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A 3D GIS for Mapping the Via Appia: an explorative survey

The use of three-dimensional geographical information systems (3D GIS) in archaeology is not yet widespread or well documented. Indeed, 3D GIS in general is still very much in development, challenging the Mapping the Via Appia project to be progressive and innovative. This paper is about the development of a methodological framework for the creation of a 3D GIS for this archaeological project. The Spatial Information Laboratory (SPINlab) of the VU University Amsterdam is at the centre of these activities, taking on an active role in bringing together different parties and disciplines involved in the technological development of 3D GIS, and in transferring the best of their techniques to the archaeological purpose.

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Mapping the Via Appia and 3D GIS

The Mapping the Via Appia project is an NWO-supported archaeological project by the Radboud University Nijmegen, VU University Amsterdam, and the Royal Netherlands Institute in Rome (KNIR). At the invitation of the Soprintendenza Speciale per i Beni Archeologici di Roma, the archaeological service of Rome, the project investigates the fifth and sixth miles of the Via Appia and her hinterland.

The Via Appia, whose construction started in 312 BC, ran south-eastwards from Rome to the newly conquered lands of Campania, and was extended over the years all the way to Brundisium in the south of Italy. For centuries, the road, which was nicknamed regina viarum – the queen of roads – already in antiquity, was of great strategic and economic importance for Rome. As a consequence of the Roman custom of cremation and burial outside the city walls, the first miles of the Via Appia developed into a boastful necropolis. Through the centuries, the adjacent suburban area gained a wide range of activities and facilities – from industrial to religious to residential – as indicated by sanctuaries, workshops, stopping places, luxurious villas, and bathhouses. During the Middle Ages, the road decayed, and the many functions of the hinterland disappeared. Whereas some monumental tombs along the Via Appia were put to a new use, for instance as fortress or farmstead, most got stripped of their valuable stone facings and were left behind as ruins. From the 18th century onwards, official excavations and restorations – most notably those by architect and archaeologist Luigi Canina in the 1850s, who restored and re-arranged many of the archaeological remains and introduced the now iconic cypresses and pines that flank the road – transformed the first eleven miles of the Via Appia into the romantic picture that is nowadays being preserved by the Parco Regionale dell’Appia Antica.

The Mapping the Via Appia project aims for a thorough inventory and analysis of the Roman interventions in this suburban landscape. The investigation focuses on a section of two kilometres that covers parts of the fifth and sixth miles of the Via Appia. In order to gain insight into the spatial development and impact in different periods of the Via Appia itself, the surrounding monuments, and the outlying areas, the project consists of several research components: architectural survey (inventory of aboveground archaeological objects), geophysical prospection and remote sensing, excavation, field survey, and study of archival sources.

This multitude of research components produces a variety of data types, which leads to the challenge of data integration for efficient data analysis and querying. The use of a geographic information system (GIS) linked to a relational database enables the researchers to perform spatial analyses of this complex and vast dataset, which covers thousands of archaeological objects in a large and – due to its elongated shape – unusual research area. A standard GIS, however, links data to a two-dimensional representation of the research area. This is sufficient for the two-dimensional data from the field surveys and remote sensing, but the data from the architectural survey, the excavations, and also the study of archival sources (pictures, drawings, prints, et cetera) strongly involve the third dimension. The architectural survey specifically deals with upstanding archaeological remains and thus records data with explicit regard to the vertical dimension. When linked to flat, two-dimensional representations of these features, these vertical data are in fact rendered irrelevant. In order to fully exploit all collected data for thorough, efficient and insightful analysis and visualisation, we have to move towards a three-dimensional GIS.

Our aim is to be able to group archaeological objects according to type of material, decorative style, dating, dimensions, et cetera; either through queries or by creating three-dimensional thematic maps. The objects involved in an analysis can be studied, measured and visually scrutinised directly from behind the computer. This three-dimensional
analytical tool will form the essential basis for the process of producing archaeological reconstructions of this section of the road and its monuments. The idea is that the resulting archaeological reconstructions will be imported into the same 3D GIS environment, enriching these 3D models with attribute data concerning the process of interpretation, sources, and analogies. This way, the 3D GIS not only allows for thorough, efficient and insightful analysis, but also for visualisation of the overall picture of this tract of the Via Appia and its development through different stages of the past.

The exploratory survey that is reported on in this paper focusses on existing methods and techniques that could be used for the realisation of the three essential steps towards the intended 3D GIS (figure 1). First, we have to capture the landscape and the archaeological objects in their current state in virtual 3D models (section ‘From physical reality to virtual 3D’). Then, the actual 3D GIS must be created by positioning those models in a 3D platform that can handle GIS functionalities (section ‘From 3D captures to 3D GIS’). Based on the captures and data that are in the 3D GIS, archaeological 3D reconstructions of the monuments can be produced and integrated into the 3D GIS environment (section ‘From 3D GIS to 3D archaeological reconstruction and back’).

**From physical reality to virtual 3D**

For the creation of a three-dimensional model of the Via Appia and its adjacent ruins, there are several continuously developing techniques of reality-based modelling. Since the archaeological objects need to be more detailed – and thus in a higher resolution – than the terrain and the road itself, we can combine two methods of reality-based modelling: *range-based modelling* for the terrain and *image-based modelling* for the archaeological objects. Range-based modelling, which uses active optical sensors, is better known as laser scanning. In order to capture the terrain of our research area, we have teamed up with Fugro, who applied their DRIVE-MAP service to the Via Appia in March.
of 2013 (figure 2). This range-based modelling method is ideal for our purpose, since the terrain of our research area consists of an elongated strip of land: two kilometres of the Via Appia with an approximately ten metres wide verge on each side of the road. The DRIVE-MAP car is equipped with 360° panorama photo cameras, four high resolution metric photo cameras, and a Riegl laser scanner. This setup delivers a dense, accurate and scaled coloured point cloud, which can be overlaid with 360° panorama photos. The point cloud covers everything that can be seen at any moment from the roof of a car driving down the Via Appia. As a consequence, it lacks the rear sides of the monuments. The combination of the car’s GPS equipment and data from Italy’s permanent GPS stations make sure that this point cloud data is entirely georeferenced.

To make up for the missing rear sides of the ruins, the DRIVE-MAP terrain model can be complemented with more detailed 3D captures of the archaeological objects using image-based modelling. This type of reality-based modelling, which uses passive optical sensors, is regularly referred to in many different ways: concepts like multi-view stereo, computer vision, dense stereo matching, 3D photogrammetry, and structure from motion often come down to similar methods of image-based modelling. This way of 3D modelling is based on the same principle as the human stereo vision. Our brain extracts depth information from the parallax that is caused by the slightly different positions of the two eyes. Image-based modelling software uses mathematical formulations to do the same trick. At least three photographs of the same object – each from a slightly different point of view – are needed for such software to reconstruct the camera positions and orientations, to detect common points in each stereo pair of images, and ultimately to derive depth information for each common pixel. If provided with enough and adequate images taken from all around the object, this results in a dense point cloud and subsequently in a 3D model of the object.
The great advantage of image-based modelling is the low-cost and user friendly hardware. A digital photo camera of at least five megapixels is all you need. There is a lot of choice when it comes to image-based modelling software. Costly commercial options are PhotoModeler and PhotoModeler Scanner, but there are a lot of free alternatives. Some top applications are Microsoft Photosynth, ARC 3D, VisualSFM, and 123D Catch. We have concluded that 123D Catch—a free tool by Autodesk—is the most suitable option for our project. Compared to the other software packages, the results of which need substantial post-processing, 123D Catch instantly delivers good-looking textured meshes in high resolution and good detail. Photographs of the object need to be uploaded to the servers of Autodesk 123D Catch. All modelling is done in the cloud, and the resulting 3D model is delivered by e-mail. This simple workflow makes 123D Catch easy to use and suitable for a project with many participating archaeology students with varying levels of computer skills. If necessary, cleaning and post-editing of the 3D captures can be done in MeshLab and CloudCompare, which are both open source.

**From 3D captures to 3D GIS**

The greatest challenge in the Mapping the Via Appia 3D GIS subproject is to find a way to assign attribute data to segments of the detailed 3D models created in the previous step. Examples of existing GIS packages that support 3D visualisation are OSGeo GRASS, Bentley Map V8i, AutoCAD Map 3D, and ArcScene, which is part of the most widely used GIS package ESRI ArcGIS.

At the moment, the functionalities of these GIS packages are limited with respect to our aims and thus not suitable for the purposes of our 3D GIS project. The huge amount of 3D data that has to be imported and the desired level of detail are some of the present obstacles. Theoretically though, it should be possible to do the job on a small scale using ESRI’s GIS and 3D modelling software through a specific workflow and workarounds. Point cloud data, like that from Fugro’s DRIVE-MAP, can be imported into ArcScene and be used as a base map. The detailed 3D captures of the archaeological objects created with 123D Catch can only be imported into ArcScene via ESRI CityEngine, due to file format incompatibility. In ArcScene, the three-dimensional GIS features can be assigned attribute data and they can be linked to a relational database. After that, analysis can be performed through queries and thematic maps.

**From 3D GIS to 3D archaeological reconstruction and back**

Ideally, the analyses and visualisations of the 3D GIS will help producing archaeological reconstructions of the monuments that flank the Via Appia. For the creation of 3D models of these archaeological reconstructions (which can be placed in the 3D GIS environment at a later stage to add a fourth dimension: time) we can make use of manual and procedural 3D modelling methods.

For manual modelling there is a wide variety of choice when it comes to software packages. Well-known are the expensive commercial programs 3Ds Max and Maya, and the open source Blender. From personal experiences, however, the right option for our project seems to be the free Trimble SketchUp, which is, compared to the extensiveness and complexity of programs like Blender and 3Ds Max, very user friendly and easy to use.

Procedural modelling is the generation of large 3D scenes, such as cities, consisting of numerous—but unique—3D models from sets of CGA (Computer Generated Architecture) shape grammar rules. Instead of “building” a virtual 3D model by hand,
a set of rules is written. According to these rules, the software can generate a vast multitude of unique 3D models, which all comply with the predefined rules. ESRI CityEngine is in fact the only procedural modelling program on the market.\textsuperscript{25}

Manually reconstructing those monuments along the Via Appia of which a ruin is still present in the current situation will give satisfactory results in the individual cases, but the overall picture of the reconstructed section of the Via Appia will not be complete. Since there is the hypothesis that there were many more monuments than only those of which the ruins can be seen today, a lot of gaps will have to be filled in. In this case, procedural modelling is the ideal solution.

The workflow that can be established using all of the tools mentioned above is schematically illustrated in figure 3. Making use of several file formats for import and export, the different software packages and their multitude of functionalities are fully interoperable.

**Future prospects**

This explorative survey for 3D GIS methodologies has shown that the first and last of the three essential steps in creating a 3D GIS are well-covered by tools that are already available: Fugro DRIVE-MAP, 123D Catch, Meshlab, and CloudCompare for capturing the landscape and the archaeological objects in virtual 3D models and point clouds, and SketchUp and CityEngine for producing archaeological reconstructions.

The next phase of the Mapping the Via Appia 3D GIS subproject will focus on tackling the obstacles that appear in the second step. How to identify and define both individual objects and segments of those objects within the 3D environment? How to enrich these objects and segments with attribute data? And finally, how to cope with huge amounts of highly detailed and complex data? In 2014, we will be collaborating with the Netherlands eScience Center with the aim to develop a set of generic 3D GIS tools that overcomes these problems, and that will take the development and use of 3D GIS in archaeology and other disciplines to the next level.
Endnotes

1 http://www.feweb.vu.nl/gis/research/?ResearchID=267&MenuStat=15
   (All websites referred to in this article were accessed on 7 November 2013).
2 www.facebook.com/MappingTheViaAppia.
3 Status, Silv. 2.2.
4 In the cases of the tomb of Caecilia Metella and the so-called Casal Rotondo respectively.
5 The following sections on range-based modelling and image-based modelling are based on
   Remondino & El-Hakim 2006; Manferdini & Remondino 2010, 112-114; Remondino 2011;
   Limoncelli 2012, 131-139
6 Fugro is a Dutch multinational company that provides geological, geotechnical and
   geoenvironmental investigation services (http://www.fugro.com/).
7 http://www.drive-map.eu/.
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