From the point cloud to virtual and augmented reality: digital accessibility for disabled people in San Martin's Church (Segovia) and its surroundings

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Abstract. This article explains the working methodology followed to carry out a project in which the 3D laser scanner survey of San Martin's Church (placed in Plaza Juan Bravo, in the historic city centre of Segovia Spain), has been undertaken. There is also a virtual tour through the nearby streets, which lead us to the Jewry Museum, going through the Paseo del Salón. The final aim is to obtain derivative CAD products such as technical plans, solid models and different videos, as well as a simplified 3D model. This project has been funded by the MICINN (Ministerio de Ciencia e Innovación [Department of Science and Innovation]), within the project ADISPA, BIA2009-14254-C02-01, and will constitute a mathematical base of a scenario of augmented reality which will make accessibility for disabled people possible. This will be framed within the "PATRAC" project (PATRIMONIO ACCESIBLE: I+D+I para una cultura sin barreras [ACCESSIBLE HERITAGE: R+D+I for a culture without barriers]).

Keywords: Laser scanner, CAD (Computer Aided Design), accessibility, augmented reality.

1 Introduction

The 3D information obtained through laser scanner has spread quickly in the last decade because it is a non-destructive remote sensing technique which allows a massive and quick capture of millions of points. Its implementation in the field of Architectural and Archeological Heritage is already a reality. However, even though we can obtain a lot of data with great accuracy thanks to this technology, the success of its exploitation and spreading are subject to a quality simplification of the data, which will lead to the handiness and use by other tools and platforms. Accordingly, one of our aims is to build a precise 3D mathematical model by means of the terrestrial laser scanner (TLS) in order to obtain a number of cartographic and technical results in CAD format. All of this will be the basis for the development of a platform of virtual and augmented reality, geared towards giving easier access to disabled people.

This article will deal with the following sections: after the introduction, the 2nd section will cover a brief summary on the current state of art concerning this kind of applications and also the working goals. In the 3rd section we'll focus on the study we have developed by describing a methodology articulated in three stages: data gathering, data processing, and obtaining the 3D model and the technical-cartographical results. The 4th section will explain in detail the conversion process to augmented and virtual reality. Last but not least, on the 5th section we'll set out the conclusion and future implementations in users with reduced mobility.

2 State of the Art

The TLS (Terrestrial Laser Scanner) has been extending its use in lots of applications as its technology has been progressively improved. Most of the applications take place in fields such as mining, industry, archaeology, architecture, cultural heritage, engineering or mechanics [1]. Despite the fact that computer's performance has been greatly developed, the digital reconstruction of big areas -which means a considerable load of manual labor- and the processing of large amount of data is really tedious [2]. Nowadays the so-called dynamic TLS is used for capturing data of big scenes like streets or façades on a large scale in a semi-automatic way [3,4]. 3D laser models have been used in other projects as mathematic basis of scenes that have been applied to virtual and augmented reality [5]. In order to use them in models of Augmented and Virtual Reality (AR/VR), it is necessary to carry out a reduction. The MoBiVAP group has developed a strategy that consists of the automatic extraction of dominant planes from regions of the triangle mesh that share a common normal vector.

2.1 Aims

The main aims of this project are the following:

- To create 2D technical drawings (ground plans, elevations, sections), orthophotos and 3D CAD solid and photorealistic models out of the integration of laser scanner and digital cameras.
- To develop a platform based on augmented and virtual reality underpinned on the cartographic products that have been obtained, which might lead to an improvement in the accessibility for disabled people.

3 From the Point Cloud to Augmented and Virtual Reality: Working Methodology.

3.1 Working Area

This project is focused on the historic city centre of Segovia. Specifically on Saint Martin's Church (see Fig. 1) and its square (purple area), Juan Bravo street (green area), the Old Jewry Museum (red area), Puerta de la Luna street, Salón Avenue and Puerta del Sol street (blue area).

Fig. 1. Working area. Aerial view of the historic city centre of Segovia.

Saint Martin's Church is located within the current Juan Bravo square, in the Spanish city of Segovia, which has been declared World Heritage. This temple dates back to the 12th century and has Mozarabic origins and Romanesque style.

The Jewish Quarter Education Centre, former home of Abraham Señero, is a place devoted to everyday life in the Jewish Quarters of Segovia. Also, the Salón avenue is one of the most ancient city gardens, created in 1786.

3.2. Equipment

For the development of this project we have used a laser scanner Faro Photon which uses the phase-shift principle for ranging, and collects data within a field of view of 360º in horizontal by 320º in vertical. It sports a near-infrared laser beam with a wavelength of 785 nm, with a measurement rate of 120.000 points per second and a scope that ranges from 0.6m to 70m. Furthermore, it offers the possibility of color scanning by having a high resolution camera (Nikon D200) mounted on top. We have used together with the laser scanning device a photographic hardware for taking panoramic images consisting on a digital slr camera (Nikon D80) with a fish-eye lens and a panoramic tripod head that allows the shooting of panoramic images in a semi-automatic way.

3.2. Planning and Data Capturing of the Laser Model

The great scene and the great number of people who walk along this area has made it difficult to plan the data capturing. The impossibility to scan the roofs and upper facings of the church has been a critical factor because of the geometric complexity of its surroundings. This problem has been solved by scanning from higher points. It has also been decided to tackle the scanning on a variable resolution: ¼ of the maximum (6,3 mm to 10m) for Saint Martin's Church and the Jewry Museum, and 1/5 (7,8mm to 10m) for the streets and the church surroundings. Likewise, in the 1/4 setting captures we put up control points consisting on spherical targets, so that they would allow an automated registering and alignment. In the 1/5 scans, this strategy is not used anymore. The elements belonging to the street furniture are used as ground control points for geo-referencing.

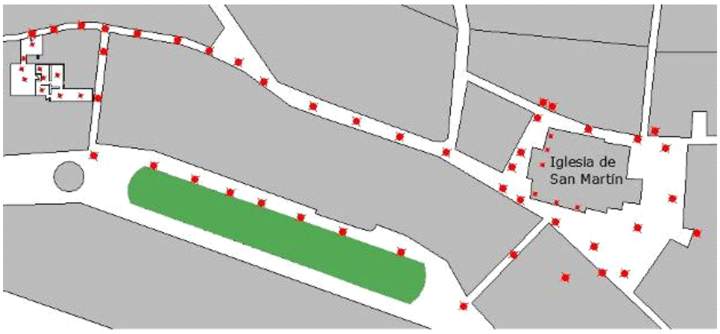

Fig. 2. Location of the scanner stations (red points).

Every laser capture was made with full FOV (360ºH x 320ºV) enabled and high resolution color shots taken from every scanner station.

There is also the capturing of spherical images. For this purpose we use a Nikon D80 with a fish-eye lens mounted and a panoramic tripod head, which allows any rotation of the camera about the so-called nodal point. Data capture have taken place along the streets of the historic city centre of Segovia and also the inside of the Jewry Museum, located on the Judería Vieja street. (Table 1).

Table 1. Technical features of the photographic equipment used in the laser and the panoramic.

NIKON D200 - D80	
Sensor type	CCD (DX format)
Sensor resolution	10 MP
Image size	3872 x 2592
Sensor size	23.6 x 15.8 mm
NIKKOR Fisheye	
Focal	10.5 mm
Viewing angle	175º

The next table (Table 2) displays a summary of the data captured in fieldwork

Table 2. TLS work and Camera stations

TLS	
Nº laser stations	84
Point density	6,3-7,8 mm to 10m
Reference System	Local (level)
Overlap	40-60%
Nº points captured	$2500*10^6$
Nº points optimized model	$85*10^6$
Nº hours Laser	24 h
CAMERAS	
Nº camera laser stations	84
Nº photographs camera laser	756
Nº estac. fisheye	36
Nº photographs fisheye	252
Nº hours fisheye + camera laser	4 h + 9 h = 13 h

3.3. Laser data processing

The processing of laser data needs a good organization as to make the refinement, registration, geo-referencing and filtering works of the point cloud much easier. These are essential steps to obtain a precise and good-quality metric product. One of the main issues with regard to the processing of laser data is that scanners capture a huge amount of points, which required a process of optimization, refinement and filtering. This basic data preprocessing allows the removal of those points which are not important to describe the scene or the object. The presence of “noise” caused by different sources and unnecessary data makes it necessary to use filtering and segmentation tools [6]. All the objects or people that have interposed between the scanner and the object of interest have caused some negligible points which should be removed. Furthermore, the areas that are not relevant for the project are also to be removed. For this purpose a manual refinement and segmentation is carried out, as well as a filtering to improve the point clouds.

We obtain the scene or object to be recorded in a common reference system by aligning all the point clouds to each other. We set a local or global reference system by defining an origin and a direction of the axes X, Y, Z. It is necessary that two adjacent point clouds had an overlap of more than 10% to get a good alignment result (clouds fusion) in order not to have problems or inability to align captures. The alignment of different point clouds has been carried out in two ways: (i) automatically, by using artificial marks (spheres) which are automatically recognized by the scanner’s software; (ii) manually, by selecting matching-points in corresponding features identified by user within the overlap regions of two scans. In both cases the mathematical solution of that alignment will consist on the calculation of a transformation matrix for each cloud, which is made up of three shifts and three rotations without scale change. The alignment phase has followed a hierarchic structure supported on three levels and three basic scenes: the church, the museum and the surroundings, which in turn have been divided in accordance to the number of façades (church), rooms (museum) and streets (surroundings). That means that when we define several grouping levels, the rotation matrices start to link together, as shown in Table 3 and Fig. 3.

Table 3. Established hierarchic structure for the alignment of every laser capture.

<table>
<tr><th>Level 1</th><th>Level 2</th><th>Level 3</th></tr>
<tr><td>Cloister</td><td rowspan="5">Church</td><td rowspan="11">Church
+
Street
+
Museum</td></tr>
<tr><td>Northern Façade</td></tr>
<tr><td>Eastern Façade</td></tr>
<tr><td>Southern Façade</td></tr>
<tr><td>Western Façade</td></tr>
<tr><td>-</td><td>Calle Juan Bravo</td></tr>
<tr><td>-</td><td>Paseo del Salón</td></tr>
<tr><td>-</td><td>Calle de la Judería</td></tr>
<tr><td>-</td><td>Calle Puerta del Sol</td></tr>
<tr><td>Outer Museum</td><td rowspan="2">Museum</td></tr>
<tr><td>Inner Museum</td></tr>
</table>

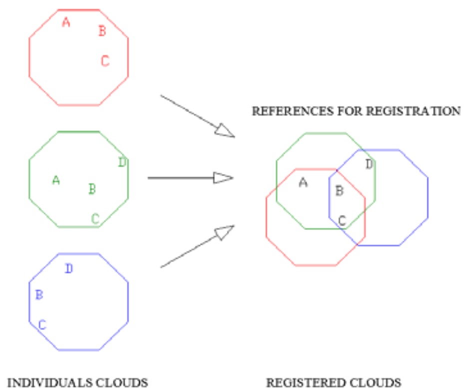

Fig. 3. Alignment diagram at different levels.

The register of the point clouds and the high-resolution images come automatically as we have the camera’s calibration parameters. Moreover, any movement between the centers of both sensors is resolved by capturing the images from the same point of view as in the actual scanning. The result can be seen in Fig. 4.

Fig. 4. Picture (left) and 3D image (right) of a colored point cloud.

Finally, we wrap a mesh on the point cloud and we create this way a surface model. The creation of meshes made out of triangles allows us to achieve a photorealistic model (Fig 5).

Fig. 5. Example of the creation of a mesh in an arcade of the church.

3.4. Photographic Data Processing: Panoramic Images

The processing of this kind of images has the following steps:

1. Establishing the connection among adjacent images. It is essential for this purpose that images overlap each other so that one can identify and connect pair-wise tie points on overlapping areas.
2. Once we have established a common geometric framework for all the images, we proceed to project the pixels of all of the images onto a unique geometric surface: typically a sphere.
3. If we want to store these panoramic images in the usual image format (as a rectangular matrix) we should be aware of the fact that a sphere can't be developed. It is necessary therefore to use a projection model that allowed "flattening" the sphere onto a planar image. The most suitable one would be the equirectangular projection.
4. The final step consists on displaying the spherical view. The panoramic image viewers allow users to watch the sphere without breaks. The viewer has built-in algorithms that allow to render a rectangular sector of the spherical panorama on a

window without distortion. By means of mouse actions the user is allowed to zoom in and out and also pan and tilt the viewing angle to explore the whole image from the center of the sphere.

3.5. Creation of CAD Products

Once the poin clouds have been aligned and coloured, and using them at their highest resolution, we have proceeded to the creation of technical cartographic products both in 2D and 3D, which will make up the base for the development of the augmented and virtual reality platform. (Fig. 6).

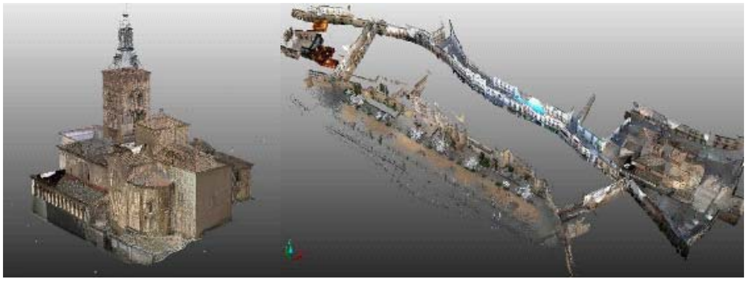

Fig. 6. 3D aligned and colored models: Saint Martin's Church (left) and surroundings of the city centre and the museum (right).example of the creation of a mesh in an arcade of the church example of the creation of a mesh in an arcade of the church.

We have also created a system of spatial information (Fig. 7) based on the capture of panoramic images, that allows users an interactive computing wherever their Internet connection is. At the same time this represents a scalable tool which might be useful to carry out management and cataloguing tasks applied to Segovia's historical city centre.

Fig. 7. Spatial Information System supported in panoramic images.

We obtain different technical planes (elevations, sections) from the laser data model that has been created, as well as orthophotos and CAD models out of the different elements. The following figures illustrate the process (Fig. 8) and the results

(Fig. 9-13). The technical planes are obtained through the manual vectorization onto the orthoimages.

DEFINITION OF A NEW REFERENCE SYSTEM

CREATION OF THE ORTHOIMAGES

VECTORIZATION OF THE ORTHOIMAGES

DRAFTING OF VECTOR 2D-DRAWINGS

Fig. 8. Diagram of the creation of technical CAD planes.

Fig. 9. Orthoimages of Saint Martin’s Church façades.

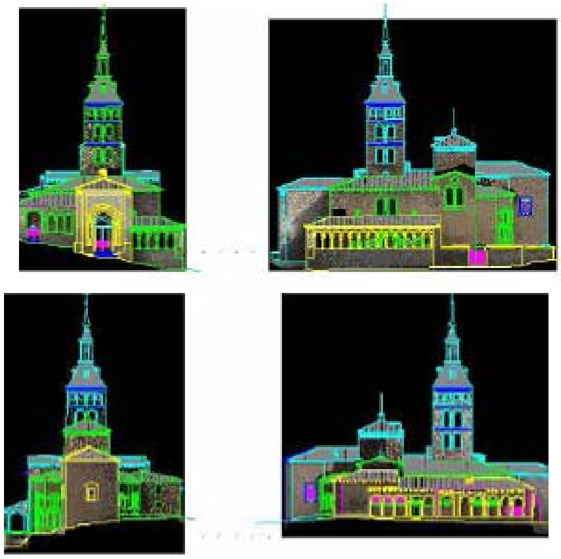

Fig. 10. Vectorization onto geo-referenced orthoimage.

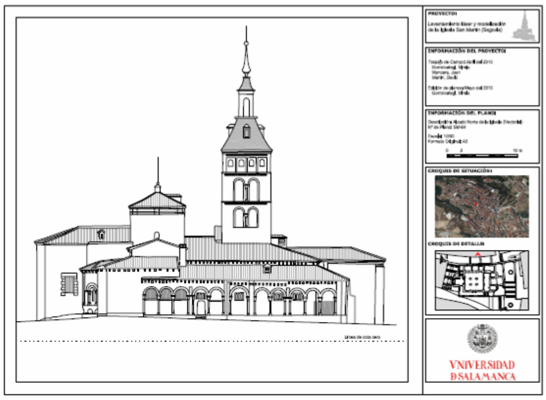

Fig. 11. Technical plane to scale of 1/200 of the northern elevation of Saint Martin's Church.

To create the roof plan it is important to define the eaves line, as well as the slope of the different fields that compose the building's roof. For this purpose, in the same way as done with the elevations, we have used an orthoimage to create this plane by direct drawing onto it (Fig. 12).

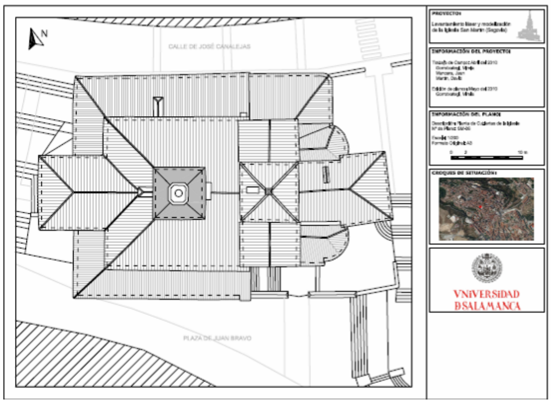

Fig. 12. Technical plane on a scale of 1/200 of Saint Martin Church's roof.

Finally, the creation of 3D sound models has consisted on the extraction of basic geometries and primitives. We have extracted in a semiautomatic way planes, cylinders, spheres, etc., in those parts of the scenes where geometry was simple enough, as in flat façades or streets. In those cases where we could not model geometry through this type of geometries (concave and convex shapes) we have proceed to mesh and further edition. (Fig. 13).

Fig. 13. Solid model of Saint Martin's Church.

4. Development and Implementation of the Augmented and Virtual Reality Platform

This section will explain in detail the conversion to augmented and virtual reality models.

4.1. 3D Modelling

The information processing and analysis phases place 3D modelling in the foreground. Due to the great volume of data that TLS technology provides, it is necessary to have information in different resolutions and to provide contextual content to the user (according to their needs and position). We use the following two methods to obtain 3D realistic models:

Analytic creation of 3D models: there's a need for tools which allow the creation of low resolution models to reduce the information provided by laser devices. The drastic reduction of 3D data in order to get simplified models is carried out by detecting the ruling planes of the façades, roofs and the building's floors (Figure 14) from the grouping of connecting triangles that have a near common normal vector. At a low level we can obtain 3 kinds of ruling planes corresponding to the floor, façades and roofs. The intersection of "adjacent" ruling planes provides edges which allow the clipping of the same planes and thus to obtain a low-level approach to the façade boundaries and sharp lines. This simplified representation takes up a few dozens of KB for small urban areas of streets, squares or blocks segments. This way it is possible to provide AR/VR services suitable for mobile devices. There are also mid-level models or models which affect bigger urban areas that will require the use of portable computers in order to supply in situ services. In our case, we have chosen the approach based on discrete information to make use of the metrical accuracy provided by LS technology to create realistic models. The detection of 3D primitives from information of dense point clouds follows a similar strategy as in 2D: filtering, local analysis and grouping, where critical parameters are linearity and closeness in direction vector.

One of the tools that we have developed allows us to process dense point clouds to extract in a semiautomatic way the ruling plane: flat polygons labeled as façades, floors and roofs conforming a polytope that simplifies the representation of the point cloud. This polytope will afterwards allow the creation of the volumetric segmentation of the urban model, i.e., the breakdown of the 3D scene on a finite union of solid surfaces with an uneven boundary. We take advantage of the great metric accuracy that provides the scanning device to create realistic representations of the urban model.

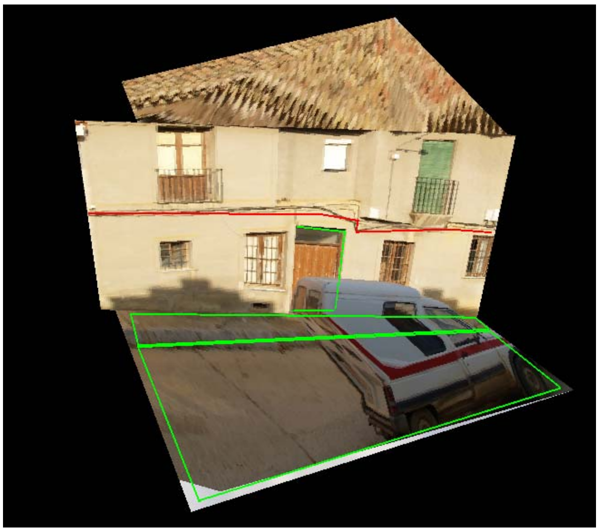

Fig. 14. Simplified model by means of synthetic modeling.

Synthetic creation of 3D models: we need to have a detailed standard model to represent not only the model's geometry but also relevant architectural details for the documentation. This models are created by means of CAD modeling tools (Blender, Maya, 3D Studio, Google Sketchup,…). As shown in Fig. 15.

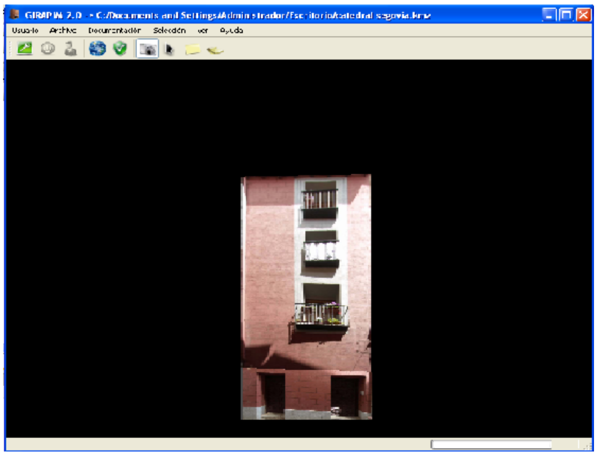

Fig. 15. Virtual reality engine with a 3D model synthetically created.

4.2. Interactive Displaying, the Closeness to Virtual Reality

Interactive displaying is one of the mainstays of virtual reality, the interaction of the user with the virtual environment must be complete. A graphic application based on the OpenGL render technology has been developed. This application displays the superposition of different information layers related to geometry and semantics. At the same time, this element is responsible for the compilation and selection of scene objects by means of mouse inputs, which will provide interactivity allowing a virtual tour of the recorded site.

4.3. A Three-Dimensional Geographic Information System

The 3D information management of urban settings is an important issue nowadays. The traditional 2D geographic information systems are a challenge that has been overcome. A new information system to support virtual representation of 3D models and to document heritage settings has been developed.

GIRAPIM (Gestión de Información Relacionada con el Análisis Previo de las Intervenciones en Monumentos [Information management related to the analysis previous to intervention in monuments]) provides a framework for the documentation of accessibility problems and the management of small extension urban environments. Furthermore, our virtual GIS (Geographic Information System) allows us to solve several problems which are related to the linkage of semantic information to the model's geometry at a different levels of detail. It is a tool that allows us to add, store, manage, administer, analyze, access, show and edit data in 3D representations of heritage sites with accessibility problems. Its interface is shown in Fig. 15 and Fig. 16.

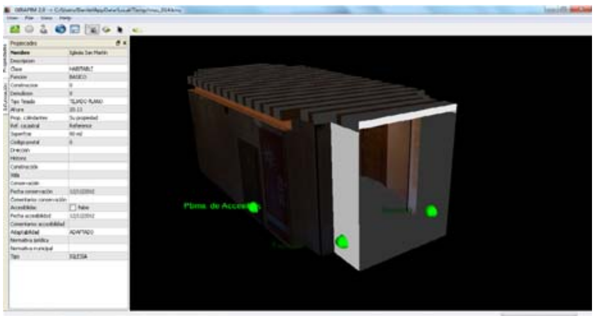

Fig. 16. 3D information system for the representation and documentation of virtual environments.

4.4. Virtual Reality. A Gateway to Reality

On top of the information system described, we find the Virtual Reality application made for the recorded environments. There are 3D models of these environments at different resolutions that share the same basic geometry both on the GIRAPIM application and the Virtual Reality one.

In our VR application the user is conceived as an invisible avatar on a 3D interactive setting. We set out the user as a virtual being, whose point of view is handled by 4 degrees of freedom; mouse and keyboard inputs enable interaction with point of view and point of aiming. The analysis, design and implementation philosophy that has been used to create the virtual reality tool has its basis on a 3D videogame engine (OGRE 3D engine).

4.5. Services Supply a Direct Approach of Augmented Reality.

The *in situ* services supply linked to VR/AR is carried out depending on the location as a web service. The location requires the monitoring of the setting, which can be global (GPS), urban (Bluetooth antennas network in Segovia) or local (RFID). The design and implementation as a web service means that the services supply associated to multimedia contents doesn't depend on particular devices or operating systems but on a web browser and an Internet connection. The multimedia contents provided as a web service associated to the setting can be customized according to the user's preferences. These contents can have different format and type such as text, audio, image, video, 3D or Virtual Reality/Augmented Reality contents. It is possible to add tags which store additional contents related to the points of interest, that will allow the user to display a representation of temporal (past and future) or added aspects to the object selected on the screen and which are also related to the aforesaid object.

5. Conclusions

The model that has been developed allows, apart from the usual geometric and radiometric aspects, to incorporate different multimedia contents that can be displayed according to the user input or the location. Those contents may refer to both real objects of virtual ones. The display has been designed and implemented as a customizable web service. This design has a universal nature (platform independent). The interaction can be carried out locally (in monitored environment) or remotely (through the appropriate desktop applications). The display uses different graphic resources, like Google Sketch-Up for the design and is compatible with the use of varying Level of Detail according to on the bandwidth available on the devices used for the navigation and information enquiry and update. This project is intended to make the access easier, in a remote and virtual way, to those spots in Segovia to which disabled people haven't an easy access due to the complicated architecture.

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