities (Yu *et al.*, 2012).

GIS are growing to involve higher real-time assessment and will need new kinds of functions and tools to interoperate and manage information while it is continually changing, shifting from processes of analysing static data to a futuristic dynamic process of real-time monitoring and decision making, having several relevant applications. Examples of this predisposition of GIS might be the use of GNSS fed by sensors to show traffic in the road system on a computer (or on a smartphone, tablet, goggles, or projected hologram device) in real time; aircraft traffic information shown to the air-traffic controller; disaster response in real time, or monitoring the state of a disease event in real time (Goodchild, 2011⁸⁶). According to Yang *et al.* (2011)⁸⁷ the challenges in GIS are related with the intensity of information, datasets, concurrent access, and computing and spatiotemporal issues. These challenges require the readiness of a computing infrastructure that can support research, access and use of information and data processing so as to relieve technicians and researchers of ICT tasks to focus on technical-scientific achievements, providing real-time resources to enable in-time responses and applications, offering more reliable and scalable services for massive numbers of users, and contributing to public knowledge. This demand for geospatial implementation of standards and interoperability is shifting GIS from traditional client-server architecture to web service architecture. In the web service infrastructure, there are diverse capabilities including not only sharing data, but also geo-processing functionalities that can be enclosed in interoperable web services (Anderson & Moreno 2003 *in* Zhang & Li, 2005⁸⁸). The Open Geospatial Consortium (OGC⁸⁹) plays an important role in terms of geographic information web services (via the Internet). OGC web services provide a neutral interoperable agenda for web-based requests, research, access, integration, analysis and visualization of multiple online geospatial data sources.

⁸⁶ ESRI website, available at URL: <http://www.esri.com/news/arcwatch/0211/future-of-gis.html> (June, 2013).

⁸⁷ Available at URL: <http://www.tandfonline.com/doi/pdf/10.1080/17538947.2011.587547> (June, 2013).

⁸⁸ Available at URL: http://www.cp-idea.org/documentos/tecnologia/8_zhang.pdf (June, 2013).

⁸⁹ The OGC is an international industry consortium of several companies, government agencies and universities participating in a consensus process to develop publicly available interface standards. OGC standards support interoperable solutions that geo-enable the web, wireless and location-based services and mainstream information technology. These standards empower technology developers to make complex spatial information and services accessible and useful for all kinds of applications (Available at URL: <http://www.opengeospatial.org/ogc> June, 2013).

Examples of OGC Web Service standards⁹⁰ include Web Map Services (WMS), Web Feature Services (WFS), Web Coverage Service (WCS), and Catalogue Service (CS). These services not only allow to exchange relevant information that is constantly updated (with direct access from producer to user), but also eliminate time-consuming tasks in terms of data translation, while simultaneously reducing physical allocation, integration requirements, and avoiding numerous static datasets catalogues and their associated costs (adapted from Zhang & Li, 2005). The emergence of Spatial Cloud Computing⁹¹ provides a potential solution with a flexible, on-demand computing platform, integrating systems, parameters, simulations, analytical visualizations and decision support, simultaneously providing social impact and user feedback (Yang *et al.*, 2011).

Advances in computer graphics hardware, software, algorithms, visualization, and interactive techniques for analysis offer the components for a highly integrated, efficient real-time 3D GIS. By connecting these capabilities, users are able to develop Virtual GIS, with truly immersive ability for digital representations, interacting, and understanding the complex and dynamic world (adapted from Koller, 1995)⁹².

⁹⁰ According to OGC in Zhang (2006), WFS is an OpenGIS implementation specification that allows a client to retrieve, query, and manipulate feature-level geospatial data encoded in Geography Markup Language (GML - XML grammar defined by the OGC to express geographical features) from multiple sources. The OGC WMS specification is capable of creating and displaying maps that come simultaneously from multiple heterogeneous sources in a standard image format. WCS provides access to potentially detailed and rich sets of geospatial information, in forms that are useful for client-side rendering multi-valued coverage, and input into scientific models and other clients. CS provides catalogues for OGC web services and supports the ability to publish and search collections of descriptive information (metadata) for data, services, and related information objects.

⁹¹ SCC refers to the paradigm that is driven by geospatial sciences, and optimized by spatiotemporal principles to enable geospatial science and cloud computing within a computing environment (Yang *et al.*, 2011).

⁹² Available at URL: <http://smartech.gatech.edu/bitstream/1853/3559/1/95-14.pdf> (June, 2013).

Chapter III

Virtual Environments, Networks and Cultural Heritage

Chapter III - Virtual Environments, Networks and Cultural Heritage

1. Virtual Environment

Representations can transmit the idea of a presence or sense that is there to be embodied, which corresponds to the notion of meaning; above and beyond different signs or signifiers there is a sense of ideal content (Colebrook *in* Pløger, 2010). Presence can be defined as a psychological state in which virtual objects are experienced as actual objects in either sensory or non-sensory ways; it is the extent to which humans feel being in the intermediary environment rather than in the immediate physical world (Steuer, 1992 *in* Ch'ng, 2009); a state of consciousness, the (psychological) sense of being in the Virtual Environment (VE)⁹³.

According to the Chicago University Glossary⁹⁴, “the word virtual derives from the Latin *virtus*, which means strength”. The Oxford English Dictionary, besides other definitions, refers the most “common usage of the word, is ‘a virtual (as opposed to an actual) thing, capacity, etc.; a potentiality.’ but in such a way as to be as effective in terms of representation as the actual thing”⁹⁵. In other dictionaries, the term virtual means usually the loss of the materiality of objects. With the widespread of media technology, the emphasis on television as the main system of circulation of images and world representations has introduced an ontological confusion in terms of the image that is not present. For Baudrillard *in* Goorich (2002)⁹⁶,

“the virtual does not indicate a difference across orders, but indeed the complete collapse of orders, so that the real and the virtual become indistinguishable (on an

⁹³ Slater & Wilbur *in* Ch'ng (2009).

⁹⁴ Available at URL: <http://lucian.uchicago.edu/blogs/mediatheory/keywords/virtuality> (November, 2011).

⁹⁵ Available at URL: <http://csmt.uchicago.edu/glossary2004/virtuality.htm> (December 2011).

⁹⁶ Available at URL: <http://csmt.uchicago.edu/glossary2004/virtuality.htm> (February, 2016).

ontological level) [...] what once was designated as virtual is now more present than reality itself (or reality is so imbricated with these images that the difference becomes moot)”.

The author gives the example of building replicas of an environment⁹⁷ while protecting the original, sealed from the public contact (the public can access the replica in a place nearby).

A computer-generated or a computer-synthesized VE dimension is one in which a plurality of human participants, appropriately interfaced, may engage and operate simulated physical elements in the environment, and interact with representations of other individuals in past, present or fictional beings, giving the user a strong sense of presence (Nugnet, 1991; Warburton 2009 *in* Mallan *et al.*, 2010). Through technology, humans have the ability to present or represent VE, which can exist (i.e., be real), sometimes in a way that goes beyond reality itself: e.g., social networks⁹⁸, where the virtual relations or digital representation between people and/or entities/agents can reach a vast number of individuals, stakeholders (in different domains) or the society as a whole (regardless of their physical location on Earth⁹⁹) in a continuous structure system (real-time based). VE does not replace the real world, but in some aspects it can be an alternative since it is (re-)present. Nowadays, VE are contributing to (re)shape anthropological relations and organizational systems in the planet¹⁰⁰, mostly through mobility (and physical allocation of people and data)¹⁰¹. In some cases, this has shortened distances (up to no distance at all) and has been able to be (re-)presented in multiple VE at the same time. The ultimate representational system would allow the observer to interact naturally with objects and other individuals within a simulated environment, as an experience indistinguishable from reality. Although, such a representational system might conceivably use direct brain stimulation in the future, it will more likely use digitally controlled outputs that stimulate the human senses (Loomis *et al.*, 1999).



Fig. 16 – Virtual synthesized world. Image captured in the Kraftwerk concert 2016.

⁹⁷ More precisely the Caves at Lascaux in southwestern France (which contain its Paleolithic cave paintings, estimated to be around 17300 years old).

⁹⁸ Or other technological means, such as Chat Rooms, Skype or the Internet itself.

⁹⁹ If reached by these technological networks, such as the Internet, considering that not every area in the world is covered, even if there have been recent developments to solve this issue. A good example is Google's project called Loon (filled balloons carry antennas, computers, batteries and navigational equipment, collecting power from solar panels that dangle below. Each can provide internet coverage over an area of 1200 km². The first test from this project was realized with success in June 15, 2013 in New Zealand).

¹⁰⁰ And outside the planet in digital representations for example of the Moon or Mars (e.g. Google Moon or Google Mars).

¹⁰¹ Positively or negatively.

VE can offer enhanced opportunities and provide additional tools for people to communicate with others and interact with urban models (Sarjakoski, 1998 *in* Zhang, 2004). Many authors (Myers *et al.*, 1995; Weiner *et al.*, 1995; Harris & Weiner, 1998; Kellogg, 1999; Stillwell *et al.*, 1999; Nedovic-Budic, 2000; Sieber, 2000 *in* Zhang, 2004) refer that this technology¹⁰² could be used to improve public access to information and increase public participation in the planning and policy-making process. The sense of place can be enhanced by generating and developing the virtual world with buildings, objects, and settings, which are expected to be found in the real situation. The importance of 3D quality (realism¹⁰³) is highlighted in several research results,¹⁰⁴ showing that users in highly realistic 3D reconstructions experience significantly higher levels of reaction (based on physiological measures) and higher levels of reported presence (adapted from Bellotti *et al.*, 2009). There is a growing interest among technicians to use 3D virtual reality models for the designing and planning of buildings, neighbourhoods and cities, providing opportunities for people to move through and interact with spaces, as virtual representations of people or avatars (Mallan *et al.*, 2010).

Luck & Aylett, 2000 (*in* Ch'ng, 2009) showed that the use of artificial intelligence in VE can provide a valuable and effective way for research within specific application areas. Some researchers in the field of virtual reality and computer graphics information seek to progress beyond visually compelling, incorporating other aspects of physical reality that require intelligence or agents with characteristics of life. Computer environments endowed with intelligence are beginning to change the contents of virtual worlds, especially the ability to learn and adapt using artificial intelligence techniques, such as neural networks, simulating the processes of the human brain. However, according to Pawlik (2001), it is still difficult to categorize VE considering the different types of technologies and (other possible) sub-categories. Generally, according to immersivity, VE can be categorized (Jackson, 1994 *in* Pawlik, 2001) as:



Fig. 17 – HMD
(Immersive environment).

¹⁰² Particularly GIS,

¹⁰³ Which usually requires high performance computer graphics (Hugues, 2011).

¹⁰⁴ Regarding serious games (Bellotti *et al.*, 2009) [considered by Foni (2010) as computer games for education and training].

- Non-immersive (e.g. PC based systems, where the VE is displayed on the monitor);
- Partially immersive (e.g. Binocular Omni-Orientation Monitor¹⁰⁵, or Projection VE Systems);
- Fully immersive (e.g. Head-Mounted Displays (HMD)¹⁰⁶ or Cave Automatic Virtual Environment / CAVE¹⁰⁷).

Immersive is related with the digital technologies or representations that intensely involve human senses and may create an altered mental state. For example, while an Augmented Reality (AR) system augments the real world scene requiring that the user maintains a sense of presence in that world, by contrast, Virtual Reality (VR) strives for a totally immersive environment, where the visual and in some systems aural and proprioceptive senses are under control of the system (Hugues, 2011).



Fig. 18 – C.A.V.E. example of immersive experience in the Portuguese Environment Ministry headquarters with the collaboration of the author. Evolution of the environment policies in 30 years with support of geographic information. Lisbon, 2015. Image by the author.

2. Reality to Virtuality Continuum

2.1. Virtual Reality

The term Virtual Reality (VR) is an oxymoron, a deliberately provocative verbal paradox, it is formed by two contradictory and mutually exclusive concepts, since something cannot be real and virtual at once (Gubern, 1996). VR has become a mainstream term for referring to the creation and manipulation of a VE within a computer context (Eve, 2012). For Gubern (1996), it is like a mirror, entering an alternative reality (illusionary

¹⁰⁵ Binocular Omni-Orientation Monitor is a head-coupled stereoscopic display device, which consists in screens and an optical system fixed in a box that is attached to a multi-link arm. The user sees the VE and can guide the box to any possible position of the device (Beier, 2000 available at URL: <http://www-vrl.umich.edu/intro/>, June, 2013).

¹⁰⁶ The Head-Mounted Display was the first device providing its user with an immersive experience [According to Beier (2000), it is an helmet that contains two miniature display screens and an optical system that channels images from the screens to the eyes, thereby, presenting a stereo view of a virtual world; available at URL: <http://www-vrl.umich.edu/intro/>, June, 2013].

¹⁰⁷ It provides the illusion of immersion by projecting stereo images on the walls and floor of a room-sized cube (Beier, 2000 available at URL: <http://www-vrl.umich.edu/intro/>, June, 2013).

and represented) that seems to possess all the attributes of reality, truly and objective. The term was defined as “a computer generated, interactive, three-dimensional environment in which a person is immersed” (Aukstakalnis & Blatner, 1992 *in* Hugues, 2011:5). This definition involves several key points related with a VE generated in computer, 3D environment, iterative and immersive, increasing the engagement of the user by providing a natural interface between human and machine (Teylingon *et al.*, 1997; Burdea & Coiffet, 2003 *in* Zhang, 2004) and getting closer to natural ways of interacting with the world, rather than with maps or other static models (Jacobson, 1992; Neves & Camara, 1999 *in* Zhang, 2004).

Devices such as HMD held by users are identifying features of a VR System (VRS). These displays intend to block out the entire external world and instead present a view that is under the complete control of the computer. The user is totally immersed in an artificial/created world and becomes disconnected from the real world. For a realistic immersion, the VRS must accurately interpret the user movements and actions, determining what consequence it will input onto the scene to be rendered back in the device (Hugues, 2011). Langendorf (1999) *in* Shen & Kawakami (2010) evaluated VR technologies for public involvement, emphasizing that the virtual image is more persuasive and more effective than traditional representations such as common planning documents. VR technology also contributes to approximate agents working on the field (e.g. technicians, citizens, and politicians) especially in cases where mutually distrusting parties must collaborate. The digital representation of scientific data within a VE aims to provide access to relevant local and global data, with the ability to access, visualize, compare, interact, manipulate, transform, and project data within a certain case study. These tools constitute an opportunity and a powerful ally for online collaboration, technical experimentation, and divulgation for researchers, also applied in environments that are either remote or no longer exist (Magerko, 2010).

Virtual Time Travel (VTT) in experimental research is becoming possible through the progress of the networks, available data and technology (Ch’ng, 2009). In the near future¹⁰⁸, VTT will be able to provide more than an enhanced experience of a historical situation for the full engagement of all the five senses¹⁰⁹ into a physically based experience. This assumption is supported by the argument that all physical matter, including living

¹⁰⁸ Due to present technological limitations.

¹⁰⁹ Looking, sounding, smelling, tasting, and feeling real.

beings, can be represented digitally in the VRS, which culminates in the reconstruction of the ancient past (Ch'ng, 2009). VR simulations on real-time applications provide users with the possibility of freely manipulating the visualized items and directly exploring the modelled VE by allowing the modification at will of the elements featured in the simulation and the generation of real-time visual feedbacks for their performed actions and choices. However, in stereoscopic representations, the level of presence, as well as the overall perceived consistency, can be considered slightly superior to basic real-time simulations. The capacity to stimulate in the VRS user depth perception implies, in fact, both the availability of an increased amount of information, allowing the system to generate properly the stereographic pairs, and an enhancement of the photorealistic potential exhibited by the digital representation (Foni, 2010).

The current debate highlights the similarities and differences between VR and Augmented Reality (AR) systems. A very visible difference between these two types of systems is the immersiveness of the system. VR strives for a total immersive environment¹¹⁰, while AR technology has been advancing to the possibility of merging computer-generated environment with the real world, creating Mixed Reality (Ohta & Tamura 1999 *in* Eve, 2012).

2.2. Mixed Reality and Augmented Reality

Several authors and studies suggest that the frontier between virtual and real worlds may be more diffuse and permeable than experts had previously imagined (Ch'ng, 2009). The real environment and the VE are at the two opposite ends (Fig. 17) of one continuum,¹¹¹ while the middle region is called Mixed Reality (MR). Unlike VR, which provides a synthetic environment as a replacement for (represented) reality to the user, MR ensures that the user sees the real/virtual environment augmented and mixed with information from the opposite environment (Milosavljevic *et al.*, 2010).

¹¹⁰ Available at URL: <http://www.se.rit.edu/~jrv/research/ar/index.html> (June, 2013).

¹¹¹ The “Reality-Virtuality Continuum” can be considered as a scale of realities, ranging from a pure virtual reality at one end to a pure physical reality at the other end, with a continuous scale of augmented realities in between. First introduced in 1994, in the paper: “*Augmented Reality: A class of displays on the reality-virtuality continuum*” by the four authors Paul Milgram, Haruo Takemura, Akira Utsumi, & Fumio Kishino, the concept of reality-virtuality continuum has become essential to classify the notions of Virtual, Mixed and Augmented reality (Milgram *et al.* 1995, available at URL: <http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=981543>, June 2013).

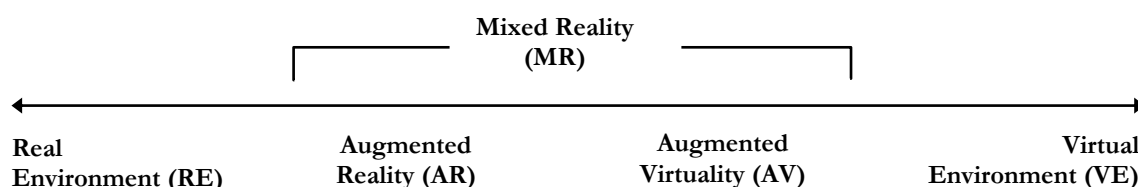


Fig. 19 – The Reality-Virtuality Continuum (adapted from Milgram *et al.*, 1995).

Thus, MR includes both virtual and real-world elements, dealing with the combination of real world and computer-generated (represented) data (Che *et al.*, 2012). In the MR, Augmented Reality (AR) is near the real-environment, while Augmented Virtuality (AV) is closer to the virtual-environment (Milosavljevic *et al.*, 2010).

MR complements reality/virtuality rather than completely replacing it, appearing to the user that the virtual and real coexist in the same space (Ch'ng, 2009). This technology is becoming increasingly popular at overcoming numerous issues, such as the obstacles related with the successful public participation, regarding, for example, flexible solutions adapted to different scenarios that may arise¹¹² (e.g. public consultation meetings). MR as a tool has the potential to assist decisional processes in the context of urban design and planning, adding the capability to increase representational information (virtual or real) into the selected environment presented (also virtual or real). These characteristics are also valid to understand temporal and spatial changes, manipulate geographical data and navigate through this alternative space (Che *et al.*, 2012).

The integration of AR technology to basic 3D GIS functionalities allows the quick and simple creation of a 3D geospatial scene and implements intuitive methods of interaction assisting for example, public participation, creating a fully collaborative solution system (St-Aubin *et al.*, 2010).

Augmented Reality (AR)

The term Augmented Reality (AR) refers to the enrichment of the real world with a complementary virtual world (Robinett, 1992; Caudell & Mizell, 1992; Bajura & Neumann, 1995 *in* Hugues, 2011). The digital information or representations are merged with the real

¹¹² Adapted from St-Aubin *et al.* (2010).

view via a device that combines both real and virtual. An AR system expands the real world scene allowing the user to maintain the sense of presence in that world (Hugues, 2011). Azuma (1997¹¹³), in his review, defines AR as a system that has the following three characteristics:

- It combines real and virtual elements;
- It is interactive in space (position) and time (past, real-time, future);
- It operates in a 3D environment.

The fast development of computing systems has allowed for more sophisticated equipment interfaces to be employed, particularly the alignment and combination of real and virtual objects in a device that runs interactively (Correia, 2005 *in* Foni, 2010). Currently, the main procedure is based on simplified digital representations (usually geometrical models) to achieve real-time capabilities even if perhaps sacrificing its overall quality, visual consistency, and precision¹¹⁴. However, despite all the limitations (associated to technology resources), AR digital representations, restitutions and simulations can offer interesting possibilities and useful applications, due to their fairly good interactive capabilities and their capacity to visually stimulate and engage the user, for example, when applied to cultural heritage on-site visualization and exploration tools (Foni, 2010).

According to Riera (2013), AR software systems and libraries like ARToolKit¹¹⁵, MXRToolKit¹¹⁶, ARtag¹¹⁷, Studierstube¹¹⁸ or Osgart¹¹⁹ have been extremely relevant for the

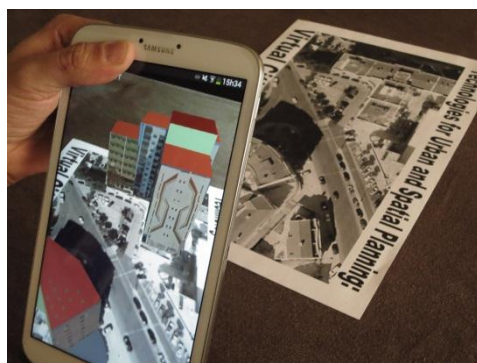


Fig. 20 – Augmented Reality visualization in Almada (Lisbon Metropolitan Area). Image by the author. 2013.

¹¹³ Adapted from Milosavljevic *et al.* (2010).

¹¹⁴ In general.

¹¹⁵ ARToolKit was first demonstrated publicly at SIGGRAPH in 1999. Released open source in 2001 and commercialized by ARToolworks under a dual licensing model, ARToolKit and its variants have been downloaded nearly 1 million times. RTToolKit SDK empowers programmers to develop open source augmented reality applications. Available at URL: <https://artoolkit.org/about-artoolkit> (October, 2016). FLARToolKit is an ActionScript port of NyARToolKit, a Java/C#/Android port of ARToolKit. Available at URL: <http://www.artoolworks.com/support/library/FLARToolKit> (October, 2016).

¹¹⁶ MXRToolKit: Library of routines to help with all aspects of building mixed reality applications. Available at URL: <http://mxrtoolkit.sourceforge.net/> (October, 2016).

¹¹⁷ ARtag is an AR system where virtual objects, games, and animations appear to enter the real world. Available at URL: <https://web.archive.org/web/20120814082107/http://www.artag.net:80/> (October, 2016).

¹¹⁸ STUDIERSTUBE software framework for the development of AR applications, developed at Graz University of Technology for Windows and is freely available. Available at URL: <http://studierstube.icg.tugraz.at/main.php> (October, 2016).

generation of AR scenes and the development of AR applications. Considering the mobile devices technology, the most significant examples of AR technology initiated in 2007 with the introduction of iPhone, especially the appearance of multiple AR applications, practically all based in GPS and recognition markers. In that same year, Parallel Tracking And Mapping (PTAM) was presented to estimate the position of the camera. In 2008, the Wikitude¹²⁰ Software Development Kit (SDK) and BuildAR¹²¹ were launched. In 2009, the Layar¹²² platform as an AR navigator was launched, using virtual information positioned and superimposed allowing the users to create and publish their own data. In 2010, the Google Googles¹²³ App was presented to search relevant information over image recognition as other Apps such as Augmented ID¹²⁴, individual recognition, and data association. In 2011, the introduction of the Vuforia platform allowed to create AR Apps for mobile devices, based on optical recognition supporting the Android OS and Unity¹²⁵. More recently, a vast number of innovative software (e.g. SDK and multiple Apps using AR, such as Augment¹²⁶ or Locus¹²⁷) and hardware (e.g. Google Glasses) have contributed to the advance of AR technology, allowing it to combine the virtual and the real environments applied to many different purposes.

Riera (2013) presented some AR studies and applications implemented in the past few years and their respective authors, showing the potential of AR technology for domains such as Medicine (Vidal *et al.* 2006; Lamounier Jr. *et al.* 2010; Essig *et al.* 2011; Shamir *et al.* 2011; Paiva *et al.* 2012; Ashab *et al.* 2012); Advertising and Marketing (Honken *et al.* 2012; de Sa *et al.* 2011; Valjus *et al.* 2012); Maintenance and Assembly Operations (Benbelkacem *et al.* 2009; Hincapie *et al.* 2011; S. Henderson & Steven Feiner 2011);

¹¹⁹ OSGART is a library that simplifies the development of AR applications by combining the well-known ARToolKit tracking library with OpenSceneGraph. Available at URL: <http://www.artoolworks.com/community/osgart/> (October, 2016)

¹²⁰ Presented as the world's easiest augmented reality tool to publish AR projects: to the Wikitude app or your very own app. With Wikitude Studio, no programming skills are needed. Simply hop on to your web browser, login and create your first AR project in a minute (Android, IOS and Smart Glasses). Available at URL: <http://www.wikitude.com> (October, 2016).

¹²¹ BuildAR (renamed as Envisage now) is a tool for building Augmented Reality scenes in seconds, with no programming required. Available at URL: <http://www.buildar.org/> (October, 2016).

¹²² Layar: based in Amsterdam, the Netherlands, intends to easily create the user own interactive AR experience. Available at URL: <https://www.layar.com/> (October, 2016). Subsequently, other Apps with similar characteristics were launched, such as the Bionic Eye or Locus.

¹²³ Google Googles: Recognize images and present relevant information. Available at URL: https://play.google.com/store/apps/details?id=com.google.android.apps.unveil&hl=pt_PT (October, 2016).

¹²⁴ Facial Recognition. Available at URL: <https://www.technologyreview.com/s/417655/augmented-identity/> (February, 2016).

¹²⁵ Unity: Renowned throughout the industry as the multiplatform game engine, Unity allows you to target more devices more easily. With Unity, users get one-click deployment to the full range of mobile, VR, desktop, Web, Console and TV platforms. Available at URL: <https://unity3d.com/unity> (October, 2016).

¹²⁶ Augmented: end-to-end augmented reality platform to configure, manage and view 3D content. Available at URL: <http://www.augment.com/> (October, 2016).

¹²⁷ Locus Map was developed by an independent software company called Asamm Software, focusing on the development of mobile applications for the Android platform. Multi-functional mobile outdoor navigation app for sports activities and traveling. Available at URL: <http://www.locusmap.eu/> (October, 2016).

Museums (Woods *et al.* 2004; Zimmermann & Lorenz 2008; Tillon *et al.* 2011); Tourism (Linaza *et al.* 2008; Guttentag 2010; Hsu 2011), especially for great visual experiences; Spatial Planning and Urbanism (J. R. Sánchez & Borro 2007; Allen *et al.* 2011); Building Rehabilitation (Tonn *et al.* 2008) as the impact of edifications in the territory; Interior Design (Harasaki 2001; X. Wang 2008) experimenting indoors object implementation; or Cultural/Historic Heritage (Benko *et al.* 2004; Haydar *et al.* 2008) for virtual reconstructions¹²⁸. This author refers that AR as a tool that superimposes data generated digitally over a real space may produce higher knowledge and better interpretation of the objects and space around us. Consequently, this technology has certain characteristics that are highly relevant for the domains of pedagogy and education, helping to improve the motivation and comprehension, with the advantages of having a collaborative experience (verifying in the real space and promoting a real-time interaction); tangible interactions (possible to change and manipulate scale, position and place of virtual objects allowing an active participation in the formation and communication abilities, considering that mistakes do not have a real consequence). Riera (2013) refers that this technology is already robust enough for teaching activities, especially using mobile devices and as a complement to the traditional methods.

According to Milosavljevic *et al.* (2010), AR systems can be divided into two main categories based on the environments in which they are used:

- Indoor AR;
- Outdoor AR.

Indoor AR systems usually accomplish registration by tracking artificial symbols or marks and representing virtual features in the real environment. An outdoor AR system also uses these marks or optical recognition for vision tracking in order to accomplish stable registration. However, outdoor scenes are usually much more complex and dynamic, making it difficult to capture the natural features in a stable and consistent form. Nevertheless, outdoor AR research is growing in interest considering its large spectrum of applications using geographical information as their basic recourse to provide a digital platform in the AR system (Min *et al.* 2007 in Milosavljevic *et al.*, 2010).

¹²⁸ In Riera (2013).

Incorporation of GIS database into a VR or AR system is potentially suitable for navigation systems, urban and environmental planning, cultural and natural heritage modelling, impact or disaster assessment, military simulation, education, among other applications (adapted from Haklay, 2002 *in* Lin, 2008). The range of AR systems is especially useful to update field maps and databases or to measure, reconstruct, and analyse existing objects or areas from acquired field images (Lin, 2008). A pertinent application of this idea is the ability to take a device, like a smartphone or tablet, to a site and using of its technical features, such as the inbuilt GNSS¹²⁹ (e.g. GPS and/or GLONASS), gyroscope/compass, acceleration sensors, microphone, speakers and (photo/video) camera, accessing virtual information, representations, simulations, reconstructions of that site, directly over the real environment where we are looking. For instance, we can point the camera at the real ancient heritage position and see in the device's display its full virtual reconstruction. It is then possible to walk around the site in the real world and view that representation from different angles and distances, and even to change the reconstruction to experiment with different colours, designs, heights, and so on (adapted from Eve, 2012). Another example is to understand the dynamics of temporal changes in the territory and their characteristics to support both representation and planning (regarding 3D in space and time, concerning observation, reconstruction or simulation), when compared the (spatial-temporal) models aligned and merged with the real view in the device's display.

3. Communication Networks

Regarding Guber's (1996) reflexions, iconic images¹³⁰ are characterized for their semantic, i.e. what they represent, and have existed as cultural manifestations and ways of communication since the Palaeolithic drawings. These representations have been improved by pictographic technics¹³¹, photographs, mass media television and cinema, videogames, and cyberspace¹³².

¹²⁹ The physical conditions on site, GNSS systems and device features (e.g. computation capacity) can influence the precision and accuracy.

¹³⁰ Image-Scene (Isomorphic and Ostensive) and Image-Labyrinth (Sensory and Symbolic).

¹³¹ We can find examples in religion, allowing the revival of the memory of historical facts, encouraging imitation of the characters represented and veneration; or secret societies and many professional codes and icons.

¹³² Introduced by writer William Gibson in 1984, defining appropriately as "a consensual hallucination", adding that it is not really a place. It is not really a space. It is a conceptual space. Gubern, 1996.

The development of Information and Communication Technologies (ICT), and more specifically the Internet¹³³ and the World Wide Web¹³⁴ (henceforth simply Web), has originated major digital changes that have revolutionized the concept and usage of spatial representations. The production of geographical information and cartography is no longer exclusive to professionals, considering, for instance, the availability of Digital Globes (Goodchild, 2001; 2007 *in* Marques, 2009) or Geobrowsers¹³⁵ (e.g. Google Earth, Yahoo Maps, or the Microsoft Bing Maps). This democratization of digital cartography is partly due to the development of the GeoWeb, which refers to the merging between the Web, Geographic Information Technologies and geospatial data, presently relying on a continuous evolving Web¹³⁶ infrastructure (Roche *et al.*, 2011¹³⁷). Thus, regarding the main communication networks, the Internet and the Web constitute the essential basic infrastructure and resource for the gradual improvement of digital representations, and therefore GIT developments (including their applications to heritage and its value for the main agents in the different domains). GIS usually consumes enormous data resources and is therefore an excellent example to understand the importance of communication networks such as Internet, providing information on demand. In connection with the Internet, it would be extremely hard to have an application (mobile or not) with all the data, for example of the world street or imagery maps at all scales available. However, it is applied to any kind of information that heavily consumes the resources of a device. To illustrate this idea, it might be extremely relevant for mobile applications to divide essential data available in the App installation and complementary data constantly available in the Cloud via the Internet.

¹³³ The Internet is a massive network connecting millions of computers worldwide (Peng & Tsou, 2003).

¹³⁴ The World Wide Web is a system of interlinked digital documents and programs that can be accessed via the Internet.

¹³⁵ Analogous to a Browser. Geo-Browser may be understood as a geographic browser or referent to spatial data (Marques, 2009).

¹³⁶ Such as the concept of WEB 2.0 (understood as a more interactive Web or one that uses technology beyond the static pages of earlier websites) or Cloud Computing (defined as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” (National Institute of Standards and Technology, 2011, available at URL: <http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf> (June, 2013).

¹³⁷ Available at URL: <http://link.springer.com/article/10.1007/s10708-011-9423-9#page-2> (June, 2013).

3.1. The Internet and the World Wide Web

The Internet did not gain popularity until the 1990s, although it was complex to use, its content was not nearly as rich as it is today, and its users were mostly restricted to research institutes and government agencies. The advent of the Internet and the Web represents a gigantic milestone in the evolution of human civilization, allowing an unprecedented information-based society and changing the human behaviour, especially when it comes to sharing information/knowledge and communication, metaphorically developing one virtual world parallel to the real one¹³⁸. The field of GIT and digital representations is no exception (ESRI, 2010¹³⁹). While the progress of ICT has highly influenced the expansion of the Internet, the Web and GIT, their development provided fast access to various geographic databases. The Internet and the Web have become an immensely valuable information resource and been widely recognized as an important means to rapidly disseminating information and acquire spatial data from diverse sources (Crowder, 1996; Greenwood, 1997; Green & Massie, 1997; Plewe, 1997; Rohrer & Swing 1997; Craig, 1998; David *et al.*, 1998; Doyle *et al.*, 1998; Carver, 2001; Zhu, 2001; Pundt & Bishr, 2002; Peng & Tsou 2003 *in* Zhang, 2004).

Since the creation of early GIS, different types of software¹⁴⁰, Spatial Data Infrastructures (SDI), geographic information models and formats, have been evaluated and adapted to the development of ICT and especially the Internet and Web resources. Consequently, GIS offers several online solutions¹⁴¹ to share spatial data, mostly for viewing, analysing, manipulating, or downloading data (Peng & Zhang, 2004; Zhang *et al.*, 2003 *in* Zhang, 2004). However, this relatively abundant offer has raised numerous difficulties regarding data interoperability, communication, and integration. The geographical information based on this wide range of software, could not communicate without data conversion, an imperative to exchange information and share computational geo-database resources. The data interchange, assisted by the advances of network technologies is then vulnerable, considering the incompatibility of a variety of data models

¹³⁸ Sometimes, the virtual world becomes even more present than the real one (e.g. social relations and communication forms through e-mail, stakeholders' online lists/forums, official websites or social networks; online promotion, submission and communication of documents such as articles, scholarships applications or job opportunities or even the huge investment/market in advertising products/sales, sometimes exclusively online, associated to a progressive usage of Internet).

¹³⁹ Available at URL: http://downloads2.esri.com/ESRIpress/images/188/115391_WebGIS_Chapter01.pdf (June, 2013).

¹⁴⁰ Both proprietary software of commercial vendors or open source software.

¹⁴¹ Such as ESRI MapObject IMS and ArcIMS, AutoDesk's MapGuide, Intergraph's Geomedia WebMap, MapInfo's MapXtreme, GE SmallWorld's Internet Application Server and ER Mapper's Image Web Server.

and formats used (Choicki, 1999; Zhu, 2001 *in* Zhang, 2004). Thus, distributing interoperable geographic information became imperative (Doyle, 1997; OGC, 1998; Ackland, 1999; Bennett, 2000; Zhu, 2001; Zhang *et al.*, 2003 *in* Zhang, 2004). The use of open standards, protocols and technologies suggests the potential to overcome the difficulties of data interoperability and therefore simplifying the feature-level spatial data sharing over the web. Various organizations and initiatives such as World Wide Web Consortium (W3C¹⁴²), International Organization for Standardization (ISO¹⁴³), OGC or the INSPIRE¹⁴⁴ initiative, have dedicated to developing and promoting the adoption of open standards to achieve data and metadata interoperability, simultaneously contributing to reduce the duplication of datasets and providing catalogues of relevant available geographic information. W3C provides the information technology baseline standards, ISO/TC211 has developed abstract nevertheless detailed baseline standards, the OGC focuses on the implementation of oriented standards that fit into the abstract frameset defined by ISO/TC211, and the INSPIRE initiative intends to implement a European Spatial Data Infrastructure (adapted from Kresse, 2004 *in* Zhang 2004). Currently, GIS communities, vendors and open source projects are adopting the open standards developed by W3C, ISO/TC 211 and OGC. The rapid development and adoption of open standards has provided a stable foundation for making GIS interoperable. The recent development in Web Services¹⁴⁵ makes the construction of interoperable GIS possible. With Web Services it became possible for applications to acquire and integrate spatial data from heterogeneous sources in real-time over the Web. Thus, the Internet and the Web established the foundations for ubiquity, lower risks of obsolescence and isolation, higher flexibility, reduction of costs and accessing geographical information (in real-time), through an inner network form, reforming the idea of an existing physical support, such as CD-ROM, pen drives and systematic versions of cartographic series datasets (adapted from Anderson & Moreno, 2003 *in* Zhang, 2004).

¹⁴² The W3C is an international community where member organizations, a full-time staff, and the public work together to develop Web standards (W3C, 2012, available at URL: <http://www.w3.org/Consortium> June, 2013).

¹⁴³ ISO is the largest developer of voluntary International Standards in the world. International Standards provide state of the art specifications for products, services and good practice, contributing to make the industry more efficient and effective (Available at URL: <http://www.iso.org/iso/home/about.htm> June, 2013). Regarding ISO, standards from the Technical Committee 211 (TC/211), concerning geographic information are extremely relevant (more information available at URL: <http://www.isotc211.org/> June, 2013). It is also important to refer that CEN / TC 287 (European committee for Standardization / Technical Committee) will support the consistent use of geographic information in Europe in collaboration with ISO/TC211 and the INSPIRE initiative (Marques, 2009).

¹⁴⁴ Directive 2007/2/EC from the EU Parliament and the Council establishes an Infrastructure for Spatial Information in the European Community (INSPIRE) available at URL: <http://inspire.jrc.ec.europa.eu> (June, 2013).

¹⁴⁵ Such as: WMS, WFS, WCS.

The combination of the Web and geographic information science has grown¹⁴⁶ into a rapidly developing field, stimulating people to take advantage of the Web (ESRI, 2010). Internet GIS become a research and application area that utilizes the networking systems (including besides the Internet, wireless communication and intranets) to promote the access, processing and dissemination of geographic information and spatial analysis knowledge. The Internet supports GIS in three major areas (Peng & Tsou, 2003¹⁴⁷):

- GIT data access, considered an infrastructure that provides access¹⁴⁸ to acquire geographic information, e.g. through visualization, downloading, or web service catalogues¹⁴⁹, available from different data providers [regardless of the platforms used: e.g. desktop/laptop computers, Personal Digital Assistants (PDA), tablets and mobile phones];
- Dissemination of geographical information, enabling a wider audience to access directly spatial data and project results, conducting the users to search on-line, make queries, and analyse spatial information;
- GIS processing/modelling, enhancing the accessibility and reusability of GIS analysis tools¹⁵⁰ by dynamically downloading or uploading GIS processing components, so users can work on GIS data interactively, even without installing GIS software on their local machines¹⁵¹.

The multilateral effect and intimate relation between ICT, Internet, Web, GIT and their self-influenced development, evolved from Mainframe GIS to Desktop GIS or Distributed GIS¹⁵², which includes Mobile GIS or Internet GIS (Peng & Tsou, 2003). Distributed GIS take advantage of the Internet as a giant distributed system so that GIS data and analysis tools can reside in different locations (computers and/or servers and/or

¹⁴⁶ From static raster maps, interactive vector maps (with alphanumeric information databases); visualizers and platforms WebGIS, or GeoWeb Services, such as Web Map Service, Web Features Service or Web Coverage Service, including their normalization and standardization, Marques (2009).

¹⁴⁷ Available at URL: http://www.google.pt/books?hl=en&lr=&id=sk5UHK-FJM8C&oi=fnd&pg=PR25&dq=geographic+information+mobile&ots=FvTugmIMac&sig=03oA21CHPOQmZneknovhF6k7kE8&redir_esc=y#v=snippet&q=%22gis%20data%20access%22&f=false (July, 2013).

¹⁴⁸ With or without coasts, even if supposedly significantly reduced.

¹⁴⁹ E.g. the Portuguese iGeo Portal (www.igeo.pt), launched in 2014 or Monumentos website (IHRU), catalogues (www.monumentos.pt) of geographical information (about heritage).

¹⁵⁰ Reducing duplication of systematic tasks and research by contributing to knowledge creation.

¹⁵¹ Resorting for example to portable software or to Cloud Computing.

¹⁵² Relies on the Internet and wireless networks for data and processing communication, which allows the user to access geographical information and GIS analysis tools from anywhere with access to Internet or to the Cloud.

in the Cloud¹⁵³). Users can access those data and applications on demand from anywhere. Distributed GIS can take advantage of these distributed data systems and potentially query and extract these distributed databases or even geospatial analysis tools *in situ* rather than simply download the data directly into end user local machines or devices to combine with local data. Because it is a distributed system, it is dynamically linked to the data sources, allowing it to be more capable of linking real-time information (e.g. gathering real-time satellite information, images or events/hazards, such as traffic movements, earthquakes, fires, floods, pollution).

The challenge that Distributed GIS face is the ability to access many forms of GIS data and functions in the heterogeneous environment, to be able to access and share remote GIS data and functions, answering the request of Internet GIS programs interoperability (Bishr, 1996 *in* Peng & Tsou, 2003). The Open Geodata Interoperability Specification and Geography Markup Language (GML) by the OGC are attempting to lay the base standards for GIS interoperability (Peng & Tsou, 2003).

The OGC and the Web3D Consortium¹⁵⁴ have been working together for digital tree-dimensional geographical representations, building cohesive and durable standards. This effort provides a membership sharing and enables OGC and Web3D Consortium members to collaborate in cooperating Working Group development activities, aiming to align the Web3D Consortium's X3D (eXtensible 3D) standard with OGC standards to improve location-based 3D visualization (Hetherington, 2006). Considering the evolution to enable three-dimensional models to be displayed over the Internet, the Virtual Reality Modelling Language (VRML) was developed in the early 1990s and more recently a new standard, X3D, has been established by the Web3D Consortium. This new standard received International Standards Organization (ISO) approval in August 2004.

The Internet is an infrastructure that can hosts all type of information and applications (usually based on the client/server model) as well as additionally more advanced client/server applications that are yet to emerge (Peng & Tsou, 2003). The benefits of the association between GIT tools and the use of these types of networks (such

¹⁵³ Cloud Computing consists of interchangeable parts providing computation, data storage, and communications. This vast system is cheaper to operate than many individual computers scattered among different businesses and agencies, because both the hardware and the administrative staff can be utilized much more efficiently (Garfinkel, 2011, available at URL: <http://www.technologyreview.com/news/425623/the-cloud-imperative/> July, 2013).

¹⁵⁴ Web3D is a “nonprofit organization that develops and maintains the X3D, VRML, and H-Anim international standards. These are 3D graphics file formats and run-time specifications for the delivery and integration of interactive 3D data over networks. Web3D Consortium members work together to produce open, royalty-free and ISO-ratified capabilities for the Web.” (Web3D Consortium, 2013, available at URL: <http://www.web3d.org/realtime-3d/> July, 2013).

as the Internet and the Web and/or Cloud computing) constitutes the essential basis to access and transmit distributed data and analysis tools, conducting spatial analysis and creating multimedia and multidevice GIT digital 2D, 3D and 4D (re)presentations (adapted from Peng & Tsou, 2003).

4. 3D and 4D Mobile GIT, Including Virtual and Augmented Reality

The mobile market is expanding and exceeding by far computer sales. Within this scenario, smartphones and tablets are undoubtedly the most interesting platforms, since they combine in a small device features and functions with multiple advantages, such as portability (size and weight); battery life (longer than laptops); computational and graphical capabilities (when compared with traditional phones); wide range of connectivity spanning from 3G, 4G, GPRS¹⁵⁵, HSPA(HSPA+)¹⁵⁶ to Wi-Fi; Bluetooth and Infrared interfaces, built in GPS/GLONASS receivers (plus Assisted capability); electronic compass; gyroscope; accelerometers; touch screen capability; light and proximity sensors; front and rear cameras; microphone; speaker; possibility to run non-proprietary Operating Systems – OS (such as Android OS, iPhone OS or Windows Mobile); and a varied offer of applications and functions with or without cost for the end user and further developments¹⁵⁷ (adapted from Magliochheti *et al.*, 2012¹⁵⁸). Progress in geographic information acquisition and development (hardware and software) has allowed for innovative perspectives for territorial management using 3D, enabling advanced possibilities of visualisation and analysis in virtual, immersive, or mixed environments (Valencia *et al.*, 2015).

Three-dimension (3D) DR are generating innovative forms of visualisation and conceptualisation in the field of territorial and urban management enabling the observation



Fig. 21 – 3D modelling and visualization using anaglyph glasses (university NOVA of Lisbon). Image by the author. 2016.

¹⁵⁵ System for mobile communication network (data service).

¹⁵⁶ Mobile protocols.

¹⁵⁷ Such as hologram or interactive projection capabilities, which may considerably reduce the size of the device, regarding the display and operating (through the projection).

¹⁵⁸ Available at URL: <http://link.springer.com/article/10.1007/s12008-012-0150-3#page-1> (June, 2013).

of objects and structures at different distances, angles and scales (space/time – 4D). The concept of Augmented Reality is often referred to as the enrichment of the existing world through the virtual environment, expanding it without requiring the observer to change the sense of presence in reality as opposed to total virtual immersion. This (mixed) environment is often generated on site using mobile platforms. The AR environment, based on GIT and Mobile Platforms, contributes to the construction of external representations. 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, which was 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) has introduced a flexible, low-cost and rapid response as an alternative to other traditional methods, such as ground acquisitions and manned vehicles, allowing to collect data to generate diverse types of geographical information products, and particularly very detailed 3D models, practically on demand. The fast acquisition data, high frequency attainment, simplicity in setting the flight parameters and operation, combined with very high resolution cameras, GNSS systems (predetermined flights and georeferenced outputs), and powerful data processing algorithms/software, constitute some of the main features behind the success of this technology (Nex & Remondino, 2013).

3D point cloud data automatically generate 3D models, including Digital Terrain Models (DTM - simple 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 (Tenedório *et al.*, 2014). Presently, there is an enormous variety

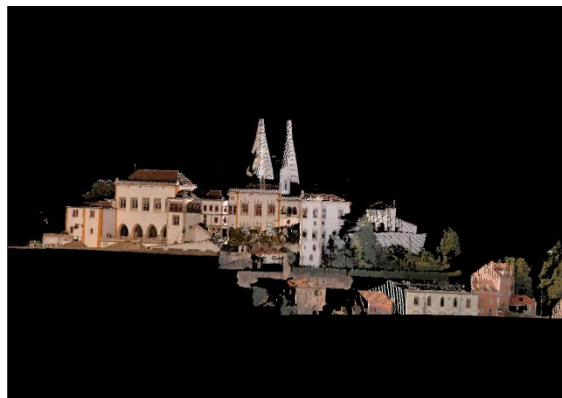


Fig. 22 – 3D point cloud from National Palace in Sintra. Image by the author. 2003.

of tools able to acquire 3D information, and at the same time, the solutions for rendering and displaying it are at an advanced stage of development (Valencia *et al.*, 2015).

Using mobile devices for exploring and interacting with the user's physical environment is among the most promising improvements for commercially successful future telecommunication services and applications. This trend is confirmed by the rollout of latest mobile devices equipped with advanced navigation features (like built-in GPS¹⁵⁹). The positioning features are essential for mobile devices that need to identify their accurate position systematically, and resorting to geographical information offering multiple solutions to operate interactively answering several requests, such as viewing the position in a map; multiple navigation and transportation types and schedules (vehicles or on foot); or showing nearby objects in different representational ways¹⁶⁰. This capability is especially relevant in mixed environments where the device needs to present virtual information in the real place (or vice versa) and thus it may be considered as the fundamental base connection feature between the synthesized and the real world. Presently, numerous producers of geographical information¹⁶¹ are developing location-based services, offering a great number of basic services for mobile applications. These solutions are often based on existing GIS tools and complementary functionalities (Schilling, 2003¹⁶²). Recent research projects are dealing with how mobile devices can be used as an interface with this growing body of geographical information to enable direct access and interaction for the user near the environment and their surroundings. The development of location-based data has moved cyber-information to the real place (Sui & Goodchild, 2011). Currently, new forms of georeferenced data and services, such as map-mashups¹⁶³ or navigation systems¹⁶⁴, are emerging almost on a daily basis (adapted from Fröhlich *et al.*, 2008). Thus, the idea of combining geospatial information with mobile communicational, informational and representational technologies is growing in interest concerning the agents (especially in the Academia and Industry) and user communities, applied to the different existing domains.

¹⁵⁹ Fröhlich *et al.* (2008).

¹⁶⁰ E.g. the Portuguese iGeo – Património App for IOS and Android (launched in 2014).

¹⁶¹ Also driven by virtual globes, such as Google Earth or Microsoft Virtual Earth.

¹⁶² Available at URL: <http://webcache.gisline.no/documentation/imc2003-schilling-et-al-final.pdf> (June, 2013).

¹⁶³ Mashups typically function through an application programming interface (API), which facilitates communication between technologies. Mapping mashups interoperate with an online mapping service (e.g. Google Maps or Yahoo Maps), combining data with the mapping application's locating service, available at URL: <http://net.educause.edu/ir/library/pdf/eli7016.pdf> (June, 2013).

¹⁶⁴ Such as NDrive, which was founded as a spin-off of a digital map player in 2007, has headquarters in Porto, Portugal. NDrive is an independent developer and provider of state-of-the art Turn-by-Turn navigation software for Smartphones and Personal Navigation Devices and has developed a customer base of several million active users in more than 30 countries. More information available at URL: <http://www.ndrive.com/about> (June, 2013).

Since the popularization of the Web in the early 1990s, GIS have developed towards more powerful, flexible and mobile platforms, being able to share and communicate geographic knowledge (Goodchild, 2003). GIT are traditionally involved in mapping the world in two spatial dimensions, focusing on aspects related with geographic territories that are essentially static, such as topography, soils, and land cover (Goodchild, 2011). Two-dimensional digital representations of a 3D environment require cognitive resources and topological reasoning in order to read the mobile representation and relate it to reality. The development of new techniques that bring together location-aware portable devices and visualization of interactive 3D representations is interesting and it is an exciting pervasive environment for users.

Examples of that are the recent sequences of conferences such as Virtual Cities and Territories – VTC¹⁶⁵, or the Mobile World Congress¹⁶⁶. However, there are severe technical and technological limitations that have precluded the widespread adoption of 3D representations on portable devices. Computational resources in these tools are usually

smaller than the hardware commonly used in normal computers (adapted from Noguera *et al.*, 2012a¹⁶⁷). With the advent of low energy-consumption Graphic Processing

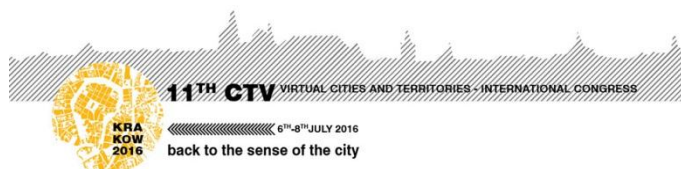


Fig. 24 – 11th VTC held in Krakow, Poland (2016).

Units (GPU), the graphics capabilities of mobile devices are being boosted, opening new perspectives for the development of interactive 3D applications that were inconceivable just a few years ago. As a result, mobile devices manufacturers have rapidly adopted this new hardware and the market is now demanding new applications, featuring advanced 3D graphics and interactive virtual worlds (Noguera *et al.*, 2012b¹⁶⁸).

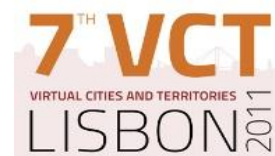


Fig. 23 – 7th Virtual Cities and Territories (VTC), held in Lisbon (2011).

¹⁶⁵ Proposed as an annual meeting point to present virtual model developments and tools for representing the built environment. The first VCT took place in Barcelona in 2004, followed by other cities in sequential order: Concepción, Bilbao, Guadalajara, Barcelona, Mexicali, Lisboa, Rio de Janeiro and Roma (already in 2013). It is also important to refer that this project was born within CPSV / UPC, to which this thesis is associated. More information available at URL: <http://www.9cvtroma2013.com/en/index.html> (June, 2013).

¹⁶⁶ Conference involving the mobile market company leaders, held annually in Barcelona. More information at URL: <http://www.mobileworldcongress.com/industry-learning/> (June, 2013).

¹⁶⁷ Available at URL: <http://link.springer.com/article/10.1007%2Fs00779-012-0598-y#page-2> (June, 2013).

¹⁶⁸ Available at URL: <http://link.springer.com/content/pdf/10.1007%2Fs00779-012-0595-1.pdf> (June, 2013).

High-quality geographic data sources are becoming increasingly more consistent as a resource that contributes to territorial management and the creation of detailed 3D models of the real environment (Goetz, 2012¹⁶⁹). Prototypical representations for mobile devices can be developed in order to experiment different input types depending on the device technical features. Examples of this are the digital representations on low-end devices, which may be rotated using the numerical or cursor keys; if the device is equipped with acceleration sensors, then the view can be adapted to the measured angle; or if a digital compass enables a really intuitive orientation it can rotate the view mimicking the user's movement. Independent from the chosen type of interaction, the importance is the possibilities of adaptation of representation prototypes to these devices in which the Point Of Interest (POI) closest to the display can be dynamically selected and activated pressing a certain button (Fröhlich *et al.*, 2008). The availability of extensive and detailed 3D models, offers completely new visualization possibilities on mobile devices, e.g. in navigation or guidance (video or audio) and representation of geo-referenced content. Presently, there have been major advances in the ability to characterize and monitor the world in real-time, through the use of networks of sensors and information through the Internet. Thus, the third spatial dimension is becoming more important in an extensive range of applications and it seems likely that in the future geospatial technologies will operate in the full four dimensions (three spatial dimensions plus time) of the geographic environment (Goodchild, 2011¹⁷⁰).

VE and VR representations were until now limited to desktop computers. Nowadays, they can take full advantage of the unique attributes provided by mobile computing (as the examples referred before, such as portability, connectivity, context-awareness, and multimodal interfaces). However, these advantages have created a major challenge considering the capacity to improve their performance that is affected severely by their characteristics¹⁷¹. Mobile devices must be small and powered by batteries, which limits their computing power and graphics capabilities (when compared with a current desktop computer). Thus, power-efficient and adequate techniques will be required, considering the



Fig. 25 – VR glasses for total immersiveness.

¹⁶⁹ Available at URL: <http://www.igi-global.com/article/content/66861> (June, 2013).

¹⁷⁰ Available at URL: <http://www.geog.ucsb.edu/~good/papers/499.pdf> (June, 2013).

¹⁷¹ Even if in constant improvement, considering that any smartphone has more computing capability than early computers [e.g. such as ENIAC, considered as the first computer, announced in 1946 and occupying around 162 m² (Marques, 2009)].

applications requirements for handling larger and more complex virtual 3D scenes. The small display sizes coupled with the limited input technologies have motivated the study of new ways of interacting with 3D applications (Noguera *et al.*, 2012b). In the AR system, the main key problem is to determine the position and orientation of the camera to enable overlaying the real world image with virtual 3D digital representations (Chen *et al.*, 1999¹⁷²).

However, while VE or VR require features that are more associated with immersiveness,



Fig. 26 – AR glasses enriching the real world with synthetic digital representations.

usually demanding more static background and higher level of realism in order to embrace a larger amount of human senses to activate the user's absence from that place and feel existing in the VE; by contrast, AR requires a more dynamic system that is portable and in continuous interaction with the real world in order to view the physical environment augmented with digital representations (Pinto *et al.*, 2013¹⁷³).

Recently, users were only able to carry out very limited modifications on the available applications offer, modifying only some symbolism or types of augmentations. However, several applications have evolved, which enable users to define their own AR, through their geographic datasets and other digital representations. Over web interfaces or creation modules directly integrated into applications, certain solutions allow users to build their own augmentations of the territory¹⁷⁴, available as AR search engines. These applications offer users the ability to define layers of information or POI by themselves. When these layers are activated in the interface of the different respective applications, the device uses the hardware capability to show the position of the POI on the mobile screen (this representation has indeterminate ways of presentation). Managing their own information or searching/requesting the Internet to gather the latest available services of information, the user can obtain not only the current position and the nearest location of relevant POI, but also ways to navigate towards the selected POI, learn, observe, present, simulate, or reconstruct digital representations¹⁷⁵. Thus, allowing each individual user to create their own Augmented Territory on demand, these tools provide the basis and

¹⁷² Available at URL:

http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=815705&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxppls%2Fabs_all.jsp%3Farnumber%3D815705.

¹⁷³ Example given considering visualization through 3D Augmented Reality.

¹⁷⁴ E.g. Layar, Locus, Wikitude, Tonchidot, Qualcomm or Junao.

¹⁷⁵ Through image and sound.

constitute a powerful ally to support decision-making, simultaneously contributing to technical-scientific knowledge and human development (adapted from Hugues, 2011).

5. Cultural Heritage Representations

Heritage¹⁷⁶ preservation includes mainly research, field exploration, archive management, conservation, data visualization, and utilization. Technology has been playing an important role in a transversal way, especially in terms of data acquisition, management, and visualization¹⁷⁷. Considering the advances of technology, their contributions for representational heritage (register and visualization) and their relevancy for the cultural aspects of humanity, it is possible to synthesize some main chronological events and relevant documents regarding this concern.

The acquisition of precise information has been involved in the knowledge of the natural and built environment. With the production of usable photographs (heritage representations) by Niepce & Daguerre in the beginning of the 19th century (Mateus, 2007), graphic representations (besides painterly drawings, paintings or other form of art representations) of the most valuable constructions could be gathered, stored, and visualized. In fact, “one of the first applications of the image was the catalogues of monuments and their surroundings. Meydenbauer remains the most representative author of them. Thanks to him and his work many monuments could be reconstructed after the World Wars” (Andrés & Pozuelo, 2009:105). This awareness indicates the importance of cultural heritage representations as documents themselves and their value for the agents in the several domains.

In 1931, The Athens Charter for the Restoration of Historic Monuments expressed the wish that “Each country, or the institutions created or recognized competent for this purpose, publish an inventory of ancient monuments, with photographs and explanatory notes”¹⁷⁸. This wish reflects the need of preserving faithfully the memory of the object, regarding its representation and recommending that “the historic and artistic work of the past should be respected”, referring also that “Modern techniques and materials may be

¹⁷⁶ Concept identified at the Convention Concerning the Protection of the World Cultural and Natural Heritage held in 1972, from United Nations Educational, Scientific and Cultural Organization (UNESCO) available at URL: <http://whc.unesco.org/en/conventiontext> (July, 2011).

¹⁷⁷ Example of the Portuguese iGeo Portal (launched in 2014) or the Monumentos website (from IHRU/SIPA) catalogues about heritage.

¹⁷⁸ Available at URL: http://www.icomos.org/docs/athens_charter.html (July, 2011).

used in restoration work”¹⁷⁹, thus engaging the use of new approaches and techniques and the available technology.

Since World War II, policies, techniques and science of the modern conservation movement have evolved in an international context, increasingly involving all sectors of society, with the establishment of United Nations Educational, Scientific and Cultural Organization (UNESCO, 1946) and the International Council of Museums (ICOM, 1946), followed by the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM, 1956), and later the International Council on Monuments and Sites (ICOMOS, based on the principles enshrined in 1964 with the Venice Charter), promoting international collaboration and policy guidelines applicable to different realities (Jokilehto, 1998). These strategies often resort to the use of existing resources, techniques and accessible technology to acquire, record, and promote the heritage through their representations.

The Venice Charter (1964) determines that

“In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs (regarding the importance of representations for the heritage management). Every stage of the work of clearing, consolidation, rearrangement and integration, as well as technical and formal features identified during the course of work, should be included. This record should be placed in the archives of a public institution and made available to research workers (showing the importance of registering, cataloguing and documenting heritage through their representational information). It is recommended that the report should be published”¹⁸⁰

concerning the importance of the documentation for preservation, restoration and publication.

In 1969, the ICOMOS and the International Society of Photogrammetry and Remote Sensing (ISPRS) joined efforts and created the International Committee for Heritage Documentation (CIPA), with the main objective of improving all the methods for surveying, considered as an important contribution to record and monitor cultural heritage (for preservation, restoration, support, and research)¹⁸¹, emphasizing the value of heritage representations.

¹⁷⁹ Available at URL: http://www.icomos.org/docs/athens_charter.html (July, 2011).

¹⁸⁰ Available at URL: http://www.international.icomos.org/charters/venice_e.htm (July, 2011).

¹⁸¹ Available at URL: <http://cipa.icomos.org/OBJECTIVES.HTML> (December, 2011).

The Convention Concerning the Protection of the World Cultural and Natural Heritage (1972 - World Heritage Convention; UNESCO General Conference) drew attention to the problem of the deterioration or disappearance of cultural or natural heritage and their protection at national level often remains incomplete because of the lack of (economic, scientific and technological) resources even if the importance of safeguarding them is evident for all mankind (WHC, 1972). In fact, the importance of “identification, protection, conservation, presentation and rehabilitation of the cultural and natural heritage”¹⁸² is constantly mentioned. Lu & Pan (2010:3) noted that “Authenticity and integrity are two important concepts conceived in the Convention [...], and also are the basic objectives of cultural heritage preservation”. These statements argue for the importance of investment especially regarding the technological resources needed to accurately document the cultural heritage, not only as a contribution towards knowledge, but also avoiding the deterioration of what this information (re)presents, concerning preservation. In this General Conference form UNESCO, Cultural Heritage is defined¹⁸³ as:

- “Monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science;
- Groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science;
- Sites: works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view.”

The European Charter of the Architectural Heritage (1975, Amsterdam) refers that architectural heritage is “a capital of irreplaceable spiritual, cultural, social and economic value”, calling for an “integrated conservation depending on legal, administrative, financial and technical support”¹⁸⁴. These aims were strengthened by the Convention for the Protection of the Architectural Heritage of Europe signed in Granada, in 1985, identifying

¹⁸² Available at URL: <http://whc.unesco.org/en/conventiontext> (July, 2011).

¹⁸³ Available at URL: <http://whc.unesco.org/en/conventiontext/#Article1> (January, 2017).

¹⁸⁴ Available at URL: http://www.icomos.org/docs/euroch_e.html (January, 2012).

the need for all conservation issues to be considered in urban and regional planning, advising for coordinated European actions on the matter. Thus, the importance of using technical and scientific resources applied to cultural heritage is referred.

When the ICOMOS¹⁸⁵ launched the “Principles for the Recording of Monuments, Groups of Buildings and Sites” in 1996, the term “Recording” was defined as “capture of information which describes the physical configuration, condition and use of monuments, groups of buildings and sites, at points in time, and it is an essential part of the conservation process”. This document also establishes the principal reasons to record “Monuments, Groups of Buildings and Sites”, considering: essential actions, level of detail in providing information, and definition of priorities for recording¹⁸⁶. Furthermore, the following issues were also developed: Responsibility for Recording, Planning for Recording, Content of Records and Management, Dissemination and Sharing of Records. These principles lead directly to the fundamental issue of the important use of technological, technical and scientific means available to capture, record, plan, manage, and spread cultural information.

In the ICOMOS International Cultural Tourism Charter, approved in 1999, Cultural Heritage is defined as “an expression of the ways of living developed by a community and passed on from generation to generation, including customs, practices, places, objects, artistic expression and values. Cultural Heritage is often expressed as either *Intangible* or *Tangible Cultural Heritage*”¹⁸⁷.

The International Conference on Cultural Heritage Management and Urban Development, which was held in Beijing (China) in July 2000 (UNESCO, World Bank and China Government) highlighted the relevance of regulations as a prerequisite for the protection of cultural heritage that need to involve both decision-makers and local communities. As Luxen (2000) in Giaoutzi & NijKamp (2006:203) stated in Beijing, the preservation of cultural heritage has been usually perceived as a “public expenditure therefore excluded from cost/benefit analysis”. These authors further state that a new

¹⁸⁵ The International Council on Monuments and Sites (ICOMOS) provides the World Heritage Committee with evaluations of cultural and mixed properties proposed for inscription on the World Heritage List. It is an international, non-governmental organization founded in 1965, with an international secretariat in Paris. Together with The International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) and The International Union for the Conservation of Nature (IUCN), constitute the Advisory Bodies of named in the UNESCO World Heritage Convention to the Committee in its deliberations. More information available at URL: <http://whc.unesco.org/en/advisorybodies/> (July, 2011).

¹⁸⁶ Adapted from the document, available at URL: http://www.international.icomos.org/charters/recording_e.htm (July, 2011).

¹⁸⁷ ICOMOS, ICTC, 2002, available at URL: <http://webcache.googleusercontent.com/search?q=cache:9PpaYP3apuoJ:www.charts-interreg4c.eu/app/download/5796628919/ICOMOS%2BInternational%2BCultural%2BTourism%2BCharter%2B1999.pdf+&cd=6&hl=pt-PT&ct=clnk&gl=pt> (January, 2017).

strategic attitude needs to be developed, where “preservation and restoration works may be perceived as real investments”; that the acknowledgment of the valuation of cultural heritage is strategic in order to modify the current uninterested attitude; and that the role that valuation methods can play is therefore contributing towards more integrative and policy-oriented actions.

The several events, treaties or documents mentioned above reveal the continuous need of preserving heritage through technology, especially applied to gather, record, manage, and disseminate heritage representations, documentation and other information. Presently, the increasing use, interest and heterogeneity of GIT available on cultural heritage are leading to a vast number of international initiatives. The growing number of conferences, seminars, symposiums, workshops, programs, and many other initiatives held worldwide¹⁸⁸ discloses not only the current focus on this issue, but it also indicates that digital representations are becoming gradually more important for the preservation of heritage. In the context of these events, several approaches and available proceedings establish cooperation channels and knowledge connections between different fields that involve cultural heritage preservation. The publication of *Digital Heritage (2010)* comprises the proceedings of the Third International Euro-Mediterranean Conference (EuroMed, 2010)¹⁸⁹, held in Cyprus, reflecting “the benefits of exploiting modern technological advances for the restoration, preservation and e-documentation of any kind of cultural heritage” (Ioannides *et al.*, 2010:VI).

Following the major concerns expressed in this and other events and initiatives, the European Parliament and the Council launched Directive 2007/2/EC¹⁹⁰ that establishes an Infrastructure for Spatial Information in the European Community (INSPIRE) to ensure the compatibility and usability of spatial data in a community and trans-boundary context, requiring common implementing rules (metadata, data specifications, network services, data and service sharing and monitoring and reporting) for several spatial data themes,

¹⁸⁸ Such as the “*Conference on Cultural Heritage and New Technologies*” URL: http://www.stadtarchaeologie.at/?page_id=889; The “*Digital Media and its Applications in Cultural Heritage*” (URL: <http://www.csaar-center.org/conference/DMACH2011>); The several European Association of Remote Sense Laboratories (EARSeL) Symposia with special emphasis on topics usually invited in the area of “*Heritage and New Technologies*” (URL: <http://www.earsel.org/symposia/2011-symposium-Prague/topics.php>); And the growing number of conferences taking place considering Virtual Cities, such as the “*International Workshop for Virtual Historic Cities*” (held in Lisbon, 2010 URL: http://www.uevora.pt/index.php/a_ue/destaques/virtual_historic_cities_reinventing_urban_research), or the “*International Conference on Virtual Cities and Territories*” (URL: <http://www.7vct.dec.uc.pt/>). To protect the values upheld by several international treaties, such as those set out by UNESCO and its Advisory Bodies, mandated by the World Heritage Convention: ICCROM, ICOMOS and IUCN, inventories of cultural and natural heritage will be necessary (e.g., monuments, historic centres, archeological sites, biotic species, habitats or landscapes). In order to complete this task proper data and documentation will be necessary (all website links in this footnote were last accessed on July 10, 2011).

¹⁸⁹ Available at URL: <http://www.informatik.uni-trier.de/~lev/db/conf/euromed/euromed2010.html> (July, 2011).

¹⁹⁰ INSPIRE Directive (14 March, 2007) available at URL: <http://inspire.jrc.ec.europa.eu> (January, 2012).

which include (among others): Protected Sites and Buildings (INSPIRE directive, annexes I and III, respectively). The main priorities defined in the Work Program (WP) of the Information and Communication Technologies (ICT) of the European Commission (EC) rely on several Challenges that mostly include considerations and crucial developments in aspects connected with Network and Infrastructures¹⁹¹, digital content and preservation¹⁹²; Enhancing the meaning and experiences of digital, cultural, and scientific resources responding to societal and economical needs of the agents (individuals and organizations), regarding networking technology and mobile computing, including “tools for virtual reconstructions”¹⁹³; Creative experience tools¹⁹⁴ that make use of all our senses and allow for richer, more collaborative and interactive experiences; More efficient and affordable solutions for digital preservation¹⁹⁵; High quality cloud computing¹⁹⁶. The Horizon 2020 in the Reflective Societies: Cultural Heritage and European Identities (H2020-REFLECTIVE-7-2014¹⁹⁷) also stresses the importance of advanced 3D modelling for accessing and understanding European cultural assets, stating that

“Given the key role the digital model now plays, it is vital that its representation benefits new scholarship, research and developments in interpretation alongside the practical elements of curation, display and dissemination of knowledge. The 3D representations should go beyond current levels of visual depictions, support information integration/linking, shape-related analysis and provide the necessary semantic information for in-depth studies by researchers and users. This will offer new perspectives to researchers and new understandings to citizens, research users and the cultural and creative industries”.

In terms of future initiatives, large-scale integrating collaborative projects are often revealed as objective-driven research projects, which aim to generate new knowledge, including new technology or resources for research in order to improve competitiveness addressing major societal needs.

The synthesis of these examples of actions, purposes and documents expose the increase of the frequency of the events (congresses, summits, conventions, others) and the

¹⁹¹ 2011-12 and 2013 ICT WP – Challenge 1 – Network and Service Infrastructures (2011-12); Pervasive and Trusted Network and Service Infrastructures (2013).

¹⁹² 2011-12 ICT WP – Challenge 4 - Digital Content and Preservation: representing cultural and scientific content in digital form

¹⁹³ 2011-12 ICT WP – Challenge 8: Access to Cultural Resources, available at URL: ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/ict-wp-2011-12_en.pdf (June, 2013).

¹⁹⁴ 2013 ICT WP – Challenge 8: Real time simulation and visualisation, augmented reality, 3D animation, visual computing, games engines, and immersive experiences.

¹⁹⁵ 2013 ICT WP – Horizontal actions, 11.2, available at URL: <http://cordis.europa.eu/fp7/ict/docs/ict-wp2013-10-7-2013-with-cover-issn.pdf> (June 2013).

¹⁹⁶ 2013 ICT WP – Horizontal actions 11.3

¹⁹⁷ H2020 REFLECTIVE-7-2014, available at URL: http://cordis.europa.eu/programme/rcn/664971_en.html (May, 2017).

growing number of entities associated with the permanent concern over the confluence of these issues. The development of Technology and the evolution of the techniques used play an important role to meet the progressive growing needs of new tools for several scientific Domains and their related Agents.

6. Technological Support for Cultural Heritage Progress

Technological developments have facilitated faster and more efficient acquisition of ever more accurate field data. A good example of this idea is the simple process of digitalization that allows the expansion of the capacity of storing heritage information (in terms of physical space in the archives) prolonging the lifecycle (promoting security), easy duplication and access to the documents. Digital utilization can synthetically apply the historical, cultural and scientific values of cultural heritage items by applying modern science and technology to heritage preservation, and the research has further extended to heritage information acquisition, digitally aided research, digital conservation, and digital exhibition and utilization.

Heritage management information practices are currently associated with two-dimensional imaging, mapping and analysis, usually resorting to GIS. This capability has great advantages when compared with the also relevant heritage inventories, based on entries and registers that are exclusively descriptive, albeit less dynamic and interactive. Nevertheless, with the addition of 3D visualization and modelling capabilities it is now easier for planners to communicate simultaneously simplifying the study of complex urban environments in their full spatial extent including shape, size, volume, and the spatial configuration in all x, y and z dimensions (adapted from Yao *et al.*, 2006 in Yin, 2010).

Virtual or Augmented Heritage or 3D GIS Cultural Heritage are relatively new branches of knowledge that use information technology to digitally capture or represent the data studied by several domains. These data include 3D objects, such as works of art, buildings and even entire villages, cities, or cultural landscapes. Whereas the cultural heritage community previously used static 2D forms of documentation (plans, sections, elevations, reconstructions) created on paper and published, it is now increasingly using 3D interactive digital tools, also adding the time dimension (4D). The transformation of the expression and publication of heritage representations may disclose that virtual heritage

spreads rapidly through a large, well-established field, which has generally embraced the new technologies in recognition of their obvious superiority to what they have replaced (Eve, 2012).

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. This growing collection of models provides new opportunities for the academic community and the public alike. Heritage representations depend on efficient access, interoperability, and scientific endorsement of the 3D models. A long-term objective, then, should be the creation of centralised, open repositories of cultural heritage virtual environments with high technical-scientific value, underlying design documents and metadata, published along with the model. Uncertainties in the 3D data and hypotheses in the reconstructions must be clearly documented and communicated to users. The creation of 3D cultural heritage archives also requires new solutions for the interoperability of these models among themselves in the archive, as well as with external sources (Koller *et al.*, 2009).

AR applications are currently used at some heritage sites. These are mostly aimed at enriching the tourist's experience, adding information to the real environment merged and over the device display (e.g. Virtual Time Travel) or through audio (e.g. museum audio guides). Nevertheless, new forms of DR are becoming available on a daily basis, consisting basically of 3D models (reconstitutions) used to explore the present, past or future experiences, or approach research questions (Eve, 2012).

7. Geographic Information Technologies and Systems at Two-Three-Four-Representational-Dimensions, Broadband Networks and their Value to Cultural Heritage

Generally, interactive 2D maps are exceptional to represent information, which has a limited or no vertical element, e.g. land use and occupation cartography (adapted from Zhang, 2004). Most GIS users have been operating with 2D GIS datasets, representing

urban characteristics in the form of points, lines or polygons, challenging the human capacity to visualise (the complex) built environment¹⁹⁸. However, urban planning is intimately connoted with spatial relationships between objects, buildings, blocks, streets, neighbourhoods, and cities, and often 2D representations are considered insufficient to address real 3D planning problems, especially at the scale (in area and height) of the modern city (Hernandez & Hernandez, 1997; Evans & Hudson-Smith, 2001 *in* Yin, 2010). 3D representations generate more intuitive methods of interaction between the user and the represented data. Considering that the general public does not possess GIS skills, 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 understanding and communication (adapted from Geertman, 2002; Crampton, 2001; Neves & Camara, 1999; Jacobson, 1992 *in* Zhang, 2004). Thus, 3D representations and analysis tools are more adequate for volume variation and enriching spatial representations (Zhang, 2004).

While 3D modelling has a strong visual representational capability and corresponds to a faithful exemplification of reality, GIS has a powerful capacity for querying and analysis (Yin, 2010). Li *et al.*, (2004) *in* St-Aubin *et al.* (2010) expressed the necessity for 3D GIS for urban environments in order to understand the territory three-dimensionally, particularly regarding form, components, and texture. Coors (2003) *in* St-Aubin *et al.* (2010) stated that there is a strong need for 3D GIS to manage 3D geometry and topology, integrating semantic information to analyse both spatial and topological relationships, and visualise data in a suitable form. Therefore, it is not difficult to assume that 3D modelling will gradually become more common, especially concerning hardware and software developments. However, the interoperability between 3D and GIS systems is still difficult to perform, considering the multiplicity of formats (Valencia *et al.*, 2015).

Regarding 3D modelling and GIS (3D GIS), the user can acquire, manage, and observe different data configurations, creating Virtual Environments (Virtual, Augmented

¹⁹⁸ E.g. the difficulty of representing thematic cartography for an urban area with information per accommodation and the relations between each floor of a building vertically.

and Mixed Reality), within which individuals can virtually walk, drive, fly and see the world in real, past or future time (Virtual Time Travel) and/or even communicate, meet and work (creating new forms of human interaction and locational settlements, reducing the needs for transportation, being represented in the virtual environment). 3D GIS representations can also be linked to the attributes of a database, allowing, for example, to query the spatial data infrastructure and visualise the results also in a 3D form, or conducting spatial analysis, such as visibility analysis enabling a fully interactive 3D environment that allow users to navigate in the built VE. The integration of data acquisition, 3D modelling and 3D GIS data into an AR environment through mobile platforms provides the opportunity for DR, interaction and dissemination, enabling dynamic 3D contents to be built, visualized and interacted with, supporting attributes and spatial analytical features, and being more powerful than traditional methods (Yin, 2010). The construction of virtual objects and models that can be visualized *in situ* create conditions that can be compared with pre-existing experience and knowledge simplifying their understanding, offering potential advantages in all stages of a planning process, from the initial problem to its representation and verification within the same place where the proposal will be implemented (Riera, 2013).

There are several methods to combine GIS and Virtual Reality (VR)/Mixed Reality (MR), although it is still difficult to achieve full integration, considering technical limitations, which restrict the distribution and display of 3D representations on personal computers and mobile devices. However, hardware developments (especially graphic capabilities, related with rendering 3D models) together with broadband networks have created the conditions towards making it possible to advance in the field of 3D GIS and the resulting production of DR within VE/MR systems over the Internet, including portable devices (adapted from Zhang, 2004). Efforts have been made to model the built environment and planning scenarios using 3D GIS and VE/MR platforms to envision, for example, the protection of buildings, sites, urban settlements, and landscapes (e.g. changing use), as well as to explore and understand the potential impacts and interplay between adjacent structures or adulterations (adapted from Bosselman, 1998; Kwartler & Bernard, 2001; Al-Kodmany, 2001; Arefi & Triantafyllou, 2005; Steinicke *et al.*, 2006 *in* Yin, 2010).

3D visualisation requires appropriate resources to visualise 3D spatial analysis as tools to effortlessly explore and navigate through large models in real time (Zlatanova *et al.*,

2002 in Milosavljevic *et al.*, 2010). 3D GIS digital representations can provide information on heritage, which is extremely valuable for several agents in the territory (e.g. decision/opinion-makers, technicians, public, and promoters) in different domains (e.g. political-administrative, social-economic, technical-scientific, and ideological-symbolic-religious). One example of that is the value added to planning at different scales in real-time (through web services/broadband networks) in their past, present and future (fourth dimension), producing unprecedented opportunities for communication and collaboration in different fields of knowledge. 4D GIS digital representations can be built to reflect the past, existing and possible future conditions of cultural heritage with the current or proposed appearance, façade, style, material and size, applied to buildings, urban settlements, sites and landscapes (Yin, 2010).

DR bring the agents from different domains closer to a virtual/mixed/real site and (re)present, for example, the impacts/consequences of a heritage analysis¹⁹⁹ and intervention, regarding for instance the relations between objects or use, function, proportion, texture, volume, light and colour of a proposed development from any perspective or navigation form that the stakeholder might select/decide.

According to Roussou & Drettakis (2003:1), “The area of virtual heritage has long been concentrated on generating digital reconstructions [...] to be truly accurate representations of their real-world counterparts”. For Le *et al.* (2005:579), “Recently, virtual heritage has emerged as a promising technology for conservation, preservation, and interpretation of our culture and natural history”. According to Andrés & Pozuelo (2009:105), “Discrete and subjective techniques to acquire information led to other massive data acquisition techniques, including space and theme-related” in the article with the suggestive title “Evolution of the Architectural and Heritage Representation”. Those technologies reproduce faithfully the real world, going far beyond geometry or spatial position (Andrés & Pozuelo, 2009). Salinas & Almirall (2010) reproduced a virtual 3D model of Barcelona for the year 1714, creating a database with a wide variety of information from ancient cartographic plans, drawings and other documents up until the present. The Rome Reborn (Frisher, 2008) project uses 3D digital technology to represent the evolution from the late Bronze Age (~BC 1000) to the Middle Ages (~ 552 AC), with the peak of its development in 320 AC. The Rome Reborn project has several versions

¹⁹⁹ E.g. the work developed for the morphological analysis of heritage façades with the survey Terrestrial Laser Scanner Technology (Sarmiento *et al.*, 2013).

available through Google Earth software (without cost) and it has over 650 million polygons²⁰⁰. Another example of using these tools is the project PATRAC²⁰¹ made for the Barcelona Museum developing a 3D model creation and incorporating virtual and augmented reality to improve the accessibility and user experience of a museum in a wheelchair (Marambio Castillo *et al.*, 2010).

The digital representations of cultural heritage have implications, perhaps stimulating more travel (e.g. tourism) as a result of the initial available interaction (thus potentially damaging the heritage) or maybe help to collect information, create better accessibility and planning, managing, and coordinating human activities and conservation (in a 4D real-time monitoring and assessment situation). The advances in GIT are placing the world in a fast track to the knowledge of where all physical objects are located on Earth in the present, but also in the past or future, especially regarding the interaction of Web-based and mobile technologies (Sui & Goodchild, 2011). These emerging representations of the physical world (regarding external affordances at different moments) and even the mental world (through internal minds or imagined/simulated/synthetized) are also creating opportunities for the development of virtual and real space realities (mixing digital representations with the real world), not only on desktop computers, but increasingly also on the people's daily use of mobile devices.

²⁰⁰ Version 2.1. (October 2010) available at URL: <http://vimeo.com/11805593> and http://www.romereborn.virginia.edu/project_news.php (July, 2011).

²⁰¹ Accessible Heritage: Patrimonio accesible: I+D+i para una cultura sin barreras.

Chapter IV

Case Studies: Models and Mobile App Development

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1. Real and Expanded Synthetized Mixed Environments

Information and Communication Technologies have had important impacts in recent decades, ranging from people’s lifestyles and ways of learning and working to the interaction between institutions and society. Technology has transformed the procedures involved in searching for information into a more interactive and fast process, increasing the range of data dissemination and individual expectations (Fritz, 2005). Large amounts of information in digital format have become more accessible to the user through the Internet at fast growing speed and broadband access (increasing amount and size of transmitted content). Social networks and other tools provide instruments to communicate and share information within a synthetized virtual environment (parallel and associated with the real environment), where people interact with each other in nearly real time. Several tasks that once could only be done at the desk of an institution or, more recently, using a computer (e.g. mail, bank transfers, and searching data) are now possible to realize everywhere, for example, while in transport (Celewicz, 2016). Thus, there is an expansion of the public (virtual) space and the users become “omnipresent” (e.g. re-presented online through Skype) while meeting and communicating, being physically almost anywhere. However, this space is invisible, creating an invisible society and technology is the link between the real and virtual spaces. Mobility increased the influence of (social) networks through individuals, being able to react or share instantaneously posts, events or photos, allowing the fast and global dissemination of



Fig. 27 – Technological omnipresence through digital representations

information and, as a consequence, making these structures apparently alive and vital. These social networks might be dangerous for human privacy, isolation and physical absence; however, on the other hand, they have allowed for the development of new forms of human interaction, sometimes promoting previously inexistent contact between people and creating new opportunities for humans (such as people meeting/finding each other or getting together through technology).

Recent technical-scientific research has tried to analyse, replicate, and develop technological structures and aptitudes analogous to the human brain. Several technological innovations and concepts have been introducing significant words, such as smart or intelligence, tied with the human brain and its capabilities (e.g. Smart building, Smart house, Smart cities, Smartphone, Smart watch, Smart TV, Artificial Intelligence, Business Intelligence). Cities are becoming “smart” and in many ways the kind of science reported here can describe how they might become smarter, particularly through the dissemination of this science using new forms of visualization and offering new ways of thinking about the form and design of future built spaces (Batty, 2013). Townsend (2013) says that the Smart city concept is hard to define because “smart” is an adjective that can convey several meanings; however, this author refers that information technology makes part of it. Smart city is then defined as a place where information technology is combined with infrastructure, architecture, everyday objects, and even our bodies to address social, economic, and environmental issues. Computers have been promoting digital data acquisition, processing, and dissemination; however, with the emergence of mobile devices a revolution in Human-Machine or Real-Virtual environment interfaces was initiated,



Fig. 28 – The expansion of the mind through technology.

regarding multiple functions and applications and their special features, such as portability and mobility (fitting in the pocket and taken almost anywhere by its user). The use of smartphones had a huge impact on society, changing human behaviour, individually and between each

other, with information and communication technologies, and their perception of the virtual and real spatial environment. As cognitive mapping, these devices can assist the user in their position, relation to surroundings (knowing which objects, facilities, services, or

people are near us) and help in navigation (e.g. Navigation Systems, such as GPS or GLONASS). Moreover, they can also allow us to geotag or report a situation in a specific place feeding powerful databases (such as Goodchild's concept of "Human as Sensors" and Volunteered Geographic Information - VGI), including the relatively new concept of Big Data. The digital revolution has now penetrated our culture so deeply that the many new forms of communication that have been transforming spatial environments are now revealing previously unknown aspects in the form of large databases, providing us with opportunities for analysis and modelling, quite different from the methods applied earlier (Batty, 2013).

The use of a navigational coordinate system allows linking virtual data to the real environment (the device knows where the user is) as a camera permits capturing real images and mixing them with virtual synthesized digital representations, visualizing in real time in the device screen. 3D virtual representations of objects allow us to model and (virtual) travel through time, creating new methods of special analysis and visualization as we perceive them in our heads (e.g. internal representations or imagination). Through technology, both the virtual and the real worlds can be combined expanding the space/time dimensions, human connectivity, and information/intelligence. Thus, through technology individuals are able to expand the mind (adapted from Celewicz, 2016).

Rather than immersing a person into a completely synthetic world, Augmented Reality (AR) attempts to embed synthetic supplements into the real world. This leads to a fundamental problem: a real environment is more difficult to control than a completely synthetic one (introducing unknown variables in a dynamic system). Augmented Reality enhances the real world instead of replacing it. The users can view the real world enriched with additional 3D graphics superimposed to their field of view. The possibility of combining real and virtual objects will allow a huge amount of applications. In the field of Cultural Heritage, AR is of the most outstanding technologies, considering the possibilities to recreate 3D representations, to Virtual Time Travel (fundamental for cultural elements that are often historically relevant), and Combine the virtual with the real world (e.g. recreate some object from the past or viewing several phases of construction). This is more valuable when using mobile devices since these are portable and can be used on site, knowing the user's position through navigation systems. Thus, AR made it possible to enhance the real world with data and synthesized 3D detailed representations, changing the

way we perceived the world and having spatial aids to navigate and alert us to our interests' proximity in the field (e.g. emitting a sound or vibrating while navigating near some relevant object), virtual time travel on site, and recreate or foresee objects in evolution or that are nor even there. Therefore, technology is surely relevant for Cultural Heritage, increasing its intrinsic value.

2. Mobile Apps Applied to Cultural Heritage

The phenomenon of smartphones and their capability to congregate broadband Internet access, touch screen (allowing to access and perform several different tasks), navigation systems with built-in GPS/GLONASS receivers (plus Assisted capability), electronic compass, gyroscope, accelerometers, light and proximity sensors, front and rear cameras, microphone, speakers, and other features, within a mobile device used every day is remarkable, especially when combining virtual and real spatial information on site. Moreover, society has been revealing to be extremely open and interested in these main capacities (e.g. network connection as the Internet, mixed environments or navigation support), demonstrated by the number of smartphone sales (estimations point to one third of the world population shall possess a smartphone by 2017)²⁰². Thus, mobile technology cannot be ignored and the potential of growth is tremendous when it is clearly easy to envision futuristic capabilities, such as using innovative materials (e.g. organic and/or flexible screens); modular abilities; built-in projection capability (3D projection or holograms²⁰³); potential brain connection or other similar concept of innovative “smart connection”. Consequently, in the field of cultural heritage, it is important to embrace and develop systems or applications with mobile capability to promote, enrich, and add value to the existing (or not: projected/vanished) heritage.

²⁰² In 2009, the number of smartphones sold worldwide was up to 170 million. By 2015, smartphones sold globally were more than 1.4 billion. By 2017, it is estimated that over a third of the world's population will own a smartphone. Symbian's sales (larger operating system used in 2009) declined to about 28 million units in 2012, and later on were discontinued while the number of Android smartphones sales increased from about 220 million units in 2011 to around 1.2 billion in 2015. Android's market share jumped from 2% in early 2009 to nearly 85% by 2016. Apple's iOS is presently the second most popular operating system in the world, accounting for around 17% to 24% market share (in the last few years). In 2015, Apple sold about 225 million iPhones (IOS). Microsoft's operating system is the third most popular operating system in the world, as the company sold around 26 million Windows Phone smartphones in 2015. Available at URL: <http://www.statista.com/statistics/266219/global-smartphone-sales-since-1st-quarter-2009-by-operating-system/> (September, 2016).

²⁰³ Special type of three-dimensional image made with a laser or other coherent light source in which the objects shown looks solid, as if it were real, rather than flat. Adapted from Cambridge and Oxford dictionaries, available at URL: <http://dictionary.cambridge.org/dictionary/english/hologram> and <http://www.oxforddictionaries.com/definition/english/hologram> (September, 2016).

2.1. Virtual Environments, Gaming Technology, and Cultural Heritage

Gaming technology has been relevant for the development of AR capacities. Devices such as consoles have incorporated the detection of movements and voice recognition as input technology (e.g. Sony Play Station, Microsoft Xbox, or Nintendo Wii - Wiimote). These examples of new system interfaces allow users to interact with applications using voice commands, gestures, and body actions (Riera, 2013). A higher level of interactivity²⁰⁴, mobile capacity, and AR capability allowed the release of games where the user plays interactively in the real environment, using virtual or augmented data, introducing new perspectives in gaming and connecting the virtual goals achieved with the real world²⁰⁵. As these games became more popular, the limitations of the commonly called labyrinth games referred by Gubern (1996) were tied with the fact that the structure of the game is highly reduced: it is a path with a beginning, a sequence of movements peppered with redundant incidents that the operator must try to control, and finally the users' punctuation will reward or disqualify the user²⁰⁶. Using the real environment as a support for the game can still be limited; however, it offers new choices and itineraries and presents the user with real spatial location of, for example, points of interest, landmarks and icons (contributing to the spatial recognition and navigation, while transmitting information about the environment).

The geocaching²⁰⁷ game is an example of how to use real coordinates to find several containers (similar to a treasure hunt). Commonly, the containers are placed in real spaces, associated with relevant cultural or natural heritage, memories, legends, or scenic views, attracting users and other people (revealing also the society's demand for spatial data and digital information on cultural/natural sites).

²⁰⁴ Such as "serious games" (Bellotti *et al.*, 2009) [considered by Foni (2010) as computer games for education and training and by other authors as interactive games].

²⁰⁵ E.g. the numerous Apps available on the market to view in real time through the device camera some fun drawings over the real user's face (e.g. Face Swap; Animal Face; Snap Filter; Snap Photo; Camera PIP).

²⁰⁶ This structure has many similarities to the labyrinth; it is also an itinerary-puzzle where you must save yourself from threats and consecutive obstacles.

²⁰⁷ "Geocaching is a real-world, outdoor treasure hunting game using GPS-enabled devices. Participants navigate to a specific set of GPS coordinates and then attempt to find the geocache (container) hidden at that location." Available at URL: <https://www.geocaching.com/guide/>.

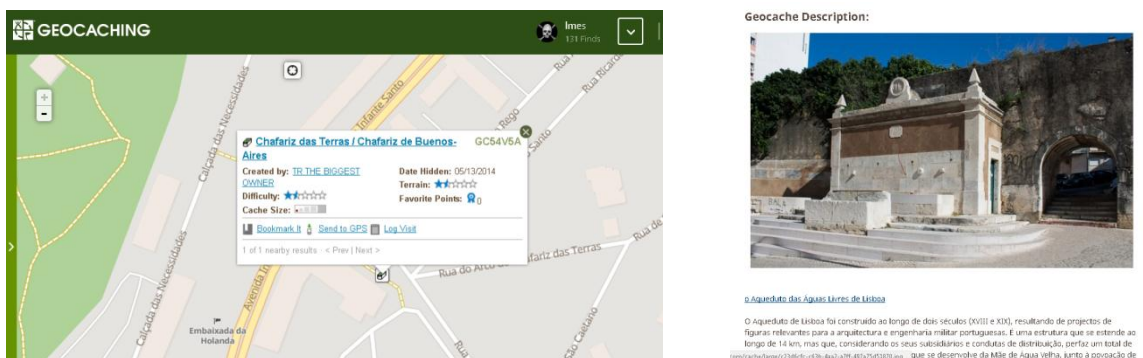


Fig. 29 – Geocaching map and register (description, coordinates and hints for the game quest). Example of the Lisbon Aqueduct System element: Terras fountain.

This game was launched in 2000 and coincided with the decision of turning off the GPS Selective Availability (SA) feature, making available an accuracy of 10 meters to civilians (before, it was around 100 m), which led to the use of computers with internet access to search for geocaches (with tips and descriptive texts), entering the coordinates into a GPS receiver. Presently it is easier to access to all data using a smartphone with Internet access, a GPS, or other navigation systems. There are several Apps available in the market and we can access all the data, being online (or saving for offline use), and navigate with the GNSS systems embedded in the mobile device. This game enables the user to find interesting locations where the geocaches are positioned, helping them to navigate through space, presenting relevant data about objects, regions, landscapes, or territories.

The phenomenon of the game Pokémon Go²⁰⁸, introduced a mass smartphone playing game with a huge rate of downloads in a really short period of time. This game announced several new approaches combining virtual and real worlds, using GNSS navigation systems to locate the user in the real environment and the Internet to access virtual data superimposed through the device camera in an AR environment. This game has had a huge impact on society, probably due to the strong

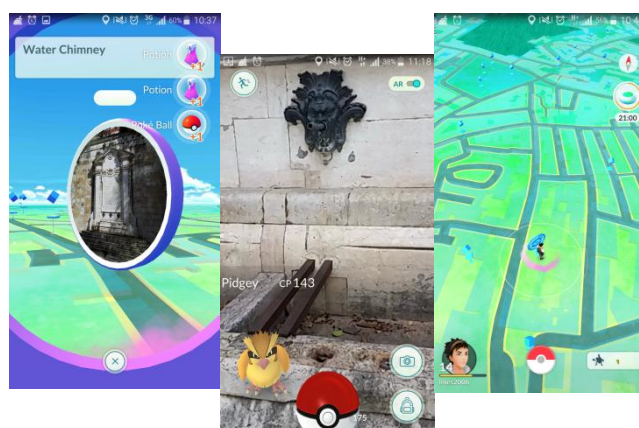


Fig. 30 – Pokémon Go. Image of a map quest and AR environment hunt for Pokémon's (over Século fountain).

²⁰⁸According to the website of the Guinness World of Records, the game Pokémon Go beat several records: the most downloaded game in the first month (130 million times, even if was not launched in the same date across the world – launched in the US on July 6, 2016); the most profitable game (206 million dollars in the first month); it featured in most international top charts in the first month simultaneously (reaching the top of the charts in 70 countries and the top income in 55 countries); it took the fastest time to gross 100 million dollars by a mobile game (20 days).

transition between common games, that used 2D virtual graphics, to a more exiting and mixed environment interaction between the user physical (and mental) skills, the real world, and the synthetized (virtual) world. This application intends to have the user navigating through the real world determining spatially relevant locations represented in the device screen. There are Pokémon Stops and Gyms that correspond to relevant landmarks in the territory, simulating navigational skills, such as path integration and using spatial key elements, such as the ones mentioned by Lynch, providing the user with knowledge of an important location, such as Cultural Heritage elements. While “hunting Pokémon” the device might alert the user to the proximity of a Pokémon (to catch), which can be done in an augmented reality environment. This application can also identify if the user is walking or in a transport considering the speed, asking if you are a passenger or else blocking the game if the user is driving. Because of AR, and the success of games such as Pokémon Go, users are gradually becoming aware of what it is like to play games or Apps using smartphones merging the real and virtual environments. Therefore, the development of other games and similar experiences using AR is stimulating the production of Apps that are technologically advanced and engaging people²⁰⁹. These games can trigger several new capabilities that might be applied to other purposes. The potential of applying Apps for cultural heritage, especially for visitors, or for example considering tourism is enormous and might take an individual to travel through an environment helping them to define a certain type of decisions and choices, perhaps even aiding visually impaired people or people with other disabilities.

2.2. Relevant Apps for Cultural Heritage

In the mobile device App markets, there are numerous offers suitable for using the information required for a given request. There are several Apps that allow us to produce interoperable information using our own data to Navigate (e.g. Sygic, NDrive, Meo Drive); Access aerial imagery or other base cartography and visualize our own data online or offline in a 2D, 3D, or even AR environment (e.g. Orux maps, ESRI, Collector, Google Earth, Locus); Capture, process, and represent 3D models (e.g. DJI Apps, Autodesk 123D

²⁰⁹ Augment App blog. Available at URL: <http://www.augment.com/blog/augmented-reality-changing-the-gaming-landscape/> (October, 2016).

Catch²¹⁰); Represent 3D models in an AR environment (e.g. Augment); and Access specific heritage data (e.g. IGeo Património, Rewind Cities Lisboa, Barcino). However, these applications do not have always count on the support of official entities and the information is sometimes outdated, which originates public distrust.

2.3. The iGeo Initiative and the App iGeo Património

In 2013, the former Portuguese Secretary of State of *Ordenamento do Território e Conservação da Natureza* (*Landscape Management and Nature Conservation*) created a work team called “*Grupo de Trabalho para a Iniciativa Dados Abertos*” (GTIDA - *Open Data Initiative Work Team*) and invited the institution *Sistema de Informação para o Património Arquitectónico – SIPA* (*Architectural Heritage Information System*) to participate in the development of the IGEO initiative (iGEO).

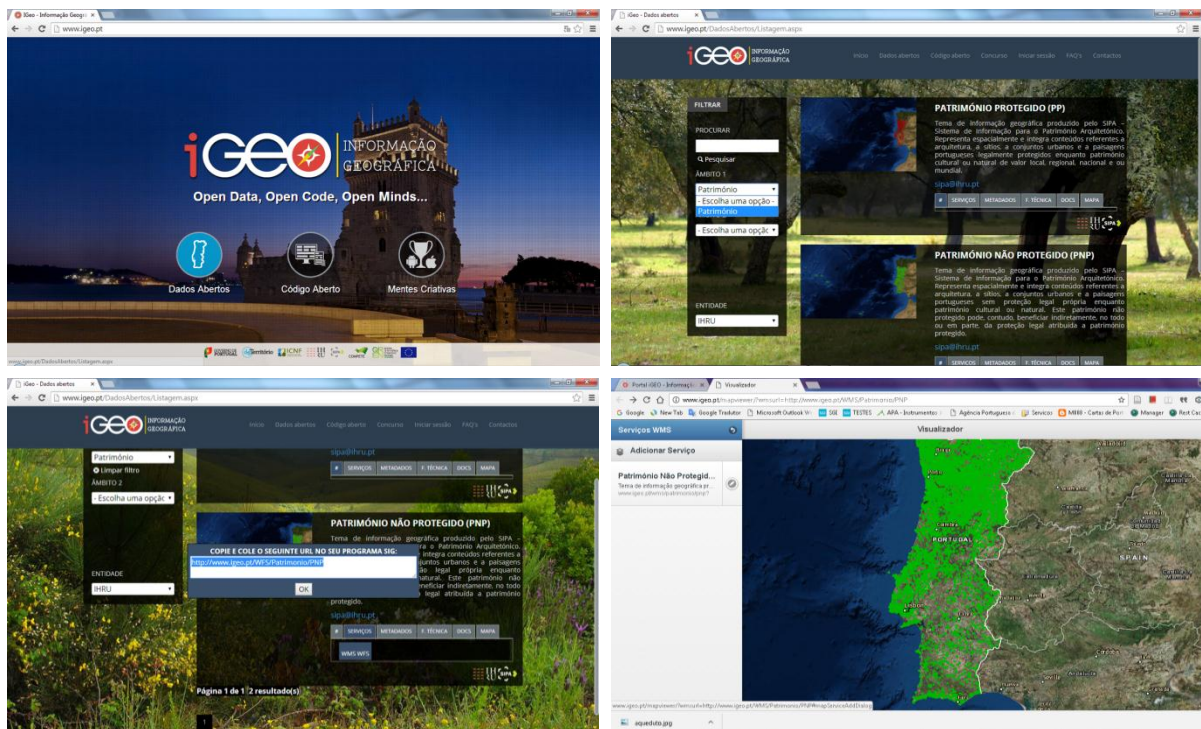


Fig. 31 – iGEO portal with heritage information available through WMS/WFS web services (SIPA Heritage Inventory).

²¹⁰ 3D modeling software from Autodesk, discontinued in January 2017 as reported in its official website: <http://www.123dapp.com/> (April, 2017).

Considering the previous work developed in SIPA's Spatial Data Infrastructure, geographic information and tools development, web services and viewers, the author of this thesis was invited to represent and being SIPA's spokesperson within the GTIDA group. This initiative has been collecting several geographic data from the institutions within the Ministry of the Environment, making this information available for companies, education entities, and the public in general. The IGEO is based on geographic Web Services (WMS/WFS) supported from the official institutions directly through the Internet. These services (constantly updated by the producer in near real time) are available to users through online resources (via portal igeo.pt), assisting geographic information users (mainly GIS users), feeding online geographical viewers and three main mobile Apps:

- *iGeo Natureza* (“Nature”, using data from the ICNF – Institute for Nature Conservation²¹¹, such as Protected Areas and Habitats);
- *iGeo Ordenamento* (“Spatial Planning”, using data from the DGT - General Directorate for Territorial Management²¹², such as spatial planning plans);
- *iGeo Património* (“Heritage”, using data from the SIPA, such as protected / non protected Heritage).

The *iGeo Património* App²¹³ had information from the Natural and Cultural Heritage from the SIPA Inventory²¹⁴ within the *Open Data Initiative Work Team* and *iGeo Initiative* (concerning the geographical data associated with SIPA's Inventory) within the scope of a partnership between the Secretary of State's Office and Bitcliq (a private company) for the development of the source code (open source and available). The assignment of the GTIDA group was to develop the institutional geospatial data/metadata and collaborate in the definition and implementation of iGEO portal (e.g. accessible data, contents, useful links, FAQ, web service instructions) and iGEO mobile Apps (e.g. adapting geospatial and digital resources for mobile search: protected/non-protected; updating administrative

²¹¹ Instituto da Conservação da Natureza e Florestas.

²¹² Direção-Geral do Território.

²¹³ Available for Android and IOS (in the respective markets).

²¹⁴ Managed since 2007 by the former IHRU, presently DGPC – Direção Geral do Património Cultural (Directorate-General for Cultural Heritage), the SIPA is characterized as a set of specialized information and documentation resources and interrelated architectural / urban / landscape heritage. One of the key components of SIPA is the inventory, composed of about 40,000 records that include several categories: building / structure, green space, urban and landscape together. Each of these registers is associated with photographs, drawings and 63 alphanumeric data fields that characterize the inventoried object (e.g. designation, protection, type, location, coordinates, or metadata). Within the INSPIRE directive, the need to create additional fields for the automatic extraction of BDSIPA information was identified (subject, category, and type). Thus, it promotes the availability and geographic information visualization through www.monumentos.pt website (Download Catalog, Web Map; WMS / WFS Services and Geographical viewer).

boundaries, direct URL access to images and cartography, operation with the App, menus, contents). In case of SIPA’s inventory, it only required data for mainland Portugal (excluding islands and the Portuguese heritage in the world).

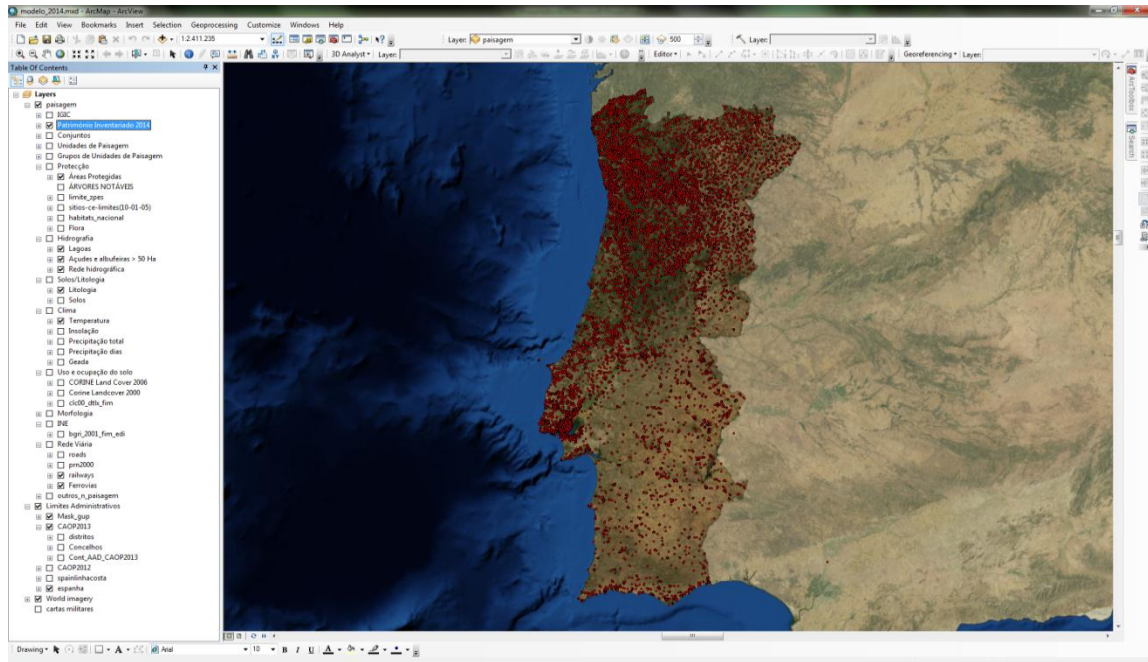


Fig. 32 – SIPA’s heritage inventory for Mainland Portugal, integrating 34145 registers; 26359 georeferenced, 3665 protected elements.

The App *iGeo Património* allows searching for heritage in Portugal (mainland²¹⁵) by administrative boundaries or by proximity to the current position, within two main data

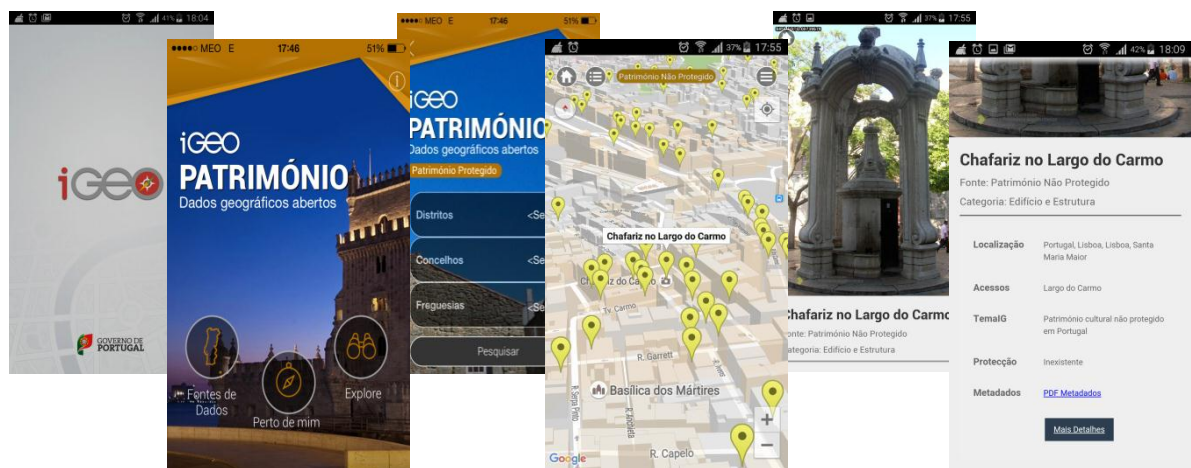


Fig. 33 – App iGeo Património, available in the Android and Apple IOS App markets. 2016.

²¹⁵ Although the SIPA Inventory and repositories have data for the whole Portuguese territory, including islands. Moreover, includes also the Portuguese heritage in the world, with special focus on the former Portuguese colonies (e.g. Angola, Brazil, Cabo Verde, East-Timor, Goa-Damão-Diu Índia, Guinea-Bissau, Macau-China, Mozambique, and São Tomé e Príncipe).

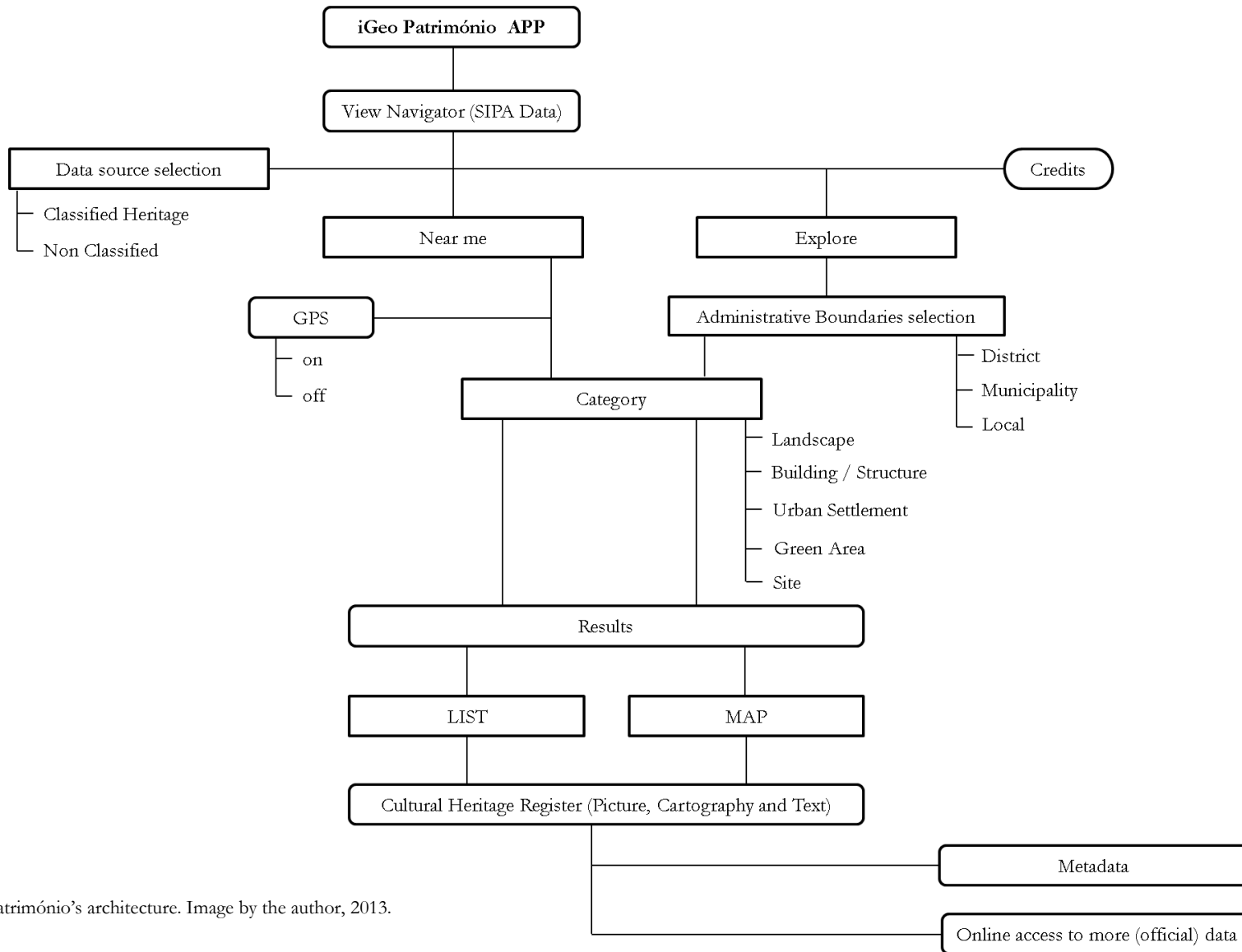


Fig. 34 – App iGEO Património’s architecture. Image by the author, 2013.

sources: Protected and Non-Protected. Then, we can visualise a map with the location of our search (and our position in the map through GPS) or in a list, giving access to a small register for each element with picture and cartography, ensuring also the possibility to link it with more information through the SIPA website (Fig. 33 and 34).

These three Apps were developed with the same basic structure source code (open and available in GitHub for Android and IOS) and shared the same goals: promoting the use of open data through web services and intentionally triggering the idea of using official data to feed mobile apps (launching a challenge for the best mobile App using data from the iGeo initiative).

2.4. Augmented Reality Mobile App Applied to Cultural Heritage

The idea of whether technology increases or influences the value of Cultural Heritage has led us to analyse and research a combination of current available technology to be applied to cultural heritage, namely Remote Sensing, Unmanned Aircraft Vehicles (UAV), 3D data acquisition, processing and representation, Geographic Information Systems (GIS), Navigation Systems, Augmented Reality (AR), and Mobile Devices and Applications.

Developing an AR App for Cultural heritage required a large amount of data acquired from producers of geographic information, and creating datasets from base cartography or acquired on field. Remote Sensing imagery supported all the spatial base data, for example to georeference old cartography and to be able to identify ancient cultural heritage systems (Lisbon Aqueduct System): paths and related elements (above ground or underground), and verifying and validating the sections on the surface (with satellite/aerial imagery). GIS supported the georeference process and vectorization of the path/objects (lines and points) from the cultural heritage object, associating alphanumeric data (and coding) within a database. The process involved drawing vectors and dots over the limits shown in the ancient cartography and associating a database that identified the type of object (e.g. aqueduct, fountain, other), title (official name given), building process (projected, built, displaced), brief characterization (historical and descriptive), and

possibility of visits for each element. 3D data was acquired using photography captured in the field for this purpose (photographs with a minimum of 30% overlap around the object, covering all the desired area), building 3D point clouds and meshes using a 3D modelling processing software, and treating and defining 3D modelling parameters. To provide more consistency to the model a base with a strong visible colour was created to facilitate the identification of the model orientation when superimposed on the AR marker. UAV was used to collect (aerial) data and 3D modelling of taller and larger objects harder to acquire (from ground). Navigation Systems (GPS and GLONASS) supported the UAV position in the field for the determination of the path and row, also placing the images taken and permitting the fundamental (longitudinal and lateral) overlapping. Then, within the application, the navigational systems were needed to recognize the position of the user in space, when walking through the environment. The texts and ancient photographs were based on analogic and digital bibliography research (especially books and heritage inventories) and complemented with (georeferenced) photographs made in the field. Using a 3D model App builder software and an AR platform, it was possible to construct one prototype to visualise this information within a mobile device. Thus, we were able to use a common and costless available plan of the city (Lisbon) as a marker and augment (through the smartphone camera) the represented data with the path of the aqueduct and associated elements, animate the water distribution over the city, represent over the map the 3D models for each element of the structure, recognise the city morphology with the Digital Terrain Model, understand the water flow by means of the gravity or visualise ancient cartography from the city at the time the aqueduct system was built, recognizing the city boundaries and further developments. Each element of the structure has access (pressing the 3D model or represented vector) to a record that contains simple information, such as text, ancient and present pictures. Beside this AR environment, it is possible to visualise the cultural heritage elements in a digital detailed map and recognize our position in relation to the system through the GNSS position. It is also possible to receive alerts from the device when we are close to one of these elements with a vibration or sound (e.g. you are 150m from object “x”).

3. Case Studies: 2D, 3D, and 4D Models (Lisbon Aqueduct)

3.1. Lisbon *Águas Livres* Aqueduct System

The foundation of the city of Lisbon started in the hill of “São Jorge” castle (which remained significant until the Middle Ages). The implantation in this location was due to the defensive position associated with the fact that there were water resources, mostly supplied by wells, fountains or existing tanks in the surroundings (“Alfama”). The Tagus River would not be an alternative, since it is an estuary of reasonable dimensions, where fresh river water is mixed with the salt water from the ocean. With the expansion and modernization of the city towards the west (“Bairro Alto hill”) and the consequent population growth, the water supply problem worsened. On the other hand, the hygiene habits that came with the Renaissance, as well as the period of the Portuguese Discoveries that required supplying ships, emphasized the lack of drinking water in Lisbon. According to Chaves (1989) *in* Bruno and Inácio (2012), in 1720 at the period of the implementation of the tax assessment (mainly on products such as wine, meat, olive oil, salt, or straw) for the construction of the Aqueduct, the number of inhabitants of the city was estimated around 200 000. The “Águas Livres” Aqueduct System was projected as one of the boldest



Fig. 35 – Lisbon Aqueduct in Alcântara valley: a) in 1912 (source - Arquivo Municipal de Lisboa: doc. PT/AMLSB/PAG/000402); b) in 1930 (source - Arquivo Municipal de Lisboa: doc. PT/AMLSB/PAG/000401); c) in 2013 (source - FCT-UNL at URL <http://eventos.fct.unl.pt/enterface13>); d) in 2015 (source - from author).

hydraulic engineering structures built in Portugal, crossing the municipalities of Loures, Sintra, Amadora, and Lisbon. The works for the construction of this complex system were initiated in the 18th century. The appointment of Antonio Canevari (an Italian architect) to direct the works in the aqueduct (in 1731) especially surprised the military engineer Manuel da Maia, who had made much of the preparatory work accompanied by the Engineer-Major Manuel de Azevedo Fortes, who was sceptical about the transportation flows to Lisbon. In 1745, the direction of the works was handed to Carlos Mardel (a Hungarian Architect) who developed a subsequent stage in the inner city with the creation of 4 (from 5) supply galleries within the city (“Rato”, “Loreto”, “Esperança”, and “Necessidades”). In 1763, the architect Carlos Mardel died, and Miguel Angelo Blasco was appointed to the position (prolonging and/or building subsidiary aqueducts of “Salrego”, “Rascoeira”, “Bertão”, “Salgueiro Grande”, and “Francesas”). In 1771, Reinaldo Manuel dos Santos became the director and architect of the works of the “Águas Livres”, accomplishing the aqueducts of “Salgueiro Grande”, “Moura Grande”, “Moura Pequena”, “Carvalheiros”, and “Olival Santíssimo” (and a derivation from “Pia do Penalva” in the “Loreto” Gallery to “Praça da Alegria” and to “Passeio Público” gardens - nowadays Av. da Liberdade). He also intervened in the “Necessidades” Gallery and initiated the works of “Campo de Santana” Gallery. In 1777, King Joseph I died and Maria I was crowned. After the death of the architect Reinaldo Manuel dos Santos, the works continued under the direction of Francisco Cangalhas (from 1792), who was replaced by his assistants, with a brief interruption during the French governance period (when the works were directed by José Therésio Michelotti). The works were completed in 1799, although the construction of fountains and extensions continued up to the first half of the 19th century.

Built in limestone, the Águas Livres Aqueduct System, which has been deactivated for 50 years, is presently an important historical and cultural heritage landmark in Lisbon. The Lisbon aqueduct collected, transported, accumulated, and distributed water by gravity (with a descent of ~3 mm per metre); it included the general aqueduct (14 km), the subsidiary extensions, reservoirs, underground galleries and fountains, which in total extended for a length of approximately 58 km. The highest point of the system is the “Águas Livres” main spring, located in the municipality of Sintra, at a height of ~172



Fig. 36 – Mãe de Água reservoir (interior). 2016.

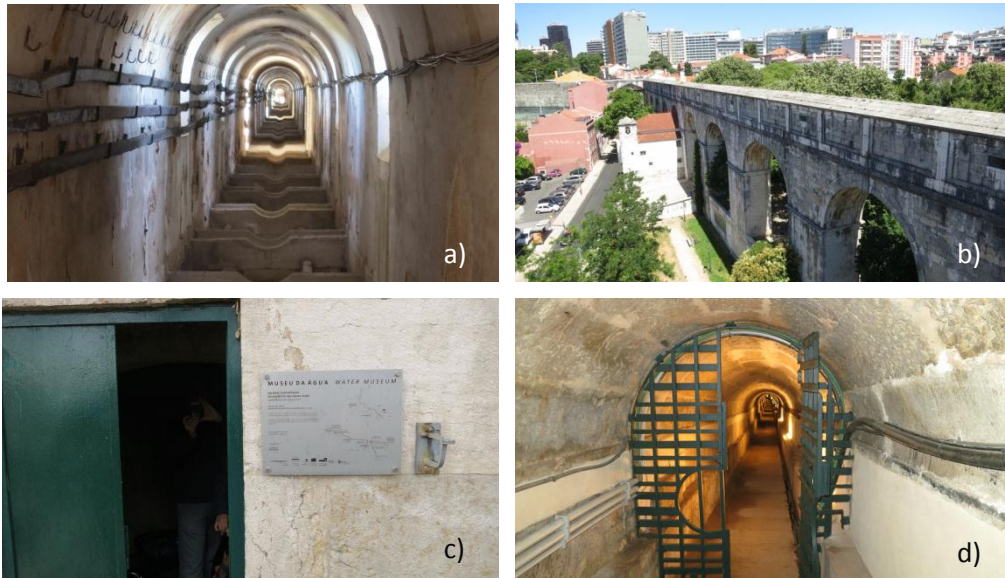


Fig. 37 – Lisbon Aqueduct in Amoreiras (Lisbon): a) Inside the aqueduct section over Alcântara valley; b) Aqueduct at surface, near Mãe de Água reservoir; c) Entrance for Loreto Gallery (underground); d) Overview of Loreto Gallery (underground).

meters, and the main reservoir, Mãe de Água (Fig. 36 and Fig. 37b), is located in the centre of Lisbon, at a height of 94 metres, culminating in the various fountains that provided water to the population of Lisbon. When the aqueduct was completed in 1799, it distributed daily around 1300 m³ of water (tripling the initial resources). However, the structure had a problem associated with the lack of flow and therefore it still needed



Fig. 38 – Patriarcal reservoir (interior).



Fig. 39 – Esperança fountain. 2016.

to incorporate more water sources (springs) into the system. The aqueduct was built to overcome the growing need for water at that time, especially in the western part of the city, contributing to the definition of Lisbon's urban morphology, although it subsequently became insufficient to meet the city's water demand. The system was extended repeatedly

throughout the 19th century and this problem was only solved with the introduction of the “Alviela” system in 1880. The aqueduct system remained in operation until 1967 and was totally deactivated in 1968.

The aqueduct was classified as a National Monument in 1910 and its most remarkable section is located in the Alcântara Valley (Fig. 35 and 37a). It is also registered in the Guinness book of records as the largest stone ogive arch in the world (65m high and 29m wide). The existence of this structure in the city is not obvious, especially because it is not visible (it is mostly underground), although it has contributed to define in part the evolution of the territory (with regard to water supply, but especially considering the impact of the implementation of the aqueduct system). The use of technology applied to cultural heritage has enormous advantages to better visualise and understand the importance of such elements, recognising the connection between the structural elements (visible) and areas (known by its path). In view of the importance of the Lisbon Aqueduct monument, research was undertaken for the elaboration of a mobile device App (Android) that enables the visualisation of GIS information and 3D modelling in the AR environment on site.



Fig. 40 – Aqueduct demolition to give space to what would be nowadays Infante Santo Street. 1949. (source - AML: PT_AMLSB_FMC_000006).

3.2. Mobile Applications Experimentation

Several trials were developed in the first experiment to analyse the potential and availability of the mobile App constellation aiming at gathering, visualising, and representing cultural heritage.

3.2.1. Lisbon Aqueduct Geographic Information

The structure of the aqueduct, mostly invisible in Lisbon, is only over ground in Campo de Ourique and Infante Santo and is visible also in the fountains (Baroque). These elements, despite their functional character connected to the urban water supply, still play an important role in the scenic squares designed for that purpose by Carlos Mardel. Less

exuberant are the fountains that deduct water along the main section of the structure, mainly by the architect Reinaldo Manuel dos Santos.

The project of georeferencing “Planta Topográfica do Aqueduto Geral das Águas Livres” (PTAGAL1856), from 1856, the “Planta Geral da Cidade de Lisboa”, from 1868



Fig. 41 – Example of georeferenced ancient cartography in several transparency stages over satellite imagery (Cartography source – Planta Topográfica do Aqueduto Geral das Águas Livres, Lisboa, 1856: PTAGAL - IHRU/DSID, Desenho n.º 0131731, DGPC/SIPA).

(PGCL1868) and the mosaic of “Atlas da Carta Topográfica da Cidade de Lisboa” (ACTCL1856), from 1856/58, directed by Filipe Folque, constituted the primary resources to obtain the path of the aqueduct and were subsequently enriched with the research on associated elements (through Remote Sensing or acquired on site) and spatial analysis, enabling us to understand the infrastructure as a whole, regarding the different stages of its implementation and the constraints overlaying land use and planning information. After the survey of the required information and comparative analysis with various geographic information themes at different time scales, we found new possibilities of approaches concerning the study and analysis of missing elements and the location *in situ* by geographical coordinates. Regarding the Águas Livres Aqueduct, a complex structure several kilometres long and with numerous sections, the use of cartography PTAGAL 1856, PGCL1968, and ACTCL1856, scanned (and mosaic built for ACTCL1856) and positioned, revealed to be extremely useful for the identification of much of the path of the main aqueduct, adductors, distribution galleries and associated elements, enabling the delimitation of traces on the territory, as well as missing objects, displaced or projected but never executed.



Fig. 42 – Ancient cartography georeferenced with the aqueduct path (Source of cartography: Planta Geral da Cidade de Lisboa (1868), Lisbon Municipality).

The identification of the Lisbon Aqueduct System structure and associated elements was conducted to develop a dataset (location) within the GIS project, consisting mainly of georeferenced segments and dots (X, Y). The identification of the aqueduct system was obtained through the ancient cartography (built mosaics) georeferenced using the ESRI ArcGIS 10.1/2/3 and QGIS Lisboa /Valmiera GIS software (Fig. 42 and 43).

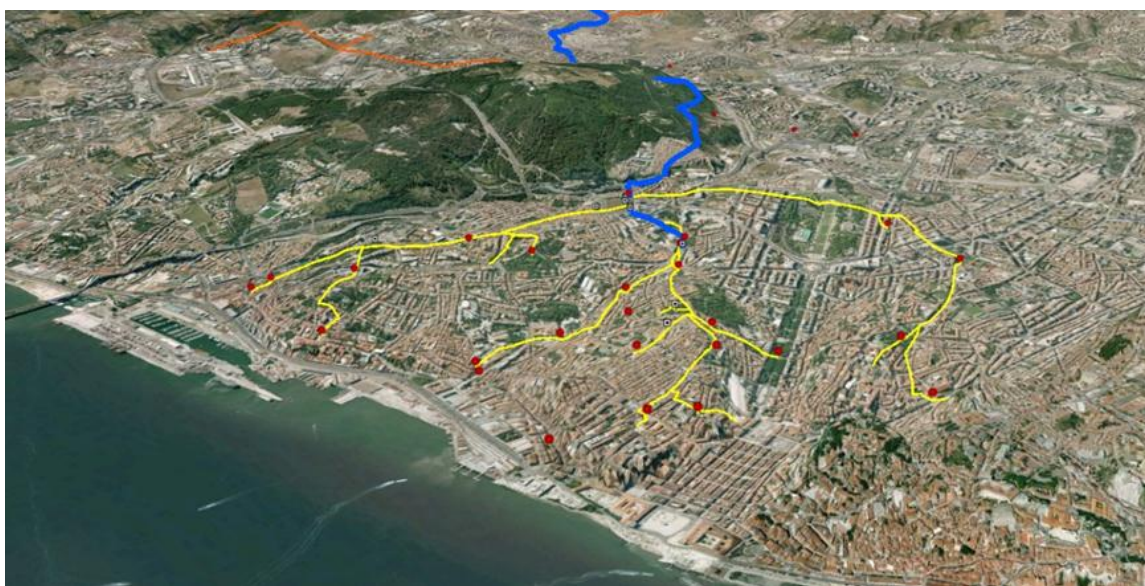


Fig. 43 – Lisbon Aqueduct System delimitation over Google Earth's satellite imagery and 3D terrain model (vectored in GIS software and imported to Google Earth KML format).

The Aqueduct System (path and elements) was vectorised (lines and dots) with the support not only of ancient cartography, but also of current satellite imagery (from ESRI Web Services and Google Earth Pro, as complementary data sources)²¹⁶ and Google Earth Street View. Different colours and symbols were defined to better recognize the main aqueduct section, subsidiary galleries and elements, such as fountains (projected but never built, built, displaced, and vanished), reservoirs, and ventilation. Official institutional²¹⁷ alphanumeric information about each element and gallery of the aqueduct was added to the final dataset (e.g. identification of the element, author/architect, description, chronology, link to an online institutional register).

After integrating this dataset within the markets available for mobile apps (e.g. Google Play, IOS²¹⁸), individuals can use the device's GPS/GLONASS, gyroscope/compass, acceleration sensors and camera, for the on-site visualisation of the elements of the aqueduct location, not only over ground but also underground (therefore not visible).

Digital Terrain Model (DTM)

The DTM was built using the contours (lines) and heights (dots) for the Lisbon municipality terrain dataset and the results can be viewed interactively using a fly through tool (3D Scene from ESRI ArcGIS 10 software). The general aqueduct was drawn in orange and the distributing galleries (mostly underground) in yellow. The reservoirs were represented with red squares and the fountains with circles, with different symbols to denote their current condition: existing, demolished, moved, or projected (and not built). Considering that the demonstration of this 3D scene has a higher impact when visualised in an interactive digital form (3D GIS software), to visualise this representation in a static image, the content was simplified showing the terrain surface (DTM) with 50% transparency, allowing to see the extent of the infrastructure and existing fountains (Fig. 44).

This 3D Scene enables users to have an impressive overview of the entire structure and better understand the aqueduct system throughout the city and the base terrain

²¹⁶ With the support of the former team, Architectural Heritage Information System (SIPA) integrated in Housing and Urban Rehabilitation Institute, nowadays Directorate-General for Cultural Heritage.

²¹⁷ www.monumentos.pt- Sistema de Informação para o Património Arquitectónico da Direção-Geral do Património.

²¹⁸ App markets for Apple IOS and Android mobile operating systems.

(verifying the water distribution through gravity), and of pertinent associated information (e.g. author, description, or chronology) and operating principles (e.g. elements that can or cannot be visited). This experience gives the users a faithful correspondence of the reality

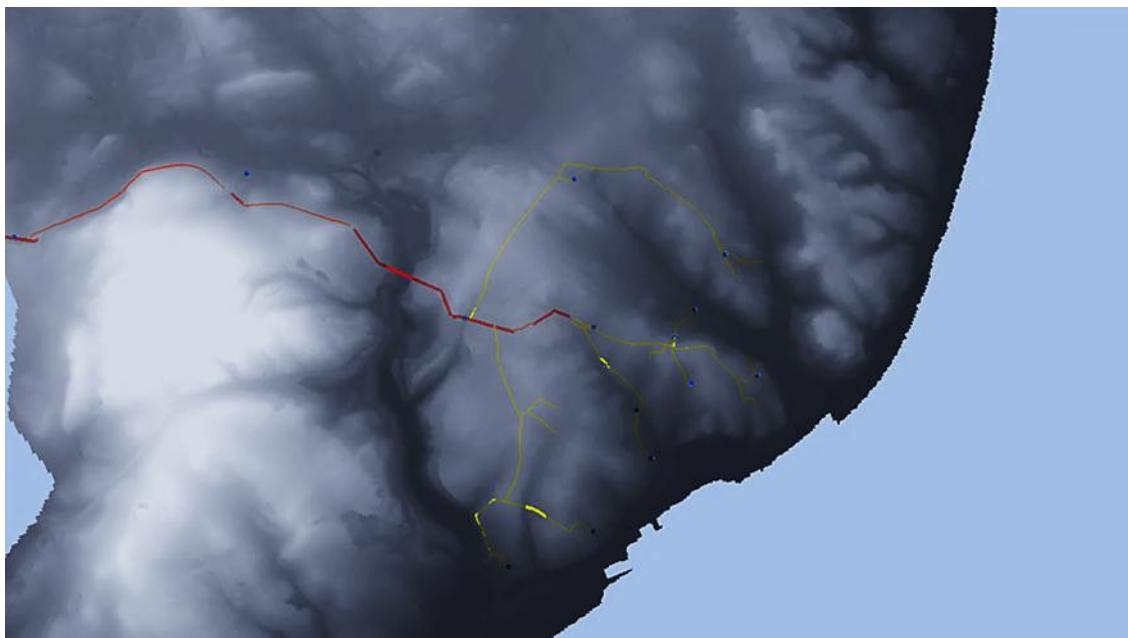


Fig. 44 – Detail of the 3D representation of the Lisbon Digital Terrain Model and the plan of the Lisbon Águas Livres Aqueduct.

and in some cases, where the path or elements were interrupted or vanished (demolished or changed), it provides them with a perspective from the past, understanding the complex linkages and transport/distribution of water in the 18th, 19th and 20th centuries.

3.2.2. Mobile App Trials

The first application used was the ESRI App, available in the market within the Android mobile operating system. Considering ArcGIS users it is extremely simple to connect a (MXD²¹⁹) project (already built or created for this purpose) to ArcGIS online and make a map (or web map) available through the Internet, which is possible to visualise within a mobile platform. The shapefiles created within the MXD ArcGIS project for the aqueduct system were divided in lines (e.g. main collector and galleries) and dots (e.g. fountains, air vents, system entrances). The base data was satellite imagery and the alphanumeric information associated was the type of object, title, schedule/cost of visits

²¹⁹ ESRI ArcGIS software project file.

and a link to the object register available in SIPA's official online data (with text, photos, and cartography).

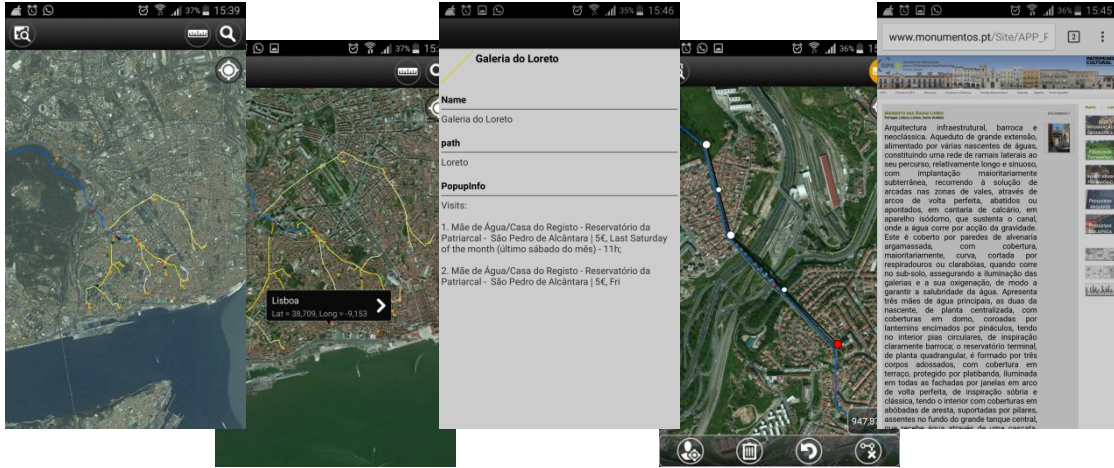


Fig. 45 – ESRI App with geographic information overlay, capability to search, measure, access alphanumeric data, and available links to official website (SIPA).

The ESRI also developed the Collector App, which allows visualising data in a mobile device, but with the particularity of working offline and editing or adding information in the field, e.g. changing the text (e.g. updating data) or adding a picture and later synchronising it online and uploading (updating) all the data. It is also possible to convert georeferenced raster (in TPK file format), add it to the App and altering these data in the field (rasters and vectors) turning the geographical themes on or off.

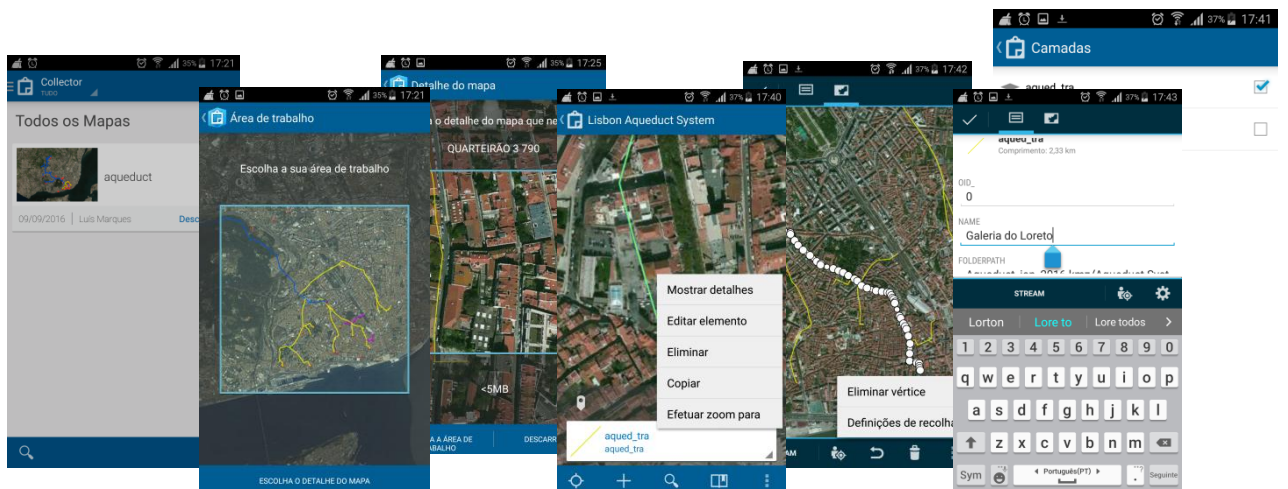


Fig. 46 – ESRI Collector App with geographic information overlay, capability to search offline, measure, access alphanumeric data, and edit (further synchronization through ArcGIS online).

The Locus Map App reveals an enormous potential to recognise on-site the configuration of the very complex aqueduct structure, having dynamic information, such as the distance and azimuth or (when installed) the possibility to use a common navigation application (e.g. CoPilot, MeoDrive, NDrive, Sygic).

As with many other applications available in the market, it is possible to visualise the dataset in an online/offline map and with the availability of GNSS, we can identify one's relative position to the elements on site. This trial was particularly relevant considering the use of the App's augmented features, especially because the main elements are located under the city and the aqueduct system can be recognised while the user is walking above ground. Thus, the objects can be identified by visualizing the designation and location using the mobile device camera while walking (Fig. 47).

Additionally, the radius can be enlarged, adapting the amount of data displayed (in the area around the current position) and finally accessing several relevant datasets

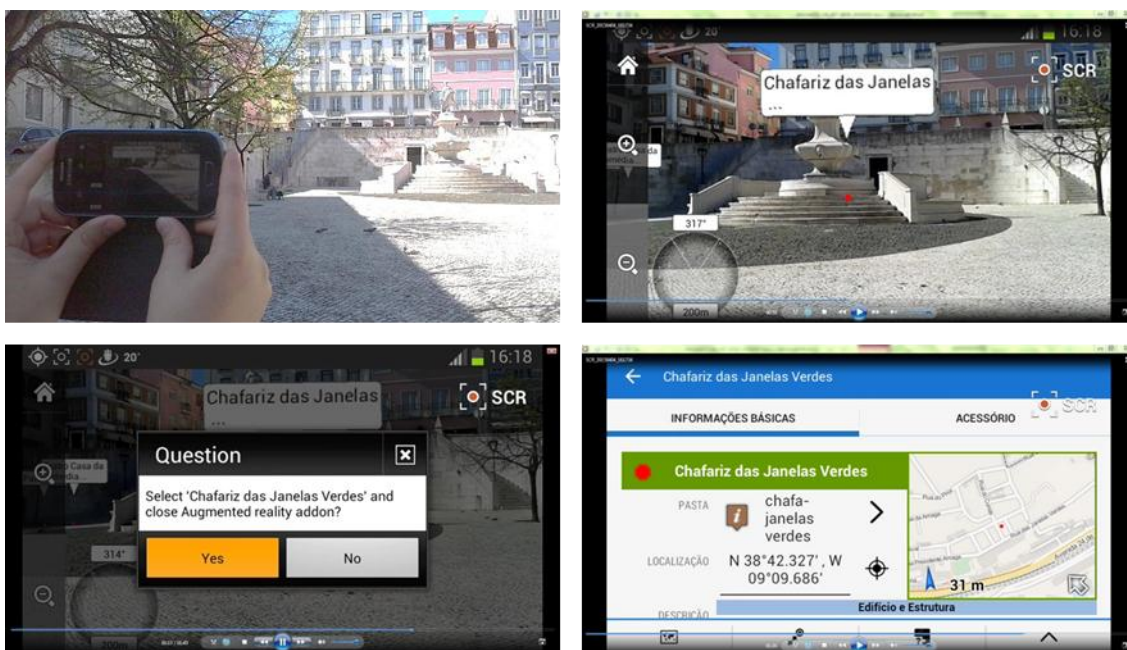


Fig. 47 – Sequence of examples using GIS data in an Augmented Reality environment (Janelas Verdes Fountain).

associated with that element (including an Internet link to additional institutional online information) by pressing the displayed identification dot.

Another trial consisted of carrying out research for the existence of 3D models in Internet catalogues with a relevant LoD and visualise them in the Augment Mobile App.

The procedures involved the adaptation and conversion formats, compatible with the AR application to be used in the mobile device. Once imported, an AR marker (e.g. satellite imagery as in the example used in Fig. 48) can be defined or visualised over any 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. This application is extremely useful, especially when the available data is of a high quality. It therefore enables the visualisation of 3D models in an AR environment, allowing to augment the



Fig. 48 – Using a built 3D model (from internet catalogues) in an Augmented Reality environment. Example of Lisbon Águas Livres Aqueduct over the Alcântara Valley.

information in a 2D format regarding the advantages explained above. However, this application can prove to be unsatisfactory, considering the general LoD of the 3D models available in the general catalogues.

Figure 49 schematically synthesises the methodology, procedures and fluxes of data involved in the trial that were performed and discussed above.

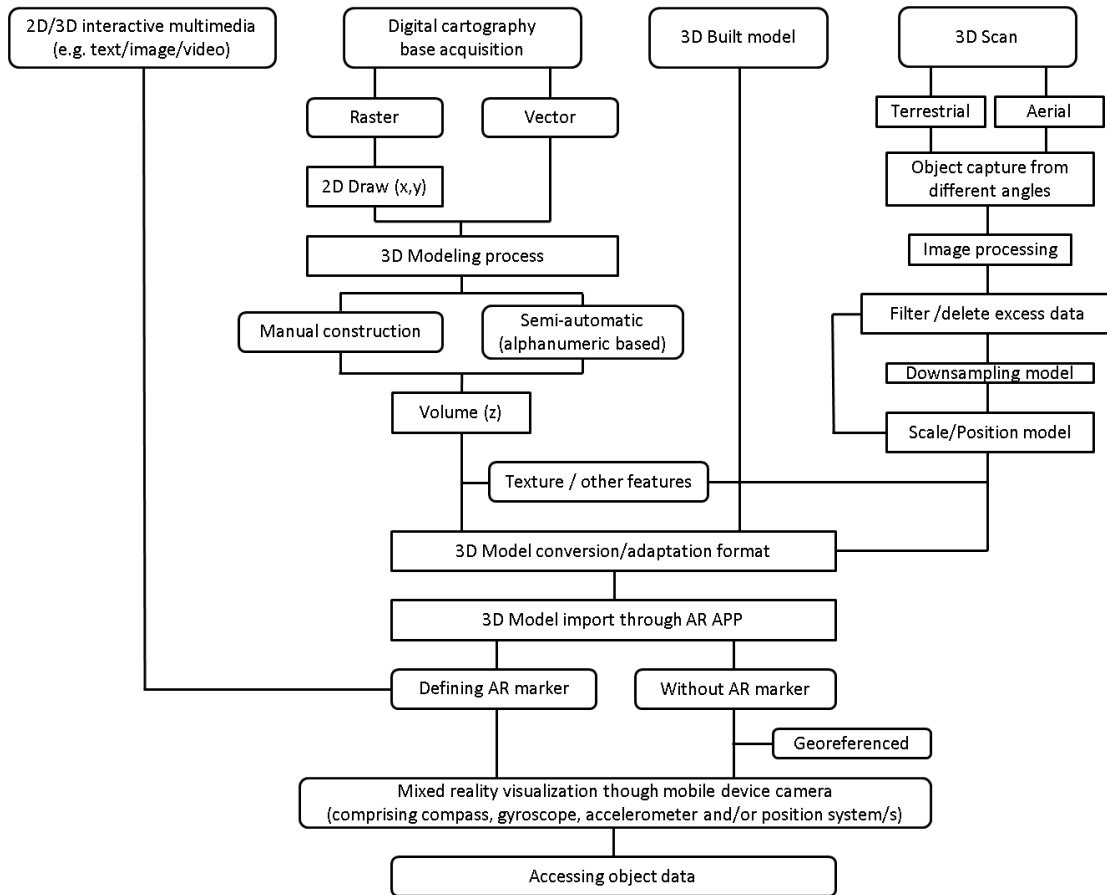


Fig. 49 – Final approach to model / represent 3D models and their visualisation in an augmented reality environment.

Based on digital cartography, in the case of the 2D vector, the volume associated with alphanumerical “z” values can be created (in the case of a building that has, for example, the number of floors, the user can assign a medium height and multiply it 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 mobile devices. 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 LoD and the large amounts of data retrieved from 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 tourist map, as in the previous 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.

Smartphone cameras and Surround Shot modules (camera modes for Samsung Galaxy) or, for example, the Google Cardboard Camera App allow to capture and create 360° pictures (Fig. 50) and Virtual Reality experiences (Fig. 51) very quickly, simply and



Fig. 50 – 360° image of the Carmo fountain (Lisbon Aqueduct System). Image by the author, 2017.



Fig. 51 – VR image of the Carmo fountain (Lisbon Aqueduct System) to be viewed with a Google Cardboard or VR Glasses.

absent from the real world (HMD) through the represented Digital Representation in stereoscopic view and using the device sensors as magnetometers, accelerometers and gyroscopes. Thus, the user has the feeling of being (re)present in that synthesized Virtual Reality, not only stimulating sight, but other senses as well, e.g. introducing previously captured ambience sound (as the Google Cardboard Camera App) and using for example headphones to stereo atmosphere.



Fig. 52 – VR visualization of the Lisbon Aqueduct System elements. Image by the author, 2017.

The tests that were performed constituted some rehearsals to verify the potential of this technology as part of an ongoing mobile application development. The intention was to integrate the most adequate solutions for the mobile application implementation and therefore reach an understanding of this technology's potential application for heritage valuation. Specific interviews to verify these assumptions were planned to be conducted not only with specialised technicians, opinion/decision-makers, promoters, and other stakeholders, but also with common users.

3.2.3. Collecting and Modelling 3D Objects Using Terrestrial and UAV Data

3.2.3.1. Acquired Terrestrial 3D data

Besides using already built and available 3D models from several Internet catalogues, the creation of 3D models could be carried out with common software (e.g. 3D Studio Max, Blender, Sketchup, or City Engine), with a high LoD and without losing performance while inserting it into the augmented reality application. However, the use of a survey point cloud based on a collection of fieldwork photographs proved to be surprising,

taking into account its rapid acquisition and processing capabilities with the additional advantage of being authentic²²⁰ (Fig. 54, 55, 56).

The Agisoft – Photoscan software²²¹ is a smart automated processing system, allowing for the creation of rapid and authentic 3D models with the simple use of pictures with a pre-determinate capturing method carried out in the field (Fig. 53).

The processing stages of the workflow, besides being very organised and intuitive for the user, allow for the adjustment of several specific tasks and adequate different types and sources of data (multiple scales, objects, environments and/or using different devices and techniques). The software generates 3D models extremely quickly, with regard to the procedures of inserting and aligning photos, and building dense clouds, meshes and textures (with a wide variety of output formats). However, the technical challenge is to simplify these 3D models (with the elimination of faces for example) without losing the realism of urban elements. With this software, it is possible to draw masks in the pictures taken to reduce the area of the image that the software has to process, identifying common pixels. The position of the pictures (cameras) made by the software (alignment) is commonly amazingly accurate and very near the reality. During the modelling process, it is possible to eliminate data that could introduce unnecessary noise to the final result. The parameters used depend on computer capacity and final results objective, considering the limited resources of the current most commonly used mobile devices²²².

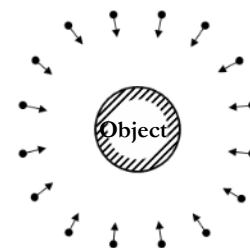


Fig. 53 – Capturing photos in Agisoft PhotoScan (source: Agisoft).

²²⁰ This is valid for existing buildings, although it is also interesting to capture present pre-existences and develop 3D virtual recreations of non-existing constructions; in this case, with the previously mentioned common 3D available software (e.g. 3DS, Blender, Sketchup or City Engine).

²²¹ Considering the data processing and 3D modelling software, it is important to refer that besides the software Agisoft (and Bentley) used, there are other software resources relevant for 3D modelling, such as: 1. Bundler – “takes a set of images, image features, and image matches as input, and produces a 3D reconstruction of camera and (sparse) scene geometry as output.” Available at URL: <http://www.cs.cornell.edu/~snaveily/bundler/>; 2. Visualsfm – “GUI application for 3D reconstruction using structure from motion (SFM)” Available at URL: <http://ccwu.me/vsfm>; 3. Microsoft Photosynth – “Photosynth is a free service from Microsoft that stitches your digital photos together into a 3D model and provides an interactive viewer for exploring the model in detail”. Available at URL: <https://www.microsoft.com/web/solutions/photosynth.aspx> (April, 2017).

²²² It was intended to develop a mobile App accessible to the main current mobile devices and a broad number of people. Therefore, it needed to be realistic, but also very responsive, simplifying the 3D models for its overall performance.

The parameters used were:

Align photos:

Accuracy: high (accuracy of the position of the photo)

Pair preselection: generic (Allows you to speed up the process of aligning photos, or identifying photos that probably do not overlap)

Key point limit: 40 000 (Accuracy for each photo / maximum limit of key points in each image / higher values mean more resources)

Tie point limit: 1 000 (Sets a limit on the number of points that link one image to another)

Constrain features by mask: mask done: enable (Masking region information is discarded / check mask usage)

Build dense cloud:

Quality: high (Precise geometry and more detailed)

Depth filtering: moderate (Mild for complex geometry and Aggressive for images with less detail, Moderate is an intermediate parameter)

Build mesh:

Surface type: Arbitrary (Arbitrary for objects, Height Field for flat surfaces)

Source data: dense cloud

Face count: high (Number of faces)

Interpolation: enable (Closes "holes" with enable; extrapolated tries to close the maximum)

Build texture:

Mapping mode: generic

Blending mode: mosaic (default)

Texture size: 2048 (Texture size)

Unable colour correction (Only for results with high brightness)

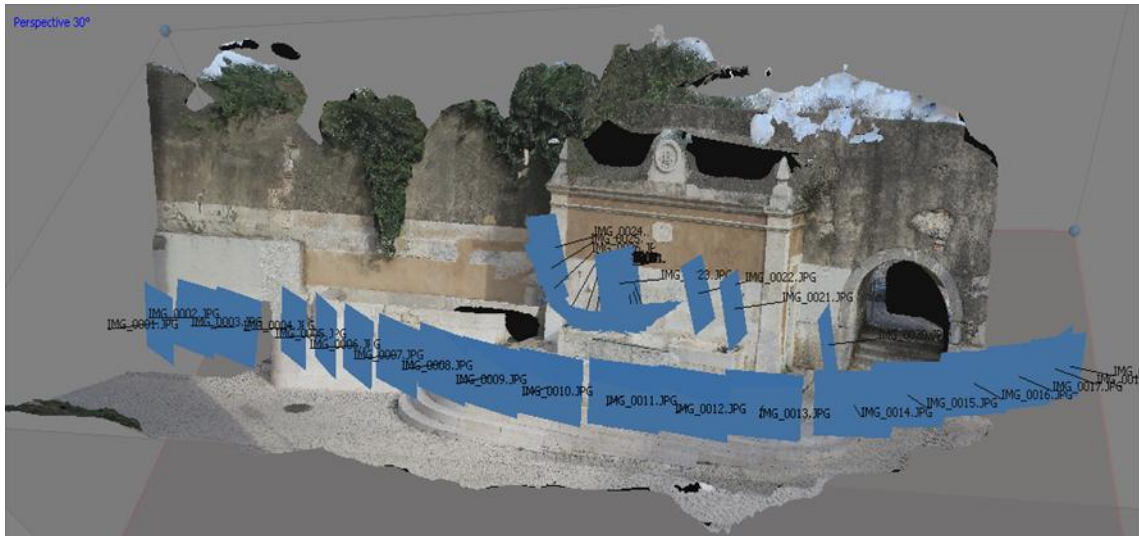


Fig. 54 – 3D Model generation. Terras fountain example, through fieldwork image collection.

The 3D models produced with the Agisoft software can be exported into Collada format and imported into the Augment Mobile App. As the 3D model did not stand out, in the AR environment, a bright coloured 3D base (under or/and behind the model) was added to increase the contrast when visualised and associated with the AR marker (Fig. 55).



Fig. 55 – Using 3D developed model in an Augmented Reality environment. The *Janelas Verdes* Fountain example.



Fig. 56 – *Janelas Verdes* Fountain 3D developed model and graphic improvement created with the SketchUp software.

The Agisoft Photoscan software has also the possibility of visualising the built 3D models in the Stereo feature, which allows the user to have a 3D experience (out of the screen), using simple 3D anaglyph glasses (red and blue lenses). Figure 57 has this stereo effect to be visualised with anaglyph glasses.

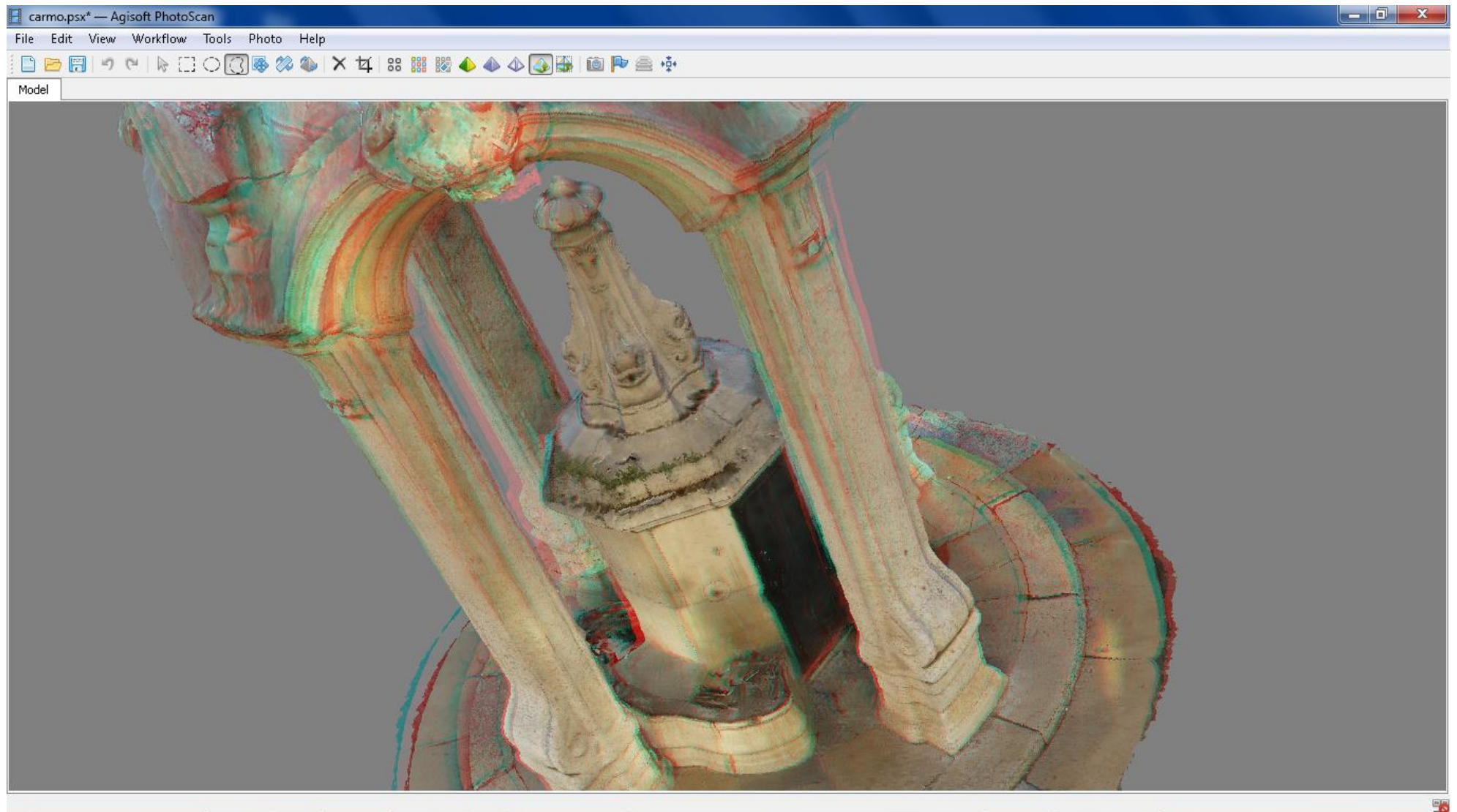


Fig. 57 – 3D model of Carmo fountain (element of Lisbon Aqueduct) in stereo mode. To be visualized with a pair of anaglyph glasses (red and blue lenses).

3.2.3.1. UAV Acquired 3D Data

The *Águas Livres* aqueduct system has several elements that permit the collection of data by using simply terrestrial images (on site) and creating point cloud meshes. Otherwise, considering the dimension and volume of objects such as “*Mãe de Água das Amoreiras*”²²³, it is very difficult to conduct a survey without using high or aerial platforms. Thus, the usage of a UAV greatly simplifies the assignment of collecting data and processing them, although these data are authentic with an impressive LoD. The flight was prepared with the support of the start-up company GEODRONE²²⁴, with the personal effort of its founder, João Marques.

The survey required a number of preparation tasks:

- i) Authorisation permits to use the object aerial space;
- ii) Weather and safety circumstances, light conditions, radio frequency and signal interference tests;
- iii) GPS and compass calibration;
- iv) Flight path determination (considering flight height and surrounding objects).

Considering the permit obtained (in July, 2015) from the president²²⁵ of the Board of the *Águas de Portugal* (AdP) group²²⁶ to access the “*Mãe de Água*” reservoir building, more specifically to the roof (an open area with more than 1300 m²) to launch the UAV, the flight was set to the 2 September, 2015, for the aerial data acquisition. However, on that specific day, the winds were more than 30 km/h and therefore, we decided to perform on that day only tests of interferences and analyse possible constraints to the flight (e.g. like cables or antennas) and postpone the survey to other day. Thus, we scheduled the flight for the 10 September, 2015, at 4.30 pm.

²²³ Built between 1746 and 1834 by Carlos Mardel and Reinaldo dos Santos, the reservoir has a parallelepiped form measuring 37m x 33m, with a height of 17m.

²²⁴ Geodrone, more information at URL: www.geodrone.pt (February, 2017).

²²⁵ Mrs. Mariana Castro Henriques.

²²⁶ Through its holdings, the AdP Group operates nationwide, right from the north to the south of the country, providing services to the municipalities that are simultaneously shareholders of the companies that manage the multi-municipal systems. Available at URL: <http://www.adp.pt/en/adp-group/who-we-are/?id=5#sthash.Dv6zZ1ed.dpuf> (November, 2016).

After the authorization and flight preparations, the release of the drone was made with a safe distance, complying with legal requirements (flying within Line Of Sight and lower than 120 meters). After gaining the predetermined altitude (~50m) the drone flew autonomously, according to the flight plan previously set in the computer (with a path/row established) and accomplished the acquisition of 201 georeferenced pictures, using the inbuilt GPS.

The camera was set to take the pictures according to the altitude and velocity to capture the area needed according the image overlay. In this flight, the operator (João Marques from Geodrone) preferred to control the UAV in the take-off and landing for precautionary measures.

UAV image and flight parameters:

- Date: 10 September, 2015
- Height: 50.3 meters
- Images: 201 (198 used) with:
 - 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 on the information collected by the UAV, several experiments were conducted using different advanced processing software packages to develop the 3D models of the Lisbon aqueduct structures. With the pictures acquired in the survey, the next stage involved transferring the data to the computer and preparing the processing phase. The software used to build the point cloud was, once again, Agisoft PhotoScan and Bentley Context Capture.

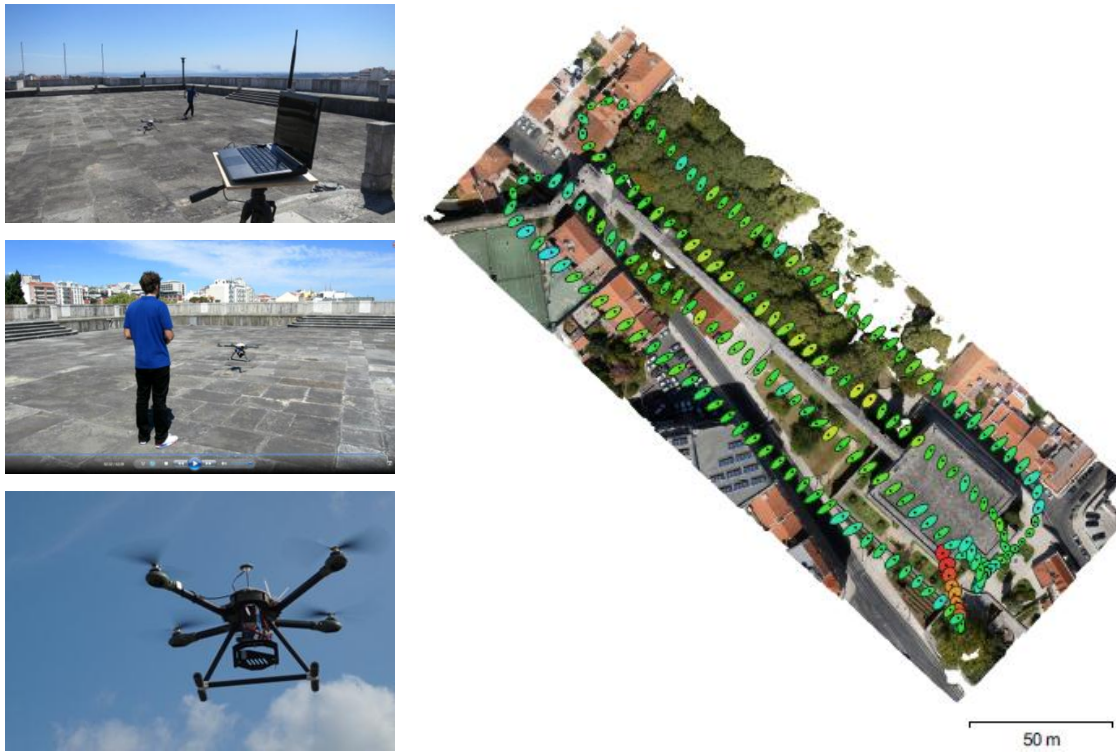


Fig. 58 – UAV data acquisition in Mãe de Água reservoir (Lisbon Aqueduct Structure): Setting the UAV flight plan (left) and camera locations (right).

The following workflow processes and results are quite dissimilar regarding Agisoft Photoscan and Bentley ContextCapture.

To conduct the UAV survey, the following steps were necessary: Flight preparation; Data acquisition; Data processing; and Model construction.

- i) Flight preparation: flight plan parameters (height, overlapping, time, focal distance, camera data, spatial resolution, image coordinates) and survey security (regarding aspects such as safety, interferences and calibrations);
- ii) Data acquisition (flight);

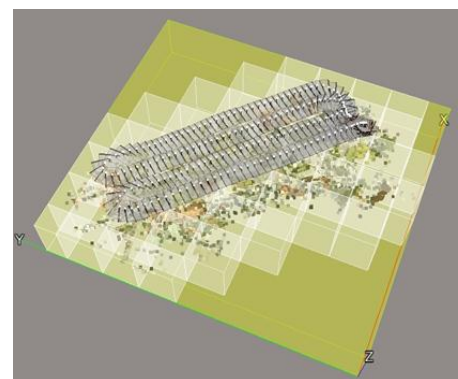


Fig. 59 – Flight plan and images taken in Mãe de Água building for 3D modelling.

iii) Data processing and model construction (Agisoft Photoscan software):

- a) Loading photos; inspecting loaded images and removing unnecessary images;
- b) Inspecting loaded images, removing unnecessary data (and creating masks);
- c) Aligning photos;
- d) Building dense point cloud;
- e) Building mesh; 3D polygonal model;
- f) Texturing the 3D model;
- g) Calculating Digital Elevation Model and Digital Terrain Model;
- h) Ortho image;
- i) Exporting results.

Area: 298.000m x 309.000m

Dots: 105 million dots

Average density: 1747,104 point/m²

Size: 2.6GB

iv) Data processing and model construction (Bentley ContextCapture software)

- a) Loading photos (georeferenced);
- B) Aerotriangulation;
- C) Building mesh (47 tiles);
- D) Final product (texture automatic added);
- E) Exporting 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 extended in Agisoft than in Bentley and for the same area and data (number/quality of images), Bentley creates a tiling mesh superior in density and overall number of the point cloud; however, the size is also higher. The results can be visualised in Figures 60 and 61, taken approximately from



Fig. 60 – 3D modelling of the Mãe de Água (Lisbon Aqueduct System) and detailed area results using Agisoft Photoscan software. Source: images by GEODRONE, 12-03-2016.

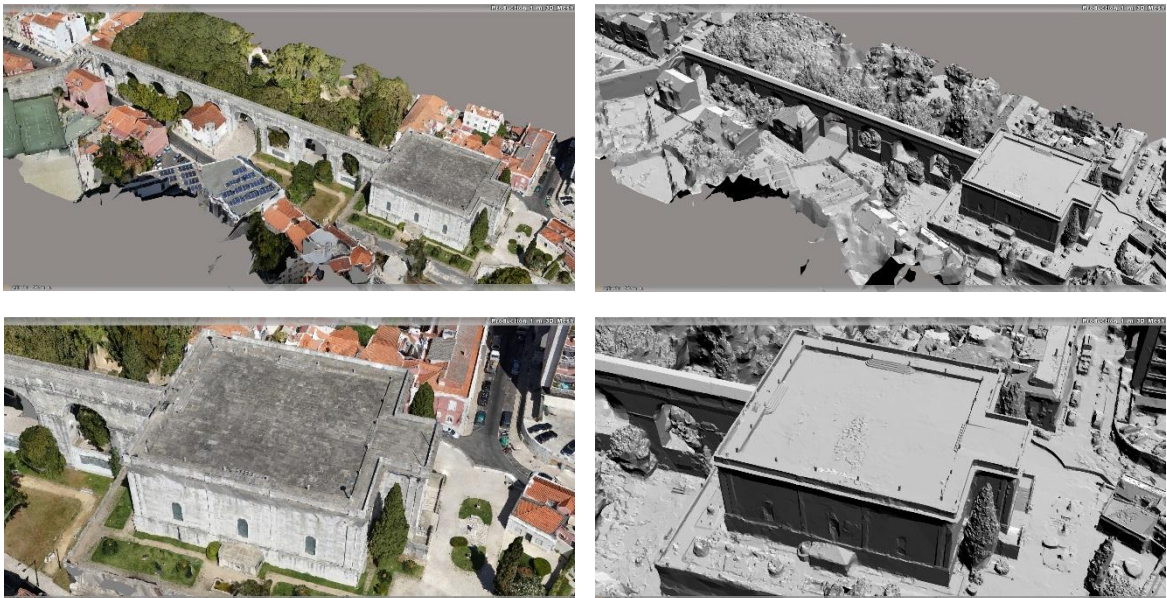


Fig. 61 – 3D modelling of the Mãe de Água (Lisbon Aqueduct System) and detailed area results using Bentley software. Source: images by GEODRONE, 12-03-2016.

the same angle allows to verify that they are quite dissimilar, especially when observed in detail and without texture.

The results of the UAV survey consist in several outputs and visualization in different perspectives, such as 3D Point Cloud; Mesh (solid, wireframe); Texturized 3D model (anaglyph stereo visualization); DEM; DTM; and Ortho Image.

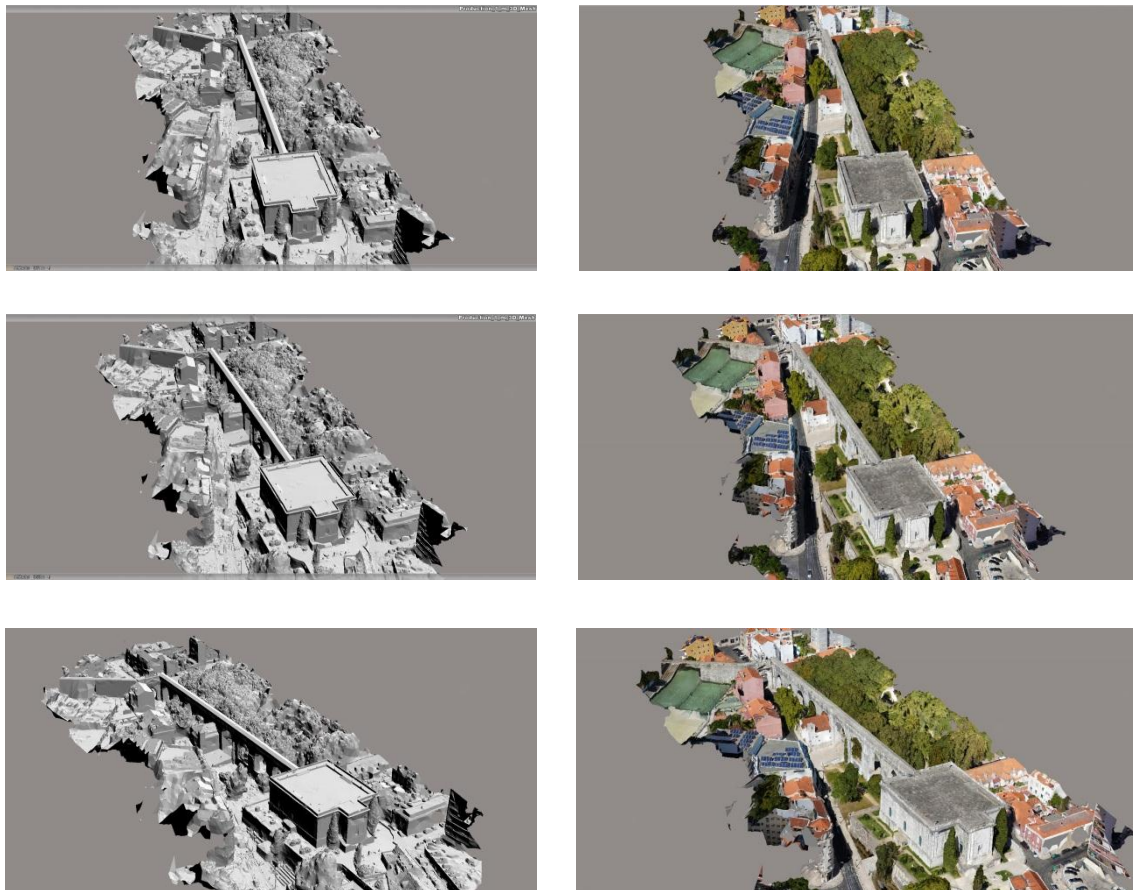


Fig. 62 – 3D model of the Mãe de Água reservoir (Lisbon Aqueduct System) with data acquired using UAV. Results obtained from Mesh (left) and texturized in the 3D model (right) in different perspectives. Other results: Digital Elevation Model, Digital Terrain Model, and Ortho Image.

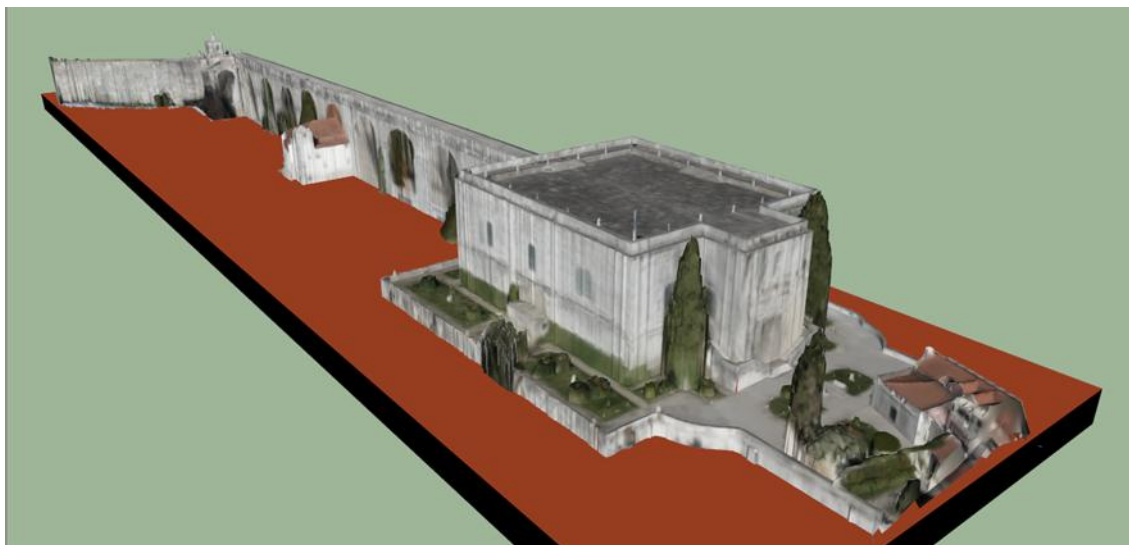


Fig. 63 – Mãe de Água Reservoir 3D model (UAV) and graphic improvement for AR visualization.

Similar to the terrestrial 3D models, this UAV-acquired 3D model also needed a base with a bright colour to increase contrast and make it stand out, while pointing the camera to the official Lisbon plan (as a marker) the AR environment using mobile platforms.

Chapter V

Building an App for the Lisbon Aqueduct

Chapter V - Building an App for the Lisbon Aqueduct

1. LX_W App Architecture

Using a constellation of applications available in the markets and applicable to several possible study objects in the field of Cultural Heritage, it was performed several experiments with and analyses of the main (mobile) technologies and capabilities perceived as potentially significant for the valorisation of heritage²²⁷. Thus, our intention was to integrate these main capabilities expected to increase the intrinsic value of the study object into a single developed App. The idea of using an existing infrastructure, object²²⁸ or free distribution brochure/map as an AR marker led to four main potential solutions: i) using a certain position (given by GPS) and pointing the device camera in a specific angle to the aqueduct elements, functioning as markers (image matching); ii) QR codes spread near the aqueduct elements; iii) City map available in several MUIPs²²⁹ spread across the city (usually with the place location “You are here”) or; iv) A convenient and simple map that a tourist can get for free in any tourist information desk. A portable map that could be taken everywhere, including navigating through the city and being enriched with (thematic) information in an AR environment was the preferred solution. This simple map already exists (and is distributed in tourist information centres) as an available resource, with the advantage that



Fig. 64 – Tourist in a terrace programming their tour in Lisbon consulting the official city free plan.

²²⁷ Some of them presented in the previous chapter (IV).

²²⁸ Monument recognition through image matching techniques over a certain angle.

²²⁹ French acronym “Mobilier Urbain Pour Information” (Urban Furniture for Information).

the user can be anywhere with no need to move to a specific and particular location (this is especially relevant when there is limited access to a site, e.g. due to construction works or the tourist's incapacity). This map can be taken everywhere; it can be stored (to reuse later); and it is available for free.

Therefore, considering the possibility of mixing the existing analogic representation and virtual environments, digitally augmenting and enriching this map with unlimited (thematic) data resources, accessing diverse information, might increase the value of the cultural heritage



Fig. 65 – Portable city free map enriched by digital thematic AR data.

objects, introducing new forms of visualizing them. The main objective was to augment (through mobile devices) non-visible or non-existing cultural/historical data over a simple tourist map, distributed for free and obtained in any part of the city of Lisbon. Several possibilities were proposed, such as: i) The ancient Fernandina City Wall (Fig. 66), built in 1373-1375, from which only a few parts are still visible in the city. Thus, it would



Fig. 66 – Georeferencing ancient cartography with the limits of the Lisbon Fernandina Wall. Vectorization, visualization and analysis. Image from the author. 2011.

be interesting to visualize the city within the walls, its main gates and implantation; ii) Another possibility was Lisbon before the 1755 earthquake, helping to understand how the city was before this event, that deeply transformed the city (buildings, morphology, relation of the city with the river and urban boundaries) and relating it with the reconstruction and evolution until today; iii) The Water and the City theme (which gathered more consensus), regarding the importance of this vital resource for the people in the city.

The Lisbon Aqueduct System, protected as National Monument (since 1910²³⁰), was relevant for the urban development and city morphology, with the enormous advantage of being partly existing and possible to visit. However, in the city centre, the remains of this important landmark are mostly underground and are not known by visitors or even by some inner residents. The idea was to increase the intrinsic value of this cultural heritage object; in this case, considering not only the individual elements of the aqueduct, but also the wider delimitation of the entire system (over years of constant construction), identifying the most relevant path and associated elements, starting from several springs, subsidiaries and distribution aqueducts and galleries, vents, connections with the exterior and culminating in the fountains, spread throughout some of the most relevant and growing locations within the city (18th to 20th centuries). Most of these places are within the most touristic and visited areas of Lisbon²³¹, which could not be detached from cultural heritage knowledge and dissemination, considering the potential interest of a tourist to discover the city. However, this map has several versions, launched every year, which created a problem when associating the App with the map as a marker and thus it needed constant updating. Even though, for example, the map of 2016 could be recognised when the first base used was the map of 2015, this only happened because the new version of the map had some minor changes, which were not very significant.

With the support of the Computer Science Department of the Faculty of Sciences and Technology of NOVA University of Lisbon, namely Professor Teresa Romão, Professor Fernando Birra and Antero Pires, it was presented a proposal for the App's architecture (Fig. 67) together with its main features taking into consideration the experiments that had previously been performed and the available (build) data²³² to construct a mobile App. This proposal of architecture had several enhancements until the final project (as well as the App's features). The architecture proposed had several adaptations and could easily be adapted for other thematic approaches within the main idea of augmenting the value of cultural heritage.

²³⁰ Legislation Decree 16-06-1910, DG,1.ª serie, n.º 136 of 23 June, 1910.

²³¹ Neighborhoods/parts of the city, such as Baixa-Chiado, Bairro Alto, Rato, Santos, or Janelas Verdes. These areas concentrate high number of tourist interests and related services (e.g. cultural sites and heritage, temporary accommodation, museums).

²³² These data were developed with the support of SIPA (Portuguese Inventory and Archives of Cultural Heritage at the Central Level) in particular Luís Marques (Geographer) and Paula Figueiredo (Historian), during 2010 (georeferencing ancient cartography, using the source- planta topográfica do Aqueduto Geral das Águas Livres de Lisboa, 1856, SIPA desenho n.º 0305626). However, these data were totally verified and remade in 2014/15 after obtaining several collections of ancient cartography (Planta Geral da Cidade de Lisboa - 1868, Lisbon Municipality and Atlas da Carta Topográfica de Lisboa, Filipe Folque 1856-58).

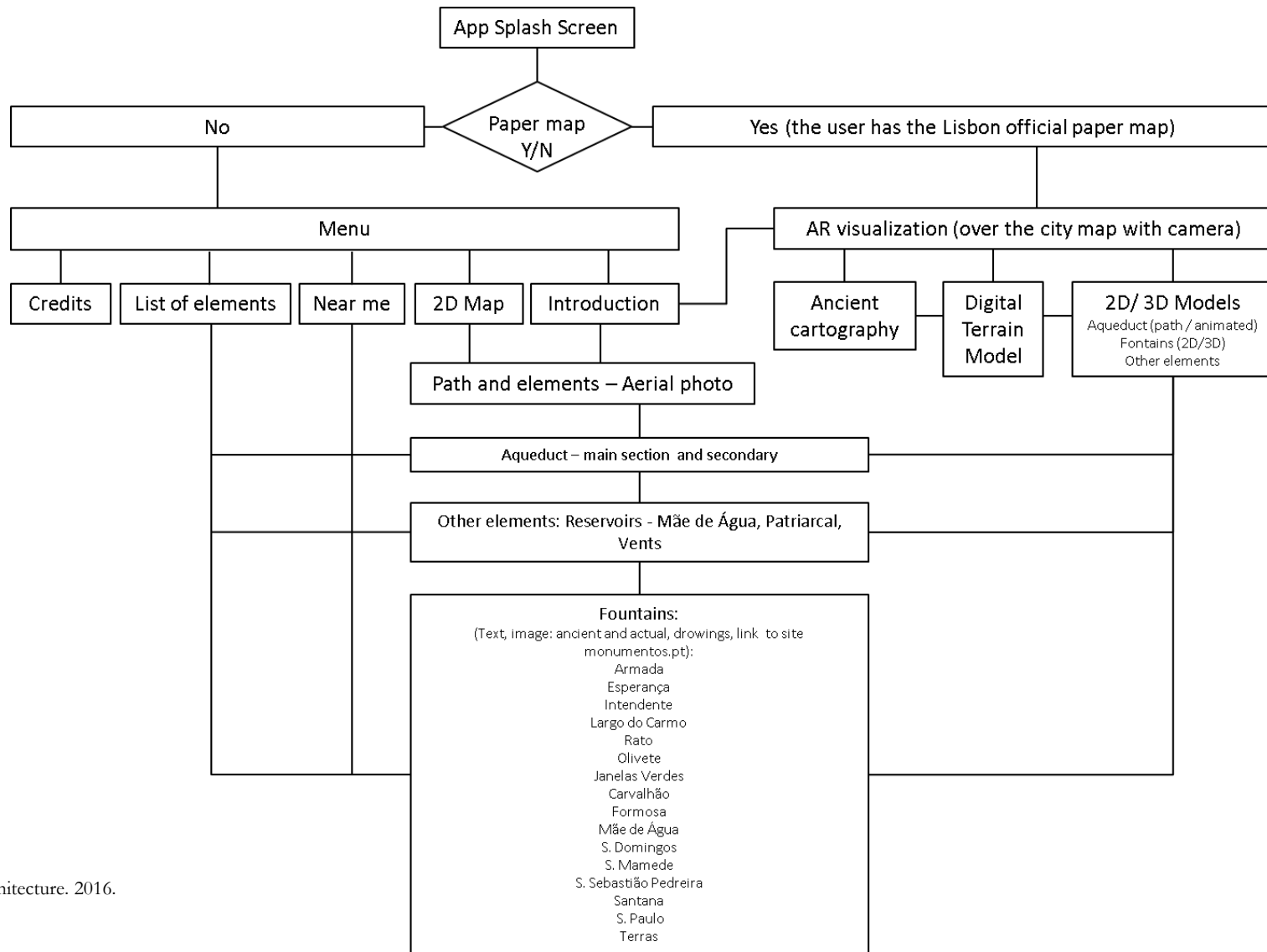


Fig. 67 – Lx_W App architecture. 2016.

2. App Development

The visualisation of 3D models in an AR environment can be achieved by recognising (a marker's) features of an image, such as the Official City Plan, that is free and easily available (Figs. 68, 69, 70, and 71). This procedure is carried out with the digitalisation of the Lisbon Plan and the definition of samples of image targets, which will then be detected by the AR software development kit, superimposing the Lisbon Aqueduct System (LAS)



Fig. 68 – App icon to view over the Official Lisbon Plan *in situ*.

representation on top of it by recognising key elements in the target image. Thus, users are able to simply open the application (App), point the camera to the paper city map and visualise the information in an AR environment.



Fig. 69 – Mãe de Água reservoir 3D model and AR environments using the city map as a marker.

Chapter V – Building an App for the Lisbon Aqueduct

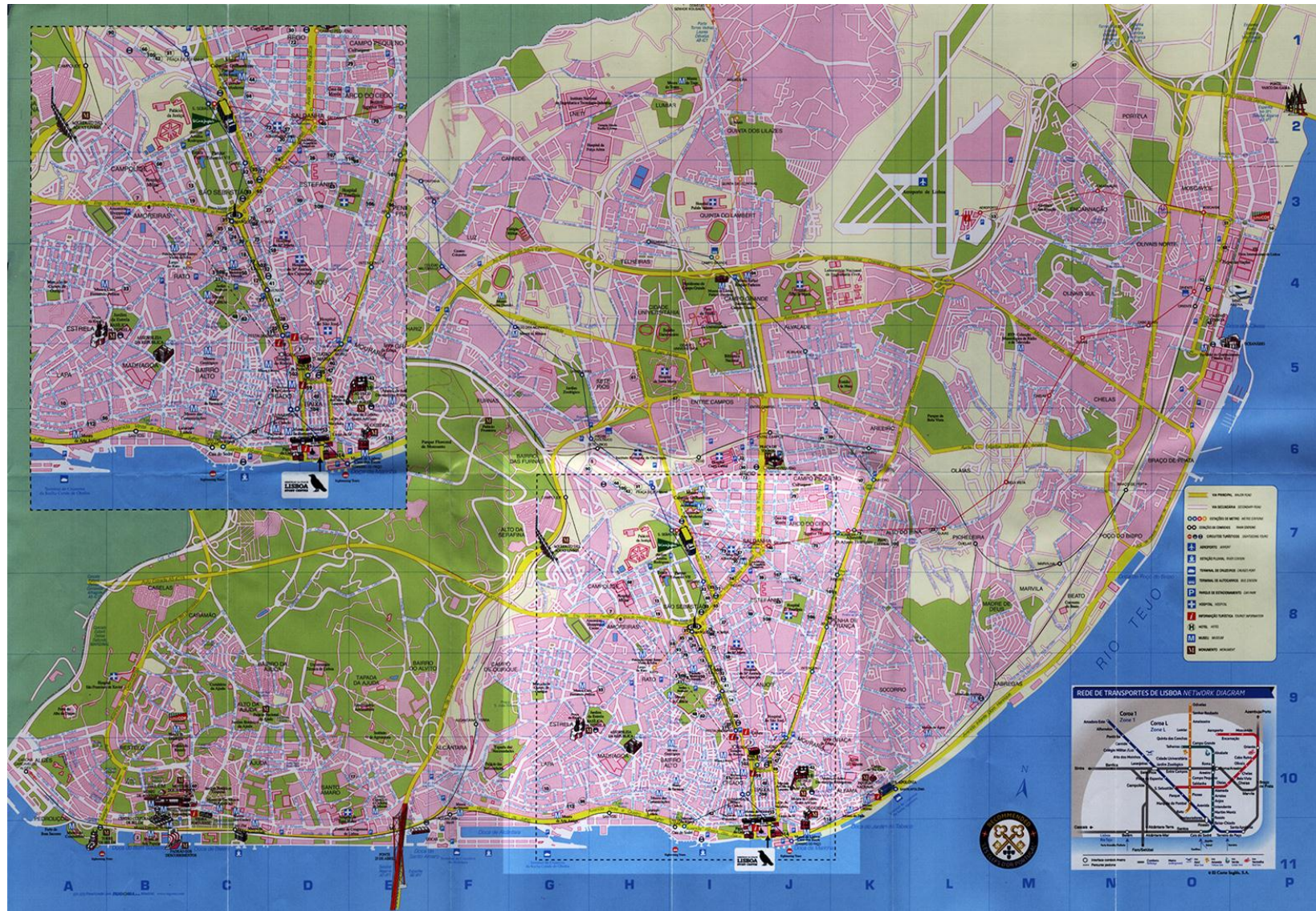


Fig. 70 – Official Lisbon Plan of 2016 used as image target for the AqueductAR App (source: Turismo de Lisboa and El Corte Inglés). Use to visualize the Lx_W App available at URL: www.luisfilipemarques.com.



Fig. 71 – 3D models (terrestrial, UAV) from the main elements of the structure of the Lisbon Águas Livres Aqueduct.

The App's development required an enormous effort to reduce the size of the geographic information and cultural heritage elements of the LAS, such as 3D models, ancient cartography, photographs (old and current), vectors, maps, and digital terrain models, without losing the Level of Detail. This is particularly relevant when we consider that mobile App's performance and the need for it to adapt to multiples devices. However, although the main objective was to develop an App prototype to include at least one feature to demonstrate the potential of this technology, as the 3D models and cartography started to be inserted into the App to be represented within an AR environment, it was soon evident that it would be better to divide the App into two related Apps:



1. The first App – Aqueduct AR²³³, with the AR environment through the mobile device camera (3D models, Ancient cartography, DTM and respective animations);



2. The second App – Aqueduct GPS²³⁴, with the associated multimedia (Text, Pictures, List, location and LAS representation over a Map) and the feature of proximity alert [which alerts the user within 150 meters of the object (LAS)].

²³³ AqueductAR, Available at URL: <http://www.luisfilipemarques.com/site/doctor/> (February, 2017).

²³⁴ AqueductGPS, Available at URL: <http://www.luisfilipemarques.com/site/doctor/> (February, 2017).

The AR component of the AqueductAR App was developed using the paper map as a marker (Official Lisbon Plan) recognized by the Vuforia AR framework. However, these maps changed every year during the App development (from the end of 2014, 2015 and beginning of 2016). Although, the software recognized all the maps as image targets, due to the similarities between them, they had to be updated to the most current one each time. Since Vuforia SDK uses OpenGL ES (GLES) that accepts basic matrix of geometric vertices, vertex normal and texture coordinates, corresponding to a single texture file, we had to create a conversion from FBX, OBJ or Collada 3D outputs (exported from Agisoft) to GLES format (through a small parser/program built)²³⁵. Therefore, we used the Vuforia's Unity extension that accepts most common 3D formats, such as Collada (format used), plus this extension had more documentation on placing 3D models than Vuforia (Pires, 2016). Using Vuforia's Unity extension allowed us to import successfully the 3D models without draining the battery or slowing down the device. This App was developed exclusively for Android devices and it was tested with several versions (4.2 Jelly Bean, 5 Lollipop; 6 Marshmallow) and smartphone/tablet screens (Samsung Tab 3 - 8"; Nexus 5 - 4, 95"; Samsung S5 - 5.1", respectively). The Official Lisbon Plan has the representation of the whole of Lisbon municipality, with a small detached square that represents the downtown area. Both areas (Large map and this small square) recognise the aqueduct data, when we point the camera to view it within an AR environment. This characteristic proved to be very useful: while using this App in the field, a user would have no need to open the map (no need to stop) and therefore the user could simply use the shorten version in one hand while walking through the city, consulting the paper map and visualising the AR data when relevant.

The following sequence of icons and images summarises the main features available in the AqueductAR App. The layout is very simple, having the real environment captured by the device camera in the centre of the screen and some buttons in the corners and on the bottom of the screen for the user to interact with the App and visualise the several features and characteristics that are available. This sequence of icons and images should be interpreted as the icon on the left (what it is and what it does) with the generic image of what the user can visualise on the right.

²³⁵ The results were not satisfactory considering that the conversion functioned for the model meshes, but not for the textures while merging all into one and reassigning them to their polygons and processing power required, draining the device battery. The task to adapt the textures to the model could be programed, although it was time consuming at the development stage (Pires, 2016).

Chapter V – Building an App for the Lisbon Aqueduct



AqueductAR

Button:
AqueductAR App

View over the
Official Lisbon
Plan or go to the
AqueductGPS
App.



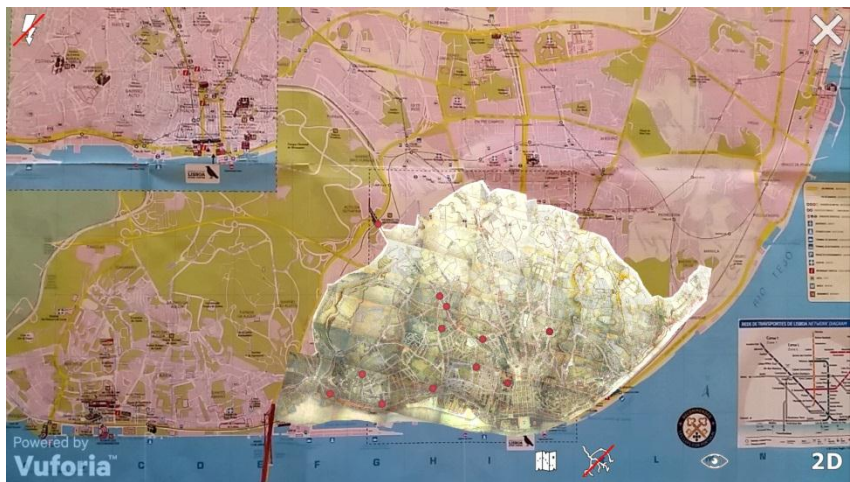
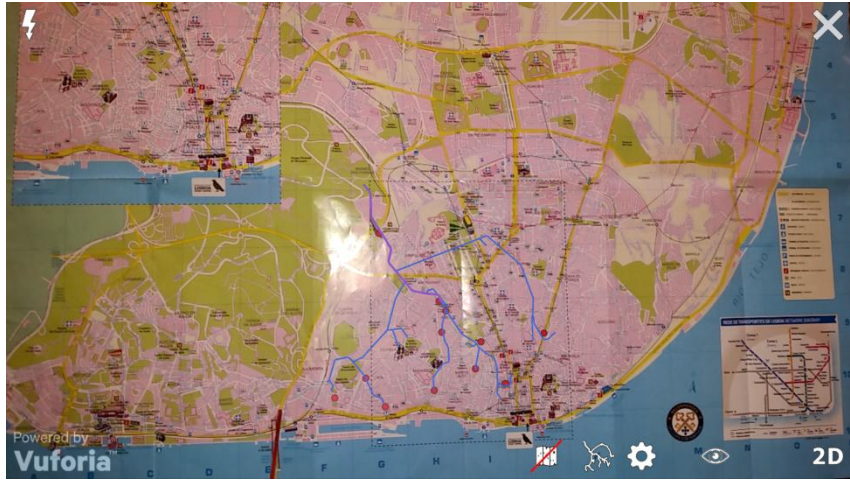
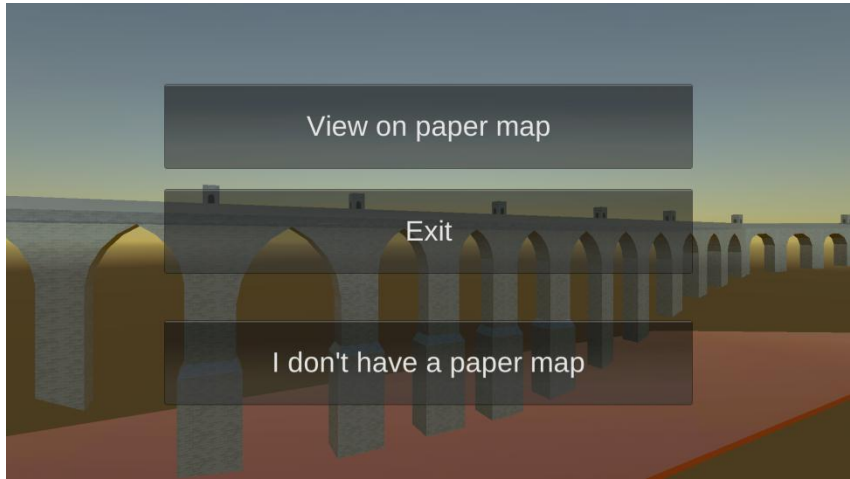
Button: Flash
on/off


Visualize the map
with more light and
better capture the
AR environment.



Button: Ancient
cartography on/off


Visualize the
ancient cartography
over the paper
Official Lisbon
Plan. This
cartography was
produced in 1856
under the direction
of Filipe Folque,
providing a detailed
perception of the
city extension in
this period.





Button: Aqueduct path on/off


Visualize the aqueduct path within an AR environment.



Water Flow
Surface Pathway
Underground Pathway
Visitable Pathway

Button: animations

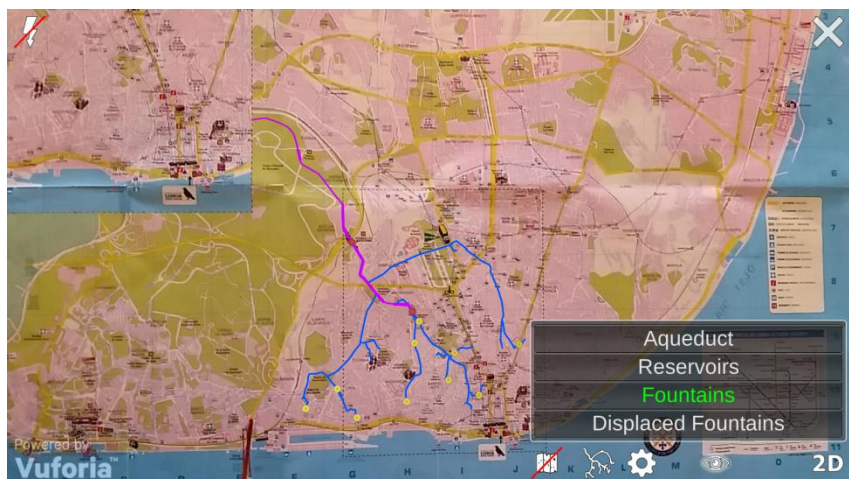
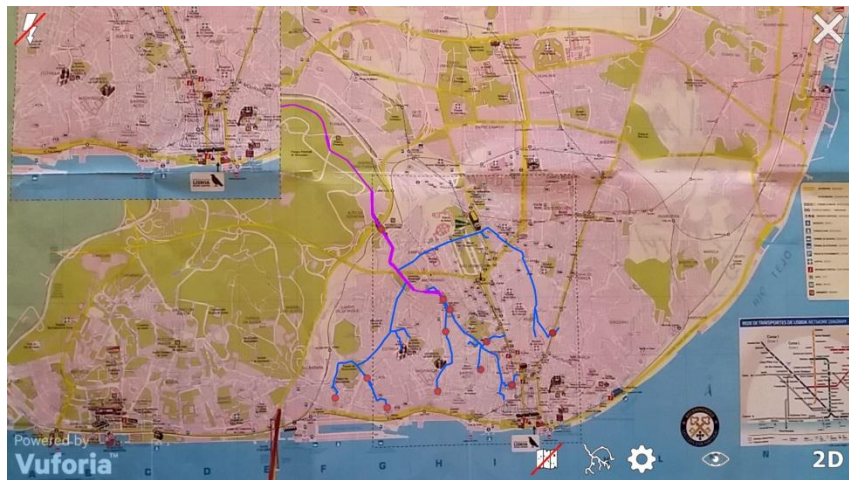
Visualize the aqueduct path at surface and underground, water flow and the possibilities to visit.



Aqueduct
Reservoirs
Fountains
Displaced Fountains

Button: animations

Visualize the elements of the Lisbon Aqueduct System. Animation of the location of the Aqueduct (over the Alcântara Valley), Reservoirs, Fountains, and displaced Fountains.




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2D 3D


Button: 2D/3D

Visualize the elements of the Lisbon Aqueduct System in 3D. It gives access to the button of the DTM (terrain).




Button: 3D elements in AR and link to **AqueductGPS** App

Visualize the 3D model (rotate) and access to the second related App **Aqueduct GPS**: text, current and ancient pictures, Google map and navigation, near me...



Button: DTM on/off.


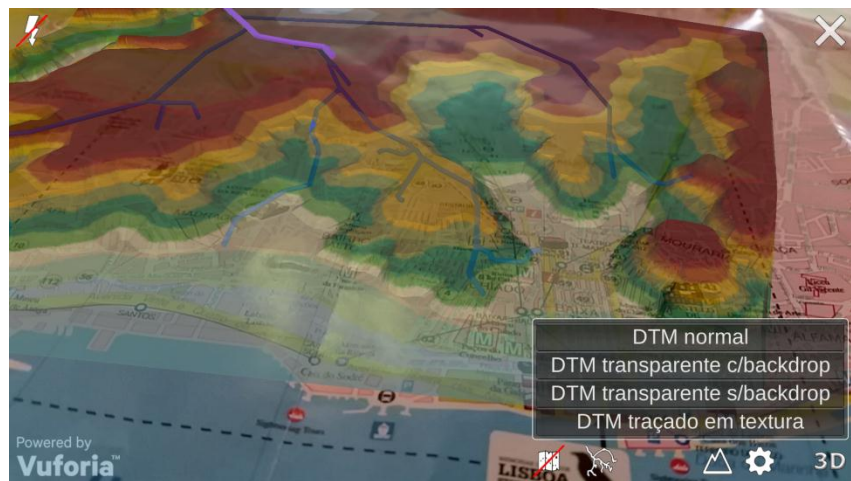
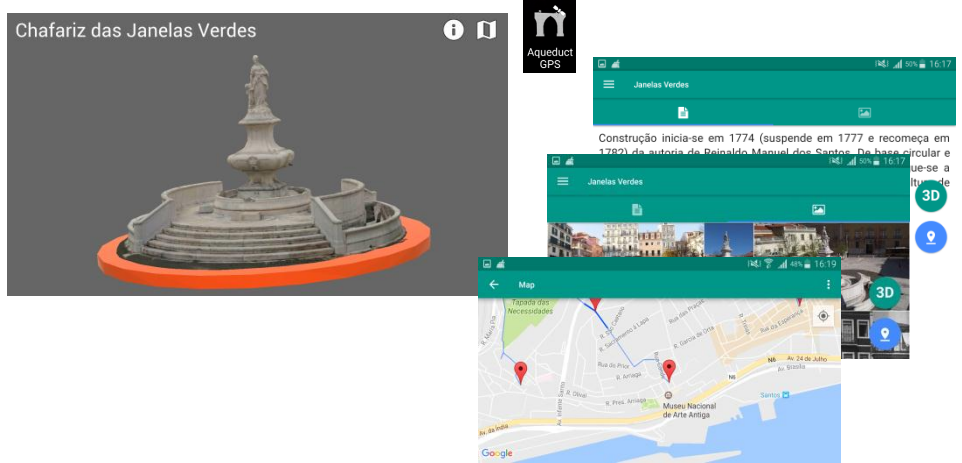
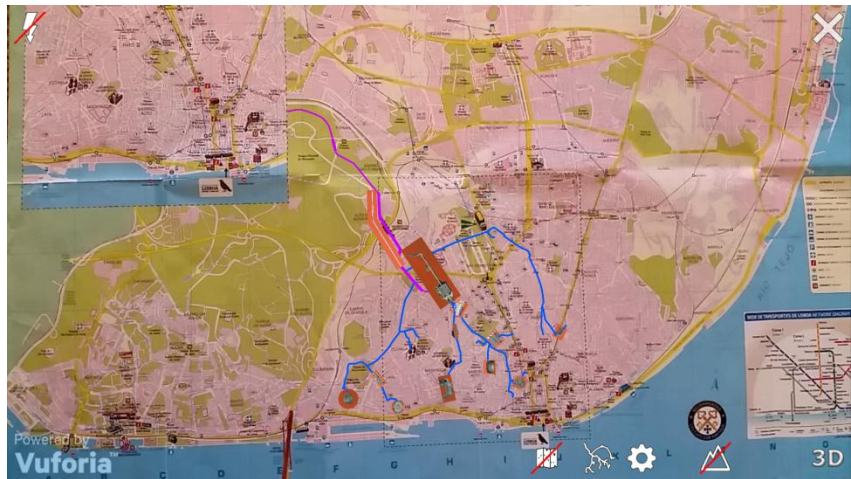


DTM normal
DTM transparente c/backdrop
DTM transparente s/backdrop
DTM traçado em textura

Button: DTM representations

Visualize the Digital Terrain Model opaque, with transparency and/or texturized path.

Button: Close

After installing the AqueductAR App in the Android smartphone/tablet, the user will see the icon to access the App. Most of the uses of both Apps are offline, except the visualization of the path and elements over the Google Maps API (in the Aqueduct GPS App). The access to a navigation system depends on the user's device pre-installed software (and if it is on-or-off line). The app will recognise the device language interacting with the user in Portuguese if this is the language defined, or English if the device has any other preselected language. Before accessing the main App screen, users will have to choose whether they have a paper map. After choosing using the map, they need to point the device camera to the paper map so it can recognise the AR data. It is possible to focus the camera of the device as the normal camera by touching any part of the screen. The App has one button in the top left corner to turn on the flash providing more light and subsequently better and faster positioning the aqueduct data (especially with no light or in low light conditions) and in the top right corner there is always the possibility to close the App with the button identified as "X". If users switch the GPS on they will see the location marked on the map.

Ancient Cartography

The mosaic created from 65 cartographic sheets of the topographic atlas of Lisbon "Atlas da Carta Topográfica da Cidade de Lisboa", dated from the period between the years 1856/58, at a scale of 1:1000, watercolour painted and directed by Filipe Folque, was very useful for the delimitation of the LAS path but also extremely relevant to superimpose it on the current Official Lisbon Plan, giving the idea of the city boundaries and morphology in that period and the subsequent growth. This capability is relevant to "time travel" and verify pre-existences within the city, but mostly its intention was to better understand the water distribution in the city and the main beneficiary areas at that time, allowing us to understand how the LAS might have contributed to the subsequent development of the city (with possible impacts on the city morphology). This mosaic of ancient cartography had several chromatic differences, and it was corrected to be better visualised when superimposed on the paper map. The main objective was to provide an example of what can be made, showing what might be done with several other thematic

cartography or aerial images (from different years). Thus, we can use a time line to go back and forward in time to visualise the city in different periods.

Lisbon Aqueduct System's Path

The aqueduct system's path was developed for the entire structure, which intersects four municipalities in Portugal (Amadora, Lisbon, Loures, and Sintra). The main section (the structure between “Mãe de Água Velha” and “Amoreiras”) has about 14 km in length; however, when the subsidiary aqueducts and galleries are included, this system totals approximately 58 km of extension. The identification of the LAS path was performed georeferencing ancient cartography and vectoring the main structure, adductors, distributing galleries, and associated elements. For this purpose, we mostly used the ArcGIS 10.1/2/3 software and QGIS Lisboa/Valmiera (both GIS software). However, other types of relevant software such as geobrowsers like Google Map/Earth (free and intuitive geographic information software), supported also the delimitation of the LAS, especially with the feature Street View (visualizing the world at street level), as described in Chapter IV. Nevertheless, the area available in the Official Lisbon Plan was only the municipality of Lisbon and since it is the most complex area, from the point of view of identifying the structure, conflicts with the built urban space, and tourist interest, we considered only the course inside the boundaries of the Lisbon municipality, ignoring the rest of the identified path. When the user turns on the button of the path and points the camera to the paper map, this user is able to see the digital path represented over the paper map in an AR environment, enriching the simple data printed on paper with the unlimited thematic digital data, combining both and forming the idea of the structure within the city. This is especially relevant because most of the path shown digitally is underground and not visible from the city surface, except for some visible exterior paths or elements such as system ventilation, access doors, and fountains. Thus, the user can have extra information while traveling through the city and discovering what is above, but also underground. This is even more interesting if users turn the GPS on and check their position in relation to the aqueduct system, understanding the complexity of this structure. This Cultural Heritage corridor and its configuration led to the use of the dataset with the representation of the system's path, identifying the water flow direction (very important considering the

distribution of water using only gravity), the sections that are above and underground, and those that can be visited.

Elements of the Lisbon Aqueduct System

The App shows not only the path where the water was flowing through, but also the associated elements that can be visualised in two ways: 2D (dots) and 3D (models developed). Using the dots, the user can identify the position of the main relevant elements of the LAS, such as the Aqueduct over the Alcântara Valley, the main water reservoirs and the fountains. While in 2D it is possible to select the different element groups or the displaced fountains, in 3D it is possible to pick and access the 3D visualization of the structure and interact with the model, using rotation/zoom and/or access the features of the **Aqueduct GPS** App (e.g. texts, images, navigation). The possibility of visualising the LAS elements in 2D or 3D is provided by this button (2D/3D). The 3D models were produced and treated so they would have the least possible weight (reducing the number of faces) to improve performance, preventing the App from crashing. In the 3D models, a colourful base and/or background (orange) were added to facilitate the identification of the object's position in the AR environment.

Digital Terrain Model (DTM)

The DTM was added especially because the LAS distributed water through the city using exclusively gravity. Therefore, the relief is an important visual data asset to understand the relevance and monumental complexity of this structure. The hypsometry has a variation of 10 meters and it is represented by the generic colours (palette from higher to lower altitudes: dark red, red, yellow, green) attributed by the GIS software (ESRI ArcGIS 10), which in this case was not modified considering its remarkable result when represented over the map. The DTM can be opaque or transparent to better view the 3D path over the city and its relief. This allows the user to understand the logic of the LAS trajectory, also identifying the spaces where the aqueduct flows underground, but also where it emerges to the surface (on the valleys).

The (multimedia) content component of the LAS project was developed with a simple App, without the need of using the Official Lisbon Map on paper and therefore not depending from this external input. Thus, it allows users to have a higher possibility of using the Apps and better understanding this important cultural heritage landmark of the city, even if they do not possess or if they do not want to use this map. The main objective was to make sure that any person with the AqueductGPS App installed in their smartphone would have access to the main common data regarding the whole of the LAS, as well as its individual elements in a different separate App, without the AR component. This App was designed more for people that might have previously planned their route and know what to see/visit and just want to have extra information on site with higher performance and in an App which is more oriented to that purpose and not so heavy. Thus, the AR was separated from the conventional data instead of integrating all the information into one rigid and dense App. Therefore, the user can access LAS data in two ways: AqueductAR with AR data over a paper map, or AqueductGPS, a simple App with more conventional data, such as text, images and map, easier to use and without the need for a physical map. However, these Apps are associated (in both directions) and using the resources of each other.

The decision to separate the LAS data into two Apps had several advantages:

- i. Higher level of data organization concerning each content (AR and Multimedia);
- ii. Higher level of performance for both Apps;
- iii. Autonomous usage, doing away with the need for a physical map to access the LAS information;
- iv. Different levels of complexity for different types of users;
- v. Broad and higher diversity of device operation.

The AqueductGPS App has also the function of Location Aware Service, which issues an alert to the user within 150 metres of the Lisbon Aqueduct System. For this service, it is necessary to have the GPS on. The following sequence of icons and images summarises the main features available in the AqueductGPS App. The layout is extremely simple and consists basically in a list menu with the elements of the LAS, the possibility to turn on the Location Aware Service and update the data through a web service.

Chapter V – Building an App for the Lisbon Aqueduct

Aqueduct GPS

Intro

Button: AqueductGPS

Access to the main menu with Introduction, Places, Map, and Near Me. It grants access also to update the data and show the credits. The texts will correspond to the device language.

Places

Janelas Verdes
Chafariz

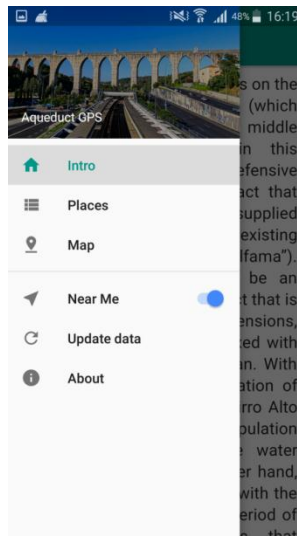
Button: Places

Access to a list of the available elements of the LAS. Visualization of the texts, pictures, and position in Google map. It gives access to the 3D model and then to the AqueductAR App.

Map

Button: Map

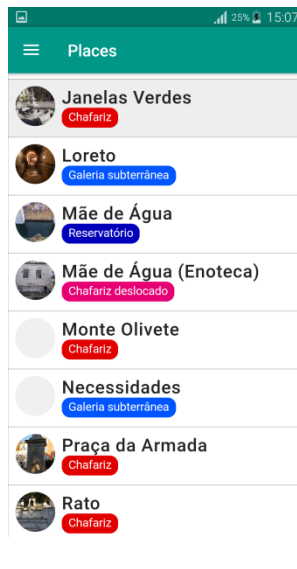
Show the position of the selected LAS element in the Google API map, with the location of the Path, and associated aqueduct Elements. With the GPS turn on shows also the user position.



Intro

inhabitants of the city was estimated around 200 000.

Classified as a National Monument (since 1910), the "Águas Livres" aqueduct system was projected as one of the boldest hydraulic engineering structures built in Portugal, going through the municipalities of Loures, Sintra, Amadora and Lisbon. Built in limestone it has in the main section (structure between "Mãe de Água Velha" to the "Amoreiras") about 14 km length, however, when counted the subsidiary aqueducts and galleries it totals approximately 58 km extension. This complex water supply system consists of the general Aqueduct from "Mãe de Água Velha" in Carenque (172m altitude) to the reservoir of the "Mãe de Água das Amoreiras" (94m

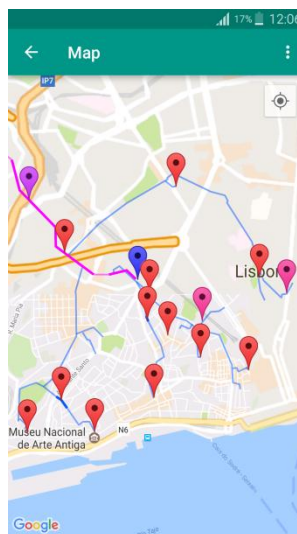


Janelas Verdes

The construction begins (suspended in 1777 and 1782) authored by "Reina dos Santos". Circular and the gate of the palace has springs and in the top statue of Venus to whom delivery an arrow ("António sculpture).

Janelas Verdes

3D



Chapter V – Building an App for the Lisbon Aqueduct

Button: Directions

It provides the LAS element coordinates and the user's position, the AqueductGPS App will ask the user which pre-installed navigation app to use and create a route.

Button: Near Me

With the GPS turned on, the user receives an alert while getting close to the LAS (path or element).

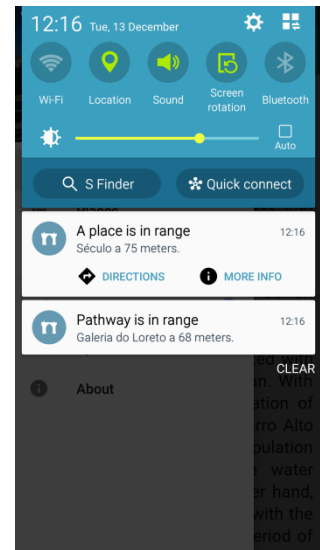
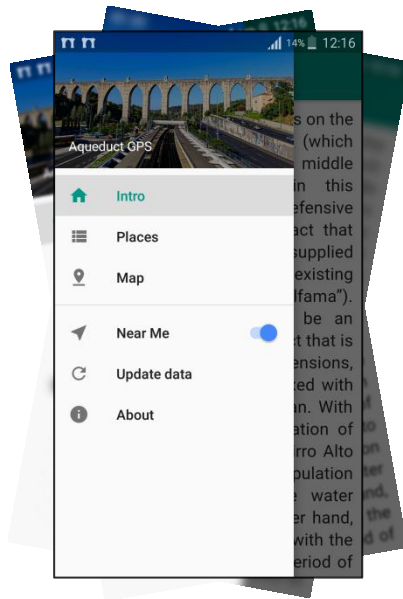
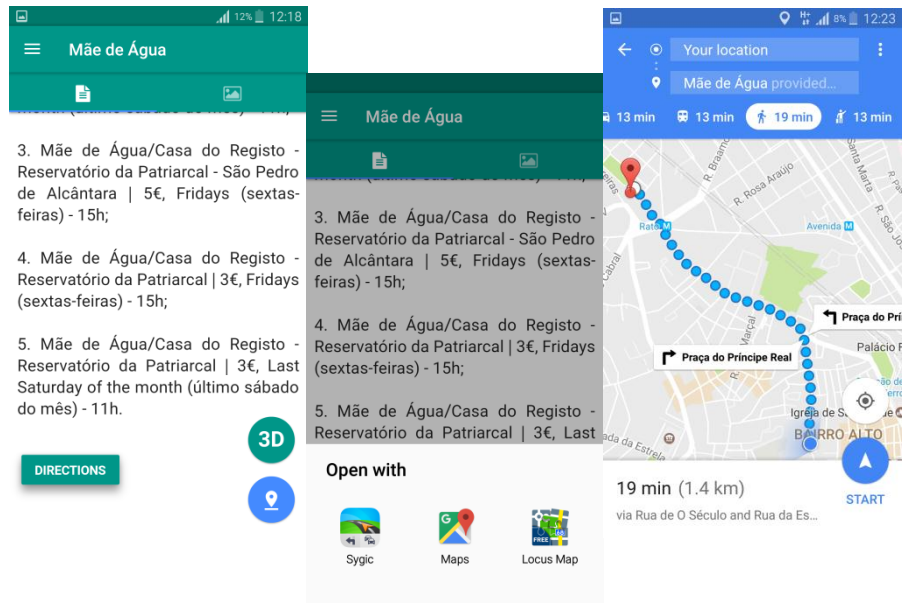
Button: Update Data

It provides online updates.

Button: About

Visualizing the credits.

Exit



Text and Pictures

It was our intention to create short and simple texts with the most relevant and interesting data about each element of the LAS: Aqueduct, Galleries, Fountains, and Reservoirs. This data was obtained fundamentally from books and SIPA/DGPC inventories. Beside the information for each element, an introduction to the theme “Lisbon and Water” was created with some relevant information about the city growth and the increasing demand of water, its relevance and availability. Associated with each record and beside these simple texts, it is given the possibility of visualizing ancient images (mostly from the Lisbon Municipality Archive – AML; Directorate-General for Cultural Heritage-DGPC and Bibliography) and current pictures (made on site, with or without associated coordinates). The records have some information about the visiting hours, ticket prices (when applied) and coordinates so they can be opened in a previously installed navigation App to assist in the route towards the object.

3D Models and position in Google Map

When users are consulting the text and images from a given element of the LAS, they can access the 3D model visualization mode using the link to the Aqueduct AR App and the AR environment through the device camera. Besides the icon to 3D visualization, each element’s file has also one button that gives access to Google Maps API, showing the path and elements of the LAS with the present location identified with a blue dot, when the GPS is turned on. The Google Map with the elements marked over a simple map (online), on the other hand, provides direct access to the file with texts and images.

Near Me / Location Aware Service

The Location Aware Service allows the user to switch the GPS on or off; with the device GPS on, it will alert (vibration and sound) the user to the proximity (150 metres) of an element of the Lisbon Aqueduct System.

Chapter VI

Analysis of the Lisbon Aqueduct App

Chapter VI – Analysis of the Lisbon Aqueduct App

1. Workshop

In order to evaluate the smartphone applications (Apps) in the context of the promotion of cultural heritage, a workshop was organized to perform a comparative analysis of the Apps developed and those available in the market. The workshop was directed to a limited number of people, selecting carefully a panel of experts from very different fields of work within the scope of the Apps' context: Architects, Geographers, Historians, Computer scientists and Decision-makers (at Ministerial level –Ministry for the Environment²³⁶, National Cultural Heritage²³⁷, and Municipality²³⁸). Our intention was to provide several data previously, thus overcoming the processes of installation and configuration. The place for the workshop was a restaurant with suitable conditions (large, comfortable space with internet access) located very close to one of the main elements of the Lisbon Aqueduct System: the Carmo fountain. This proximity allowed to the participants to analyse the application indoors, with Internet access and technical support, and later verify the Apps outdoors, near the object of research.

The workshop was exclusive to Android OS smartphone users, although a considerable number of participants possessed an IOS iPhone as well. The workshop was designed with a very simple program and focused on the analysis of four Apps (3 obtained in the Google Market and 1 obtained via a given link). These Apps were selected taking into consideration the trial that had been made previously with data for the Lisbon

²³⁶ Which integrates (among others) the institution *EPAL – Empresa Portuguesa de Águas Livres* (water and water related heritage management) and *IHRU – Instituto da Habitação e Reabilitação Urbana* (Urban Rehabilitation).

²³⁷ *Direção-Geral do Património Cultural* (Directorate-General for Cultural Heritage).

²³⁸ Persons responsible for Lisbon Municipality.

Aqueduct. All the data had been earlier prepared for each App (equally), showing its potential, and compared on the day of the workshop without ever revealing to the participants what they would experiment. So that the participants would understand the documents provided and the additional questionnaire better, the Apps developed, AqueductAR and AqueductGPS, were designated as a group by “Lx_W”, or Lisbon and Water.

The workshop had several stages:

- i. Defining keywords for the potential evaluation of mobile applications to prepare a questionnaire;
- ii. Developing an online survey using the *Survey gizmo*²³⁹ platform, which included 22

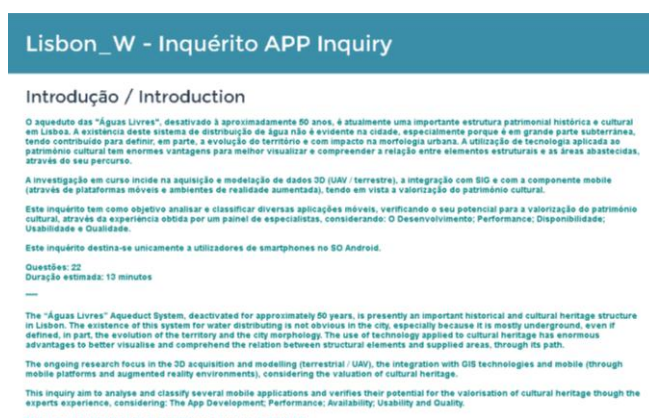


Fig. 72 – App online survey with 22 questions.

questions (13 minutes) within the group of questions that considered the potential evaluation keywords and the Apps: Development; Performance; Usability; Quality; Heritage Valuation; Identification (see annex 3 – questionnaire1). The answers were evaluated from 1 (min.) to 5 (max.) and when the Don't Know/No Opinion

(DK/NO) box was ticked, was assumed the value 0. The identification questions helped to verify the answers and establish groups by age, sex, or occupation. The questionnaire was bilingual (Portuguese and English) and had a small introduction and indication that it was intended only to Android OS smartphone users.

- iii. Inviting specific experts from different areas of studies (e.g. Architects, Geographers, Historians, Computer scientists) and field of work (e.g. Professors, Entrepreneurs, Technology companies, Students, Urban Rehabilitation, Politicians/Managers,

²³⁹ Survey Gizmo, available at URL: <https://www.surveygizmo.com/> (January, 2017).

Heritage conservation, Municipalities), providing them with basic information in tree main documents (written in Portuguese): *Event Promotion*, *Pre-requirements*, and *Procedures*.

iii.a. *Event Promotion* (two pages – see annex 2) – a document that explained that the main objective is to evaluate smartphone applications (Apps) within the context of the promotion of cultural heritage performing a comparative analysis of the Apps developed and those available in the market (Android); it also provided the research background, namely the exploratory data acquisition and 3D modelling stages, using Unmanned Aerial Vehicles (UAV)/terrestrial systems, and its integration with GIS and Augmented Reality (AR) through mobile platforms. The document also mentioned the devices and materials needed, such as the Official Lisbon Plan, Procedures + AR Marker image (given upon arrival at the event) and a Smartphone with the Apps installed - Augment; ESRI; IGEO Heritage (Market) and the developed App Lx_W (via a especial provided link).



Fig. 73 – Workshop indoors with a panel of experts testing the Apps and evaluating them using an online survey.

This document explained that the intention of the experiment was to strengthen this idea of the potential application of technology for the valuation of heritage, involving the use of geographic information in areas with a strong visual perception of space. The experiments made were related to spatial modelling (3D) and the visualization in AR of cultural heritage elements, such as the Aqueduct of Águas Livres in Lisbon.

iii.b. Upon acceptance of the invitation, two other documents were sent to the participants: *Pre-Requirements* (see annex 2) – For each App – Lx_w | iGEO | ESRI | Augment, was provided data about the App icon, size, link to download, and how to install it (provided before the event).

iii.c. *Procedures* (see annex 2) – consists in the Procedures Document (for all the Apps), Marker (Augment App) and the Official Lisbon Plan (to the use as marker for Lx_W or AqueductAR and AqueductGPS). Step-by-step to access the aqueduct data in each App, previously prepared online.

Included a link to the online questionnaire (to be able to answer later) and a marker (aerial image of the Carmo area) to visualise the 3D model developed (and made available online to interact with the App Augment). An additional Plan of the city of Lisbon (Official) was supplied to work as a marker for the Lx_W App (1 per person).

- iv. Searching a place in the proximity of the aqueduct system area (in city centre) where the workshop could take place. Verifying the restaurant “Fábulas” in Chiado, Lisbon area, considering conditions, costs, and trying the path between the restaurant (indoors) and Carmo Fountain (outdoors), analysing the Internet access and outdoor conditions to the successful course of the works, making sure that it would also be pleasant for the invited experts.



Fig. 74 – Workshop outdoors, near Carmo fountain.

- v. Online questionnaire analysis, validation and information processing – from 18 questionnaires filled (partial/full); 14 were complete and 13 were considered valid (1 questionnaire although complete had answers Don't Know/No Opinion for all the answers that corresponded to the Lx_w, iGEO and ESRI Apps).

The workshop functioned perfectly and had a considerable number and diversity of experts, which stressed the interest and pertinence of the issue. The invited experts did not know much about what they would experiment, being provided only with what was strictly necessary to the workshop day. The Android smartphones had all the Apps already installed and functioning (according to the previous pre-requirements document, referred to above), without the need of more technical support (showing that the pre-requirements document was enough). In the reception table (at the restaurant) the Procedures Document (referred to above) was available, as well as the Carmo fountain aerial image that would function as a marker (for the Augment App), and the Official Lisbon Plan (Lx_W Apps). The main objective was to verify the experts' reaction to all the Apps, while they were calmly following the procedures for each App and the presentation made, using a connection between the organization's smartphone and a 40" smart TV (connected through screen-mirroring and making it possible to visualise step by step what they needed to do). The biggest surprise came when the participants saw the Lx_W App (AqueductAR and AqueductGPS) and noticed the Augmented Reality functions over the official city plan, when almost every expert in the room released a pleasant exclamation followed by excellent reactions in terms of comments and positive criticisms made. Thus, their reaction immediately showed a greater preference towards the Lx_W Apps. The place selected revealed to be very pleasant and especially good located, being adjacent to the study object and allowing to the experts to be comfortably analysing the Apps indoors and outdoors. While they were seated and testing the Apps, they were able to make questions, share ideas and contribute towards the improvement of the App's development.



Fig. 75 – Workshop experts filling in the online questionnaire indoors with Wi-Fi access using their smartphones.

2. Questionnaire Completed by (local) Experts

This questionnaire (to local experts, see annexes 3, questionnaire 1) was developed in several stages, and was gradually adapted to the main answers needed for the research, performing a comparative analysis between the developed App and other Apps that are available in the market, mainly using closed questions. Locus (a mapping App) and ESRI Collector (offline and editing mapping App) were selected when we first started researching these apps; however, while we were designing the program of the workshop, they were dropped, considering the time consumption (and complexity) of the installation and offline data download/synchronization (ESRI Collector) and external data integration (Locus) needed. Therefore, the selected Apps for evaluation by the expert in the workshop were:

- **Augment:** 3D augmentation App (possibility to use 3D models and visualize over a defined marker in an Augmented Reality environment);
- **ESRI (ArcGIS):** Mapping App (possibility to upload GIS data and visualize over a selected base map with our location through device GNSS switch on; has additionally some tools available for measure);
- **IGEO Património:** Heritage Inventory for Portugal (SIPA's Heritage Inventory App with protected and non-protected elements divided by typologies for Portugal, visualizing the location (dot) over a map or in list form, giving access to records with text, images, and links to the official website);
- **LX_W:** Name given to the developed Apps, AqueductAR and AqueductGPS, for easy understanding of the user, identified as the App developed within the scope of this project. Historical Lisbon Aqueduct System water distribution (developed App with Augmented Reality data over official free map of the city: Lisbon Aqueduct System delimitation, with 3D models and access to records with text and current and ancient images. Possibility to overlay in an AR environment, ancient cartography and Digital Terrain Model with the aqueduct system path and its elements).

Our intention was to write short and clear questions, which could be fully answered in 15 minutes or less²⁴⁰. Therefore, the questionnaire had 22 questions, it was bilingual (Portuguese and English), and covered six groups of app- and heritage-related issues (see annex 3 – questionnaire 1):

- Development;
- Performance;
- Usability;
- Quality;
- Heritage Valuation;
- Identification.

These questions had the same type of structure, evaluating the selected Apps with a scale from one to five (where one was the minimum and five the maximum); there was also the possible choice Don't Know/No Opinion to which we attributed the value of zero (0). This questionnaire was aimed at understanding which App was adequate for each group of questions and which would be more suitable to increase the value of the heritage. The scale for the answers allowed us to perceive in the final results how many questions were not answered and what was the maximum and minimum classification for each question, inserted within a main subject or individual groups. While the first group of questions (Development, Performance; Usability) were more related with the App itself and how it works, the group of questions that focused on the Quality and Heritage Valuation, expected to connect mobile capabilities with the cultural object itself (i.e., the Lisbon Aqueduct System). The final group of questions (Identification) was aimed at characterizing the individuals (Age, sex, professional area and situation).

The value attributed to each answer corresponds to the indicated value and the DK/NA answer corresponded to zero (0). All the answers were based on the following scale:

²⁴⁰ The online survey builder software *Survey Gizmo* was used with a free account. All the questionnaires, videos, results, and other materials are available at www.luisfilipemarques.com.

| | | Values | | | | | |
|------|-----------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| | | 1 | 2 | 3 | 4 | 5 | NS/NR - DK/NA |
| Apps | Augment | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| | ESRI (ArcGIS) | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| | IGEO Património | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| | LX_W | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

Fig. 76 – Example of question (to classify each App with values from 1 to 5).

2.1. Question Relevance

Considering the groups of questions (see annexes), it was intended to obtain the following data from questionnaire:

Development

How users evaluate the Apps considering their design (form and function) attractiveness, understanding if the App has a high level of appeal and aesthetics. The idea was for respondents to reflect on the App's simplicity (easy to work with), thinking that tourism might be one of the main possibilities of usage, and therefore it is important to understand whether the App's users find it intuitive and user-friendly.

Performance

Considering mobile device data capacity, it is relevant for users to evaluate the Apps, assessing their performance, particularly as regards their readiness to respond (although this depends on the device used). Otherwise, users will probably search for another solution (mobile App or not). It is equally relevant to verify the space that the App occupies on the user's smartphone, since this might influence the operation and performance of the device. Some features of the mobile Apps might work with other already installed features (such as

mapping or navigational Apps) and interoperate without the need to have an “All in one” App. It is also relevant to understand if the file format is interoperable (import/export) between these and other available Apps/software (formats such as *.PDF or *.KML tend to be universally accepted). Considering that the developed App (Lx_W) is not available in the market and therefore needs to be installed by accepting “unknown sources” in the smartphone, this might create distrust. There is always the risk that an App from an unknown source might damage the device and thus it was necessary to verify the level of trust of the respondents in terms of accepting to install all these Apps in their personal smartphones.

Usability

It was intended to recognise which App had the highest capacity to engage users and consequently which might become more interesting for them. When the mobile Apps are developed for an exclusive language or group of users, they might be limited. Thus, our intention was to verify the universe of users considering the language and level of interest for a broad number of people. We wanted to assess user’s satisfaction, considering the initial expectations, summarising the results of the previous questions (e.g. design, user-friendliness, readiness to respond, engagement), and learn the overall evaluation concerning the initial expectations and ease with which people can use the app in order to perform a specific task and obtain useful information.

Quality

This group of questions aimed to understand how users evaluate the quality and level of reliability/credibility of the information provided. Considering the example of the case study of the Lisbon Aqueduct System, it was important to assess the potential of applying each of these Apps to other (equally relevant) cultural heritage elements. Subsequently, we wanted to ascertain how users evaluated the knowledge obtained through the Apps when they analysed the case of the Lisbon Aqueduct System. Thus, the ultimate goal was to

understand whether the respondents felt they had acquired new knowledge while using each of these Apps.

Heritage Valuation

This group of questions was aimed at verifying the potential for dissemination of the Lisbon Aqueduct System and greater valuation of this cultural structure of the city by means of technology. It was intended to understand how users evaluate the potentially increased value attributed through the use of each of these Apps (e.g. higher knowledge, engagement, dissemination, number of users), addressed to the main agents in the territory, such as tourists, local businesses, technicians, politicians, and whether they recommend the repetition of the experiment (so the level of satisfaction was quite high).

Identification

This part was associated with data collected on the following characteristics: Gender (male/female); Level of education (Basic – Compulsory; Middle level; Undergraduate; Post-Graduate – Master, PhD, Post-Doctoral; Other); Employment situation (Unemployed for more than 1 year, Unemployed; Student; Employed; Other); Area of Studies (Agriculture and natural resources; Architecture; Humanities; Social Sciences; Technologies). With these questions it was possible to gather the individuals' characteristics as a regulator variable, for example, analysing the simplicity, user-friendliness, usefulness, and knowledge valuation attributed to each App, verifying with the respondent's age, level of education, or area of studies; understand the difference between what is an end product or prototype of an App, concerning professional experience and associating the answers with the main area of studies or employment situation; and verifying the main values attributed for each App and features, according to the field of studies of the users (commonly generating different opinions regarding the device capabilities and the knowledge of the object); among other analysis.

2.2. Analysis of the Questionnaire Completed by Experts

The questionnaire results are potentially interesting and allowed us to verify the consistency of the answers and the discussion held in the workshop. Almost every invited expert filled in the questionnaire using their mobile device at the end of the workshop, still with the experiences very fresh in their minds. The overall sum for all the Apps given by individual (minimum of 0 and maximum of 340) shows that it corresponds to an average of 244, where the extremes are not too different from the average: two people attributed

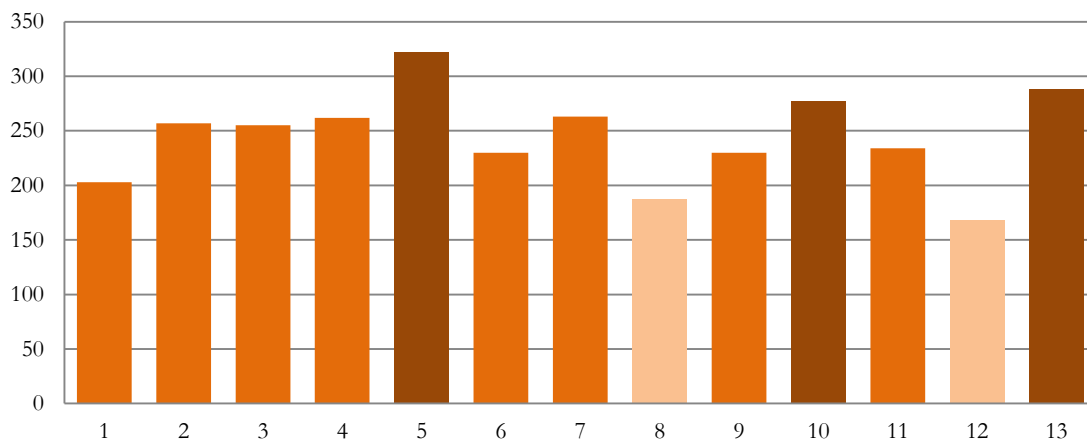


Chart 1 – Bar graphic with the sum of valuation given per individual for all the selected Apps.

lower values (under 200, but still over 150) and three individuals attributed higher values (over 250, but peaking at 322). Thus, the majority of the individuals attributed an average between 200 and 265 points to the sum of the Apps (Chart 1).

Table 2 summarises the questionnaire results and presents individual sums for each question and each App analysed, considering all the points attributed by every individual. Overall, every App achieved a good classification; however, we can see slight differences, where iGEO and Lx_W App have higher values. On the other hand, Augmented and ESRI App were attributed the lowest values. The group of questions targeted at assessing Performance had the lowest values, while the group targeted at assessing Development and Usability seems to be more homogeneous across all the Apps.

Chapter VI – Analysis of the Lisbon Aqueduct App

| | | | SUM | +and - | MODE | DK/NA |
|-------------|----|-----------------|-----|--------|------|-------|
| DEVELOPMENT | Q1 | Augment | 40 | - | 3 | 0 |
| | | ESRI (ArcGIS) | 48 | | 4 | 0 |
| | | IGEO Património | 56 | + | 4 | 0 |
| | | LX_W | 51 | | 4 | 0 |
| | Q2 | Augment | 44 | - | 3 | 0 |
| | | ESRI (ArcGIS) | 49 | | 4 | 0 |
| | | IGEO Património | 52 | | 4 | 0 |
| | | LX_W | 53 | + | 4 | 0 |
| | Q3 | Augment | 45 | - | 3 | 0 |
| | | ESRI (ArcGIS) | 51 | | 4 | 0 |
| | | IGEO Património | 54 | | 4 | 0 |
| | | LX_W | 57 | + | 4 | 0 |
| PERFORMANCE | Q4 | Augment | 38 | - | 4 | 2 |
| | | ESRI (ArcGIS) | 38 | - | 3 | 2 |
| | | IGEO Património | 39 | | 3 | 2 |
| | | LX_W | 42 | + | 4 | 2 |
| | Q5 | Augment | 40 | - | 3 | 1 |
| | | ESRI (ArcGIS) | 42 | | 3 | 1 |
| | | IGEO Património | 46 | | 4 | 1 |
| | | LX_W | 48 | + | 4 | 1 |
| | Q6 | Augment | 37 | - | 3 | 2 |
| | | ESRI (ArcGIS) | 44 | | 4 | 2 |
| | | IGEO Património | 38 | | 3 | 2 |
| | | LX_W | 45 | + | 4 | 2 |
| | Q7 | Augment | 40 | - | 4 | 3 |
| | | ESRI (ArcGIS) | 41 | | 4 | 3 |
| | | IGEO Património | 43 | + | 4 | 3 |
| | | LX_W | 40 | - | 4 | 3 |
| USABILITY | Q8 | Augment | 44 | - | 2 | 0 |
| | | ESRI (ArcGIS) | 51 | | 4 | 0 |
| | | IGEO Património | 53 | | 4 | 0 |
| | | LX_W | 56 | + | 4 | 0 |
| | Q9 | Augment | 45 | - | 5 | 1 |
| | | ESRI (ArcGIS) | 45 | - | 4 | 1 |
| | | IGEO Património | 45 | - | 4 | 1 |
| | | LX_W | 52 | + | 5 | 1 |

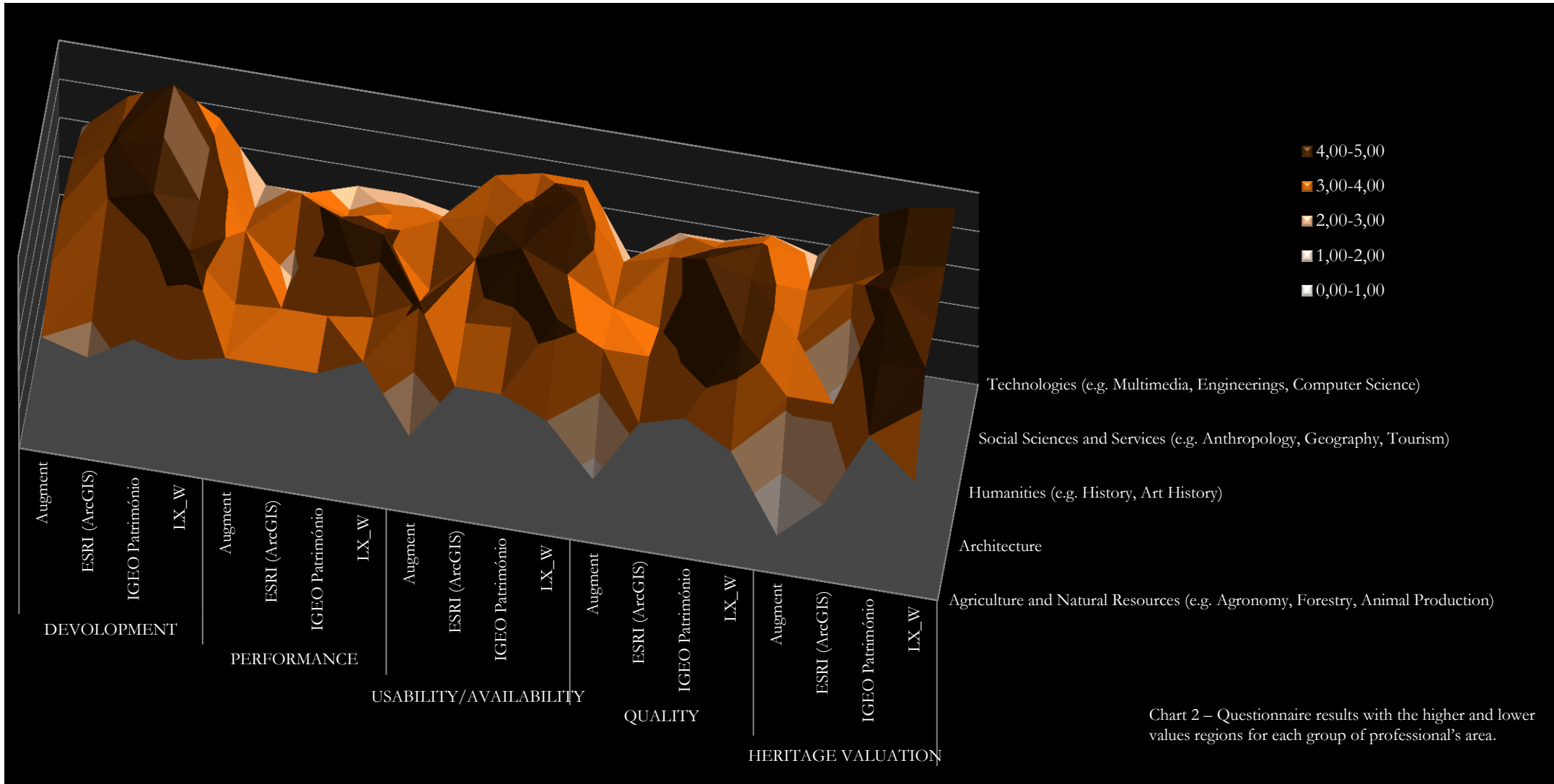
| | | | | | | |
|--------------------|-----|-----------------|----|---|---|---|
| | Q10 | Augment | 40 | - | 3 | 1 |
| | | ESRI (ArcGIS) | 47 | | 3 | 0 |
| | | IGEO Património | 53 | | 4 | 0 |
| | | LX_W | 56 | + | 5 | 0 |
| | Q11 | Augment | 40 | - | 3 | 0 |
| | | ESRI (ArcGIS) | 49 | | 4 | 0 |
| | | IGEO Património | 55 | + | 4 | 0 |
| | | LX_W | 54 | | 5 | 0 |
| QUALITY | Q12 | Augment | 34 | - | 3 | 2 |
| | | ESRI (ArcGIS) | 43 | | 4 | 2 |
| | | IGEO Património | 50 | + | 5 | 2 |
| | | LX_W | 46 | | 4 | 2 |
| | Q13 | Augment | 44 | - | 4 | 0 |
| | | ESRI (ArcGIS) | 50 | | 4 | 0 |
| | | IGEO Património | 50 | | 4 | 0 |
| | | LX_W | 58 | + | 5 | 0 |
| | Q14 | Augment | 36 | - | 3 | 1 |
| | | ESRI (ArcGIS) | 37 | | 2 | 2 |
| | | IGEO Património | 50 | | 4 | 1 |
| | | LX_W | 53 | + | 5 | 1 |
| HERITAGE VALUATION | Q15 | Augment | 39 | - | 2 | 0 |
| | | ESRI (ArcGIS) | 39 | - | 4 | 1 |
| | | IGEO Património | 57 | + | 4 | 0 |
| | | LX_W | 56 | | 4 | 0 |
| | Q16 | Augment | 38 | - | 3 | 0 |
| | | ESRI (ArcGIS) | 42 | | 4 | 1 |
| | | IGEO Património | 57 | + | 4 | 0 |
| | | LX_W | 57 | + | 5 | 0 |
| | Q17 | Augment | 38 | - | 3 | 0 |
| | | ESRI (ArcGIS) | 45 | | 4 | 0 |
| | | IGEO Património | 55 | | 4 | 0 |
| | | LX_W | 56 | + | 5 | 0 |

Table 2 – Summary with questions groups, questions, values sum, higher and lower valuation, mode (most repeated value attributed), and the total number of unanswered questions

seems to be more homogeneous across all the Apps. The major differences are in the group of questions regarding Quality and Heritage Valuation, where the highest values were attributed to the iGEO and Lx_W, and the lowest values were attributed to ESRI and Augmented Apps. The number of answers where Don't Know/No Opinion was selected, was higher in the following questions: seven (3), revealing undefined knowledge about the App's security; four (2) concerning the weight and performance; six (2) interoperability; and twelve (2) reliability and credibility, demonstrating the need that some of the users feel to have a deeper knowledge about the App's information and usage to be confident to answer, revealing a higher need for experimentation with these application in their daily use and not only in a workshop. These values can be interpreted as a confluence of relevant data about a certain object and much focused to the chosen theme (e.g. heritage) and less as a global superior or inferior application complexity (quantity of features). These results might explain the interest of users to have an App that is oriented at the intended purpose.

Chart 2 shows the ranges of values (higher with darker colours and lower with brighter colours) by group of professional area to each App separately and divided into groups of questions plotted as a 3D chart.

While regarding the Apps' Development, there is a higher classification of the Technologies group towards ESRI and iGEO, the Social Sciences group was more inclined towards iGEO and then ESRI, and Architecture and Humanities preferred iGEO and LX_W Apps. Considering Performance, this is the group of questions with the lowest values, especially those attributed by the Technologies group to the Augmented App. The highest scores were attributed by the Social Sciences and the Humanities groups to Lx_W and iGEO Apps. The Usability group of questions had high values, especially given by the Technologies, Social Sciences, Humanities and Architecture groups to Lx_W and iGEO Apps; and the lowest values were attributed to Augment App. Concerning the quality of the Apps, Lx_W and iGEO had the highest scores, especially attributed by the Social Sciences, Architecture and Humanities groups (especially relevant considering the deepest knowledge of this group about the main subject of analysis). Heritage Valuation had more homogeneous classifications with the highest values attributed to Lx_W and iGEO and the lowest values to ESRI and especially Augment App.



3. Questionnaire Completed by the Public in General

The experience of the previous questionnaire allowed us to check the experts' immediate reaction and response to the visualization of the 3D Digital Representation within an Augmented Reality environment when they pointed the camera at the Official Lisbon Plan (within the scope of the workshop) using their mobile devices. Thus, it was interesting to watch the reaction of the users when they realized the Lx_W (AqueductAR and AqueductGPS) Apps' main features, while working and exploring the Lx_W and the others Apps. It was also relevant to consider some results of the discussion and debate held in the workshop and the classifications attributed (anonymously) by these experts, who were mostly professionally related with the Public-Administrative, Social-Economical, and Technical-Scientific-Symbolic Domains. The number of participants in the workshop was restricted and so it was fairly simple to arrange an indoor location near the study object and explain to the participants how to install the Apps, how to work with them, their main features, their conceptual idea, architecture, main objectives and results. The participants were also able to compare the applications and create a collective reasoning, pondering on the Apps and evaluating the Digital Representations and Technology (e.g. GIS maps, 3D, visualizing Augmented Reality environments: raster ancient cartography, vectorial data, GPS and navigation resources, image and text contents) and their value to the Cultural Heritage related Agents and Domains. However, it was intended to have a broader range of responders that could answer remotely without the need of a schedule and arrange a formal meeting or the need for the user to install and invest time to work with and experience the Apps, deeply analysing all their features and capabilities while being near the study object (Lisbon Aqueduct System). Therefore, it was developed a short video (12 minutes), which was available online²⁴¹, with a short presentation of the Lisbon Aqueduct System structure and the App Lx_W's main features, divided into two main parts²⁴²:

²⁴¹ Available at <http://www.luisfilipemarques.com/site/doctor/>.

²⁴² We captured images inside the galleries, the aqueduct over Alcântara, over the smartphone while having the Lx_W App in use: near the Lisbon Aqueduct System elements, and indoors. The software used was: Lx_W Apps (AqueductAR and AqueductGPS); Google Maps App (supporting the map view in the Lx_W Apps); Here WeGo App (supporting the navigation capability in the Lx_W Apps); AZ Screen Record App (to capture the smartphone screen); and Moviemaker (to produce the video).

- Aqueduct system dimensions, relevant structures and historical facts. Showing the main elements of the aqueduct system and their diversity: Galleries (underground); Reservoirs (water tanks structures); Aqueduct (monumental arches over the Alcântara valley); Fountains spread all over the city;
- AqueductAR and AqueductGPS Apps' main features: Augmented Reality examples over the Official Lisbon Plan used as a marker (ancient and present cartography, aqueduct system's path and animations; 2D/3D visualizations of the elements that comprise the aqueduct system; Digital Terrain Model); Contents (text, map, ancient and present photographs); Navigation and Proximity alerts (within 150 m of the object a signal is emitted to the user).

The video can be streamed online and can be watched together with the questionnaire, through a link which can be visualized and analysed indefinitely, giving the possibility to clear any doubts while answering the questions²⁴³. The answers can be filled in anywhere and anytime, which is more comfortable for the respondent. Using the video for the second questionnaire solved the problem of the need to install and occupying essential personal space in the device and solving the limited number of respondents according with the smartphone's operating system, which increased the universe of respondents. The second questionnaire was developed using the same platform as the first, which is the online survey builder *Survey Gizmo*²⁴⁴ used via a free account. However, this second questionnaire had not only quantitative and App comparative questions, but also more qualitative ones, introducing four open questions to stimulate the responders' opinion, who had to justify their answer in detail. Most of the respondents (17) were students completing the Master in Sustainable Urbanism and Spatial Planning²⁴⁵ from the University NOVA of Lisbon and taking the seminar on Geographic Computer Technology in Urban Planning; this group had the added advantage of having a diversity of countries of origin (especially Brazil, Portugal, and Poland). In addition to this significant number of foreign students, the questionnaire was also answered by people from other countries, such

²⁴³ All the questionnaires, videos, results and other materials can be seen at the webpage: www.luisfilipemarques.com.

²⁴⁴ Survey Gizmo, available at URL: <https://www.surveygizmo.com/> (January, 2017).

²⁴⁵ University NOVA Lisbon, available at URL: http://www.unl.pt/guia/2016/fcsh/UNLGI_getCurso?set_language=en&curso=4313 (January, 2017).

as Latvia or the USA. As the inquiry was in Portuguese and English, the answers obtained in the open field type answer had to be first translated into a single language (English) for further analysis. Therefore, the following tables show the hierarchy of the most used words in the texts to answer questions 25 and 26.

25. After viewing this video, do you consider that the use of technologies add value to the experience of tourists, scholars, and interested people? Justify your opinion in detail.

26. Put yourself in the tourist’s place. Do you think that the expression “augmented valuation of cultural heritage”, an expression that is inspired by the notion of Augmented Reality, clearly translates what you saw in the video? Justify your opinion in detail.

| Question 25 | | | | Question 26 | | | |
|-------------|--------------|--------------|---------------|-------------|-------------|-----------|-------------|
| heritage | yes | information | visit | yes | heritage | tourist | augmented |
| experience | technology | interest | objet | reality | value | app | information |
| possibility | technologies | tourists | possible | object | interesting | curiosity | heritage |
| city | shape | knowledge | curiosity | technology | interest | could | interaction |
| access | interact | history | visualization | smartphone | tool | historic | relevant |
| importance | increase | disseminate | tool | history | cultural | objet | access |
| population | accessible | contribution | reality | paper | higher | map | reality |
| application | easier | aqueduct | spatial | monument | visit | Reality | perception |
| allow | search | explore | object | touristic | monument | tourist | value |
| visit | model | fast | better | | | | |
| journey | value | | | | | | |

Table 3 – Hierarchically ranked most used words in the answers to questions 25 and 26, translated into English.

Contrarily to the first questionnaire, these answers were mostly provided by ordinary individuals with very different background training and ages, presented here by hierarchically order:

- Area of Studies: Social sciences and services, architecture, sciences, arts and design, technology, agriculture and natural resources, economics, others;
- Age: 25-34; 35-44; 18-24; -18.



Fig. 77 – Word cloud of the answers to question 25.

The figures 77 and 78 were produced with the online software Wordclouds²⁴⁶ based upon Table 3. The answers to question number 25 (Fig. 77) of the second questionnaire were positive revealing primarily the words “yes” as a direct and clear answer, and then “heritage”, “tourists” and “visit”, attributing a huge focus on tourist usage. There are other considerations to be made as active, positive and suggestive words, such as “interest”, “possibility”, “allow”, “interact”, “possible”, “accessible”, “disseminate” or “value”. In sum, generally the answers reveal a high level of agreement that technologies add value to the experience primarily to tourists and other interested people.

²⁴⁶ Wordclouds, available at URL: <http://www.wordclouds.com/> (January, 2017).

about the Usability, Interactivity (higher while using indoors than outdoors), functionalities related with the interest of the App's 2D and 3D Information to explore and add value to the heritage object; the overlay of the ancient cartography got the minimum classification value (value of 2 given by one person in the universe of 24) and the Digital Terrain Model overlay capability obtained the lowest percentage (50%) of maximum values (5) in its classification. Considering the value attributed to the main agents, the majority revealed a higher impact on tourists and heritage-related technicians; while in terms of domains, the highest impact was on the technical-scientific and social-economic.

The workshop and the results of the first and second questionnaires show a high level of excitement and interest in the congregation of (geographic information) technologies (e.g. GNSS, GIS, RS, UAV, mobile, apps, 3D, Virtual and Augmented Reality) applied to the field of cultural heritage. Overall, the direct reaction verified in the workshop and questionnaire responses were extremely positive and allowed us to confirm that digital representations, especially at 3D and 4D, of the spatial environment are fundamental for cognitive perception, being particularly relevant for spatial analysis and modelling. The potential of these tools for the valuation of cultural heritage are tremendous, considering the level of interest that this area has transversally in society. These conceptions are extremely relevant for several agents, addressing important and exciting perspectives for their activities and contributing for the knowledge in the different domains.

Chapter VII

Reflections on Cultural Heritage and its Augmented Valuation

Chapter VII – Reflections on Cultural Heritage and its Augmented Valuation

1. Reflections on the Hypotheses of the Thesis

This thesis focuses on the central idea of Digital Representations and the Valuation of Cultural Heritage at the relation between Technology, Agents, and Domains (as shown in Fig. 1, page 2). Considering the key questions formulated as hypotheses in the Introduction, and as with all complex questions, there is not a single answer and thus different approaches might reveal different answers. This section and the following subsections will emphasize some of the main general insights presented previously regarding the initial outline, and the main hypotheses and objectives of this thesis.

The central topics of this thesis, Digital Representations and the Valuation of Cultural Heritage, have led to the development of Chapters I, II, and III, which establish the fundamental conceptual framework and key definitions. Chapter I presents the notion of representations and how they support cognitive perceptions, which are at the basis of how individuals recognize the physical world. Therefore, cognitive mapping and external affordances allow humans and animals to locate themselves in space (carrying a map or model of the physical environment in their heads or using technology), which is particularly relevant for navigation and spatial awareness. Through Digital Representations (Chapter I, Section 2), technology has been allowing humans to extend (represent) the physical world, as the examples addressed in Chapter II regarding Geographic Information Technologies (e.g. Satellite Navigation, Remote Sensing, and Geographic Information Systems). These technologies and innovative technical-scientific methodologies allow the Agents in the

several Domains to recreate Virtual Environments, approached in Chapter III as representational reproductions of the real world. These reproductions are particularly valuable when it is considered the ability to create detailed (3D) models of the present, frequently beyond the capacity of human perception, recreating situations and events from the past and simulating predictive scenarios for the future (4D), exploring different hypothetical situations that are often impossible to identify or observe in the real world. The application of these technologies is especially relevant in the field of Cultural Heritage, where digitally aided information acquisition, integration, modelling, and dissemination for research, conservation or exhibition purposes can contribute to the awareness of the historical, societal, symbolic, and scientific values of Cultural Heritage. The acknowledgment of the value of Cultural Heritage and the techniques for its further valuation is, thus, strategic in order to contribute to the development of more informed, comprehensive, and oriented procedures for the identification, preservation, and dissemination of tangible and intangible heritage.

The relation between Technology, Agents and Domains presented in Figure 1 of the Introduction has various approaches between Technology and Agents; Technology and Domains; or Agents and Domains. Technological advances, especially those related with technical progress and computer modelling capabilities aimed to represent the physical world, have led to the creation of an increasing number of high-quality 3D/4D Digital Representations of Cultural Heritage. However, Technology itself does not increase the value of Cultural Heritage. The Agents such as promoters, decision/opinion-makers, technicians, researchers or the general public, attribute meaning and relevance to Technology, using these (technological) tools in their activities. The value of Cultural Heritage is a quality attributed by users where technology plays an important role in helping Agents meet their objectives in the different Domains. Geographic Information Technologies have the ability to support Digital Representations of the spatial environment, in a way (digitally) augmenting the real world. Mobile capabilities are changing the way people interact with each other nearly in real time within a synthesized virtual environment, or adding digital content and representations, enriching and mixing virtual data with the real world (Augmented Reality). By means of Technology, both the virtual and the real worlds can be combined, expanding the space/time dimensions,

enlarging the public space through virtual environments, where users become virtually omnipresent, as (re)presentations, while being physically almost anywhere. Besides this space/time virtual world amplification, there is also an extension of human connectivity and information/intelligence, consecutively expanding the mind.

Chapters IV and V present the main technological methodologies applied to Cultural Heritage experimentation, gathering, integrating and modelling Cultural Heritage spatial data. These chapters describe several experiments (for the Lisbon Aqueduct System) performed with a selection of mobile Apps that are available in the market to compare them with the App that was built within the scope of this project, Lx_W (AqueductAR and AqueductGPS), with the objective to apply Virtual and Augmented Reality Environments to the field of Cultural Heritage. The Lx_W mobile App was developed in a partnership with the department of computer science of University NOVA of Lisbon allowing to congregate the main existing technological resources and apply them to explore the concept of *Augmented Valuation of Cultural Heritage*, which was further discussed.

Chapter VI describes the workshop held with the presence of invited experts (i.e., Agents involved and experienced in the field of Cultural Heritage), who were asked to fill in a questionnaire oriented to compare and evaluate several Apps available in the markets (selected from the tests made) and the built Lx_W App. The objective was to understand the main technological resources available to Augment the Value of Cultural Heritage, meeting the Agents' requirements and related Domain requests. Thus, the purpose of this workshop was to ascertain the value and relevance that the Agents attributed while using these technologies (near the case study: indoors and outdoors), considering the experience in their activities, and to the Political-administrative, Social-economic, Technical-scientific, Ideological-symbolic-religious Domains. The second questionnaire was designed for the general public. Before completing the questionnaire, the respondents had access to a video describing the Lisbon Aqueduct System and the main features of the Lx_W App. The main objective was to collect and verify, through open type answers, the respondents' perception of using Digital Representations within mixed reality environments to augment the value of Cultural Heritage. Therefore, it was intended to analyse the main objectives for each field of knowledge and the intellectual inputs given by these Agents addressing technological

solutions (or contributions) to the existing problems in the several Domains. Thus, by means of technology, Agents ensured a powerful support aiming to contribute to a better management, preservation, intervention, and dissemination of Cultural Heritage, allowing, sustaining, and developing new methods, approaches, and scientific knowledge in the several Domains.

1.1. Contributions from Technology to the Valuation of Cultural Heritage

Representations play a central role in a cognitive system. They clarify a wide variety of cognitive and perceptual abilities in terms of the occurrence and processing of mental representations. However, mental representations of the spatial environment diverge from the real world, eliminating and/or adding entities, frequently introducing distortions. Often, people have different perceptions of the distance between themselves and/or between themselves and a certain object and/or of the symbolic value of objects. However, perceptions constitute the basis of knowledge through experimentation, since we capture, using our senses, the experiences that we retrieve from the world.

Technological advances, especially those regarding the ability to represent the physical world and modelling capabilities, have led to the creation of an increasing number of digital data, objects, and environments. The use of Digital Representations (often-analogous to internal representations) and geo-science applications can provide many useful functions, such as data acquisition, navigation, object operation, inquiry, modelling, visualization, dissemination, among others. Spatial modelling techniques can be used to develop visual simulations, including diverse attribute data through time (as the world is not static). 3D settings are able to support positional cognition by offering a realistic/meaningful environment where the learning process can effectively be located giving the user the possibility of interacting with objects in their actual context (Mortara *et al.*, 2014). Modelling aids planners and other Agents to understand patterns and experiment scenarios to envision the impact of various plans and policies. Modelling a number of different variables allows testing and adjusting features to explore different hypothetical situations. Synthetized environments enabled to conduct experiments, introducing or

modifying variables and adjusting conditions that are not viable in the physical real world, such as transforming the topography, structures and their extension or height, planning, visualizing sights, colours, and lighting conditions. This is especially valuable in the field of Cultural Heritage considering the high level of technical and historical understanding, preservation, adaptation, and dissemination. When creating these models, there are endless possibilities to run experiments with empirical results that the community can measure, compare and recreate, allowing to understand, analyse, intervene, and distribute Cultural Heritage information about an object or site.

Technology has deeply changed the way spatial data is visualized (Yanzhen, 2005). The fast growing number of users and widespread Internet access represent a gigantic milestone in the evolution of human civilization, enabling the society to have unprecedented access to large amounts of information, sharing knowledge and communicating, while at the same time it is metaphorically developing a synthesized environment, albeit linked to the real world. These developments have brought main digital changes that revolutionized the concept and usage of spatial representations. The production of, access to, and dissemination of geographical information and cartography, considering, for instance, the availability of Digital Globes or Geobrowsers, have become democratic and they are no longer exclusive to professionals. The relatively recent developments in GIS Web Services made the construction of interoperable GIS possible. Web Map Services, Web Feature Services, and Web Coverage Services not only allow devices to interchange spatial data and tools, that can be constantly updated (with direct access from the producer to the user), but also eliminate dataset duplication and physical allocation (reducing the amount of time consumed in producing and searching for updated cartographic series datasets), and avoid numerous static dataset catalogues, and their associated costs. Since Cultural Heritage needs large amounts of highly detailed resources, using Web Services made possible to acquire, integrate, analyse, and manage data from heterogeneous sources in real-time over the Web. Cloud Computing provides a potential solution with a flexible, on-demand computing platform, available everywhere. Thus, the Internet and Geo Web Services constitute a fundamental basic infrastructure and resource to gradually improve digital representations and GIT developments, enabling access to geospatial data on demand (i.e. while zooming in and requesting higher detail at different scales) and taking user needs into consideration. This is particularly relevant in the field of

Cultural Heritage Digital Representations, when virtual environments are recreated, potentially augmenting their intrinsic value (e.g. significance, recreation of its time evolution, understanding its history/symbolism/importance).

Technology has been playing an important role in a transversal way, especially in terms of data acquisition, management, and visualization. Geospatial technologies allow “seeing” where human eyes cannot (Elwwod & Leszczynski, 2011). Through technology, it is possible to detect spectral bands that the human eye cannot capture, collecting larger amounts of data. Remote Sensing data acquisition and monitoring regarding (high or very high) spatial and spectral resolution images for monuments, groups of buildings, and sites (especially archaeological sites) have been progressively used (e.g. 3D models; photogrammetry metric data or spectral - visible, infra-red and/or thermal data over built structures, buildings, urban areas and landscapes). The association between 3D modelling and cultural heritage has been increasing in interest, partly due to the broader use of LiDAR (laser scanning) and photogrammetry. These technologies, used to study, archive and visualize Cultural Heritage, have become affordable and accessible, thus allowing people to record efficiently and accurately, objects remotely, which was often difficult to do with the previous survey methods. Therefore, Cultural Heritage has been one of the most used applications of the image processing and computer graphics community given its extraordinary results and interest.

Realistic 3D environments offer the user interesting possibilities of immersing in/combining with the real world, e.g. convincing reconstructions of events and contexts particularly to raise historical awareness. Virtual environments and especially Augmented Reality have, thus, a clear potential to support cultural heritage, highlighting and enriching its value in a dynamically and interactive form. It also allows users, especially the general public, to learn, intervene, and experience with higher engagement innovative approaches to the promotion, operation, and dissemination of cultural heritage (Mortara *et al.*, 2014). These procedures are changing the way in which humans perceive the territory and relate with each other. Residents cannot differentiate if an unknown individual, who is looking at one’s mobile device, is visitor (tourist) trying to access external aids to navigate (similarly to what they would do with a city plan), a technician learning about an unexplored cultural heritage object, or someone just going through a daily routine of consulting their email. The amount of capabilities that mobile devices provide through digital virtual data and

network access is so vast that no one can know by simple observation what the other person is doing when they are using a mobile device. Conversely, in virtual environments, often users do not have the knowledge of the others' physical location, except while writing or authorizing GNSS location by their own initiative.

The combination of both worlds is becoming gradually more interdependent while some features previously only available in the real world have progressively been virtualized, e.g. Lx_W (AqueductAR and AqueductGPS) Apps that connect endless superimposed virtual information over a simple available (limited) paper map, perhaps stimulating intergenerational relations (e.g. between a grandparent using the paper map and his/her grandchildren using their smartphones). Some services formerly provided at some entity's desk (e.g. acquiring products, services or accessing personal accounts and/or money and/or data) are gradually being transferred to virtual engines and portals (e.g. information search, homebanking, online shopping for products and services, such as travel or accommodation). Gaming uses virtual environments with increasingly higher graphics detail and performance isolating the user from the real world, giving the gamer the sensation of immersiveness. However, with the release of Augmented Reality games such as Pokémon Go, users need to explore the real world to capture *Pokémons*. Often, in the case of Pokémon Go, the user needs to move to a certain place that usually corresponds to cultural heritage landmarks and thus the user is led to explore those objects and sites. These preferred locations are also common in other games that use the real environment, such as Geocaching. Therefore, virtual goals set through a game might consist in relevant tools to promote cultural heritage, augmenting the intrinsic cultural value that these users would otherwise probably never recognize. Within the game, it is also important to empathize the aid provided to navigate through the territory by means of digital representations of real maps and providing the user's position through GNSS receiver. The most common example of total virtualization is the evolution of multimedia (e.g. books, photographs, video, audio – music or games/online gaming). Profound changes in accessing media collections are in the availability of audio records, more specifically music, that evolved from analogic vinyl records and magnetic tapes to digital Compact Disks/Minidisk, and currently has almost totally disappeared from the physical, being sold virtually in media libraries and stores (e.g. iTunes or Google Play). The same thing happened with research papers, journals, and books, where digital availability on Internet

portals has clearly overtaken their paper versions. In fact, most of the references used in this thesis were obtained in the Internet, and even the paper titles acquired were ordered at online portals. The use of paper maps is also being reduced, due to the democratization and general access to GNSS and free (updated) road maps (e.g. open street map project) with the advantage of real time position locator (GNSS) in the online/offline map and turn by turn navigation features. The use of paper maps enriched with digital Augmented Reality data allows users to combine the limited analogue map with limitless virtual information, as in the case of the developed App prototypes, AqueductAR and AqueductGPS, presented earlier.

Positioning and navigational (coordinate) systems are essential for mobile devices that need to identify their accurate position systematically. Thus, operating interactively these systems have to satisfy several requests, such as showing the user's position in a map, suggesting multiple navigation and transportation types, displaying nearby objects in different representational ways, or alerting to the proximity of a Point Of Interest (historical relevant site, monument, or other relevant structure). These aspects are particularly relevant for tourists, who frequently search for these cultural elements. The development of location-based data has moved cyber-information to the real place (Sui & Goodchild, 2011). This capability is especially relevant in mixed environments where the device needs to present virtual information in the real place (or vice versa) and thus the geospatial coordinates might be considered as the fundamental feature that connects the synthesized world and the real world. Therefore, it allows linking virtual data and the real environment (knowing where the user is) as a camera captures the real world images and mixes them with virtual synthesized digital representations to be visualized in real time on the device's screen. Consequently, many producers of geographical information are developing location-based services, offering a great number of basic services for mobile applications using technology. Both the virtual and the real worlds can be combined, expanding the space/time dimensions, human connectivity and intelligence, thus increasing the information about a certain object, and/or the general knowledge, altering the individual and collective perception of the world, expanding the mind (and therefore object value).

3D, GIS, Virtual or Augmented environments applied to Cultural Heritage are relatively new branches of knowledge that use information technology to digitally capture

or represent the data studied by several domains. 3D modelling and 3D GIS data in an Augmented Reality environment, through mobile platforms, provide the opportunity for Digital Representations, interaction, and dissemination, enabling dynamic 3D contents to be built, visualized and interacted with, and supporting attributes and spatial analytical features. Using technology, individuals can present or represent virtual environments that can exist (be real), sometimes in a way that goes well beyond how humans perceive space or even beyond reality itself (e.g. Remote Sensing spectral bands and Virtual Time Travel). New technological developments, especially in the field of 3D and Augmented Reality environments, have allowed time travels, i.e. recreating a structure(s) or place(s) in the past or foresee an intervention in a given cultural heritage element or site. Thus, it is possible to point the camera at the real ancient heritage location and visualise in the device's display the full virtual (re)construction (from the past or future). It is then possible to walk around the site in the real world and view the digital representations from different angles and distances, and even to change the (re)construction to experiment with different lightening, materials, colours, details, perspectives, or surroundings. In the near future, virtual time travel will be able to provide more than an enhanced experience of a historical situation, and ensure the full engagement of all the five senses into augmenting the value of the object itself. Digital representations and virtual modelling of Cultural Heritage contribute to simulation and visualization retaining or increasing the value of the object and preserving its authenticity, building replicas of an environment while protecting the original, sealed from the public contact. Making decisions about approaches to cultural heritage intervention, conservation or protection, should be based on a comprehensive assessment of the consequences of and the possibilities for different approaches and management (Stendebakken *et al.*, 2015). Computer-generated virtual environments, 3D, iterative and immersive environments increase the engagement of the user by providing a natural interface (as in cognitive space awareness) between human and machine. Augmented Reality Digital Representations restitutions and simulations can offer interesting possibilities and useful applications due to their impressive interactive capabilities and their capacity to visually stimulate and engage the user, for example, when applied to Cultural Heritage on-site visualization and exploration tools.

Technology has been playing an important role using scientific knowledge, methods, materials, and devices to capture and disseminate the Digital Representations of

Cultural Heritage. The development of technology and the evolution of the techniques used play an important role in achieving the progressively growing needs of new tools for several scientific domains and their related agents, simulating cognitive internal representations and external affordances within virtual/mixed environments.

1.2. The Valuation of Cultural Heritage Digital Representations for the Agents

Technological progress has made the use of 3D affordable in standard devices, making access to data more democratic and easier to reach anywhere, especially when we consider the growing portability of devices, such as smartphones, tablets or Augmented Reality glasses. Mudge *et al.* (2007) explored the issues that influence the adoption of decisions and gave examples of emerging digital technologies considered to eliminate existing obstacles due to the widespread adoption of digital practices. Digital Representations and technology consistently surrogate the content of the real world in a digital form enabling scientific study and personal enjoyment without the need for direct physical experience with the object or place. Their essential scientific nature distinguishes them from speculative digital representations. When Digital Representations are built transparently, according to established scientific principles, they provide authentic, reliable scientific representations, which enable the repurposing of previously collected information into a collaborative distributed system, eliminating barriers for the public's access and knowledge, besides providing faster widespread information (Mudge *et al.*, 2007). This vision supports three main general ideas:

Empirical Provenance – Widespread adoption of Digital Representations by science in all Domains, including the multi-disciplinary study of Cultural Heritage, requiring confidence that the data they represent is reliable, enhancing the development of techniques to digitally represent our world, permitting the replication of experiments that are central to scientific practice to confirm the quality of information;

Perpetual Digital Conservation – Digital Representations of Cultural Heritage can be in more than one place at a time and in more than one form, potentially assuring its longevity. However, the importance of developing sensible plans to preserve our digital heritage cannot be minimized, thinking of the Value of this digital heritage;

Digital Representations and Technology Democratization - The emergence of the new family of robust digital documentary tools offering automatic post-acquisition processing has overcome an important barrier to the adoption of digital workflows that ensure broad public access.

Technology and scientific knowledge have created virtual environments that are parallel to the real world, representing digitally the cognitive characteristics existing in the mind and the relations between humans and their surroundings. Fast and broad access to networks, such as the Internet, the growth of social networks and collective transmission of information, especially when it comes to mobile devices and ubiquitously access has become especially relevant to better understand human behaviour, interests, and patterns. Society presently has a high level of interaction between the real world and synthesized environments, where users systematically express their experience, attributing comments, recommendations, tips and tricks, valuations, associate pictures, among others features. Agents onsite are usually aware of this growing practice of manifestation, communication and collective response, with fast growing impact on specific economic sectors, especially those associated with decision making, tourism, and leisure (such as politics, public administration and participation, monument/museums and territorial promotion, temporary accommodation, commerce, and services). Digital representations and the virtual synthesized world are presently an extremely important space, where the users often search for and analyse goods or services sharing relevant data, making acquisitions and/or reservations. Therefore, it is relevant for Agents such as Promoters, Decision-Makers or Technicians to analyse and verify the potential of this vast provided “sensing” human data, aiming to recognize the value attributed by each user, considering individual and collective experiences, with the advantage of being available digitally and extensively.

Digital Representations of cultural heritage have implications, perhaps stimulating more travel (e.g. tourism) as a result of the initial available interaction (thus potentially damaging the heritage), or maybe helping to collect information and invest in better planning, managing, organising and coordinating human behaviour, e.g. promoting better conservation in the field of cultural heritage. These implications involve important Agents onsite:

- Decision/opinion-makers (e.g. politicians, managers and other institutional representatives) who are especially concerned with economic viability, proposals, end-users, efficiency, and symbolic values;
- Promoters (e.g. CH holders, CH institutions, museums, travel agents, accommodation and commerce) who are usually concerned with business valorisation and viability, type and frequency of costumers, and heritage preservation;
- Technicians (e.g. architects, engineers, geographers, urban planners), particularly those involved in analysis, evaluation, conservation, protection, management, and intervention
- Public in general (e.g. tourists, visitors, users) who frequently regard aspects such as individual perceptions, symbolism, history and value (importance), feelings through observation, and the main features of an object.

Digital Representations bring Agents from different domains closer to a virtual/mixed/real site and (re)present, for example, the impacts/consequences of a heritage analysis and intervention. 3D representations generate intuitive methods of interaction, increasing the engagement of the users making it easier for them to understand and participate by visualizing volumes, textures, shadows, sights, and the relation between this characteristics. This occurs principally because of the level of similarity with reality, which is comparable to the human approach of capturing and cognitively processing external information. Thus, 3D Digital Representations stimulate more enthusiasm and

simplify creative solutions to detect problems, improving understanding and communication. This is especially relevant for the communication and onsite intervention between Decision-Makers, Promoters, Technicians, and the Public.

3D GIS Digital Representations can provide information on heritage, which is extremely valuable for several Agents in the field. The use of digital representations, e.g. for the planning process at different scales and in real-time creates unprecedented opportunities for communication and collaboration between all the players with responsibilities in the territory, increasing the equality of participation and allowing for higher perceptual understanding, regardless of the level of education and knowledge Domains.

4D GIS digital representations can be built to reflect the past, existing and possible future conditions of cultural heritage, showing the current or proposed appearance, façade, style, material and size, applied to buildings, urban settlements, sites and landscapes, being able to altered and improve, on demand, while integrating all the Agents in this process. Thus, virtual environments can offer enhanced opportunities and provide additional tools for people to communicate with others and interact with the urban models. Consequently, digital representations might contribute to an higher valuation of the Agents in the field, involving them and providing them comprehensive and intuitive tools to construct, visualise, manipulate and integrate data, improving access to information and increasing their participation, for example, in the planning, policy-making or intervention processes. However, this sense of place can only be achieved while generating and developing virtual worlds with objects, buildings and settings, which one expects to find in the real situation. Therefore, the importance of 3D quality is highlighted in several research fields, noticing that users in highly realistic 3D reconstructions significantly experience higher levels of reaction. Technical-scientific advances in computer modelling capabilities have led to the creation of a growing number of high-quality 3D models of existing cultural heritage objects and environments. This collection of models provides new opportunities for the Agents (such as decision-makers, promoters, scientific and academic community, and the general public) to visualise and superimpose additional data onto this new developed worlds (e.g. promoting, publicizing, showing urban intervention, employing new approaches and methodologies, or programming a visit). The creation of 3D cultural heritage archives also requires solutions for storage and interoperability of these models

with each other, as well as with external sources. Thus, the Agents associated with heritage conservation must protect this valuable documentation (models) as part of the object's history and identity support (as argued by some international agreements and conventions).

Augmented Reality enriches the real world instead of replacing it. Users can visualise digital representations that enhance the real world with additional data superimposed onto their field of view (through their smartphone or glasses). The possibility of combining real and virtual objects creates huge possibilities and applications and is particularly outstanding in the field of Cultural Heritage, especially when recreating 3D representations and Virtual Time Travel (e.g. viewing several phases of construction or past edifications). Augmented Reality is specifically applicable to transversally elevate/enrich the Agents' experiences with Cultural Heritage. New forms of digital representations are systematically becoming available, adding information to the real environment on their devices' displays (e.g. 3D Digital Representations in smartphones) or through audio (e.g. museum audio guides). These characteristics might be especially relevant for tourists and the general public (visitor and unfamiliar with place), merging relevant Digital Representations of Cultural Heritage with the real environment, aiming to assist, visualise, understand, obtain the current location, verify the nearest relevant point of interest, navigate, learn, observe, present, simulate or reconstruct temporal events, with the possibility of receiving alerts when the users are near onsite interests (e.g. emitting a sound or vibrating while navigating near some relevant object), increasing the intrinsic value of cultural heritage. All these features and the capacity to attract the public might promote a higher level of demand for quality from the visitor's perspective (as a more informed community), establishing higher standards for available object-related needs, goods and services in the territory (on several fields, e.g. political, technical, managing, promotional, commercial and services). Representations of the physical world (regarding external affordances in different moments) and even the mental world (through internal minds or imagined/simulated/synthetized realities) create the opportunity for the development of virtual and, consequently, real space, mixing Digital Representations with the current world, allowing users to create, on demand, their own Augmented Territory. Therefore, Digital Representations provide the basis and constitute a powerful ally to support decision-making, contributing simultaneously to technical-scientific knowledge and human development.

1.3. The Valuation of Digitally Represented Relevant Cultural Heritage for the Different Domains

Technological advances and innovations have introduced suggestive designations corresponding to human brain capabilities, using words such as smart or intelligent (e.g. Smart or Intelligent Cities or Buildings, Smartphone, Smart TV). The acquisition of, dissemination of, and search for Digital Representations has had an extraordinary growth, in part due to the emergence of mobile devices, especially those with broadband Internet access, which started a revolution in the Human-Machine and Real-Virtual environments. Computer environments endowed with intelligence are beginning to change the contents of virtual worlds, especially the ability to learn and adapt using artificial intelligence techniques, such as neural networks, simulating the processes of the human brain. Smartphones have had a huge impact on human behaviour and society. Mobile devices have transformed the way people communicate and relate with each other, expanding the public (virtual) space, where users have become omnipresent (or re-presented) while physically they can be anywhere. Mobility has increased the influence of (social) networks in which individuals are able to react to or share almost instantaneously posts, events, or photos, allowing the fast and global dissemination of information, replicating most human social relations on a universal scale. Often, this volunteered information is associated with a place or coordinate position. The most important value of this Volunteered Geographic Information (VGI) may lie in what it can tell about human (social) activities in various geographic locations, offering interesting, lasting, and compelling value to the community (Goodchild, 2007). Thus, many domains can access enormous amounts of geospatial data (Big Data), allowing geosimulation in a bottom up perspective (Rocha, 2012). Volunteered Geographic Information (georeferenced) and the widespread usage of smartphones (considering their capabilities) are turning humans into sensors. These big (messy) data, powerful analytic software, bottom-up methodologies, and synchronic data create real time insights available through the cloud, producing ground-based knowledge (more accurate) for the enhancement of public policies, fitting them to reality, improving the spatial planning paradigm, and promoting an inclusive and better society (Morgado *et al.*, 2016). Cultural Heritage objects as symbols and relevant/protected landmarks are the most

attractive and relevant elements in the territory for building Digital Representations oriented for human interaction (e.g. explored by visitors, wayfinding navigation, and urban/conservation management). Therefore, there are huge possibilities of diagnosing and intervening in the Cultural Heritage through this collected or volunteered data, gathering for example, the limitations of the object in terms of capacity, most searched and explored entities and parts, users and object necessities, user's claims, complaints, comments or pictures. This kind of information is especially relevant and intersects several Domains, such as:

- Political-Administrative (e.g. Promoting better interpretation and stronger relationships between citizens and decisional administration; Defining priorities of conservation, inspection, intervention, and the promotion of cities/territories);
- Technical-Scientific (e.g. Fundamental for transversal studies, especially related with Social sciences, Humanities, concerning human/society behaviour and Computer science in the relation between human-machine or real-virtual-mixed environments; Visualizing realistic Digital Representations of past, present, and future Cultural Heritage objects for virtual/mixed environment recreations, navigation, interaction, promotion and intervention, understanding the relationship between the entities, its historical significance and future outcomes; Essential as pedagogical and educational tool, improving motivation and understanding with advantages arising from a collaborative experience, promoting real time interaction);
- Social-Economic (e.g. Addressing societal demands; Being in the edge of innovation, creating higher levels of user engagement; Releasing successful and profitable technological products; Promoting Cultural Heritage and nearby commerce and services; Apps for the fields of leisure and recreation, navigation, gaming, and advertising);

- Civil Protection-Security (e.g. Impact or disaster assessment - accidents, incidents, hazards, and other environmental issues; Public security issues - police and military simulations);
- Symbolic-Religious (e.g. Visualization and explanation of historical relevant facts and/or religious events).

Digital representations of Cultural Heritage can reach a vast number of individuals, groups of interest (in different domains) or the society as a whole (regardless of their physical location on Earth) in a continuously structured system (real time based). Therefore, virtual/mixed environments are contributing to transform anthropological relations and organizational systems. In the technical-scientific field, there is a growing interest among technicians for the usage of 3D virtual models, taking advantage of their enormous potential for pedagogical, documentary, and exploratory activities, as well as of their predictive power. This is especially relevant for urban studies since it facilitates interventions in historical sites, rehabilitation and planning of buildings, neighbourhoods and cities, providing opportunities to simulate past, present, or future interventions, and their respective evolution and management, where people can move through and interact with the space within a virtual/mixed environment. This emergent interest is associated with the very fast process of urban sprawl, also tied with the tendency of cities to growth in terms of height (Z axis) and consequently elevating the level of complexity of the urban processes that take place in the third dimension. Mixed Reality environments have the potential to assist decisional processes in the context of urban and environmental planning, cultural and natural heritage modelling, adding the capability to increase (virtual or real) representational information to the selected environment presented (also virtual or real).

Virtual/mixed environments provide a valuable and effective approach and have several applications in many specific Domains, such as architecture, landscape architecture, computer graphics science, education, engineering (especially civil and mechanical), design (especially interior, product, and graphic), geography, marketing and advertising, medicine, military and security, seeking to progress beyond visually compelling (superimposing virtual data to the real world aiming to support processes, operations, and decisions),

incorporating other aspects of the physical reality that require intelligence or agents with lifelike characteristics, simulating the real world.

The integration of 3D GIS functionalities and Augmented Reality technology has allowed the fast and simple development of geospatial sceneries and is especially useful to update maps and databases or reconstruct and analyse objects/areas through time, constructing and recreating scenarios, and implementing intuitive methods of interaction. These characteristics can encourage, for example, higher public participation creating a completely collaborative solution system. Citizen involvement in the management of historical environments ensures the protection of the historical Cultural Heritage. To be effective, it is necessary to provide decision-making processes with specific spaces and tools that facilitate participation at different levels (Hugony & Roca, 2008). A Fully integrating 3D GIS within an Augmented Reality environment based on Digital Representations allows to envision solutions, processes and simulations, making it possible for agents in several domains to fundament their decisions (and understand them) achieving a faster and wider consensus, supporting a broader collective and collaborative planning process.

2. Augmented Valuation of Cultural Heritage

People seem to have quite accurate mental representations of their spatial environment, coherently capturing the categorical spatial relations between elements that support perception, reorientation, and spatial inferences (Tversky, 1993). There are numerous evidences from a number of species that demonstrate that the brain's hippocampus plays a key role in spatial representation and spatial memory. The concept of space has been considered an innate organizing principle of the mind, through which the world is, and must be, perceived (Moser *et al.*, 2008²⁴⁷). Reconstruction generates systematic errors; therefore, humans rely on external representations to serve as cognitive aids for memory and information processing. The space of external representations is invented, created in order to enhance human cognition (Tversky, 2005). Thus, representations are central in the brain, being at the source of all empirical knowledge and conception of the

²⁴⁷ May-Britt Moser and Edvard I. Moser receive the 2014 Nobel Prize in Physiology or Medicine for their discoveries of cells that constitute the positioning system in the brain.

world. Visuospatial representations have many similarities to those that reside in the mind. These Digital Representations are constructed to Augment human cognition. External cognitive tools function to extend the powers of the mind by exploring the human skills at spatial reasoning (Tversky, 2005).

Generic activities such as communication, learning, simulation, and decision-making are all behaviours that are influenced by virtual interaction through Digital Representations. The range of applications is potentially huge (Batty, 1997). The construction of simulations by communities or remote users implies various forms of collaborative decision-making. Virtual geography is the study of place as ethereal space and its processes inside a synthesized virtual world, parallel to the real (Batty, 1997). The development of digital technologies, especially in what concern visualization, has been affecting many spatial processes. Digital Representations are central and the technology to Augment the Value to this information is fundamental (Batty *et al.*, 2000). Geographical information and systems are then critical for spatial processes, when an understanding of the problem's context is being built. Technologies that convert “spatial information into mathematically correlated models which inform analysis, prediction and optimization are also critical to good formal problem-solving” and to the generation and evaluation of alternative procedures (Batty *et al.*, 2000:2). In his work with the suggestive title “Augmenting Geographic Reality”, Goodchild (2005:43) refers the notion of “Augmenting the senses with information from Digital Representations: of the past; of what is beyond the senses; of the future”. Geographic representations have become more complex with time, leading to an apparently endless proliferation of concepts and creating a need for simplification (Goodchild, 2007).

Geographic visualization is a powerful research method for exploration, analysis, synthesis, and presentation. However, three particular issues are worth discussing: practical limitations, ethical concerns, and political interests (Dodge *et al.*, 2008). Digital Representations of the world are also a cultural process of creating rather than merely revealing knowledge. Virtual environments can be very valuable for the scientific community, but at the same time they should never be value-free. There are many key unknown and under-explored areas that require further research, including uncertain mapping, temporal understanding, and the limits of human visual perception (Dodge *et al.*, 2008). Virtual environments are built with the objective of allowing users to experience

Augmenting the senses and going beyond reality through geographic phenomena simulation and collaborative research (Lin *et al.*, 2013).

The use of technology to build virtual environments for researching, conserving, and conveying our cultural heritage offers exciting new ways to learn and experience the cultural resources of the world, both past and present (Ch'ng, 2015). Culture transcends material and behavioural contexts based in large part on “invented” symbolic constructions of the interaction space and its elements, being a dynamic system of representations that multiples agents can simulate and model (Frischer, 2006 *in* Ch'ng, 2015). “Culture and heritage are commonly recognized as collective identity pillars and major economic drivers” (Council of Europe, 2005; European Commission, 2006; UNESCO, 2012; Richards, 2013 *in* Papathanassiou-Zuhrt, 2015:57). However, heritage sites are a complex combination of both tangible (material objects) and intangible (customs, beliefs) content.

Augmented Reality is an enriched view of the physical world that empowers users to experience virtual data superimposed on real environments that function interactively in three or four dimensions (3D+time) in real time (Khan & Khusro, 2015). The emergence of mobile devices such as smartphones anticipated a huge potential field application for Augmented Reality applications (Khan & Khusro, 2015). When appropriately conducted, the application of three or four dimensional Digital Representations of Cultural Heritage superimposed on the real world, within an Augmented Reality environment, using mobile platforms has the power to improve temporal understanding, map the uncertain, verify the limitations of human perceptual reasoning, and create systems to form collaborative solutions, envisioning processes, simulations, and results. These external affordances enhance human cognition and help to understand societal and anthropologic behaviour besides their symbolism, considering the bases of cultural and heritage conceptions. This is highly relevant for human knowledge, enhancing and Augmenting the power of the mind. The value attributed to Cultural Heritage might be increased by the use of Digital Representations, which disclose, explain and promote its symbolic significance, technical-scientific importance, unicity, or other relevant assets, disclosing what could be considered as an Augmented Valuation of Cultural Heritage.

Augmented Valuation of Cultural Heritage

The notion of Augmented suggests the innovations introduced by Augmented Reality environments through by mobile technology. Nowadays, almost everyone has a smartphone with a vast technological capabilities to generate digital representations of cultural heritage objects and features, allowing to increase the human capability with external affordances (digital, virtual world), and enriching the senses and the user's perception of the real world, being capable to guarantee experiences beyond the human abilities. The value of the Cultural Heritage itself is then overcome through the combination of these technologies and their users, making possible either past recreations or modelling futuristic scenarios (e.g. for planning or intervention). There are great advantages to applying digital technologies to the field of relevant data acquisition over a structure, helping to uncover threats and defining priorities of intervention (such as the usage of spectral sensors to detect structural fissures, humidity, or chlorophyll production). Besides geo-visualization, there is an enormous potential in terms of material and immaterial²⁴⁸ cultural heritage, contained within virtual/mixed environments' characteristics, such as social practices, events recreation, knowledge and skills of a given society. For example, the possibility of adding the Portuguese most traditional music genre, Fado²⁴⁹, included in UNESCO's list of world intangible Cultural Heritage, and listening to songs while visualizing, for example, the Lx_W (AqueductAR and AqueductGPS) Apps. These capabilities might help to better understand the unicity and importance of a certain object, site, or intangible cultural value, giving meaning to the fundamental questions that surrounds the term Cultural Heritage: what is it and how can it be evaluated.

The introduction of this concept to the scientific community intends to define the need to explain the importance of Augmented Reality, what supports it (RS, GNSS, GIS, 3D modelling, 3D GIS, Virtual Environments, Mobile Technology), and the methodologies (correctly) applied to the field of Cultural Heritage to add, increase, enrich, or Augment its intrinsic value. The notion of this conceptual idea embodied this project and it was discussed implicitly and explicitly in the workshop held and referred to previously (in Chapter VI) that counted on the presence of several experts with much

²⁴⁸ Intangible Cultural Heritage, available at URL: <http://www.unesco.org/culture/ich/en/what-is-intangible-heritage-00003> (January, 2017).

²⁴⁹ Fado inscribed in UNESCO's Intangible Cultural Heritage of Humanity, available at URL: <http://www.unesco.org/culture/ich/en/RL/fado-urban-popular-song-of-portugal-00563> (January, 2017).

experience in the field of Cultural Heritage, in terms of decision making, management, technical and research activities; some of them involved in inventory, technical development, intervention, and information dissemination. It was very obvious that all the experts agreed with the potential Augmented Valuation through Digital Representations and Virtual/Mixed Environments applied to Cultural Heritage, especially in built (tangible) elements and particularly in the case of the Lx_W App (AqueductAR and AqueductGPS). This potential Augmented Valuation of Cultural Heritage is also visible in the results of the first questionnaire (annex 3) answered in the workshop, in terms of Usability, Quality, and Knowledge acquired with the Lx_W App, but especially concerning Heritage Valuation in terms of potential Dissemination, Added Value, and Recommendations. In the second questionnaire there were very high levels of interest in the usage and Usefulness of the Lx_W App, where respondents had to answer whether they agreed with the statement: *“technology allows to increase the intrinsic value of cultural heritage through digital representations (past, present, and future), establishing (virtual) synthetic environments superimposed on the real space”* (question 4). The results showed 29% of agreement and 71% of very high agreement. Later, this idea was stressed, but instead of the broad concept of technology, it was introduced the Lx_W App (question 20), and also gathered high levels of agreement. Beside these questions, this concept was directly surveyed in an open answer format, with transversal high levels of agreement.

The concept of Augmented Valuation of Cultural Heritage

The concept of Cultural Heritage (Chapter III) assumes the notion of Value (Introduction) and cultural inherency, often related with unicity, rareness, importance, memory, or symbolic representation of one or more specific objects, events, milestones, achievements, or historical significance. Value has always been the reason underlying heritage conservation. However, the notion of valuation might be identified or increased, when supported individually or collectively by external and/or internal representations as a process of increasing the intrinsic value of the cultural heritage. Digital representations of cultural heritage are highly valuable for scientific study, conservation, and educational purposes (Chapter I).

Geographic Information Technologies (Chapter II), while addressed to the agents in the field within different domains, allows to visualize, interact, and disseminate digital representations of the physical world, (re)creating virtual environments associated with the real space. Augmented Reality technology has the capability to enrich the real world with virtual data, generating mixed environments, where the user maintains the sense of the real place, albeit enhanced with unfindable synthetic information, extending reality itself (Chapter III). An example of that is the development of the mobile App Lx_W (AqueductAR and AqueductGPS) using Augmented Reality technology applied to the Lisbon Aqueduct System, classified as National Monument (Chapters IV and V), allowing to:

- Visualize and interact with ancient cartography (Filipe Folque 1856-1858), which allows the user to recognize, in this period, the city extension and morphology, its main limits, date of construction or urban growth, by comparing it with the present day city;
- Identify and recognize the path of the Aqueduct System, which allows the user to understand the dimension of the structure, identifying its path over and underground. The App, using GPS features, shows our position in relation to this structure and warns us when we are within 150 meters of the structure (Near Me functionality);
- Understand the path of the aqueduct system, the logic of water distribution by gravity by means of the overlay of the Digital Terrain Model, showing the city hypsometry;
- Interact with 2D and 3D models of the Lisbon Aqueduct System, creating the possibility to foresee/remember the various elements of the structure, while learning its layout, programing a visit, or navigating through its path and accessing content data (Text, Pictures, Maps);
- Access to contents, namely: text, photographs (ancient and recent), and other information.

The use Augmented Reality technology through mobile Apps, in addition to the examples referred previously, can be applied to an unending number of examples and experiences over the territory. These capabilities allow users to experience mixed

environments, achieving a higher knowledge about their surroundings. The use of Augmented Reality technology applied to the field of cultural heritage is growing in interest, especially given the possibility to better understand and disseminate its value. Usually, an expert interprets cultural heritage values of objects or phenomena within a theoretical framework, based on several principles and assumptions, according to the knowledge in their field of studies, tending to isolate them from other inputs. There are no accurate widely accepted value assessment tools. Public participation is imperative to discuss value, challenging conventional notions of conservation and professional responsibilities (Chapter VI). It is self-evident that society makes an effort to conserve what has value. However, values are, by nature, varied, and they are often in conflict. We need to understand the foundations of what allows us to establish the importance of one specific cultural heritage element, comprehending the previously referred characteristics of unicity, rareness, importance or symbolic meaning, achieving the universal values from the point of view of history, art, or science. On the other hand, we have to uphold this value by means of preservation. The capabilities of Augmented Reality technology permit the recreation of past scenarios, simulate future interventions, and/or interact with the physical environment, allowing us to analyse and test multiples situations without damaging the real object. These features often go beyond human abilities and therefore are extremely relevant to augment the intrinsic value of the cultural heritage object and, consequently, to the scientific community and general public. Thus, the notion of Augmented Reality already presupposes the idea of enriching the real environment with digital representations.

The concept of Augmented Valuation of Cultural Heritage (Chapter VII) is clearly inspired by the concept of Augmented Reality, being capable of identifying, analysing, and increasing/augmenting the intrinsic value that is already present in the notion of cultural heritage. This concept brings about the opportunity to recognize that, besides the idea of enriching the physical environment with virtual synthesized data, Augmented Reality technology can simultaneously increase the intrinsic value of cultural heritage. This concept presupposes the process of augmenting the value of cultural heritage. This valuation is dynamic since the user experience mixed reality environments as the process of dynamically augmenting cultural heritage valuation.

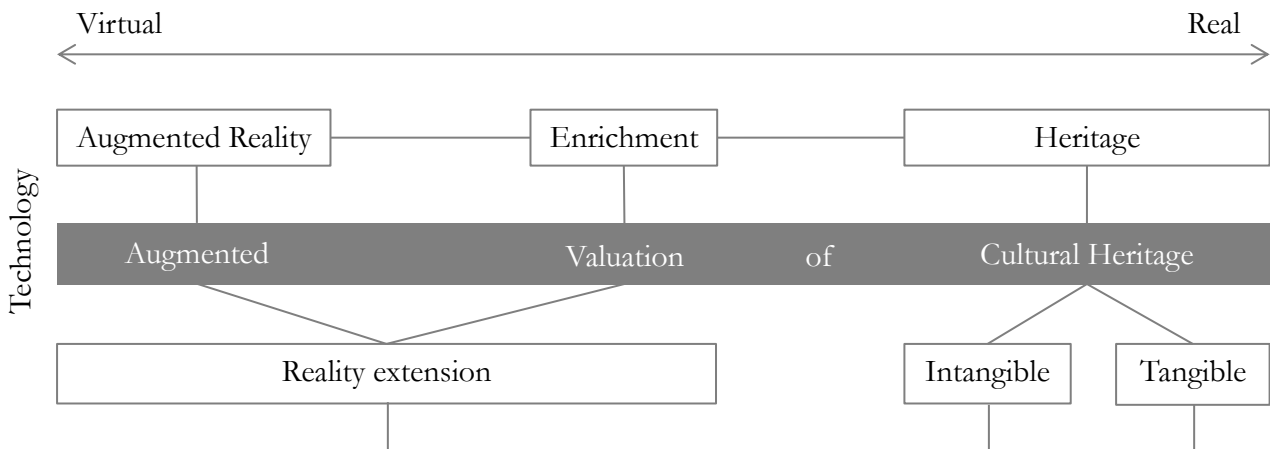


Fig. 79 – Schematic approach to the concept of Augmented Value of Cultural Heritage.

Enriching the real world with virtual georeferenced data can be illustrate of a traveller that crosses an urban area, using his augmented reality device (smartphone or AR glasses) to have access to the names and contact numbers of the surrounding stores overlaid on the real environment, while moving his body and head.

The Augmented Valuation of Cultural Heritage concept might be suggested by the idea of an individual that is perceiving the physical space with superimposed (mixed environment) 3D digital representations of the past (4D), visualizing a certain ancient period over the current city (e.g. city morphology and water distribution of ancient Barcino, over the present day Barcelona), being capable of learning, in this process, the size of the structures and the relations between them over time. Additionally, with the device's GNSS turned on, the user can identify one's position in relation to the ancient city, and be alerted to the proximity of a relevant element (e.g. ruins), where this user will be able to visualize 3D models (e.g. over the ruins). Moreover, it can support the definition of an urban intervention, manipulating virtual data and supporting, for example, a higher public participation in the planning process. When correctly applied, these features increase the knowledge we have about cultural inherency. The internal representations in the human brain are limited in terms of accuracy and storage capacity. The capabilities that are accessible by means of Augmented Reality are not available in the real world and would be extremely difficult for a traveller and even for most technicians to understand in such intuitive and empiric way the possibility of virtual time travelling and/or locating with

precision the objects' position within the ancient/present world in a vast spatial area. The possibilities of simulating onsite interventions and urban developments within virtual mixed environments, supporting non-invasive interference, besides generating a wider understanding of the cultural heritage object, increase social intervention, enabling real time changes to the initial spatial planning proposal, originating a wider public participation and consensus.

The Definition of Augmented Valuation of Cultural Heritage

The definition of Augmented Valuation of Cultural Heritage is enclosed in the domains of Architecture, Spatial Planning and Technology, more specifically within the scope of Territorial, Urban and Architectonic Management and Valuations, and (using) Geographic Information Technologies. The definition presupposes the composition of current and preferred terms or descriptors in British English in the singular form²⁵⁰:

- Augmented Reality (Noun, preferred term or “descriptor” in British English, current term)
- Cultural Heritage (Noun, preferred term or “descriptor” in British English, current term)
 - Tangible Cultural Heritage (Function in a grammatical context undetermined, preferred term or “descriptor” in British English, current term). Used terms: Physical Cultural Heritage / Material Cultural Heritage (Function in a grammatical context undetermined, not preferred term British English, current term).
 - Intangible Cultural Heritage (Noun, preferred term or “descriptor” in British English, current). Used term: Immaterial Cultural Heritage (Noun, not preferred term British English, current term)

While Augmented Reality and Cultural Heritage are used terms, we need to disambiguate the notions of Augmented Valuation or Valuation of Cultural Heritage.

- Augmented Valuation might be perceived as an extension of valuation; the process of increasing value; added value process; the process of using Augmented Reality technology to visualize and increase the value of a certain object of phenomenon.

²⁵⁰ Getty Art & Architecture Thesaurus Online. Available at URL: <http://www.getty.edu/research/tools/vocabularies/aat/> (February, 2017).

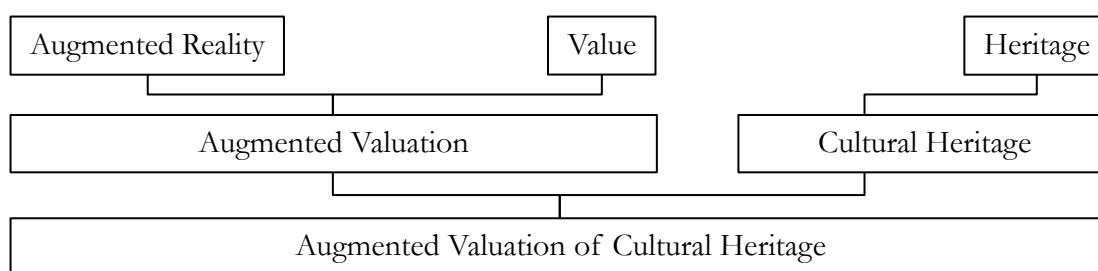


Fig. 80 – Composition of terms for the definition of Augmented Valuation of Cultural Heritage.

Augmented Valuation of Cultural Heritage: The process of using (virtual computer-generated) digital representations superimposed on the real environment through technology, with the attribution of significance by the agents in the field from different domains, aiming to increase the intrinsic value of cultural heritage, whether tangible (i.e. physical achievements: Monuments, Groups of Buildings, and Sites) and/or intangible (i.e. immaterial achievements: cultural practices, representations, expressions, knowledge, and skills).

Defined by UNESCO, Monuments constitute architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings, and combinations of features, which are of outstanding universal value from the point of view of history, art, or science; Groups of Buildings are separate or connected buildings that, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art, or science; Sites include the works of man or the combined works of nature and man, and areas include archaeological sites that are of outstanding universal value from the historical, aesthetic, ethnological, or anthropological point of view.

Conceptual notions, developing tools, standards and best practices adopted by Cultural Heritage Agents will determine the future work within different Domains. Digital Representations and Augmented Valuation of Cultural Heritage are, thus, central in the relation between Technology (e.g. RS, GIS, GNSS, WMS, WFS, Cloud Computing, Mobile App, Virtual and Augmented Reality, and 2D/3D/4D modelling) as tools for the main

Agents (Promoters, Technicians, Decision/Opinion-makers, or the Public), since users provide meaning and intelligence to meet the main objectives and thus addressing answers to the main problems of different Domains (Political-administrative, Social-economic, Technical-scientific, Ideological-symbolic).

Technology permits to extend the real world to interdependent mixed virtual environments, allowing a global access to unlimited information, virtually, without barriers, physically anywhere. The public space is no longer limited to the physical space to become virtually perpetual, unlimited and reachable by any user. Individuals can visualise, evaluate, discuss, and intervene virtually and collectively through the past, present, future and beyond human capabilities, simulating re-presentations of Cultural Heritage and its Augmented Value.

Terminologists use specialized methods to define a concept. Costa e Silva (2006) refer that

“According to ISO Standard: 1087-1 (2000), the concept is defined as: ‘unit of knowledge created by a unique combination of characteristics’, and in the same document, the concept of characteristic is defined as ‘an abstraction of a property of an object or a set of objects’. What this involves, therefore, is a succession of linguistic tasks that identify the characteristics of an object”.²⁵¹

The combination of these characteristics should lead to a “unity of thought” (Costa e Silva, 2006: 6). Definitions “(...) are textual constructions that allow delimiting the concepts between them, to relate them and to situate them within a conceptual system” (Costa e Silva, 2006: 6).

Considering the text of the thesis as the support of the conceptual system of concepts, or *corpus*, in particular what is described in this chapter, we can argue that the concept “Augmented Valuation of Cultural Heritage” results from the combination of its intrinsic value (tangible, represented in the real world value) with the technology and the data (virtual georeferenced data) (Fig. 81). This technology and data guarantee the external representation that we described in previous chapters.

²⁵¹ Translated from Portuguese (the citation retrieved from the ISO Standard is, however, original from the English version)

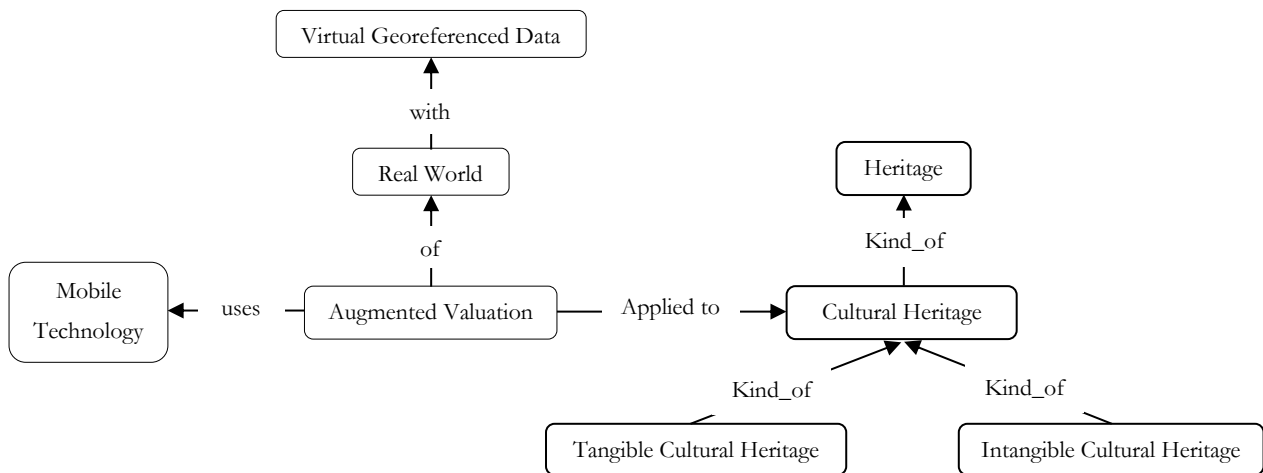


Fig. 81 – Representation of the concept “Augmented Valuation of Cultural Heritage”.

We propose that the concept of **Augmented Valuation of Cultural Heritage** be defined as: virtual georeferenced data added to the real world applied to cultural heritage using mobile technology.

This definition corresponds to a unique combination of features that complies with the already mentioned ISO standard, and emphasizes the use of mobile technology and virtualized data.

Conclusions

This thesis was conducted within the theoretical framework of what we can refer to as the technology in the service of the use of the memory of the city. The buildings with heritage value, as is the case of the Lisbon Aqueduct System (Águas Livres), are part of the city as outstanding elements of the urban space. Often, these elements are so iconic that they form a relevant part of the city identification itself (as is the case of the *Eiffel Tower* in Paris, the Cathedral of the *Sagrada Família* in Barcelona, the *Tower Bridge* in London, just to name a few examples). These cultural heritage elements have a substantial power of attraction, particularly for tourists. Tourists somehow endorse these “attractions” since they are systematically preferred for their visits. In fact, we believe that there is a matter of circular causality. It is the unique value of this heritage with “global influence” to shape the image of the cities that generates interest in the world circuits of travel agencies. These agencies, in turn, use these images to enhance tourism products. Tourist demand, therefore, tourists consume the products offered by the agencies because they aspire to be able to say: “I’ve been there” – in that iconic place.

What we have just mentioned fits into this use of the memory of the city, being also often at the source of business exploration on a world scale. Technology has always been at the service of promoting and enhancing heritage. Photography, for example, is one of the technologies that has most contributed to record what we might call “memory extension”, i.e., it has been used throughout the ages as a means to record moments of a tourist visit, to remember later (this is what we refer to as “extension of memory”); sharing with other the experience they have lived. Formerly, this act of sharing was performed using paper as the preferred medium (as attested, for example, by the relevance of postcards as a way of spreading the heritage), but more recently it has spread into the global scale with the use of (geo)browsers and/or social networks. These sharing experiences, resulting from the more or less intensive use of technology, have contributed greatly to explain how tourists use the public space. Thus, in recent years, there has been a very large increase in research using geolocated tourist data (photographs in and of public spaces), with high spatial and temporal resolution, using Big Data to map the rhythms, activities, and uses of the public space as a way to understand the collective focus, interest, and behaviour of the tourists.

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The technology referred to above is a part of the tourist's practice: photo registration, postal communication, and social networks via the Internet, as a means of sharing the moments lived and the places visited. However, we have only mentioned one phase in the tourist's agenda, which has to do with the visits they have made, and not to the preparation and travel planning. Yet, it is precisely in the planning of a trip that technology can play a decisive role by helping tourists select what they wish to visit — it is the “fight for attention”, using an expression by Innerarity (2010) — e.g., using data and online information often complemented with previous virtual visits. Will all this technology-intensive travel planning somehow diminish uncertainty as to the places to visit? Is it a preliminary assessment of the value of the existing elements in urban public space? Will the available technology contribute to reduce the strangeness of places, heritage observation, and the sensation of being lost? Having arrived at the end of this thesis, these (among many others) are the questions that we would like to place.

This preliminary reflection at the beginning of the conclusions is in consonance with what we wanted to demonstrate with this research, and now summarize below.

This thesis seeks to demonstrate that Geographic Information Technologies (specifically Remote Sensing, Unmanned Aerial Vehicles, 3D data acquisition, processing and representation, Geographic Information Systems, Navigation Systems, Augmented Reality, Mobile Devices and Applications) have been contributing to provide essential data and tools to support the (re)creation of virtual spatial environments for Agents, not only occasional users (public), but also specialised technicians, opinion/decision-makers, promoters, and other stakeholders, addressing solutions (or contributions) to the existing problems in the technical-scientific, social-economic, political-administrative, and ideological-symbolic Domains. Digital Representations of the spatial environment, while permitting to visualise past reconstructions and future simulations, allow us to present solutions, envisioning processes and making it possible for the agents in several domains to fundament their decisions (and make other agents understand them) achieving a faster and wider consensus, and supporting a broader (public) participation in a collective and collaborative planning process. The combination of synthetic digital representations and the real world, through mixed environments, allows envisioning and promoting historical

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awareness (spatial evolution), analysing the present situation (going beyond human capabilities), and simulating interventions in place (through mixed environments). These abilities have a huge epistemological importance since they aid human cognitive skills, spatial awareness, and perception, contributing to the technical-scientific and general empirical knowledge and, thus, digitally expanding the human mind. Technology permits to extend the real world to an interdependent mixed virtual environment allowing a global access to unlimited information, virtually, without barriers, physically anywhere. Geographic Information Technologies applied to the field of cultural heritage are growing in interest, especially considering the possibility to better understand and disseminate its intrinsic value. The valuation of Cultural Heritage is a quality process attributed by users, where technology plays an important role. However, technology itself does not augment the value of cultural heritage. The use of technology is only relevant when it addresses the Agents' objectives and when we consider the quality of acquired data, and provide solutions to the problems of the several Domains. Usually, experts interpret cultural heritage values of objects or phenomena within their theoretical framework, based on several standards and assumptions, according to the knowledge in their field of studies, tending to isolate them from other inputs. The value attributed to cultural heritage might be increased by the use of digital representations, which disclose, explain, and promote its symbolic significance, technical-scientific importance, unicity, or other relevant asset. Combining and enriching the real world with superimposed digital representations, using mixed environments, contributes to the Augmented Valuation of Cultural Heritage, whether we consider tangible and/or intangible elements. The acknowledgment of Cultural Heritage value and valuation techniques is strategic to promote substantiated, integrative and oriented procedures for the identification, preservation, and dissemination of tangible and intangible heritage. Public participation is imperative in the discussion of value, challenging conventional notions of conservation and professional responsibilities. This technology can be used to improve community access to information and increase public participation in the planning, management, and policy-making process.

As stated previously and within the spirit of this demonstration, we now present a complementary summary organized into four topics: i) Identifying sources of pertinent data acquisition; ii) Developing Methodologies for Augmenting the Value of Cultural Heritage;

iii) Analysing Technology with Agents and their associated Domains; and iv) Desirable Developments for Research Consolidation.

i) Identifying sources of pertinent data acquisition

For the development of the case study on the Lisbon Aqueduct System within an Augmented Reality environment, we collected spatial data from several sources through the combined use of Geographic Information Technologies:

- Remote Sensing to identify and represent the main structure and elements of cultural heritage (e.g. Satellite imagery and aerial 3D point clouds). Satellite imagery was extremely relevant for the identification of the structure's path and further representation as (current) base cartography. The construction of 3D models based on photogrammetry revealed to be fundamental, including the use of UAV as a means to collect data for taller and larger structures, such as the Mãe de Água reservoir;

- Geographic Information Systems to georeference and integrate geographic information (e.g. georeferencing ancient cartography, analysing/vectorising the structure into points, lines, and polygons, and visualise 3D scenes). Georeferencing ancient cartography made it possible to overlay it on (current) base cartography (e.g. satellite imagery) and identify/digitalize the structure and its elements: comparing, for example, urban growth between both periods, analysing major changes, dating buildings and/or verifying structures and their relation at specific periods in space and time;

- Global Navigation Satellite Systems to collect georeferenced data (e.g. collecting georeferenced pictures, surveying structure elements and locating the UAV in space). The use of GNSS allowed: on the part of data acquisition, to collect georeferenced data (e.g. pictures, 3D objects base data) and positioning the UAV; on the part of data exploration, to position and navigate in the real world through mobile devices' GPS/GLONASS and georeferenced cartography, besides generating very useful alerts of user/structure proximity (e.g. 150 meters);

- Georeferenced information to provide relevant and useful data to the user (e.g. official geographic information, world dataset projects, wiki data, volunteered information);

- Web (map/feature) Services to gather and visualise base and thematic datasets (e.g. overlaying the project geographic information on available base maps (constantly updated));
- Survey and 3D modelling (e.g. 3D model generation: drawn and from photogrammetry point clouds, based in terrestrial georeferenced photographs of objects).

ii) Developing Methodologies for Augmenting the Value of Cultural Heritage

Several methodologies were developed to visualise and create outputs:

- Geographic Information System (e.g. creating 3D scenes with available geographic information, e.g. the use of Digital Terrain Model, and analysing the produced data of the water flow through gravity);
- Modelling 3D from aerial and terrestrial data (e.g. Loading and Aligning photos, Build dense point clouds, Building mesh, Texturing the 3D model, Exporting results);
- Testing the Apps available in the market to evaluate the potential of Augmented Valuation of Cultural Heritage (e.g. verifying the produced data of the Lisbon Aqueduct System over a collection of Apps available in the market: ESRI and ESRI Collector; Locus, Augment, Google Cardboard Camera, Surround Shot modules);
- Developed Apps and Augmented Reality environments to use with mobile devices (e.g. iGeo Património or the prototype Lx_W App: AqueductAR and AqueductGPS);
- Visualizing and interacting over simple and static information, such as a tourist paper map, augmenting and enriching it with endless virtual data possibilities, allowing to highlight thematic georeferenced data addressed to the agent's requests. These capabilities extend the perspective of using practical and available information within an intergenerational collaboration (older/younger users) and combine user preferences for external aids and devices, creating targeted information over available generalised information with a specific and relevant theme;
- Interacting within the real world expanding it through virtual environments. Using the developed mobile Apps allowed users to interact with virtual data in the real world, expanding the reality and the means of interaction with it. Users can access virtual data choosing the most interesting collections of themes, exploring, navigating, and

combining both real and virtual environments (consuming and aggregating information about a certain object).

iii) Analysing Technology with Agents and their associated Domains

Promoting a workshop and implementing a survey to compare the developed App with other Apps available in the market considering the following topics: Development, Performance, Usability, Quality and the importance to Cultural Heritage Valuation in a perspective of understanding the experts' perception of the Lx_W App within the concept of Augmented Valuation of Cultural Heritage. The production of a video comprising the history of the structure, its importance within the city, and the features developed and available in the prototype Lx_W App, made it possible for anyone to answer the second questionnaire, which contained open questions to assess the proposed concept applied to the work done. These tasks allowed us to survey the main Agents: on the one hand, the general public and, on the other hand, a significant number of experts with responsibilities in the field of cultural heritage and land-use management, gauging their opinion and valuation, considering the congregation of technologies and their main capabilities for the Augmented Valuation of Cultural Heritage, and taking into consideration their experiences and domain of knowledge.

iv) Desirable Developments for Research Consolidation.

The desirable developments for the research work that gave origin to this thesis are twofold: i) the enhancement of the App; and ii) the enhancement of the App's evaluation.

As for the enhancement of the App we can identify two topics: a) virtualization of the entire aqueduct, at least within the city of Lisbon; and b) diversification of content. The aqueduct and its elements were partially dealt with within the scope of this project. Considering the objectives of this thesis, we decided that the results should constitute a base prototype. However, the heritage administration/tourism entities are expected to express their interest in financially supporting the extension of this work throughout the entire path. When diversifying the content, it will be desirable to perform an even more thorough research on the historical context, perhaps even more specialized, as well as a

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detailed description of the surrounding public space from which the elements of the aqueduct are inseparable.

Regarding the enhancement of App's evaluation, it will be important to extend the survey to new segments of potential users and ensure respondents are geographically diversified. The constraints in terms of time and resources did not allow us to increase the sample. Despite this fact, we believe that the results of the survey already show a high level of interest in combining the paper map with augmented reality, both when planning a visit and for the actual onsite visit to the aqueduct.

The work developed aimed to contribute to a broader understanding of the relation between Domains and their Agents, as well as to the discussion on the importance of Technology to the proposed concept of Augmented Valuation of Cultural Heritage. However, the abilities of Digital Representations and the conception of virtual environments go way beyond these assumptions, creating an interdependent synthesized world that is parallel but interwoven with the real one. The space is no longer an obstacle for action in the present; distance does not count and has lost its strategic significance. Fast means of transportation and information transmission and new possibilities of movement by means of territory virtualization seem to convert space in a material means, in something irrelevant, without the need, in some occasions, of physical proximity (Innerarity, 2009). Land-use policies have now the opportunity to take advantage of the process that relieves spaces from the old homogeneous politic configurations and make it possible for a new territorial pluralism to emerge. The present does not always last the same: it is different in each period of time and for each culture. The sense of time is in our head and it is not the same for different types of individuals (e.g. young, active, older, urban, rural). With the civilization process and technology, the present is shorter, it lasts less, and we spend less time where we are, as if the passage of time were abbreviated by the present. This happens because innovation (future) process is increasingly faster and present in our lives. The modernization processes are, among other things, processes of growing dependencies in space. The world seems to be in a permanent state of transition. The virtualization of society and culture can be an opportunity to test and broaden our idea of reality and understand that the current dimensions seem to have acquired an unprecedented importance in culture, which has, in a sense, dematerialized. The ultimate

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representational system would allow the observer to interact naturally with objects and other individuals within a simulated environment, conceivably (and increasingly more likely) by using digitally controlled outputs that stimulate the brain and the human senses, as an experience indistinguishable from reality. These circumstances in some cases are shortening distances (to no distance) and being able to be (re)presented in multiple virtual environments at the same time.

The past two decades have been very rich for the discussion of city virtualization and smart cities. The dominant discourse supports the notion of “Smart City” in the technological possibility of virtualizing some of the facts (e.g. historical, geographical, infrastructural, commercial) and some of the urban processes (e.g. public participation in management decisions, discussion of plans and urban projects, resource management). If it is true that virtualization is often interpreted into digital transcription, it is also true that the “smart city” is much more than that. The “smart city” is an efficient city; or one that pursues objectives of efficiency in the management of energy and public spaces, and in the preservation of the heritage, among other relevant aspects.

In this context, as far as heritage is concerned, many of the technological solutions are reserved for inventory, i.e., for the creation of repositories of elements with historical or cultural value, using, for example, LiDAR data modelling or others procedures/processes. This is, in this case, a technology-oriented perspective of conservation and management. These actions are clearly at the service of heritage valuation. However, it is not a perspective that considers the use of heritage by tourists. The use of heritage by tourists requires technology at least on three levels of action: a) when planning a visit; b) in the act of getting to know the place; c) in the action of interacting.

There is in the action of interacting a clear relation (man/machine) tourist / mobile platform in which is installed one or several App's. This interaction is increasingly becoming more important since digital content and potential connections with external information have been gradually enhanced.

The future will definitely be very rich in terms of the exploration of augmented reality using mobile applications. Batty (2013) considers that building a Science of Cities (title of one of the chapters of the work cited here) should incorporate constellations of interactions at various scales. The author even assumes that these interactions are the basis of this new Science. In this context, it seems appropriate to admit that the interaction

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mobile platform/city, and heritage in particular, are unique examples of this constellation in which augmented reality plays a key role.

As we have already mentioned, this thesis does a demonstration: the demonstration of the role played by technology in the Augmented Valuation of Cultural Heritage. The future will define the meaning of the definition we proposed here (of the concept of “Augmented Valuation of Cultural Heritage”). Presently, one fact seems obvious: this valuation can be extended to all urban public spaces, which is the tangible space of integration and urban interaction and sociability.

Conclusions

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Annexes

Annex 1 – Texts for the App AqueductGPS

Sources: SIPA – www.monumentos.pt; DGPC; EPAL; AdP; and Lisbon Municipality.

Annexes 1

| Textos para APP | PORTUGUÊS | ENGLISH | Coord LAT | Coord LONG | Acesso PORTUGUÊS / ENGLISH |
|---|--|--|-----------|------------|----------------------------|
| Texto introdutório (distribuição de água em Lisboa) | A fundação da cidade de Lisboa inicia-se na colina do Castelo de São Jorge (que se mantém sensivelmente até à idade média). A implantação nesta localização deve-se à sua posição defensiva associada ao facto dos recursos de água existentes, que se extraíam dos poços, fontes ou de cisternas na envolvente (Alfama). O Tejo não seria uma alternativa, considerando o facto de ser um estuário de dimensões razoáveis, onde a água doce do rio se mistura com a água salgada do oceano, tornando-se, portanto, insalubre. Com a expansão e modernização da cidade para ocidente (encosta do Bairro Alto) e o consequente aumento populacional, os problemas de abastecimento de água intensificam-se. Também os hábitos de higiene que surgem com o renascimento, bem como, o período dos descobrimentos portugueses e que exigem o abastecimento das embarcações, acentua a falta de água potável em Lisboa. Segundo Chaves, 1989 in Bruno B. e Inácio P. (2012), em 1720, no período do estabelecimento do imposto destinado à construção do Aqueduto das Águas Livres (essencialmente sobre produtos como vinho, carne, azeite, sal ou palha), o número de habitantes da cidade rondava os 200 000. | The foundation of Lisbon starts on the hill of “São Jorge” castle (which remains significant until the Middle Ages). The implantation in this location was due to the defensive position associated to the fact that there were water resources supplied largely by wells, fountains or existing tanks in the surroundings (“Alfama”). The Tagus river would not be an alternative, considering the fact that is an estuary of reasonable dimensions, where fresh river water is mixed with the salt water from the ocean. With the expansion and modernization of the city to the west side (“Bairro Alto hill”) and the consequent population growth, the problem in the water supply intensifies. On the other hand, the hygiene habits that came with the Renaissance, as well as the period of the Portuguese discoveries that required ships supply, emphasized the lack of drinking water in Lisbon. According to Chaves, 1989 in Bruno and B. Ignatius P. (2012), in 1720 at the period of the implementation of the tax assessment (mainly on products such as wine, meat, olive oil, salt or straw) for the construction of the Aqueduct, the number of inhabitants of the city was estimated around 200 000. | - | - | - |
| Aqueduto (totalidade do traçado) | Classificado como Monumento Nacional (desde 1910), o Aqueduto das Águas Livres projeta-se como uma das mais arrojadas obras de engenharia hidráulica construídas em Portugal, atravessando os municípios de Loures, Sintra, Amadora e Lisboa. Construído em cantaria e alvenaria de calcário, tem, no seu troço principal (estrutura compreendida entre Mãe de Água Velha até às Amoreiras) cerca de 14 km, no entanto, totaliza aproximadamente 58 quilómetros de extensão quando contabilizados os aquedutos subsidiários e galerias de adução. Este complexo sistema de abastecimento é constituído pelo Aqueduto Geral, desde a Nascente da Mãe de Água Velha em Carenque (172m altitude) até ao Reservatório da Mãe de Água das Amoreiras (94m altitude) e pelos ramais subsidiários e galerias subterrâneas, culminando nos diversos chafarizes que abasteciam a população de Lisboa. Iniciada em 1731, a obra dá-se como concluída em 1799, fornecendo 1300 m3 diários de água (triplicando os recursos iniciais), no entanto, o problema do aqueduto continuava a ser a falta de caudal e a necessidade de incorporar mais nascentes, sendo apenas colmatadas as necessidades da cidade, com a introdução do sistema Alviela a partir de 1880. Manteve-se em funcionamento até 1967, tendo sido totalmente desativado em 1968. | Classified as a National Monument (since 1910), the “Águas Livres” aqueduct system was projected as one of the boldest hydraulic engineering structures built in Portugal, going through the municipalities of Loures, Sintra, Amadora and Lisbon. Built in limestone it has in the main section (structure between “Mãe de Água Velha” to the “Amoreiras”) about 14 km length, however, when counted the subsidiary aqueducts and galleries it totals approximately 58 km extension. This complex water supply system consists of the general Aqueduct from “Mãe de Água Velha” in Carenque (172m altitude) to the reservoir of the “Mãe de Água das Amoreiras” (94m altitude) and to the subsidiary and underground galleries, culminating in the various fountains that provided water to the population of Lisbon. Initialized in 1731, the aqueduct system is completed in 1799, distributing daily around 1300 m3 of water (tripling the initial resources), however, the aqueduct had a problem associated with the lack of flow and therefore still needed to incorporate more water sources (springs) in the system. This issue was only solved with the introduction of “Alviela” system in 1880. The aqueduct system remained in operation until 1967 and was totally disabled in 1968. | | | |

Annexes 1

Cronologia: A nomeação de António Canevari (arquiteto italiano) para a direção da obra (1731), terá surpreendido especialmente o Engenheiro Militar Manuel da Maia, que efetuara grande parte dos trabalhos preparatórios acompanhado pelo Engenheiro-mor Manuel de Azevedo Fortes que tinha mostrado descrente dos caudais a transportar até Lisboa. A partir de 1745 a direção da obra fica a cargo do Arquiteto Carlos Mardel (Arquiteto Húngaro) que desenvolve uma fase subsequente no interior da cidade com a criação de 4 das 5 galerias de abastecimento da cidade (Rato, Loreto, Esperança e Necessidades), bem como a multiplicação de chafarizes para a distribuição da água (com ligações ainda a conventos e fábricas) e a necessidade constante de aumentar os caudais, associada à incorporação de novas nascentes através de aquedutos subsidiários fora da cidade. Em 1746 a obra atravessa o Vale de Alcântara atravessando Campo de Ourique (Campolide à data) e atingindo a horta do Convento das Freiras do Rato. Em 1750 morre o Rei D. João V e sobe ao trono o Rei D. José I e em 1763 morre o Arquiteto Carlos Mardel, sendo nomeado Miguel Ângelo Blasco para o cargo (prolongando e/ou edificando os aquedutos subsidiários do Salrego, Rascoeira, Bertão, Salgueiro Grande e Francesas). Em 1755 destaca-se a resistência da estrutura ao terramoto. Em 1771, Reinaldo Manuel dos Santos torna-se diretor e arquiteto das obras das Águas Livres, realizando-se as obras dos aquedutos do Salgueiro Grande, Moura Grande, Moura Pequena, Carvalheiros e Olival Santíssimo (e derivação da Pia do Penalva - Galeria do Loreto para a Praça da Alegria e jardins do Passeio Público - atualmente Av. da Liberdade). Interveio ainda na Galeria das Necessidades e iniciou as obras da Galeria do Campo de Santana. Morre o Rei D. José I e sobe ao trono a Rainha D. Maria I. Após a morte do arquiteto Reinaldo Manuel dos Santos, continuam as obras sob a direção de Francisco António Ferreira Cangalhas (a partir de 1792) e é substituído pelos seus ajudantes, com uma breve interrupção durante o período de governação francesa (sendo assumida a direção da obra por José Theresio Michelotti). A obra é terminada em 1799, ainda que se tenham mantido a construção de chafarizes e ramais até à primeira metade do século XIX. O aqueduto é desativado em 1968.

Chronology: The nomination of “Antonio Canevari” (Italian architect) to direct the works in the aqueduct (in 1731) especially surprised the military engineer “Manuel da Maia”, who had made much of the preparatory work accompanied by the Engineer-Major “Manuel de Azevedo Fortes” who was sceptical relatively to the flows transportation until Lisbon. From 1745 the direction of the works is delivered to the architect “Carlos Mardel” (Hungarian Architect) who develops a subsequent stage in the inner city with the creation of 4 (from 5) supply galleries within the city (“Rato”, “Loreto”, “Esperança” and “Necessidades”), as well as the multiplication of fountains for water distribution (with connections to convents and factories) and the incorporation of new water sources (springs) through subsidiary aqueducts outside the city due to the constant need to increase the flow rates. In 1746, the works over the Alcântara Valley through Ourique Field (nowadays Campolide) reach the garden of the convent of “Freiras do Rato”. In 1750 the King “D. João V” dies and ascends to the throne the King “D. José I” and in 1763 the architect “Carlos Mardel” dies, followed by nomination of “Miguel Angelo Blasco” for the position (prolonging and / or building subsidiary aqueducts of “Salrego”, “Rascoeira”, “Bertão”, “Salgueiro Grande” and “Francesas”). In 1755 the aqueduct structure resisted to the Lisbon earthquake. In 1771, “Reinaldo Manuel dos Santos” becomes the director and architect of the works of the “Águas Livres”, accomplishing the aqueducts “Salgueiro Grande”, “Moura Grande”, “Moura Pequena”, “Carvalheiros” and “Olival Santíssimo” (and derivation from “Pia do Penalva” in “Loreto”) Gallery to “Praça da Alegria” and to “Passeio Público” gardens - nowadays Av. da Liberdade). Intervened also in “Necessidades” Gallery and initiated the works of “Campo de Santana” Gallery. In 1777 the King “D. José I” dies and ascends to the throne the Queen “Maria I”. After the death of the architect “Reinaldo Manuel dos Santos”, the works continue under the direction of “Francisco Cangalhas” (from 1792), replaced by his assistants, with a brief interruption during the French governance period (being assumed the direction of work by “José Theresio Michelotti”). The works are completed in 1799, even if the construction of fountains and extensions continued to the first half of the nineteenth century. The aqueduct is disabled in 1968.

Annexes 1

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|------------------------------------|--|---|-----------|-----------|---|
| Aqueduto sobre o Vale de Alcântara | O Aqueduto sobre o Vale de Alcântara inicia-se no alto da Serafina e atravessa o Vale de Alcântara (bastante profundo), formando um ligeiro ângulo, tendo, nos extremos, vinte e um arcos (de volta perfeita) e, ao centro, catorze arcos (apontados), sustentados por pilares, em cantaria de calcário. Sobre as arcadas, surgem dois passadiços, protegidos por guarda plena de cantaria, com acesso pelos extremos, a partir de portas de verga recta, ao centro, o canal, com cobertura a duas águas, com as paredes rasgadas por respiradouros retilíneos. | The aqueduct over Alcântara starts at the top of the Serafina neighbourhood and through the Valley of Alcântara (deep), forming a slight angle, and, in the extremes there are twenty-one arches (perfectly round) and at the centre, fourteen arches (pointed), supported by pillars, limestone ashlar. About the arcades, there are two walking ways, protected by full guard stonework, with access by the extremes from straight doors, the centre channel is covered with ventilation (straight). | 38,724116 | -9,165459 | Aqueduto das Águas Livres 3€ - Tuesdays to Saturdays (terça a sábado), 10h-12h and 13:30h-17:30h. |
| Mãe de Água | Construído entre 1746 e 1834, por Carlos Mardel e Reinaldo dos Santos, tem uma forma paralelepípedica com 37x33m e uma altura de 17m. No seu interior o tanque mede 28x24m e 7.5m de profundidade (capacidade para 5500m3). A água jorra a partir do aqueduto das Águas Livres a partir da boca de um ser marinho sobre uma cascata até ao reservatório. | Built between 1746 and 1834, by “Carlos Mardel” and “Reinaldo dos Santos”, has a parallelepiped shape with 37x33m and a height of 17m. Inside the tank measures 28x24m and 7,5m deep (capacity 5500m3). The water flows from the “Águas Livres” aqueduct from the “mouth of a marine creature” over a cascade to the reservoir. | 38,721264 | -9,155698 | 1. Mãe de Água 5€ - Tuesdays to Saturdays (terça a sábado), 10h-12h and 13:30h-17:30h. 2. Mãe de Água/Casa do Registo - Reservatório da Patriarcal - São Pedro de Alcântara 5€, Last Saturday of the month (último sábado do mês) - 11h; 3. Mãe de Água/Casa do Registo - Reservatório da Patriarcal - São Pedro de Alcântara 5€, Fridays (sextas-feiras) - 15h; 4. Mãe de Água/Casa do Registo - Reservatório da Patriarcal 3€, Fridays (sextas-feiras) - 15h; 5. Mãe de Água/Casa do Registo - Reservatório da Patriarcal 3€, Last Saturday of the month (último sábado do mês) - 11h. http://www.monumentos.pt/Site/APP_PagesUser/SIPA.aspx?id=25486 |
| Galerias | | | | | |
| Rato | A construção da Galeria do Rato inicia-se em 1753, tendo sido concluído no ano seguinte. Faz a ligação entre a Mãe de Água e o Chafariz do Rato (164 metros) e a Galeria do Loreto. | The construction of the “Rato” Gallery began in 1753 and was completed in the following year. Connects the “Mãe de Água” and “Rato” Fountain (164 meters) and “Loreto” Gallery. | - | - | - |
| Loreto | Com cerca de 2835 metros e com um percurso subterrâneo que deriva da Casa do Registo, prolonga-se pelo traçado da atual Rua da Escola Politécnica, até à Pia do Penalva /Pia Quadrada (junto ao Jardim do Príncipe Real), onde faz a distribuição para Sul (pela antiga Rua Formosa, atual Rua de “O Século” até à antiga Imprensa Nacional / Chafariz do Século); para Norte, pela Rua da Mãe de Água onde abastecia o antigo Passeio Público (Av. Liberdade) e atual Chafariz da Praça da Alegria / Cotovia; para Este, prolongando-se pelo Jardim de São Pedro de Alcântara (Miradouro), até ao Chafariz do Carmo (onde abastecia a Guarda Municipal do Carmo), e continuando até ao largo do São Carlos. | With about 2835 meters and an underground route that starts in “Casa do Registo” extending through the current “Escola Politécnica” street until “Pia Penalva” (next to the “Príncipe Real” Garden), where the distribution continues to south (the old “Formosa” street, currently “O Século” and fountain and to the former National Press - “Imprensa Nacional”); To north, through “Mãe de Água” street which supplied the “Cotovia de Baixo” fountain and the former “Passeio Público” (Av Liberdade); to the east, extending to the garden of “São Pedro de Alcântara” (Viewpoint), to the “Carmo” fountain (which supplied the municipal guard) and continuing to “São Carlos” square. | - | - | 1. Mãe de Água/Casa do Registo - Reservatório da Patriarcal - São Pedro de Alcântara 5€, Last Saturday of the month (último sábado do mês) - 11h; 2. Mãe de Água/Casa do Registo - Reservatório da Patriarcal - São Pedro de Alcântara 5€, Fridays (sextas-feiras) - 15h; 3. Mãe de Água/Casa do Registo - Reservatório da Patriarcal 3€, Fridays (sextas-feiras) - 15h; 4. Mãe de Água/Casa do Registo - Reservatório da Patriarcal 3€, Last Saturday of the month (último sábado do mês) - 11h; 5. Reservatório da Patriarcal - Rua do Século 3€, Wednesdays and Saturdays (quartas-feiras e sábados) - 11h; 6. Reservatório da Patriarcal - São Pedro de Alcântara 3€, Wednesdays and Saturdays (quartas-feiras e sábados) - 11h, 7. Reservatório da Patriarcal - Rua do Século 3€, Wednesdays and Saturdays (quartas-feiras e sábados) - 11h. |

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| Esperança | Com 1425 metros, a Galeria da Esperança deriva da Casa do Registo até ao Chafariz da Esperança (Av. D. Carlos I), passando pelo Arco de São Mamede e pelo Arco de São Bento (ambos à superfície e com Chafarizes). Havia ainda uma ligação do Chafariz da Esperança até o Cais do Tojo ou Boavista (chafariz e tanque de lavadeiras desaparecidos). | With 1425 meters, the “Esperança” Gallery derives from “Casa do Registo” to “Esperança” fountain (“D. Carlos I” street), passing through the arch of “São Mamede” and the arch of “S. Bento” (both with integrated fountains). There was also a connection between the “Esperança” fountain to the “Cais do Tojo” or “Boavista” (fountain and tank for washing, nowadays disappeared). | - | - | - |
| Necessidades | A construção da galeria das Necessidades, inicia-se em 1752, saindo próximo ao Arco do Carvalhão e terminando nas necessidades. Esta galeria tem diversos ramais (Ramal da Estrela - até ao Jardim da Estrela; Nas Necessidades divide-se em dois ramais: para o Palácio das Necessidades e Janelas Verdes). A totalidade dos ramais da Galeria das Necessidades perfaz 3216 metros. | Construction of “Necessidades” gallery began in 1752, starting near the Arch of “Carvalhão” and ending in “Necessidades”. This gallery has several extensions (“Estrela” - to the garden “Jardim da Estrela”; and in “Necessidades” is divided into two branches: to the Palace of “Necessidades” and “Janelas Verdes”). The total extension of this gallery is 3216 meters. | - | - | - |
| Campo de Santana | Projetada em 1784 e com cerca de 4162 metros de extensão é a única galeria que abastece a parte oriental de Lisboa. Inicia-se a junto ao Arco do Carvalhão e termina no Campo de Santana (deste surgem os ramais para o abastecimento do Chafariz de São Sebastião da Pedreira, outro para o Chafariz do Intendente e outro em direção ao Hospital de São José). | Designed in 1784 and with about 4162 meters length is the only gallery that supplies the eastern part of Lisbon. Begins near “Carvalhão” arch and ends at the “Campo de Santana” (and from this gallery occur 3 extensions: to the fountain of “São Sebastião da Pedreira”, the “Intendent” fountain and the other towards the “São José” hospital). | - | - | - |
| Chafarizes | | | | | |
| Rato | Tal como a galeria com o mesmo nome, a construção do chafariz do rato inicia-se em 1753 e termina no ano seguinte (de acordo com os planos de Carlos Mardel). De estilo barroco e utilizando o lioz como material de construção (3 bicas) é ladeado pelos muros que sustentam o jardim da antiga Quinta dos Duques de Palmela (atual Procuradoria-Geral da República). | As the gallery with the same name, the “Rato” fountain construction begins in 1753 and ends in the following year (according to the plans of “Carlos Mardel”). Using limestone as a building material in a Baroque style is flanked by walls that hold the old garden “Quinta dos Duques de Palmela” (nowadays “Procuradoria-Geral da República”). | 38,719942 | -9,154099 | - |
| Mãe de Água | O chafariz da Mãe de Água, anteriormente da Cotovia de Baixo ou da Praça da Alegria localizava-se junto à porta superior do passeio público (1772 a 1791) tendo sido transferido para a sua posição atual em 1840. De formato quadrangular e com dois patamares exteriores, tinha a dupla função de abastecer a população no patamar superior (com 3 bicas) e junto aos dois laces de escadas, no patamar inferior, verifica-se também um depósito para animais. | The fountain of the “Mãe de Água” former “Cotovia de Baixo” or “Praça da Alegria” was located next to the top door of the former “Passeio Público” (1772-1791) and was moved to its current location in 1840. With a quadrangular format with two levels outside had the dual function of supplying the population in the upper level (3 streams) and near the two laces of stairs. In the lower level, there was also a tank for animals. | 38,716987 | -9,147053 | - |
| Carmo | Com o prolongamento do ramal do Loreto e com as obras no Largo do Carmo é realizada a edificação de um chafariz em 1769 e a reconstrução de um novo chafariz em 1786. Em Calcário Lioz, encontra-se implantado numa plataforma circular onde se ergue uma coluna central octogonal com 4 bicas. No topo surgem 4 golfinhos de caudas erguidas numa forma piramidal. A estrutura é protegida pelo nicho de arcos de volta perfeita. | With the extension of the “Loreto” gallery and the works (year 1769) in “Carmo” square is held the construction of a fountain (in 1769) and the reconstruction of a new fountain in 1786 (that remain until the present). In Limestone is implanted in a circular platform where a central octagonal column with 4 streams. The structure is protected by round arches-shape niches for the four dolphins (in top) with tails erected in a pyramidal shape. | 38,711933 | -9,140867 | - |

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| Século | Com a antiga designação de Chafariz da Rua Formosa, o Chafariz da Rua do Século já estaria edificado no ano de 1762, ainda que o seu arranjo urbanístico só terminaria em 1767. Construído em calcário amarelo no estilo neoclássico, tem uma pequena escadaria de cinco degraus e três carrancas em bronze. Localiza-se numa pequena praça semicircular e revela um pórtico de ordem dórica. | Located in a small semi-circular square and near the street with the old name of “Formosa”, the fountain of “O Século” street was already built in the year 1762, although its urbanistic arrangement would end only in 1767. Built in yellow limestone in neoclassical style, it has a small staircase of five steps and three bronze springs. | 38,713241 | -9,147272 | - |
| Arco São Mamede | Adossado ao aqueduto é projetado em 1805 por Honorato José Correia de Macedo e Sá, tem uma pequena edícula com duas tabelas recortadas ao centro e remate em cortina. | Aggregated to the aqueduct is designed in 1805 by “Honorato Macedo” and it has two springs and tanks. | 38,717092 | -9,154389 | - |
| Esperança | Projetado por Carlos Mardel, em 1752, e concluído por D. Miguel Ângelo Blasco, em 1768, desenvolve-se numa estrutura de dois pisos no estilo barroco. O corpo central é um balcão retangular, servido de escadas laterais, sendo o espelho central ladeado por duas colunas que suportam um frontão. No piso superior cada uma das carrancas verte água sobre um pequeno tanque. No tanque inferior implanta-se ao nível do chão com três carrancas para a saída da água que servia como bebedouro de animais. | Projected by “Carlos Mardel” in 1752, and completed by “Miguel Angelo Blasco” in 1768, it develops in a two-storey structure in the Baroque style. The central body is rectangular served by side stairs, being flanked by two columns that support a gable. Upstairs each spring lead the water on a small tank. The lower tank is implanted at ground level with three figureheads for the exit of the water that served the animals. | 38,708967 | -9,153505 | - |
| Janelas Verdes | Construção inicia-se em 1774 (suspende em 1777 e recomeça em 1782) da autoria de Reinaldo Manuel dos Santos. De base circular e alinhado com o portal do palácio, jorram 4 carrancas. Ergue-se a estátua de Vénus a quem o cupido entrega uma seta (escultura de António Machado) | The construction begins in 1774 (suspended in 1777 and restarted in 1782) authored by “Reinaldo Manuel dos Santos”. Circular and aligned with the gate of the palace has 4 water springs and in the top stands the statue of Venus to whom the cupid delivery an arrow (“Antonio Machado” sculpture). | 38,705446 | -9,161440 | - |
| Intendente | Ainda que o projeto mais antigo data de 1818 (estrutura simples) a sua construção inicia-se em 1823 da autoria de Henrique Oliveira e Honorato de Macedo e Sá. Estilo Neoclássico de formato quase cubico e enquadrado por pilastras dóricas. Tem duas bicas simples, tendo no topo a esfera armilar, coroada com as armas nacionais. No centro tem a inscrição Agoas Livres Anno de 1824. Em 1917, pela reorganização do trânsito e da abertura da Avenida Almirante Reis este chafariz é transferido da sua posição original para o local atual na esquina da Calçada do Desterro | Although the earliest design dates from 1818 (simple structure) its construction starts in 1823 drawn by “Henrique Oliveira and “Honorato Macedo” in Neoclassic style almost cubic shape and framed by Doric pilasters. It has two simple springs and the armillary sphere on top, crowned with the national arms. The center has the inscription “Agoas Livres Anno 1824”. In 1917, the reorganization of traffic and the opening of the Almirante Reis street, this fountain was transferred from its original position to the current location at the corner of “Calçada do Desterro” street. | 38,719931 | -9,135759 | - |
| Arco do Carvalhão | Adossado e abastecido diretamente pelo Aqueduto das Águas Livres o Chafariz do Arco do Carvalhão é concretizado em 1823. Composto por espaldar simples de forma retangular dispõe de duas bicas que servem um tanque retangular. Tem a inscrição CML 1890 Agoas Livres Outubro 12 de 1823. | Aggregated (to the arch) and stocked directly by “Águas Livres” aqueduct, the “Carvalhão” fountain is implemented in 1823. Composed of simple rectangular body that has two springs serving a rectangular tank. Has the inscription: “CML 1890 Agoas Livres, October 12, 1823”. | 38,724116 | -9,165459 | - |
| Santana | Construção de 1887 em Calcário Lioz, composto por espaldar retilíneo com as bicas de chumbo localizadas sobre molduras circulares que vertiam para o tanque retangular. | Constructed in 1887 using Limestone it is composed of a rectangular body with 3 circular frames that support 3 lead springs that poured into the rectangular tank. | 38,721508 | -9,139430 | - |
| São Sebastião | Da autoria do arquiteto Francisco Cangalhas, a sua construção inicia-se me 1787 e conclusão em 1789 (ainda que só tenha tido | With authorship of the architect “Francisco Cangalhas” its construction starts in 1787 and it was completed in 1789 | 38,731048 | -9,150570 | - |

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| da Pedreira | água em 1791). | (although it had only water in 1791). | | | |
| Terras | A sua construção data de 1867 tem uma planta retangular e adoçado à galeria que alimentava o Chafariz das Janelas Verdes. Tem dois tanques de dimensões diferentes e no topo, ao centro da cimalha, ostenta as armas da cidade numa moldura circular e duas pirâmides de remate nos vértices da frente. É ainda visível a inscrição: "C.M.L. 1867" | Its construction dates from 1867 and was aggregated to the "Esperança" gallery, which fed the fountain of "Janelas Verdes". Has a rectangular body with two tanks of different sizes and at the center top bears the arms of the city in a circular frame and two pyramids in the end of the front corners. It is still visible the inscription: "C.M.L. 1867" | 38,708748 | -9,165922 | - |
| Praça da Armada | Construção com início em 1845 resultante de material sobranete do Chafariz das Necessidades. O chafariz ergue-se em forma paralelepípedica com quatro bicas para humanos (nível superior) e dois tanques para animais (nível inferior). | The construction starts in 1845 resulting from leftovers material of "Necessidades" fountain. The fountain stands in a parallelepiped in shape with four springs to human (top level) and two tanks for animals (below). | 38,705300 | -9,170450 | - |
| Monte Olivete | Planta retangular irregular em Calcário Lioz com bica a verter para tanque retangular. Este chafariz esteve até 1838 junto ao Arco de São Bento (abastecido pela galeria da Esperança) tendo sido deslocado para a localização atual (recebendo água através da Galeria do Loreto). | Irregular rectangular plan in Limestone with the water falling into a rectangular tank, this fountain was until 1838 aggregated to the "São Bento" arch (demolished). Supplied by "Esperança" gallery has been moved to the current location (and then receiving water through the "Loreto" gallery). | 38,715535 | -9,151659 | - |

Annex 2 – Workshop documents (Portuguese)

Event Promotional Document

Pre Requirements Document

Procedures Text Document

Annexes 2 – Event Promotional Document



Workshop: Valorização de Património Urbano: Avaliação de Apps em 3D e AR Aplicadas ao Património Cultural da Cidade de Lisboa | CICS.NOVA | 29 julho 2016 | Chiado, Lx

Workshop: Valorização de Património Urbano: Avaliação de Aplicações Moveis em Ambientes 3D e Realidade Aumentada Aplicadas ao Património Cultural da Cidade de Lisboa (Aqueduto das Águas Livres)

Data e local: Dia 29 de julho de 2016 | Restaurante/Wine Bar “Fábulas” (Calçada Nova de São Francisco, 14, Chiado, Lisboa) e Largo do Carmo (Chiado)

Enquadramento: A pesquisa em curso consiste na aquisição exploratória de dados e modelação 3D, com recurso a *Anmanned Aerial Vehicles* (UAV) / sistemas terrestres; e a sua integração com SIG e Realidade Aumentada (AR), através de plataformas móveis. Pretende-se reforçar a ideia do potencial de aplicação desta(s) tecnologia(s) na valorização do património, associando a utilização de informação geográfica em domínios com uma forte perceção visual do espaço. As experiências realizadas prendem-se com a modelação espacial (3D) e a visualização em AR de elementos de património cultural como o Aqueduto das Águas Livres em Lisboa.



Objetivo: Pretende-se avaliar as aplicações para *smartphones* (Apps) no contexto da divulgação do património cultural, realizando uma análise comparativa entre Apps desenvolvidas e disponíveis no *Market* (Android).

Organização: CICS.NOVA - José António Tenedório, Luís Marques, Rossana Estanqueiro

Programa:

9:00h – Receção aos participantes e enquadramento da sessão / acesso a WiFi | **Restaurante Fábulas** (Calçada Nova de São Francisco, 14, Chiado, Lisboa) | Café e snack

9:15h – Análise de 4 Apps pré-instaladas (*smartphones* com sistema Android): Caso se verifique a necessidade, haverá apoio na instalação das Apps | Serão fornecidos atempadamente links de acesso a *.apk para pré-instalação

9:30h – Visualização de informação geográfica relativa ao Aqueduto das Águas Livres em Lisboa para *smartphone* (Android)

10:45h – Deslocação até ao “**Largo do Carmo**” (Chiado) e visualização das App com acesso a GPS

12:15h – Pausa: Café e *snack* | Restaurante **Fábulas**

12:30h – Avaliação comparada das App através de inquérito *online* (será fornecido atempadamente o link de acesso)

13:15h – Encerramento

Custo: Gratuito | Solicita-se a confirmação de presença até ao dia 26 de julho (para: luismarques@gmail.com)

Requisitos:

- *Smartphone* Android com bateria totalmente carregada (pré-instalação de 4 App a fornecer atempadamente pela organização);
- Outros elementos fornecidos no dia do *workshop* (Mapa e Guião).

Workshop (Pré-requisitos)

1. PRÉ-REQUISITOS

Aplicações:

Instalação das aplicações (não se encontra no *Market*):

1. Lx_w: Duas aplicações (AqueductAR e AqueductGPS)
105+42MB




Disponível em:

<https://we.tl/KTlkqnGgbz>


Nota: A instalação no smartphone poderá necessitar desligar a opção “Origens Desconhecidas” (Definições/Segurança)

Google Play: Pesquisa e instalação das aplicações:

2. IGEO Património; 
17.7MB


Disponível em:

https://play.google.com/store/apps/details?id=com.bitcliq.igeo.ui_patrimonio

3. ESRI; 
60.7MB

Disponível em:

<https://play.google.com/store/apps/details?id=com.esri.android.client>

4. Augment (Aumentada); 
67.7MB

Disponível em:

<https://play.google.com/store/apps/details?id=com.ar.augment>



Workshop: Valorização de Património Urbano: Avaliação de Apps em 3D e AR Aplicadas ao Património Cultural da Cidade de Lisboa | CICS.NOVA | 29 julho 2016 | Chiado, Lx

Guião do workshop

PRÉ-REQUISITOS

Aplicações:

Instalação das aplicações (não se encontra no Market):

1. Lx_w: Duas aplicações (AqueductAR e AqueductGPS)
105+42MB



Disponível em:

<https://we.tl/KTlkqnGgbz>

Nota: A instalação no smartphone poderá necessitar desligar a opção “Origens Desconhecidas” (Definições/Segurança)

Google Play: Pesquisa e instalação das aplicações:

2. IGEO Património; 
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Disponível em:

https://play.google.com/store/apps/details?id=com.bitcliq.igeo.ui_patrimonio

3. ESRI; 
60.7MB

Disponível em:

<https://play.google.com/store/apps/details?id=com.esri.android.client>

4. Augment (Aumentada); 
67.7MB

Disponível em: <https://play.google.com/store/apps/details?id=com.ar.augment>

Dados fornecidos:

Mapa Oficial de Lisboa de 2016;
Guião do Workshop

Annexes 2 – Procedures Text Document



Workshop: Valorização de Património Urbano: Avaliação de Apps em 3D e AR Aplicadas ao Património Cultural da Cidade de Lisboa | CICS.NOVA | 29 julho 2016 | Chiado, Lx

WORKSHOP:

App Lx_w  

- > AqueductAR > Ver no mapa de papel (mapa Lisboa) > Apontar a câmara e visualizar > Ligar e Desligar opções (Flash; Cartografia histórica; Traçado do Aqueduto e troços; MDT; 2D/3D)
- > AqueductAR > Sem mapa em papel > Visualizar: Introdução; Locais; Mapa; Perto de mim...

App IGEO Património 

- > Fontes de Dados > Património Protegido
- > Explore > Distrito: Lisboa > Concelho: Lisboa > Pesquisar > Edifício e Estrutura > Ver no mapa
- > Deslocar até ao Rato e abrir a Mãe de Água das Amoreiras > Ver registo

App ESRI 

- > Pesquisar por “Lisbon aqueduct” > Seleccionar > Abrir
- > Ver mapa com os elementos do aqueduto

App Augment  AUGMENT

- > Explorar > Pesquisar (lupa) > Escrever “workshop” > Seleccionar um modelo 3D
- > Procurar nas opções que surgem no fundo “Criar Rastreador”
- > Apontar a camara para o verso desta folha em diversos angulos e luz até ter a indicação a cor verde “toque para capturar” > Posicionar o modelo 3D (função rodar ou deslocar no touchscreen com dois dedos para baixo)
- > Visualizar modelo 3D em Realidade Aumentada

Deslocação até ao Largo do Carmo

Ligar GPS e verificar relação espacial das aplicações: IGEO Património, ESRI e Lx_w

Inquérito *online*: disponível através do URL

<http://www.surveygizmo.com/s3/2817402/New-Survey>

Workshop: Valorização de Património Urbano: Avaliação de App em 3D e AR Aplicado ao Património Cultural da Cidade de Lisboa | Lx, 29 julho



CICS.NOVA | FCSH / FCT - Universidade NOVA de Lisboa

Annex 3 – Questionnaire Reports

- **Report of the first questionnaire made in the workshop (July 2016)**
- **Report of the second questionnaire made through video (December 2016)**

Report for Questionnaire 1

Experts

July 2016

Lisbon_W

Response Statistics

| | Count | Percent |
|---------------------|-------|---------|
| Complete | 14 | 100 |
| Partial | 0 | 0 |
| Disqualified | 0 | 0 |
| Total | 14 | |

Annexes 3 – Questionnaires Report (questionnaire 1)

DESENVOLVIMENTO: DESIGN Classifique as Apps relativamente ao Design (forma e função) e Aparência (visualmente apelativo) (1 min - 5 máx)

1. DEVELOPMENT: DESIGN Classify the Apps in relation to Design (form and function) and Aesthetics (visual appeal) (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 21.4% | 3 | 42.9% | 6 | 28.6% | 4 | 7.1% | 1 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 0% | 0 | 35.7% | 5 | 50% | 7 | 7.1% | 1 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 0% | 0 | 64.3% | 9 | 28.6% | 4 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 28.6% | 4 | 42.9% | 6 | 21.4% | 3 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

DESENVOLVIMENTO: FACILIDADE DE UTILIZAÇÃO Classifique as Apps relativamente à sua Facilidade de Utilização (1 min - 5 máx)

2. DEVELOPMENT: EASE OF USE Classify the Apps considering the Ease of Use (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 21.4% | 3 | 28.6% | 4 | 28.6% | 4 | 21.4% | 3 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 7.1% | 1 | 14.3% | 2 | 64.3% | 9 | 7.1% | 1 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 14.3% | 2 | 64.3% | 9 | 14.3% | 2 | 7.1% | 1 |
| LX_W | 0% | 0 | 7.1% | 1 | 7.1% | 1 | 50% | 7 | 28.6% | 4 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

DESENVOLVIMENTO: SIMPLICIDADE / FUNCIONALIDADE Classifique a Apps segundo a sua Simplicidade e Funcionalidade (1 min - 5 máx)

3. DEVELOPMENT: SIMPLICITY / FUNCTIONALITY Classify the Apps according to their Simplicity and Functionality (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 14.3% | 2 | 35.7% | 5 | 28.6% | 4 | 21.4% | 3 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 0% | 0 | 21.4% | 3 | 57.1% | 8 | 14.3% | 2 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 14.3% | 2 | 50% | 7 | 28.6% | 4 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 0% | 0 | 57.1% | 8 | 35.7% | 5 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

PERFORMANCE: PESO (DADOS E CAPACIDADE) Classifique as Apps de acordo com o Espaço que ocupa e a influência na performance no dispositivo (1 min - 5 máx)

4. PERFORMANCE: WEIGHT (DATA AND CAPACITY) Classify the Apps according to the Space occupied and influence in the device performance (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|------|---|-------|---|-------|---|------|---|---------------------|---|
| Augment | 0% | 0 | 7.1% | 1 | 28.6% | 4 | 50% | 7 | 0% | 0 | 14.3% | 2 |
| ESRI (ArcGIS) | 0% | 0 | 7.1% | 1 | 35.7% | 5 | 28.6% | 4 | 7.1% | 1 | 21.4% | 3 |
| IGEO Património | 0% | 0 | 0% | 0 | 42.9% | 6 | 28.6% | 4 | 7.1% | 1 | 21.4% | 3 |
| LX_W | 0% | 0 | 0% | 0 | 21.4% | 3 | 50% | 7 | 7.1% | 1 | 21.4% | 3 |

Annexes 3 – Questionnaires Report (questionnaire 1)

PERFORMANCE: PRONTIDÃO NA RESPOSTA Classifique a Velocidade das Apps durante a utilização (1 min - 5 máx)

5. PERFORMANCE: READINESS IN RESPONSE Classify the App's Velocity in use (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|------|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 14.3% | 2 | 35.7% | 5 | 35.7% | 5 | 7.1% | 1 | 7.1% | 1 |
| ESRI (ArcGIS) | 7.1% | 1 | 0% | 0 | 35.7% | 5 | 28.6% | 4 | 14.3% | 2 | 14.3% | 2 |
| IGEO Património | 0% | 0 | 7.1% | 1 | 14.3% | 2 | 50% | 7 | 14.3% | 2 | 14.3% | 2 |
| LX_W | 0% | 0 | 0% | 0 | 14.3% | 2 | 57.1% | 8 | 14.3% | 2 | 14.3% | 2 |

Annexes 3 – Questionnaires Report (questionnaire 1)

PERFORMANCE: INTEROPERABILIDADE (FORMATOS) Classifique o nível de Interoperabilidade com outras app / software (e.g. Apps de navegação; possibilidade de importação/exportação de dados) (1 min - 5 máx)

6. PERFORMANCE: INTEROPERABILITY (FORMATS) Classify the Apps
Interoperability level with other app / software (e.g. Navigation Apps; ability to import / export data) (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 14.3% | 2 | 28.6% | 4 | 35.7% | 5 | 7.1% | 1 | 14.3% | 2 |
| ESRI (ArcGIS) | 0% | 0 | 0% | 0 | 21.4% | 3 | 35.7% | 5 | 21.4% | 3 | 21.4% | 3 |
| IGEO Património | 0% | 0 | 7.1% | 1 | 35.7% | 5 | 28.6% | 4 | 7.1% | 1 | 21.4% | 3 |
| LX_W | 0% | 0 | 0% | 0 | 14.3% | 2 | 42.9% | 6 | 21.4% | 3 | 21.4% | 3 |

Annexes 3 – Questionnaires Report (questionnaire 1)

PERFORMANCE: SEGURANÇA Classifique a sua perceção relativamente ao nível de Segurança da App (1 min - 5 máx)

7. PERFORMANCE: SECURITY Classify your perception about the App level of Security (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | Market | | NS/NR - DK/NA | |
|--------------------|----|---|------|---|-------|---|-------|---|----|---|--------|---|---------------------|---|
| Augment | 0% | 0 | 7.1% | 1 | 14.3% | 2 | 28.6% | 4 | 0% | 0 | 28.6% | 4 | 21.4% | 3 |
| ESRI (ArcGIS) | 0% | 0 | 7.1% | 1 | 7.1% | 1 | 28.6% | 4 | 0% | 0 | 28.6% | 4 | 28.6% | 4 |
| IGEO Património | 0% | 0 | 0% | 0 | 7.1% | 1 | 35.7% | 5 | 0% | 0 | 28.6% | 4 | 28.6% | 4 |
| LX_W | 0% | 0 | 0% | 0 | 21.4% | 3 | 35.7% | 5 | 0% | 0 | 14.3% | 2 | 28.6% | 4 |

Annexes 3 – Questionnaires Report (questionnaire 1)

USABILIDADE/DISPONIBILIDADE: POTENCIAIS UTILIZADORES Classifique a sua percepção relativamente ao universo de Utilizadores Potenciais tendo em consideração a disponibilidade em diferentes idiomas e nível de interesse (1 min - 5 máx)

8. USABILITY/AVAILABILITY: POTENTIAL USERS Classify your perception regarding the universe of Potential Users taking into account the availability in different languages and level of interest (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 28.6% | 4 | 28.6% | 4 | 7.1% | 1 | 35.7% | 5 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 7.1% | 1 | 14.3% | 2 | 50% | 7 | 21.4% | 3 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 14.3% | 2 | 57.1% | 8 | 21.4% | 3 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 7.1% | 1 | 50% | 7 | 35.7% | 5 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

USABILIDADE: ENVOLVIMENTO DO UTILIZADOR Classifique as Apps de acordo com a capacidade de Envolvimento do Utilizador (1 min - 5 máx)

9. USABILITY: USER ENGAGEMENT Classify the apps according to the capacity to engage the User (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 14.3% | 2 | 21.4% | 3 | 21.4% | 3 | 35.7% | 5 | 7.1% | 1 |
| ESRI (ArcGIS) | 0% | 0 | 7.1% | 1 | 21.4% | 3 | 42.9% | 6 | 14.3% | 2 | 14.3% | 2 |
| IGEO Património | 0% | 0 | 7.1% | 1 | 28.6% | 4 | 28.6% | 4 | 21.4% | 3 | 14.3% | 2 |
| LX_W | 0% | 0 | 7.1% | 1 | 7.1% | 1 | 21.4% | 3 | 50% | 7 | 14.3% | 2 |

Annexes 3 – Questionnaires Report (questionnaire 1)

USABILIDADE: EXPECTATIVA DO UTILIZADOR / SATISFAÇÃO Classifique as Apps de acordo com o Grau de Satisfação do utilizador relativamente às suas expectativas iniciais (1 min - 5 máx)

10. USABILITY: USER EXPECTATION / SATISFACTION Classify the Apps according to the degree of User Satisfaction and considering their initial expectations (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 21.4% | 3 | 28.6% | 4 | 21.4% | 3 | 21.4% | 3 | 7.1% | 1 |
| ESRI (ArcGIS) | 0% | 0 | 0% | 0 | 50% | 7 | 28.6% | 4 | 14.3% | 2 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 14.3% | 2 | 57.1% | 8 | 21.4% | 3 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 14.3% | 2 | 35.7% | 5 | 42.9% | 6 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

USABILIDADE: UTILIDADE Classifique as Apps de acordo com a Utilidade da informação para o utilizador (1 min - 5 máx)

11. USABILITY: USEFUL Classify the Apps according to usefulness information for the user (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|----|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 0% | 0 | 28.6% | 4 | 35.7% | 5 | 21.4% | 3 | 14.3% | 2 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 7.1% | 1 | 21.4% | 3 | 50% | 7 | 14.3% | 2 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 7.1% | 1 | 57.1% | 8 | 28.6% | 4 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 28.6% | 4 | 21.4% | 3 | 42.9% | 6 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

QUALIDADE: CONFIANÇA / CREDIBILIDADE Classifique as Apps de acordo com o grau de Confiança dos dados (e.g. históricos e relevância para o tipo de utilizador) (1 min - 5 máx)

12. QUALITY: RELIABILITY / CREDIBILITY Classify the Apps according to the degree of Reliability of the data (e.g. historical and relevance to the type of user) (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|------|---|------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 7.1% | 1 | 7.1% | 1 | 42.9% | 6 | 14.3% | 2 | 14.3% | 2 | 14.3% | 2 |
| ESRI (ArcGIS) | 0% | 0 | 0% | 0 | 21.4% | 3 | 42.9% | 6 | 14.3% | 2 | 21.4% | 3 |
| IGEO Património | 0% | 0 | 0% | 0 | 0% | 0 | 35.7% | 5 | 42.9% | 6 | 21.4% | 3 |
| LX_W | 0% | 0 | 0% | 0 | 14.3% | 2 | 35.7% | 5 | 28.6% | 4 | 21.4% | 3 |

Annexes 3 – Questionnaires Report (questionnaire 1)

QUALIDADE: POTENCIAL DE APLICAÇÃO (A OUTROS ELEMENTOS) Classifique as Apps de acordo com o Potencial de aplicação a outros elementos patrimoniais (e.g. Muralha Fernandina ou Lisboa pré terramoto de 1755) (1 min - 5 máx)

13. QUALITY: POTENTIAL OF APPLICATION (TO OTHER ELEMENTS) Classify the Apps in accordance with the Potential of application to other heritage elements (e.g. Ancient Fernandina Wall or Lisbon 1755 pre-earthquake) (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|------|---|------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 7.1% | 1 | 7.1% | 1 | 28.6% | 4 | 42.9% | 6 | 14.3% | 2 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 7.1% | 1 | 28.6% | 4 | 28.6% | 4 | 28.6% | 4 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 28.6% | 4 | 50% | 7 | 14.3% | 2 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 7.1% | 1 | 35.7% | 5 | 50% | 7 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

QUALIDADE: CONHECIMENTO Classifique as Apps de acordo com o nível de Conhecimento que adquiriu relativamente ao objeto em estudo (1 min - 5 máx)

14. QUALITY: KNOWLADGE Classify the Apps according the level of Knowledge acquired relative to the study object (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|-------|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 14.3% | 2 | 7.1% | 1 | 35.7% | 5 | 21.4% | 3 | 14.3% | 2 | 7.1% | 1 |
| ESRI (ArcGIS) | 0% | 0 | 21.4% | 3 | 21.4% | 3 | 21.4% | 3 | 14.3% | 2 | 21.4% | 3 |
| IGEO Património | 0% | 0 | 7.1% | 1 | 0% | 0 | 50% | 7 | 28.6% | 4 | 14.3% | 2 |
| LX_W | 0% | 0 | 0% | 0 | 7.1% | 1 | 35.7% | 5 | 42.9% | 6 | 14.3% | 2 |

Annexes 3 – Questionnaires Report (questionnaire 1)

VALORIZAÇÃO DO PATRIMÓNIO: POTENCIAL DE DISSEMINAÇÃO Classifique as Apps de acordo com o potencial Disseminação do objeto de património (1 min - 5 máx)

15. HERITAGE VALUATION: POTENTIAL OF DISSEMINATION Classify the Apps according to the potential Dissemination of the heritage object (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|------|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 7.1% | 1 | 28.6% | 4 | 21.4% | 3 | 28.6% | 4 | 14.3% | 2 | 0% | 0 |
| ESRI (ArcGIS) | 7.1% | 1 | 14.3% | 2 | 21.4% | 3 | 35.7% | 5 | 7.1% | 1 | 14.3% | 2 |
| IGEO Património | 0% | 0 | 0% | 0 | 0% | 0 | 57.1% | 8 | 35.7% | 5 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 7.1% | 1 | 50% | 7 | 35.7% | 5 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

VALORIZAÇÃO DO PATRIMÓNIO: VALOR ACRESCIDO Considera que as Apps aumentam o Valor patrimonial do objeto em estudo face aos agentes (e.g. turistas, comerciantes locais, técnicos, políticos) (1 min - 5 máx)

16. HERITAGE VALUATION: ADDED VALUE Do you consider that the Apps increase the Value of the study object addressed to agents (e.g. tourists, local business, technicians, politicians) (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|-------|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 14.3% | 2 | 14.3% | 2 | 42.9% | 6 | 7.1% | 1 | 21.4% | 3 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 21.4% | 3 | 14.3% | 2 | 35.7% | 5 | 14.3% | 2 | 14.3% | 2 |
| IGEO Património | 0% | 0 | 0% | 0 | 7.1% | 1 | 42.9% | 6 | 42.9% | 6 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 14.3% | 2 | 28.6% | 4 | 50% | 7 | 7.1% | 1 |

Annexes 3 – Questionnaires Report (questionnaire 1)

VALORIZAÇÃO DO PATRIMÓNIO: RECOMENDAÇÃO Recomendaria as Apps a outros utilizadores com vista a exploração do elemento patrimonial em estudo (1 min - 5 máx)

17. HERITAGE VALUATION: RECOMMENDATION Would you Recommend the Apps to other users to explore the heritage elements in study (1 min - 5 max)

| | 1 | | 2 | | 3 | | 4 | | 5 | | NS/NR - DK/NA | |
|--------------------|-------|---|-------|---|-------|---|-------|---|-------|---|---------------------|---|
| Augment | 14.3% | 2 | 14.3% | 2 | 42.9% | 6 | 7.1% | 1 | 21.4% | 3 | 0% | 0 |
| ESRI (ArcGIS) | 0% | 0 | 21.4% | 3 | 21.4% | 3 | 35.7% | 5 | 14.3% | 2 | 7.1% | 1 |
| IGEO Património | 0% | 0 | 0% | 0 | 14.3% | 2 | 42.9% | 6 | 35.7% | 5 | 7.1% | 1 |
| LX_W | 0% | 0 | 0% | 0 | 21.4% | 3 | 21.4% | 3 | 50% | 7 | 7.1% | 1 |

Report for Questionnaire 2

Lisbon_W - Main Public

December 2016

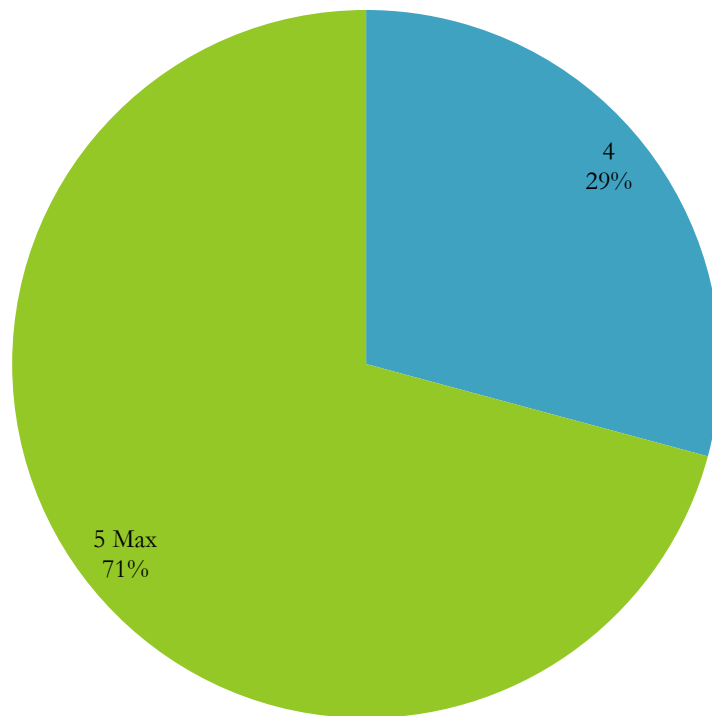
Lisbon_W - Main Public - December 2016

Response Statistics

| | Count | Percent |
|---------------------|-------|---------|
| Complete | 24 | 100 |
| Partial | 0 | 0 |
| Disqualified | 0 | 0 |
| Total | 24 | |

Classifique o grau de interesse em utilizar a App apresentada no vídeo (1 Min - 5 Máx)

1. Classify the degree of interest in use the App displayed in the video (1 Min - 5 Max)

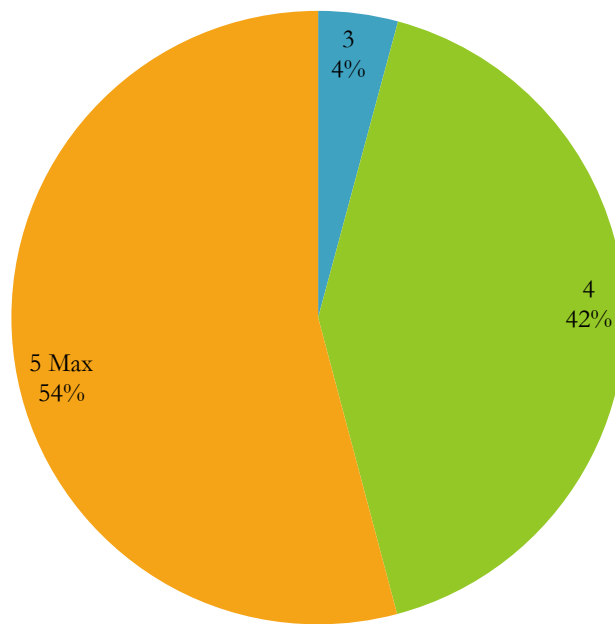


| Value | Percent | Count |
|-------|---------|-------|
| 4 | 29.2% | 7 |
| 5 Max | 70.8% | 17 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Classifique o grau de interesse em utilizar a App apresentada no vídeo na proximidade imediata do objeto de estudo / cada elemento que dele faz parte (aqueduto) (1 Min - 5 Máx)

2. Classify the degree of interest in using the App presented in the video next to the immediate proximity of the object of study / each element that is part of it (aqueduct) (1 Min – 5 Max)

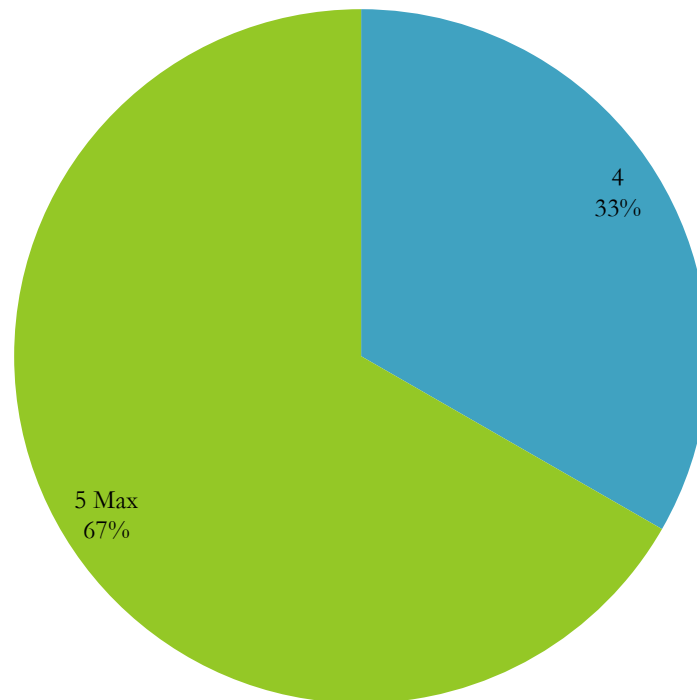


| Value | Percent | Count |
|-------|---------|-------|
| 3 | 4.2% | 1 |
| 4 | 41.7% | 10 |
| 5 Max | 54.2% | 13 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Classifique a App de acordo com a Utilidade da informação para um utilizador que pretenda explorar ou aprofundar conhecimentos sobre o objeto de estudo (Aqueduto) (1 Min - 5 Máx)

3. Classify the App according to the Usefulness of the information for a user wishing to explore or intensify the knowledge about the object of study (Aqueduct) (1 min - 5 max)

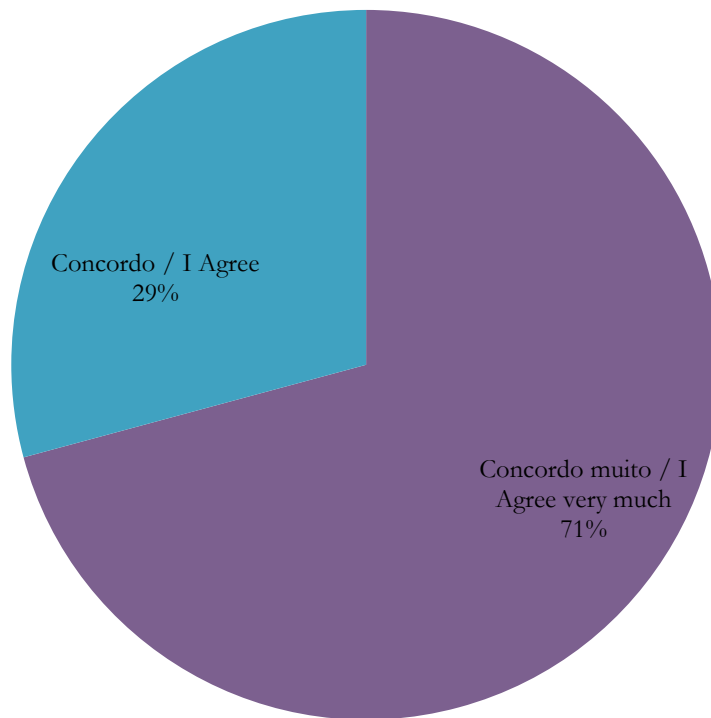


| Value | Percent | Count |
|-------|---------|-------|
| 4 | 33.3% | 8 |
| 5 Max | 66.7% | 16 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Concorda com a frase? A tecnologia permite aumentar o valor intrínseco do património cultural, através de representações digitais (passado, presente e futuro), estabelecendo ambientes sintéticos (virtuais) sobrepostos ao espaço real

4. Do you agree with the statement? The technology allows to increase the intrinsic value of cultural heritage through digital representations (past, present and future), establishing synthetic environments (virtual) superimposed on the real space

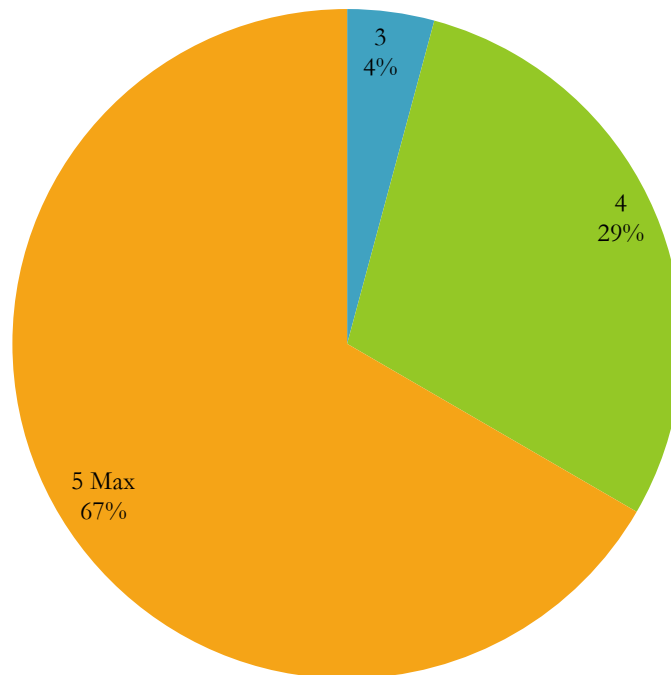


| Value | Percent | Count |
|------------------------------------|---------|-------|
| Concordo muito / I Agree very much | 70.8% | 17 |
| Concordo / I Agree | 29.2% | 7 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Interatividade com o mapa em papel (mapa turístico da cidade de Lisboa) para o planeamento de uma visita de estudo ou passeio (na fase de preparação por exemplo em casa com família, no café com amigos, etc.) (1 Min - 5 Máx)

5. Interactivity with the paper map (tourist map of the city of Lisbon) for the planning of a study visit or tour (in the preparation phase for example at home with family, at the cafe with friends, etc.) (1 Min - 5 Max)

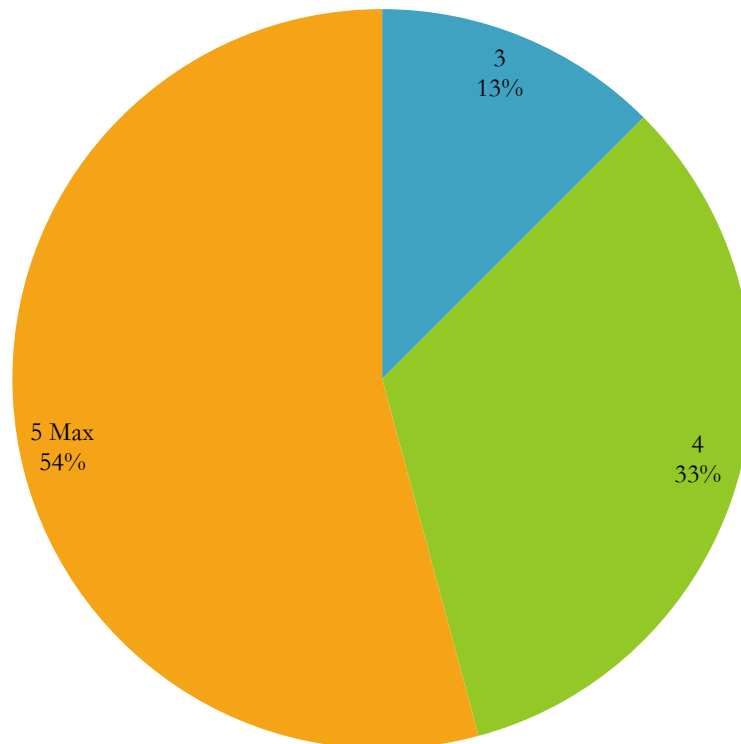


| Value | Percent | Count |
|-------|---------|-------|
| 3 | 4.2% | 1 |
| 4 | 29.2% | 7 |
| 5 Max | 66.7% | 16 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Interatividade com o mapa em papel (mapa turístico da cidade de Lisboa) para exploração do objeto de património (Aquaduto das Águas Livres) no(a) sítio / rua (1 Min - 5 Máx)

7. Interactivity with the paper map (tourist map of the city of Lisbon) for exploitation of the heritage object (Aquaduto das Águas Livres) on the site / street (1 Min - 5 Max)



| Value | Percent | Count |
|-------|---------|-------|
| 3 | 12.5% | 3 |
| 4 | 33.3% | 8 |
| 5 Max | 54.2% | 13 |
| | Total | 24 |

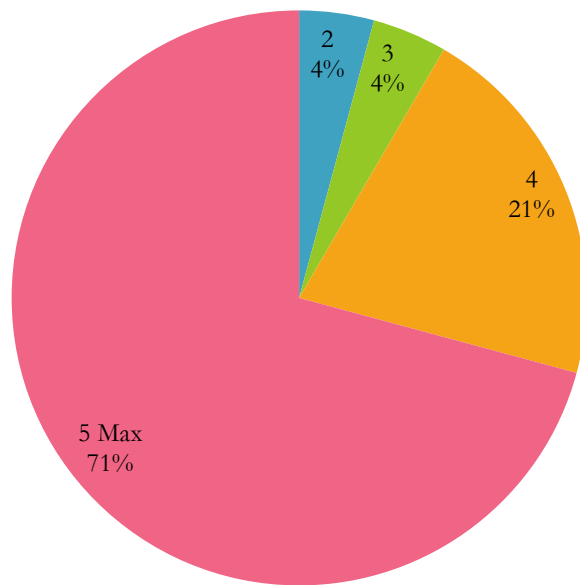
Annexes 3 – Questionnaires Report (questionnaire 2)

Classifique, na qualidade de utilizador, o interesse da presença na App de informação 2D e 3D para a exploração e a valorização do objeto de património (Aqueduto das Águas Livres)

Classify, as a user, the interest of the App's 2D and 3D Information for exploring and adding value to the heritage object (Águas Livres Aqueduct) – question 9 to19

Mapa antigo (1 Min - 5 Máx)

9. Ancient map (1 Min - 5 Max)

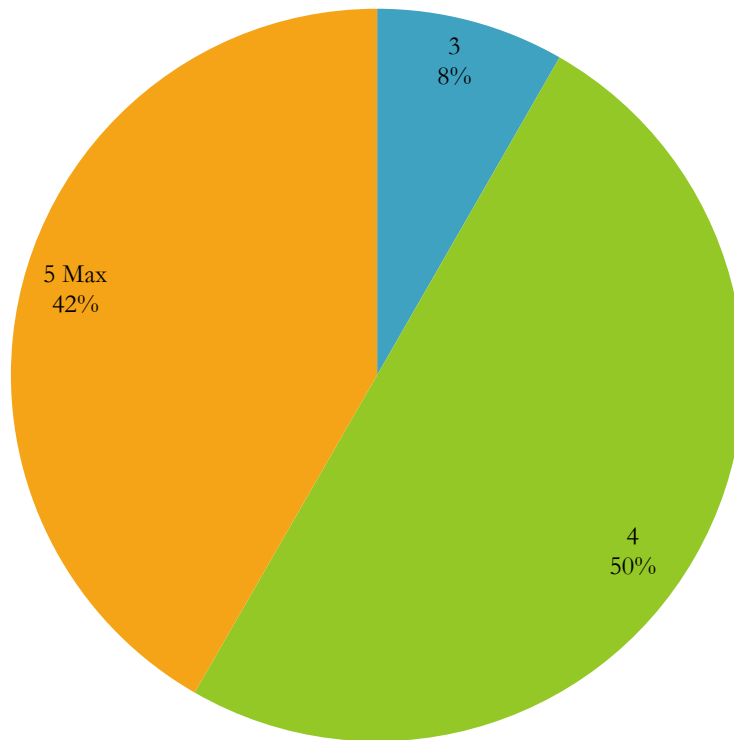


| Value | Percent | Count |
|-------|---------|-------|
| 2 | 4.2% | 1 |
| 3 | 4.2% | 1 |
| 4 | 20.8% | 5 |
| 5 Max | 70.8% | 17 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Modelo Digital do Terreno (MDT) / relevo em 3D (1 Min - 5 Máx)

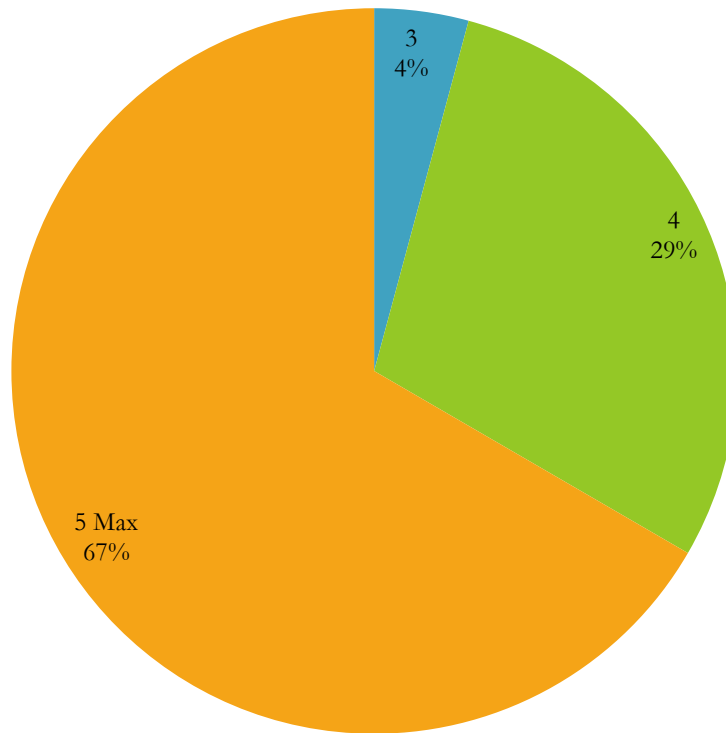
10. Digital Terrain Model (DTM) / 3D relief (1 Min - 5 Max)



| Value | Percent | Count |
|-------|---------|-------|
| 3 | 8.3% | 2 |
| 4 | 50.0% | 12 |
| 5 Max | 41.7% | 10 |
| | Total | 24 |

Modelos 3D dos chafarizes do Aqueduto (1 Mín - 5 Máx)

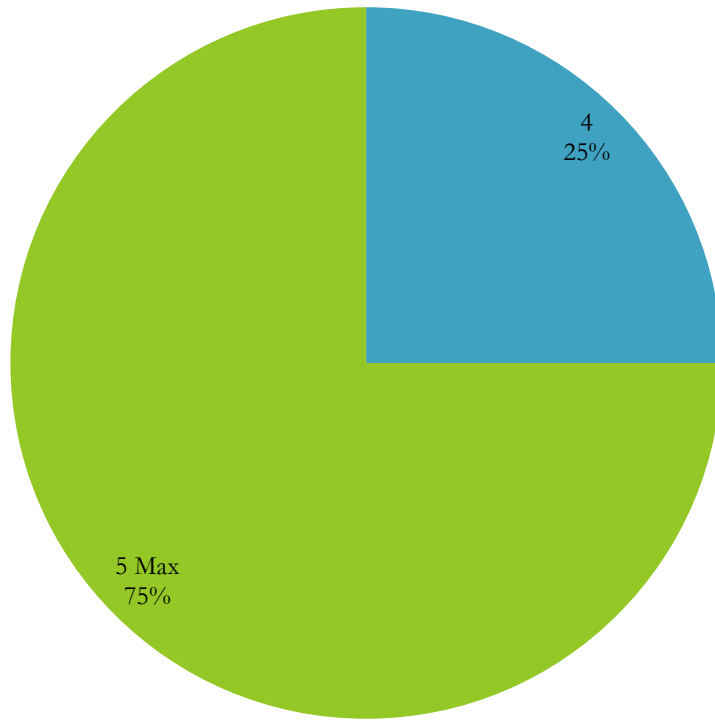
12. 3D models of the aqueduct fountains (1 Min - 5 Max)



| Value | Percent | Count |
|-------|---------|-------|
| 3 | 4.2% | 1 |
| 4 | 29.2% | 7 |
| 5 Max | 66.7% | 16 |
| | Total | 24 |

Visualização seletiva de informação (1 Min - 5 Máx)

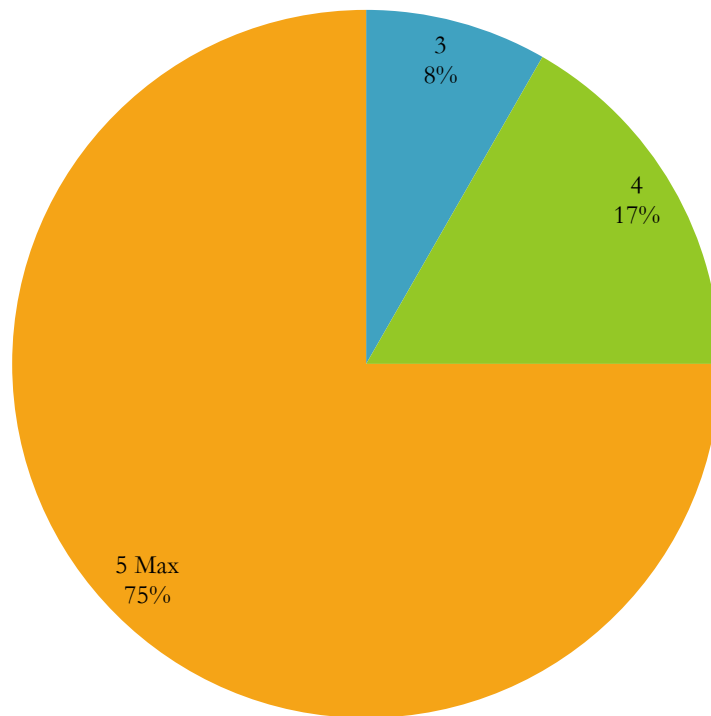
19. Selective visualization of information (1 Min - 5 Max)



| Value | Percent | Count |
|-------|---------|-------|
| 4 | 25.0% | 6 |
| 5 Max | 75.0% | 18 |
| | Total | 24 |

Sobreposição de informação com seleção de camadas (e.g. traçado e elementos do aqueduto) (1 Min - 5 Máx)

11. Information overlay with layer selection (e.g. path and elements of the aqueduct) (1 Min - 5 Max)

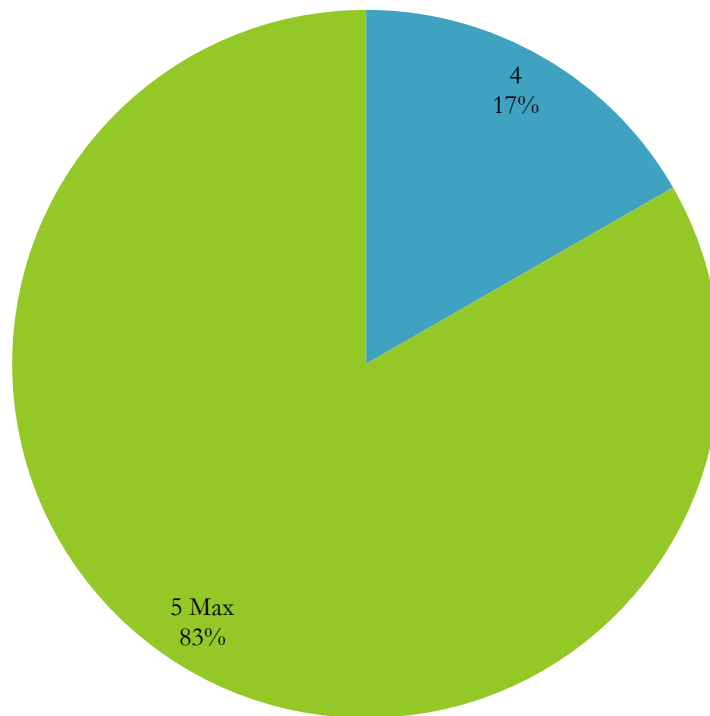


| Value | Percent | Count |
|-------|---------|-------|
| 3 | 8.3% | 2 |
| 4 | 16.7% | 4 |
| 5 Max | 75.0% | 18 |
| Total | | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Acesso a mapas Google com informação do aqueduto sobre: edifícios em 3D, marcadores de pontos notáveis (igrejas, palácios, etc.) e toponímia de arruamentos (1 Min - 5 Máx)

17. Access to Google Maps with the Aqueduct information over: 3D buildings, markers of notable points (churches, palaces, etc.) and toponymy of streets (1 Min - 5 Max)

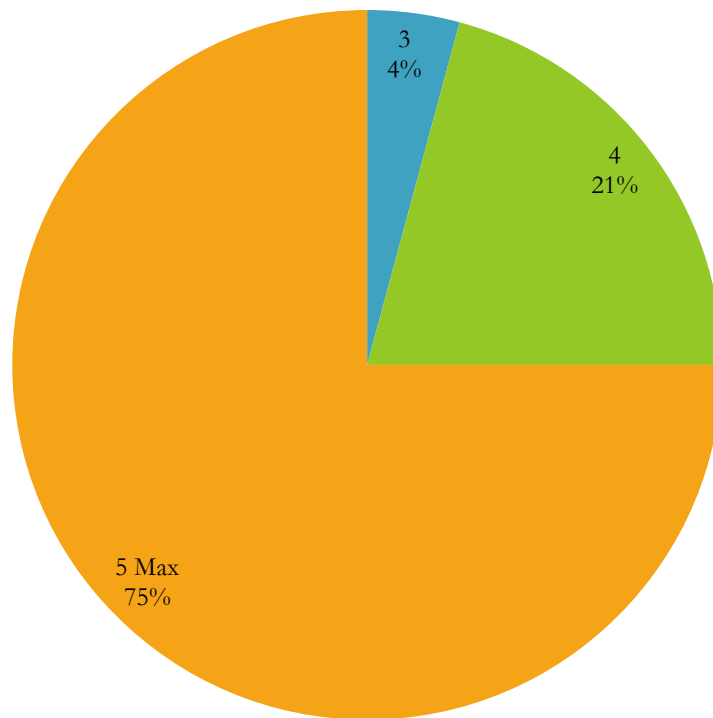


| Value | Percent | Count |
|-------|---------|-------|
| 4 | 16.7% | 4 |
| 5 Max | 83.3% | 20 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Acesso a outras Apps (previamente instaladas) como a Here WeGo para opção de navegação / routing (1 Min - 5 Máx)

18. Access to other Apps (previously installed) such as Here WeGo for navigation / routing (1 Min - 5 Max)

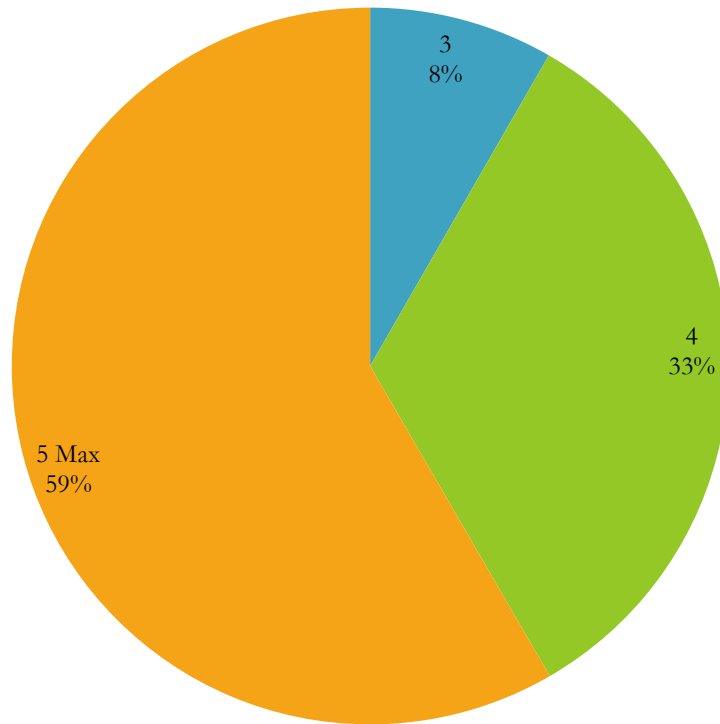


| Value | Percent | Count |
|-------|---------|-------|
| 3 | 4.2% | 1 |
| 4 | 20.8% | 5 |
| 5 Max | 75.0% | 18 |
| Total | | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Texto (conteúdos) (1 Min - 5 Máx)

13. Text (contents) (1 Min - 5 Max)

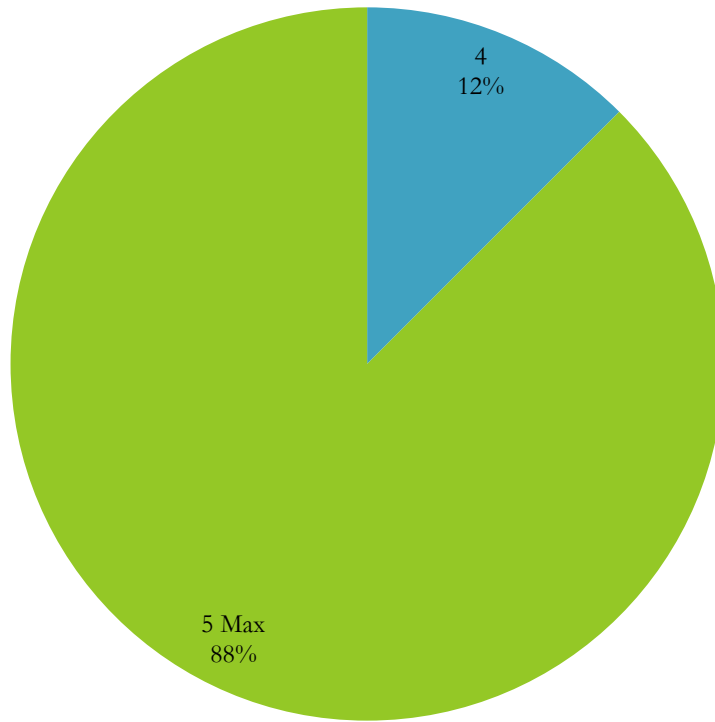


| Value | Percent | Count |
|-------|---------|-------|
| 3 | 8.3% | 2 |
| 4 | 33.3% | 8 |
| 5 Max | 58.3% | 14 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Fotografias antigas (1 Min - 5 Max)

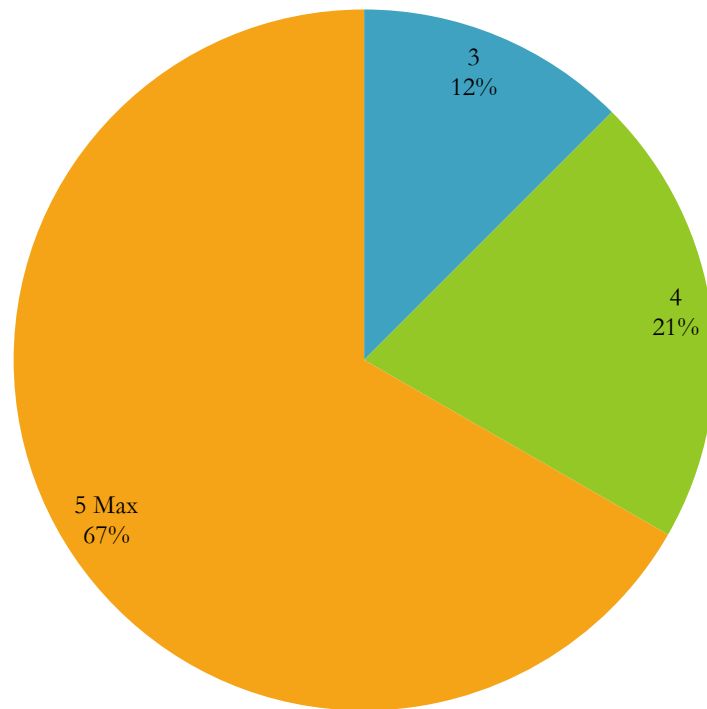
14. Ancient pictures (1 Min - 5 Max)



| Value | Percent | Count |
|-------|---------|-------|
| 4 | 12.5% | 3 |
| 5 Max | 87.5% | 21 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

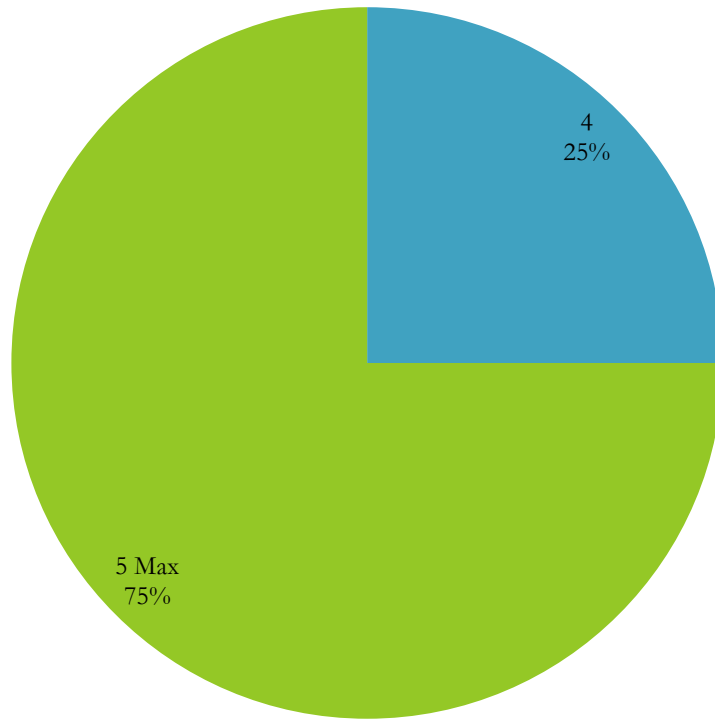
Fotografias atuais (1 Min - 5 Máx)

15. Actual pictures (1 Min - 5 Max)

| Value | Percent | Count |
|-------|---------|-------|
| 3 | 12.5% | 3 |
| 4 | 20.8% | 5 |
| 5 Max | 66.7% | 16 |
| | Total | 24 |

Informações úteis (horário de visitas, preço, etc.) (1 Min - 5 Máx)

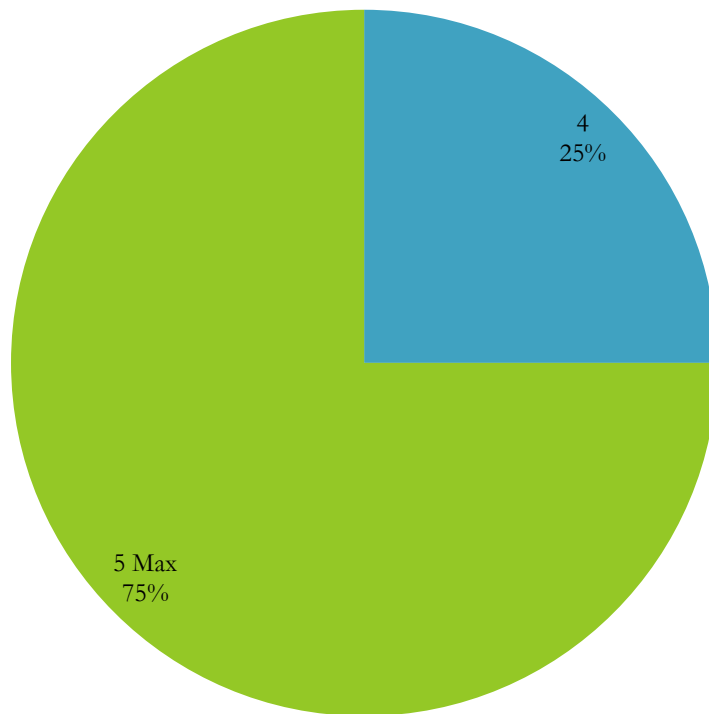
16. Useful information (Visiting hours, price, etc.) (1 Min - 5 Max)



| Value | Percent | Count |
|-------|---------|-------|
| 4 | 25.0% | 6 |
| 5 Max | 75.0% | 18 |
| | Total | 24 |

Classifique a App considerando o potencial aumento do Valor intrínseco do objeto de estudo (Aquaduto)

20. Classify the App considering the potential increase in the intrinsic Value of the study object (Aquaduct)



| Value | Percent | Count |
|-------|---------|-------|
| 4 | 25.0% | 6 |
| 5 Max | 75.0% | 18 |
| Total | | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Classifique a App considerando o potencial aumento do Valor intrínseco do objeto de estudo (Aqueduto) para cada grupo de Agentes no território (e.g. turistas, comerciantes locais, técnicos, políticos)

21. Classify the App considering the potential increase of the intrinsic Value of the study object (Aqueduct) for each group Agents in the territory (e.g. tourists, local commerce and services, technicians, politicians)

| | Min 1 | | 2 | | 3 | | 4 | | 5 Max | |
|---|----------|---|----|---|-------|---|-------|----|-------|----|
| Promotores (Entidades Publico Privadas) / Promoters (Public and Private Entities) | 0% | 0 | 0% | 0 | 4.2% | 1 | 33.3% | 8 | 62.5% | 15 |
| Técnicos Associados a Património / Heritage Related Technicians | 0% | 0 | 0% | 0 | 8.3% | 2 | 12.5% | 3 | 79.2% | 19 |
| Outros Técnicos / Other Technicians | 0% | 0 | 0% | 0 | 16.7% | 4 | 41.7% | 10 | 41.7% | 10 |
| Outros Stakeholders: e.g. Comércio e Serviços / Other Stakeholders: e.g. Commerce and Services | 0% | 0 | 0% | 0 | 12.5% | 3 | 37.5% | 9 | 50% | 12 |
| Público em Geral: e.g. turistas / Main Public: e.g. tourists | 0% | 0 | 0% | 0 | 8.3% | 2 | 12.5% | 3 | 79.2% | 19 |

Note: see graphics in the end of the report

Annexes 3 – Questionnaires Report (questionnaire 2)

Classifique a App tendo em consideração do Impacto nos diversos Domínios (e.g. técnico-científico, socioeconómico, político-administrativo, simbólico)

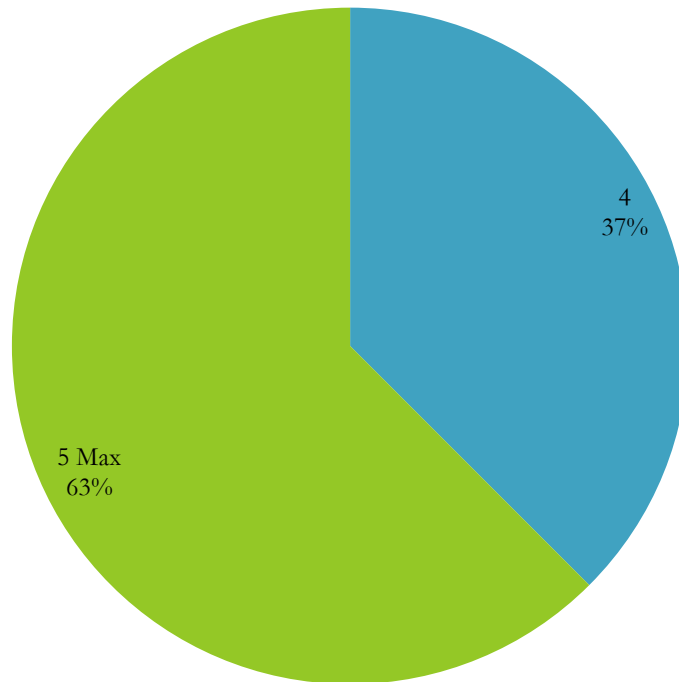
22. Classify the App taking into consideration the Impact on various Domains (e.g. technical-scientific, socio-economic, political-administrative and symbolic)

| | Min 1 | | 2 | | 3 | | 4 | | 5 Max | |
|---|------------------|---|----------|---|----------|---|----------|---|------------------|----|
| Político- Administrativo / Political- Administrative | 0% | 0 | 4.2% | 1 | 20.8% | 5 | 29.2% | 7 | 45.8% | 11 |
| Técnico- científico / Technical- Scientific | 0% | 0 | 0% | 0 | 0% | 0 | 37.5% | 9 | 62.5% | 15 |
| Socioeconómico / Socio- Economic | 0% | 0 | 0% | 0 | 12.5% | 3 | 25% | 6 | 62.5% | 15 |

Note: see graphics in the end of the report

Classifique o potencial Disseminação do objeto de património (Aquaduto das Águas Livres) através da App (1 Min - 5 Máx)

23. Classify the potential Dissemination of the heritage object (Lisbon Aqueduct) through the App (1 Min - 5 Máx)

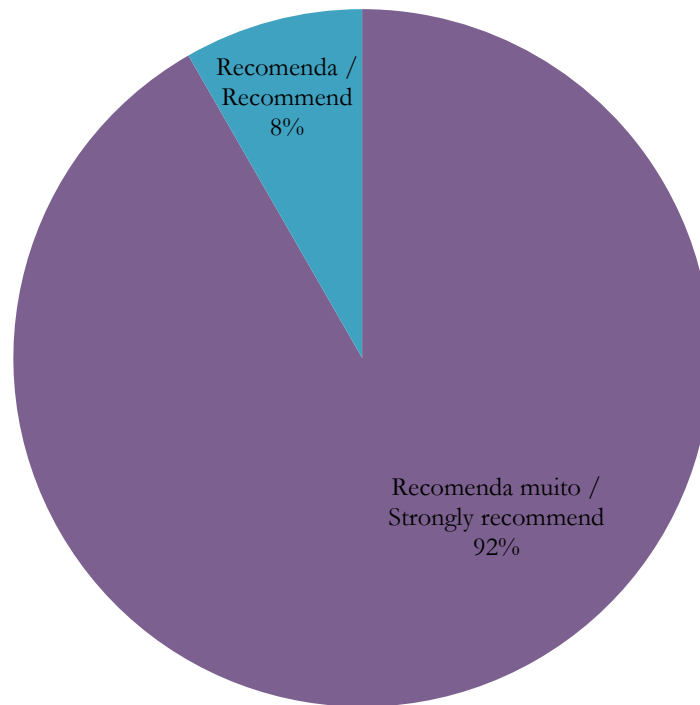


| Value | Percent | Count |
|-------|---------|-------|
| 4 | 37.5% | 9 |
| 5 Max | 62.5% | 15 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Após ter tomado conhecimento da App, Recomendaria a outros utilizadores com vista a exploração dos elementos patrimoniais em estudo

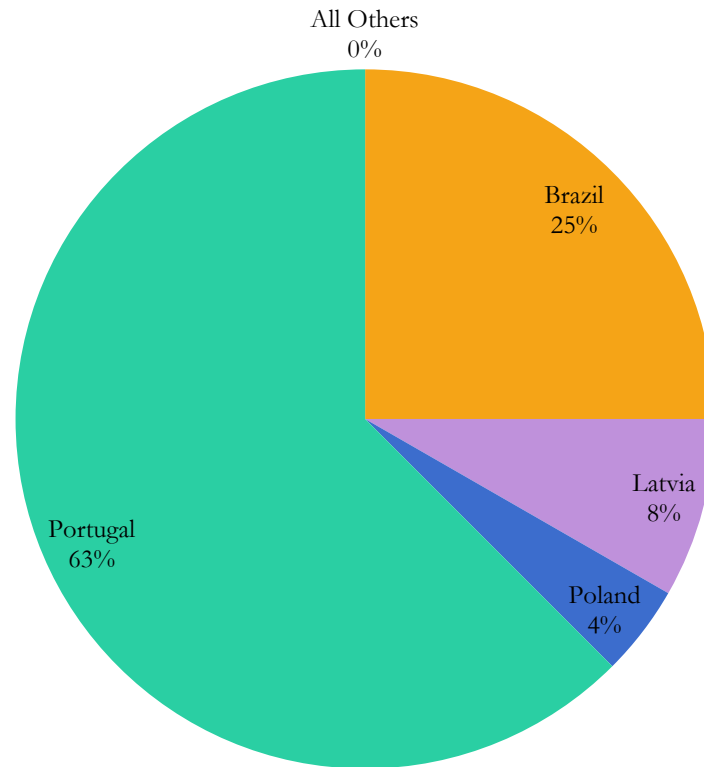
24. After becoming aware of the App, would you Recommend the App to other users to explore the heritage elements in study



| Value | Percent | Count |
|--------------------------------------|---------|-------|
| Recomenda muito / Strongly recommend | 91.7% | 22 |
| Recomenda / Recommend | 8.3% | 2 |
| Total | | 24 |

IDENTIFICAÇÃO: NACIONALIDADE (selecione a partir da lista)

27. IDENTIFICATION: NATIONALITY (Select from list)

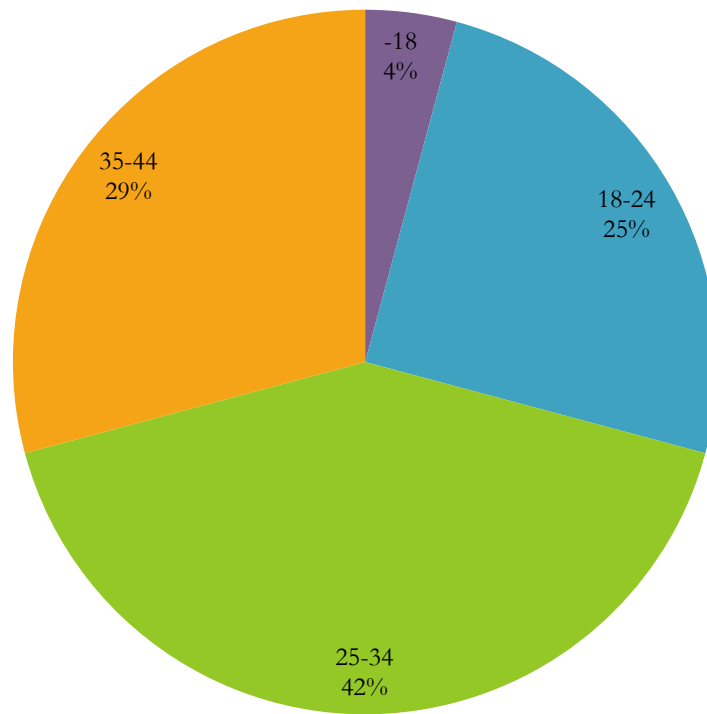


| Value | Percent | Count |
|----------|---------|-------|
| Brazil | 25.0% | 6 |
| Latvia | 8.3% | 2 |
| Poland | 4.2% | 1 |
| Portugal | 62.5% | 15 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

IDENTIFICAÇÃO: IDADE Qual o grupo etário em que se insere?

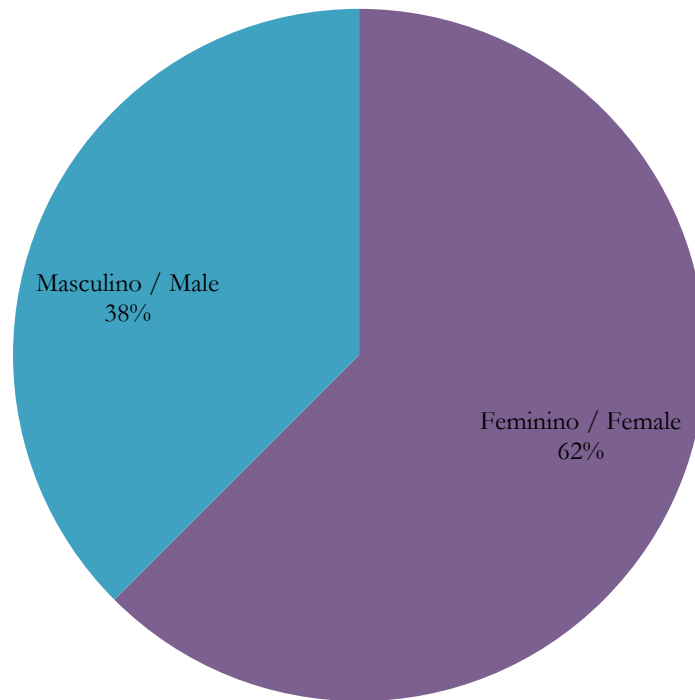
28. IDENTIFICATION: AGE - What is your age group?



| Value | Percent | Count |
|-------|---------|-------|
| -18 | 4.2% | 1 |
| 18-24 | 25.0% | 6 |
| 25-34 | 41.7% | 10 |
| 35-44 | 29.2% | 7 |
| | Total | 24 |

IDENTIFICAÇÃO: SEXO

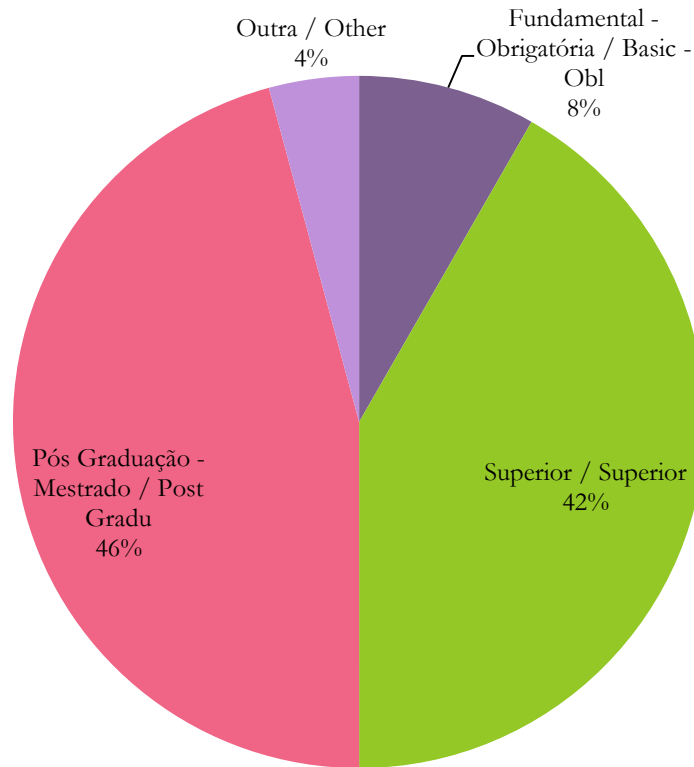
29. IDENTIFICATION: GENDER



| Value | Percent | Count |
|-------------------|---------|-------|
| Feminino / Female | 62.5% | 15 |
| Masculino / Male | 37.5% | 9 |
| | Total | 24 |

IDENTIFICAÇÃO: GRAU DE ESCOLARIDADE Qual o grau de Escolaridade?

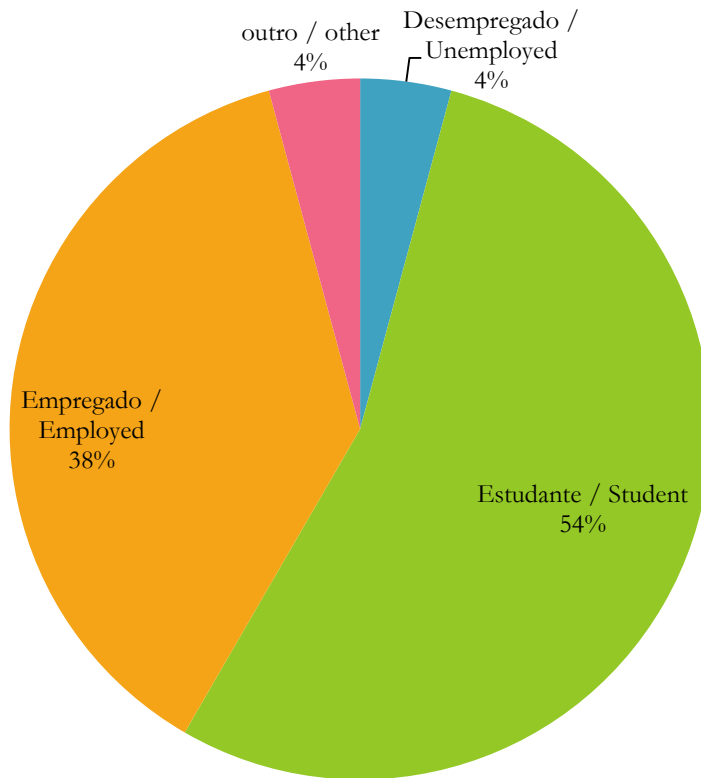
30. IDENTIFICATION: LEVEL OF EDUCATION - What is your level of Education?



| Value | Percent | Count |
|--|---------|-------|
| Fundamental - Obrigatória / Basic - Obligatory | 8.3% | 2 |
| Superior / Superior | 41.7% | 10 |
| Pós Graduação - Mestrado / Post Graduated | 45.8% | 11 |
| Outra / Other | 4.2% | 1 |
| | Total | 24 |

IDENTIFICAÇÃO: EMPREGO Situação perante o Emprego?

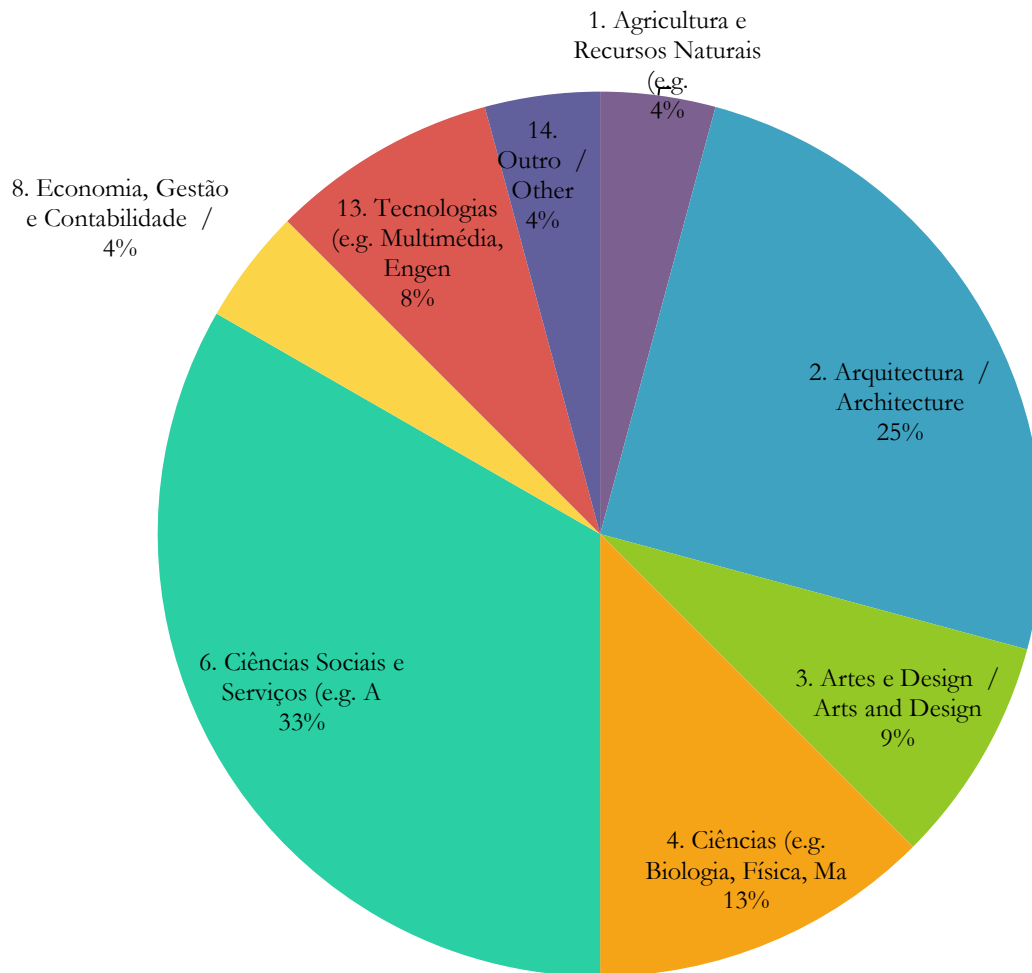
31. IDENTIFICATION: EMPLOYMENT - Employment situation?



| Value | Percent | Count |
|---------------------------|---------|-------|
| Desempregado / Unemployed | 4.2% | 1 |
| Estudante / Student | 54.2% | 13 |
| Empregado / Employed | 37.5% | 9 |
| outro / other | 4.2% | 1 |
| Total | | 24 |

IDENTIFICAÇÃO: FORMAÇÃO Qual a área de Formação em que se insere?

32. IDENTIFICATION: FORMATION - What is your area of Formation?



| Value | Percent | Count |
|--|---------|-------|
| 1. Agricultura e Recursos Naturais / Agriculture and Natural Resources | 4.2% | 1 |
| 2. Arquitetura / Architecture | 25.0% | 6 |
| 3. Artes e Design / Arts and Design | 8.3% | 2 |
| 4. Ciências / Sciences (and. Biology, Physics, Mathematics, Chemistry) | 12.5% | 3 |

Annexes 3 – Questionnaires Report (questionnaire 2)

| | | |
|---|-------|----|
| 6. Ciências Sociais e Serviços / Social Sciences and Services (e.g. Anthropology, Geography, Tourism) | 33.3% | 8 |
| 8. Economia, Gestão e Contabilidade / Economics, Management and Accounting | 4.2% | 1 |
| 13. Tecnologias... / Technologies (e.g. Multimedia, Engineering, Informatics) | 8.3% | 2 |
| 14. Outro / Other | 4.2% | 1 |
| | Total | 24 |

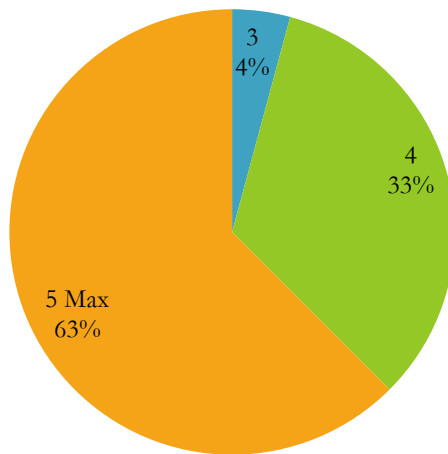
Charts of the question 21

Classifique a App considerando o potencial aumento do Valor intrínseco do do objecto de estudo (Aquaduto) para cada grupo de Agentes no território (e.g. turistas, comerciantes locais, técnicos, políticos)

21. Classify the App considering the potential increase of the intrinsic Value of the study object (Aquaduct) for each group Agents in the territory (e.g. tourists, local commerce and services, technicians, politicians)

Promotores (Entidades Publico Privadas) /

Promoters (Public and Private Entities)

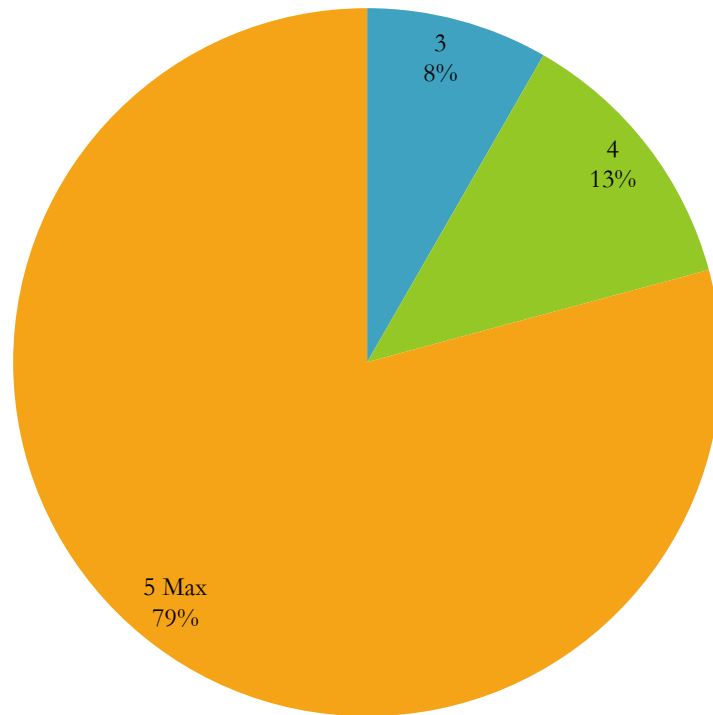


| Value | Percent | Count |
|-------|---------|-------|
| 3 | 4.2% | 1 |
| 4 | 33.3% | 8 |
| 5 Max | 62.5% | 15 |
| Total | | 24 |

Charts of the question 21

Técnicos Associados a Património /

Heritage Related Technicians



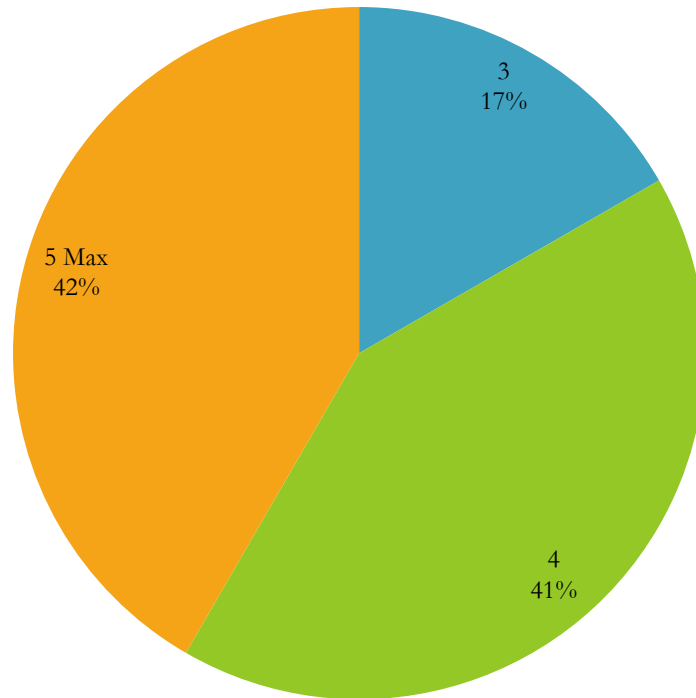
| Value | Percent | Count |
|-------|---------|-------|
| 3 | 8.3% | 2 |
| 4 | 12.5% | 3 |
| 5 Max | 79.2% | 19 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Charts of the question 21

Outros Técnicos /

Other Technicians

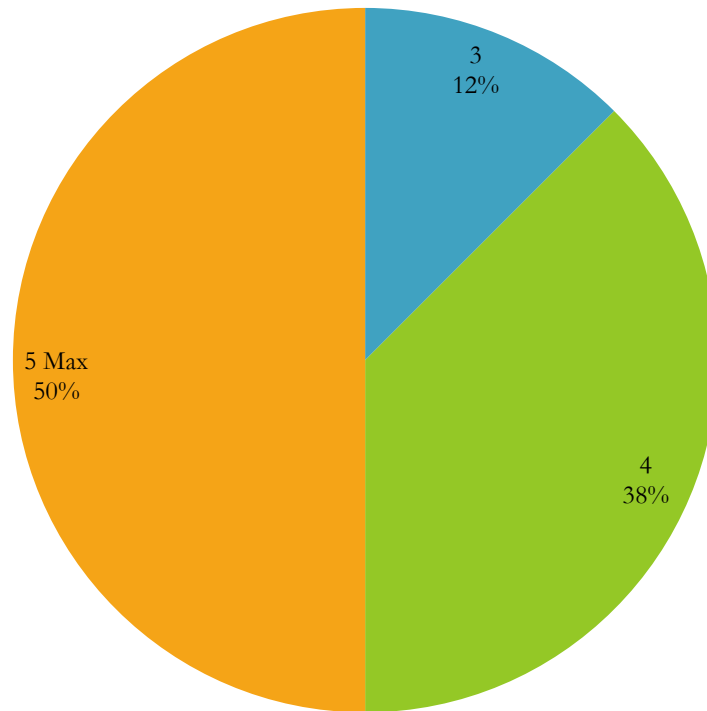


| Value | Percent | Count |
|-------|---------|-------|
| 3 | 16.7% | 4 |
| 4 | 41.7% | 10 |
| 5 Max | 41.7% | 10 |
| | Total | 24 |

Charts of the question 21

Outros Stakeholders: e.g. Comércio e Serviços /

Other Stakeholders: e.g. Commerce and Services



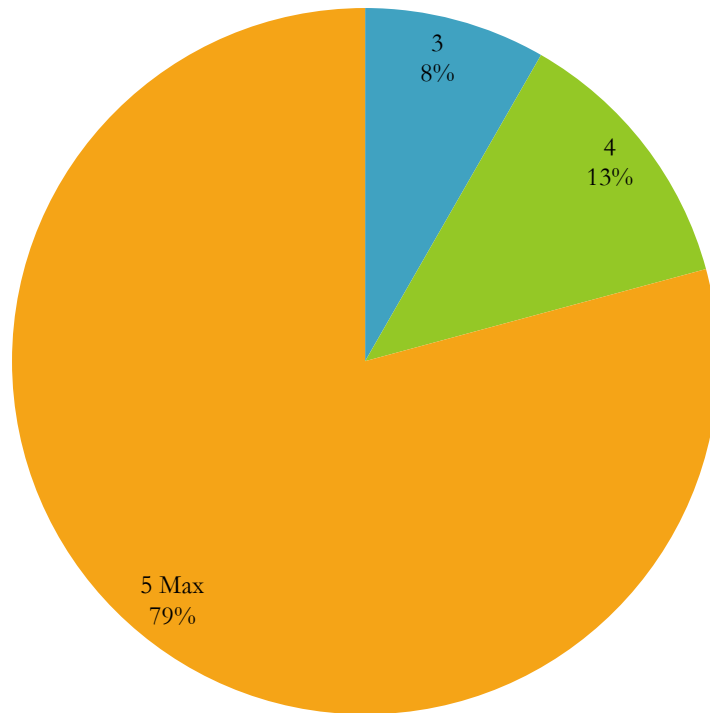
| Value | Percent | Count |
|-------|---------|-------|
| 3 | 12.5% | 3 |
| 4 | 37.5% | 9 |
| 5 Max | 50.0% | 12 |
| | Total | 24 |

Annexes 3 – Questionnaires Report (questionnaire 2)

Charts of the question 21

Público em Geral: e.g. turistas /

Main Public: e.g. tourists



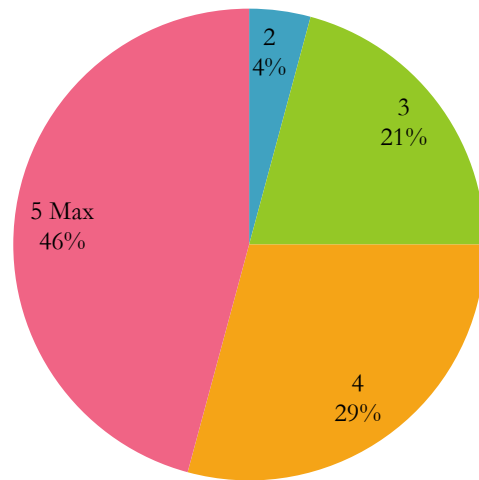
| Value | Percent | Count |
|-------|---------|-------|
| 3 | 8.3% | 2 |
| 4 | 12.5% | 3 |
| 5 Max | 79.2% | 19 |
| | Total | 24 |

Charts of the question 22

Classifique a App tendo em consideração do Impacto nos diversos Domínios (e.g. técnico-científico, socioeconómico, político-administrativo, simbólico) **22. Classify the App taking into consideration the Impact on various Domains (e.g. technical-scientific, socio-economic, political-administrative and symbolic)**

Político-Administrativo /

Political-Administrative

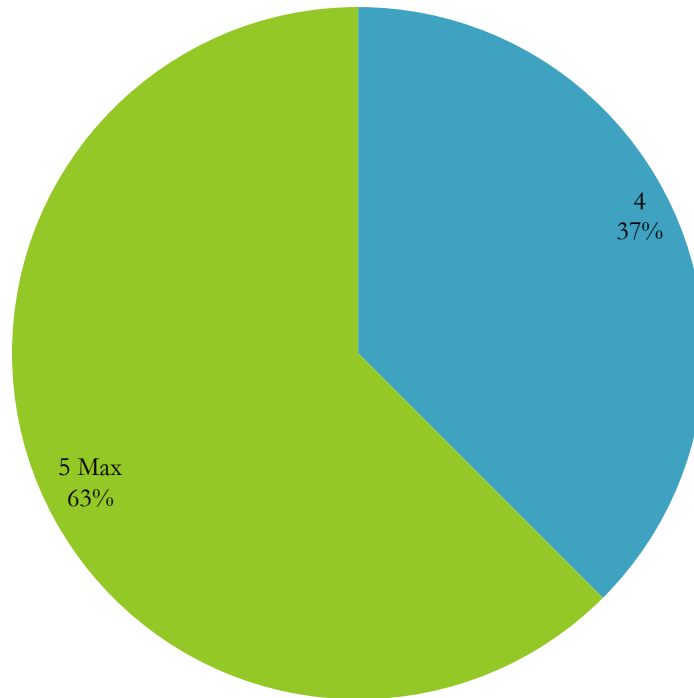


| Value | Percent | Count |
|-------|---------|-------|
| 2 | 4.2% | 1 |
| 3 | 20.8% | 5 |
| 4 | 29.2% | 7 |
| 5 Max | 45.8% | 11 |
| | Total | 24 |

Charts of the question 22

Técnico-científico /

Technical-Scientific

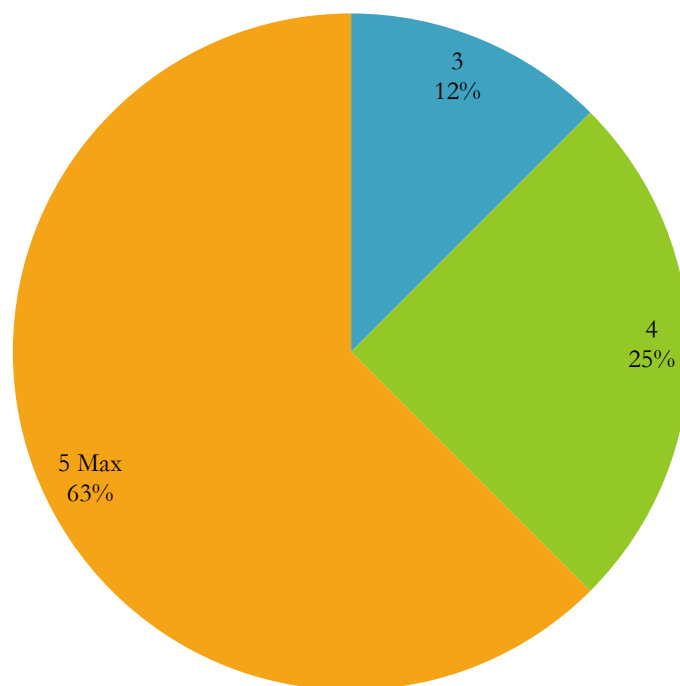


| Value | Percent | Count |
|-------|---------|-------|
| 4 | 37.5% | 9 |
| 5 Max | 62.5% | 15 |
| | Total | 24 |

Charts of the question 22

Socioeconomic /

Socio-Economic



| Value | Percent | Count |
|-------|---------|-------|
| 3 | 12.5% | 3 |
| 4 | 25.0% | 6 |
| 5 Max | 62.5% | 15 |
| | Total | 24 |

Use the URL: <http://www.luisfilipemarques.com/site/doctor/>

Official Lisbon Plan

- Download and install the prototype APP Lx_W: AqueductAR and AqueductGPS (Android OS. Enable Unknown sources);
- Visualize the Lisbon Aqueduct information pointing the camera of the smartphone to the Lisbon Plan.

Anaglyph 3D glasses

- Visualize videos and images in 3D.

Anaglyph Glasses box

Official Lisbon Plan box

