A New Approach from 3D Modelling and Scanning of Archaeological Data to RealTime Online Exploration

Bruno Fanini
CNR ITABC, VHLab, Italy. *bruno.fanini@gmail.com*

Daniele Ferdani
CNR ITABC, VHLab, Italy. *daniele.ferdani@gmail.com*

Abstract:

This paper will deal with a new approach for the reconstruction of archaeological urban contexts and its implementation on the web. Starting from archaeological information, geospatial and topographic data, we adopted a successful workflow from data generation to online real-time visualization and interactive content exploration. The process involves semi-automatic steps to provide a multidisciplinary team with a set of tools aimed at the final publication of massive landscape reconstructions and simulated environments. Optimized data and a well-structured 3D world have the primary goal of web accessibility and a fulfilling user experience through the exploration of such large datasets, especially in a context of virtual archaeology. Our main aim is to recreate entire ancient urban contexts and landscapes and make them accessible via the web. To achieve this goal, we successfully used a procedural approach, with the software CityEngine, for low poly modelling of a huge number of buildings. In fact, this method is specifically designed to create complex urban environments. It is based on L-systems to model cities which allow the user to completely control all entities in the hierarchy of the scene. In this way we can easily change the appearances and the typologies of the building by introducing some modifications in the scripts to easily simulate the distribution and randomness of the elements.

With real-time applications, dealing with large reconstructed cities and virtual landscapes is always a challenge. The rendering of large numbers of buildings, architectural elements and objects can be addressed with level-of-detail techniques, scene-graph algorithms and spatial partitioning of the virtual world. This allows a scalable approach in different scenarios with paging support for huge databases, locally or remotely located. The solid hierarchical structure generated from modules developed on top of an opensource OpenSceneGraph framework, allows for a clean and efficient load balance among the virtual world data. This has the effect of maintaining a light footprint on client system resources and 3D rendering applications, especially in dealing with the goal of web transfer minimization through a 3D-enabled browser.

We adopted this approach in a project of reconstruction and enhancement of archaeological sites of Montegrotto City entitled: "Il termalismo in età romana tra conoscenza e valorizzazione" coordinated by University of Padova. Initial data, method and software used, will be shown in the paper.

Key Words: *Scanning, 3D Modelling, Web 3D, Virtual Museums*

Introduction and Objectives

Starting from archaeological information, geospatial and topographic data, we experienced a successful workflow ranging from content and data generation to online real-time visualization and interactive exploration of massive 3D landscapes.

One of the first steps in this workflow regards the generation of the 3D landscape, starting from GIS data. Using available applications and utilities for reading geospatial imagery and digital elevation models (DEMs) large scale 3D terrain databases are generated which can be loaded and browsed in real-time. In order to produce a digital library of data to be handled online, a pipeline has been re-defined based on previous experiences. Typical dataset creation includes:

- 3D model of the actual landscape.
- 3D model of the historical landscape, reconstructed using different imagery (e.g. historical maps).
- 3D model of the potential landscape reconstructed using artificial geoimagery.
- 3D models of a few archaeological sites based on reality-based modelling techniques and acquired using mixed acquisition systems (eg. Laser Scanner, Photo Scan, Computer Vision).
- 3D models of a few archaeological sites as they potentially have been during ancient times.
- Procedural modelling (CityEngine).
- 3D models of the vegetation using semi-automated generators (e.g. *FigiX*).

In this context it is crucial to have an overview of the landscape - both at large and medium scales - and consequently develop proper navigation systems within real-time applications. The understanding of some phenomena and relationships within sites can be achieved by analysing the whole context, while others are much more related to a single site. One of the main goals is to develop real-time components where users can dynamically explore and interact with a territory, also interacting with 3D sites acquired in the field, with databases and with other information or raw data. All these data, even if processed by optimization and decimation tools, typically result in very large data sets that need an implementation of paging techniques, streaming and dynamic *Level-of-Detail* to allow web based real-time fulfilment of the Virtual World. Recently the team worked on a new case study, with the

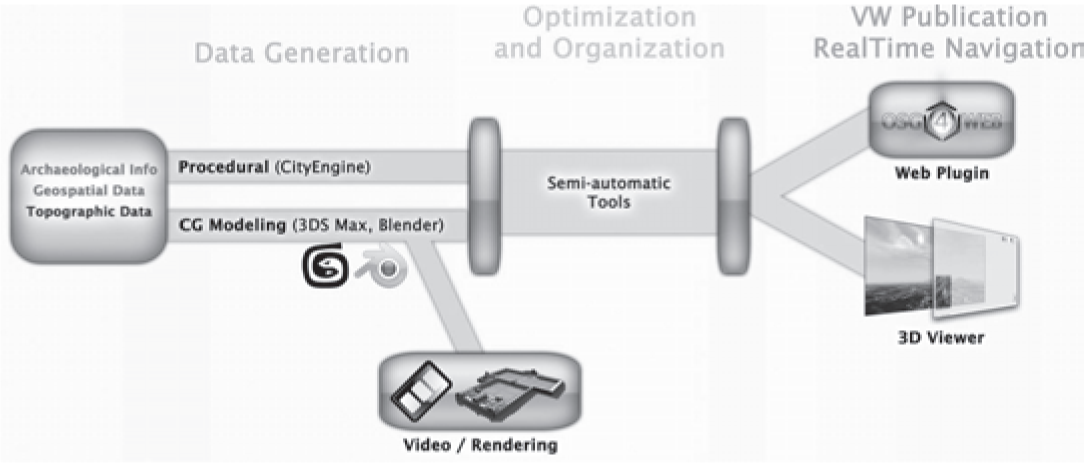

Figure 1. The workflow.

main aim of reconstructing the ancient thermal landscape around the town of Montegrotto, close to the Euganean hills, south of Padova (north of Italy) where this kind of workflow was successfully applied.

Reconstructing Montegrotto – from Fieldwork to 3D Reconstruction

Reconstructing the virtual urban landscapes of Montegrotto and making its models - both the ancient and the modern ones - accessible via the web has been two of the main purposes and challenges of this project. Thus, to obtain such a number of buildings, different approaches and technologies were necessary:

- Active and passive scanning technologies to survey and represent the discovered archaeological sites.

- Procedural and CG modelling for an efficient 3D representation of the modern city and reconstructing the missing architectural parts of historical buildings.

Surveying archaeological sites

In order to fill in an exhaustive metric documentation on the archaeological buildings of Montegrotto, a geometrical survey relying on range and image-based techniques has been conducted. The buildings involved in these two investigations were:

- the Roman theatre/odeon,
- the networked channels' system and the baths,
- the Neronian Villa.

Due to the presence of protective coverings, the surveys of the buildings turned out to be very difficult and problematic. Many parts of archaeological buildings were hidden and the complete direct acquisition of data was impossible. Thus, in order to attain a successful survey and to experience different techniques, several 3D acquisition methods were used. The 3D scanning technologies involved were:

- Photogrammetry (multi-stereo),
- Laser-scanner (time of flight).

The 3D scanning was conducted by the CNR-ITABC, VHLab team.

Photogrammetry

To obtain 3D models, an automatic multi-stereo technique was used. This enables a 3D scansion using a stream of images from uncalibrated positions. The photogrammetric survey was managed through two different approaches: firstly, the photos were taken by a photographer positioned on the ground-line; secondly, we used a Drone, a teleoperated flying vehicle equipped with a zenithal camera. The survey was executed on each building using both approaches - ground and flight - so that it was possible to reach both the parts hidden by the protective coverings and to minimize the risk of twilight areas. In detail, the photos taken from the ground-line were processed with the "Arc3D" web-service. It allowed us to upload digital images to remote servers where 3D reconstruction of the scene was performed, with the resulting output sent back. As an essential way to obtain correct positions and dimensions of the 3D models, an additional direct survey with total station laser was completed. As a matter of fact, that approach easily allowed us to scale and relate the models to the topographic network, and thus ensure a good accuracy and the transformation of all meshes into the same spatial framework.

Laser scanner

The 3D acquisition of data was carried out again this time with a time-of-flight laser scanner (Riegl), which was used to sample the large

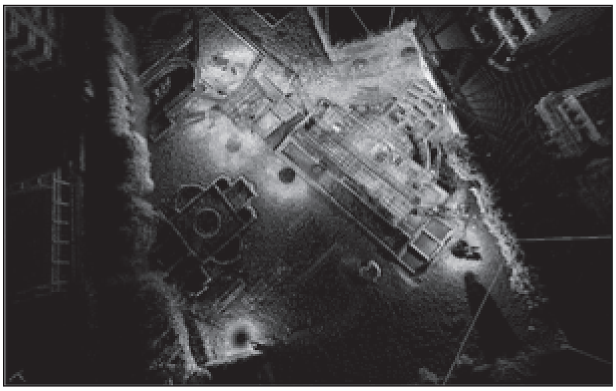

Figure 2. The pointcloud of the archaeological site of "Via Scavi" acquired with range-based technology (the circular black holes display the scanning station positions). On the right: the roman Theatre; on the left: the baths.

surfaces of the buildings. In order to detect the entire area taken up by archaeological monuments, several scanning stations were used. During the survey, each single scan was connected using markers - a set of control points - located on significant parts of the buildings, visible by each scanning station. The pointcloud produced was then processed with "RiScanPro" software to obtain and merge the multiple meshes. All the meshes obtained through both the laser scanner and the photogrammetry were post-processed with "*MeshLab*", an open-source software developed by the CNR-ISTI of Pisa. This system was used to edit and align the 3D triangular mesh, together with other filters used to optimize it.

Specifically, we adopted a set of cleaning filters (to remove duplicated surfaces, fill the holes and unify normals) and re-meshing filters (to simplify the high quality meshes handling them both in computer graphics and scientific analysis's fields).

3D Modelling

In order to reconstruct the Virtual City of Montegrotto two different approaches were pursued:

- Reality-based modelling used to reproduce the existing city taking advantage of a procedural technique.

- Computer Graphic-based modelling used to make a digital restoration of excavated Roman buildings discovered at the archaeological sites.

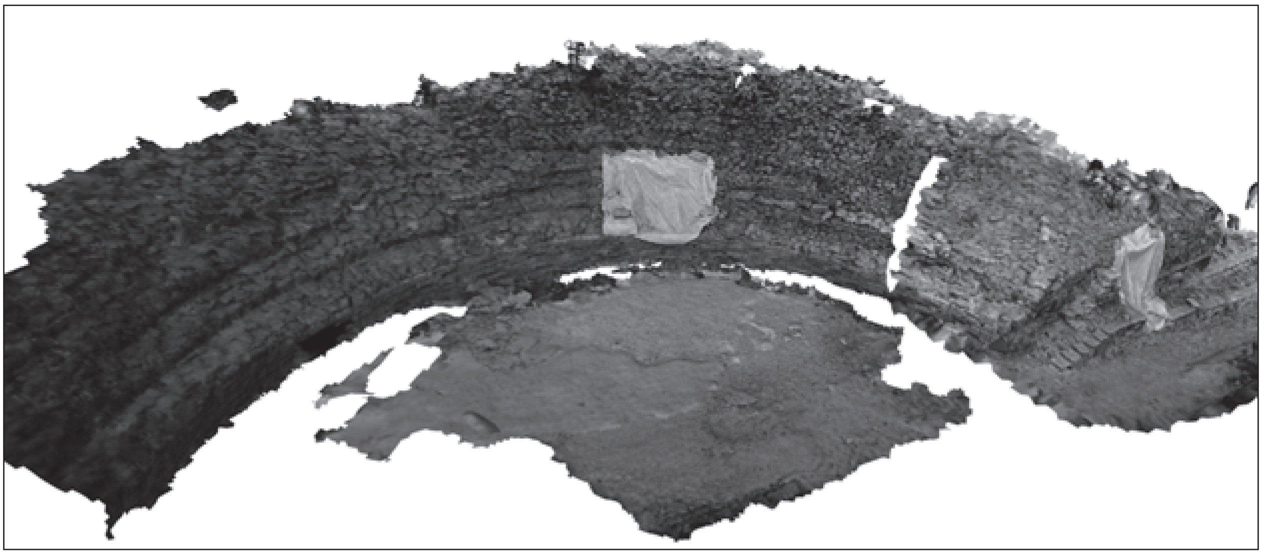

Figure 3. A textured mesh of the "Cavea" produced with image-based approach (Computer Vision) using Arc3D web-service.

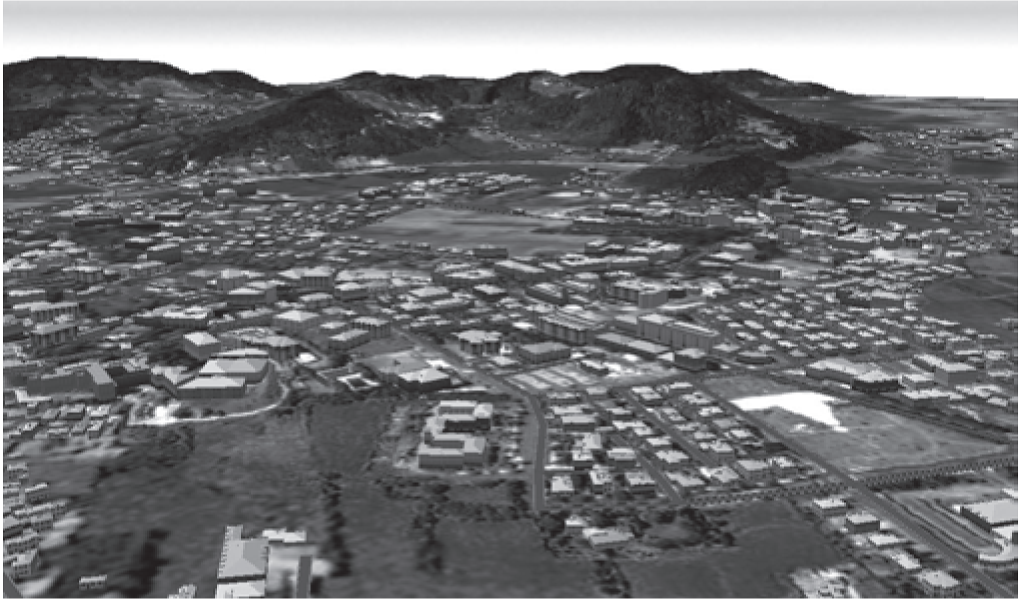

Figure. 4. CityEngine user interface: thousands of buildings generated with the procedural approach.

Procedural modelling

To improve the realism of the urban landscape of Montegrotto and its complexity and to contextualize the studied archaeological sites, a virtual reconstruction of the entire existing city was created. Modelling a large city with thousands of buildings is always a challenge because it requires huge resources, especially for real-time applications and the web. Thus, we set out to use a procedural approach. Using semi-automatic approaches based on grammar rules this technique simplifies the generation of complex cities. The software chosen for our purposes and successfully applied to past projects was *CityEngine*. Developed and optimized for urban and architectural contents this software allowed us to have complete control on the overall entities in the hierarchy of the scene and to obtain diversified buildings. The shape-files importation, as footprints and parcels, was the first step to create the city. Then these files were used as allotments for the placement of buildings. Every allotment was associated with a shape grammar rule which contains a set of instructions that define the aspect, the size and the typology of each building. The biggest challenge has been achieving the different typologies of buildings needed to reproduce a reliable virtual copy of the existing city. Through the shape grammar we have been able to define the variables used to generate different versions of the models and to make possible the automation of the modelling process. To set the aesthetic features of the buildings, a correlation matrix which randomly assigns a texture to each building was developed. Into that matrix height information is associated with each texture so that when the software generates the buildings it automatically gives each of them the correct height and proportion. Using this methodology, we were able to generate approximately 6000 buildings as single-family houses, apartment buildings, hotels and churches, etc. These models were very schematic, low-polygons featured and particularly useful for real-time applications. Indeed, their architectural details such as doors, windows, balconies etc. came from texture information and not from geometry. In order to get a set of textures, a photographic survey was made, generating approximately 50 textures, rectified and mapped into the models.

Computer graphic modelling

To reconstruct the main Roman buildings discovered in the archaeological sites of Montegrotto - the theatre, the baths and the villas - hand modelling was used. These virtual reconstructions are very useful to improve the understanding of the ancient architecture, given the aesthetic perception of the buildings in its architectural and decorative completeness. The 3D archaeological reconstructions were realized under the close supervision of consultants from the Archaeological Heritage Bureau and University of Padua, and using several datasets as references:

- Floor plans, acquired with the total station,
- Laser-scanning and photogrammetry data which documents and represents the real topology of the objects in 3D with a high level of detail,
- Historical information and photos,
- Archaeological excavation data.

Moreover, in order to comprehend the damaged parts of buildings and the missing ones, comparisons with similar examples, well known from the territory of Padua, have been made. The virtual models have been designed with software such as Blender and 3ds Max, starting from scans and surveys. The models were created to be used either in applications of computer graphics or in virtual reality environments; therefore, for each of them, different levels of detail have been modelled. Textures have been created with different approaches. When possible textures have been produced by re-arranging the images acquired *in situ*; in other cases, planned reconstruction and simulation processes of the original surfaces with a digital image processing software have been necessary. Up to now, the first century AD architectural structures were modelled, but in the next, buildings of later periods might be reconstructed.

Figure 5. A low-poly model of the Roman temple, placed behind the theatre, modelled and textured with CG techniques. Rendering performed with the Mental-Ray engine. Ambient occlusion and indirect light effects have been registered on the texture to improve the look in the RT application.

Regarding the optimization of the models for RT applications, some precautions and tricks have been used. Each model, coming from both scanning and 3D modelling techniques, has been polygon-decimated, subdivided in small portions and exported by material in *.obj* format. In conclusion, squared “atlas” textures have been generated.

Virtual World Organization and Web Optimization

Web plug-in

Through past experiences such as the *Virtual Rome project* (Pescarin et al. 2009), a 3D web plugin based on the efficient open source OpenSceneGraph framework was developed and extended by adding more features developed in response to application requirements. The diverse and growing community of over 5,000 developers of this high-quality framework is centred around the public osg-users mailing list, where members discuss how best to use OpenSceneGraph, provide mutual support, and coordinate development of new features and bug fixes. The developed web plugin is

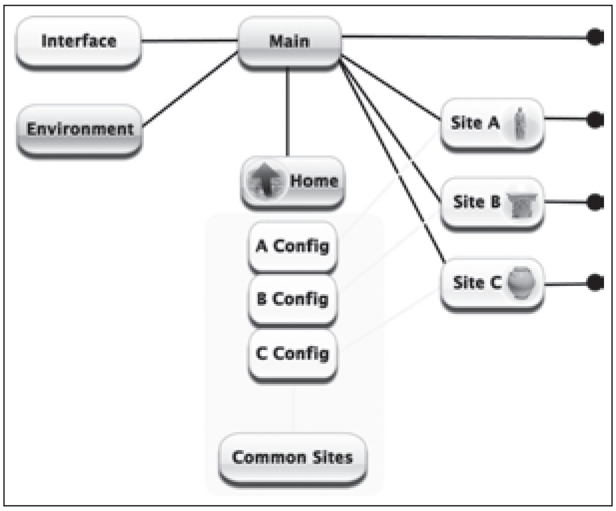

Figure 6. Interaction Graph of ActionNodes in Montegrotto project. User can start from main view (using the home position) when application starts, or directly explore archaeological site A (Area Scavi) that is based on main core and the settings relative to area A. These settings share the same "Common Sites" setup (e.g. enable Walk-Mode for all sites).

capable of self-shadowing in real-time, 3D interface management, enhanced navigation and customizable event triggers. Alongside improved navigation behaviours and interactions, recently introduced features on the framework enabled the adoption of efficient algorithms for real-time shadow techniques, providing support for the delicate self-shadowing issue and user-customized tuning for large environment settings. The primary light source can be interactively positioned during the virtual world exploration, allowing smooth transitions and possibly simulating time-slices. GLSL shaders and Light-Space perspective shadow-maps techniques also support animated (for instance animated crowds) and paged content such as terrain tiles, with aesthetically good results and a minor impact on performance for a more immersive user experience. Walk Mode has been improved, with specific attention for handling paged DataBases, with special algorithms able to automatically adapt to the dynamic nature of the landscape caused by Level-of-detail switching underneath the avatar. In such projects, it is also important to configure and tune the parameters to fulfil the user experience. For this reason more parameters have moved out with the purpose of an external and complete control over physics, surface friction, adaption and others to allow adjustment to multiple projects and applications.

Interaction graph

Support for nodes able to trigger events called "*ActionNodes*" developed for the plugin also led to a modularization of interaction graph, with overall improved scalability and portability. Every node is capable of command encapsulation and execution when the user interacts with it, thus a generic code can be associated within a 3D object: model, icon, hotspot bubble, pin, etc. The API also includes support for calling other ActionNodes execution script, allowing a fine and optimal interaction graph. Within the Montegrotto project for instance, a common ActionNode among archaeological sites is executed when the user clicks on one of the hotspot bubbles, enabling and setting up walk-mode, acceleration and other functions. The home button also requests a setup of parameters (fly-mode, etc.) and environment settings such as skydome and others have been grouped into ActionNodes (Fig. 6).

This structure has shown all the advantages of the modular approach, allowing huge flexibility and quick adaptation as the project requirements change (for example a different avatar height, shadows and other fine settings tuning over archaeological sites) and is suitable for future variations.

Optimization

In this step of the workflow 3D datasets are prepared and optimized for web publication. From past experiences the best results are achieved with well-balanced graphs, organized in *quad-tree* structures that allow tiles (or "*pages*") to be requested and downloaded on spatial demand depending on user exploration. Level-of-Detail techniques are used to provide a multi-resolution representation of terrain geometry and models, with the ability to manage very large virtual worlds and landscapes being suitable and successful in this particular context. With the main focus being on the reconstruction of specific areas scattered across the 3D virtual landscape - such as the roman Theatre and Villa - a modular approach in this step of the workflow has been adopted. Complex 3D Models are split into smaller components balancing the load on a few files (generally about 15-20) helping modularization with a better and clean 3D spatial organization, also affecting dynamic lighting and self-shadowing with increased precision. A wide customization for such parameters is possible, reducing for example the shadow frustum as the avatar switches to walk-mode during the exploration of Montegrotto sites, decreasing GPU loads and increasing shadow precision for closer objects. As this scenario is web-based, a suite of semi-automated tools (such as "*FigiX*") has been developed to handle city clusters, vegetation, generate forests and also to manage real-time object planting for garden reconstruction (Fig. 7). Some of these tools guarantee a huge performance gain using advanced algorithms (e.g. KD-Trees), also with fast placing during batch generation of massive vegetation, organized then into clusters by the application with quad-tree hierarchy using unique OpenGL StateSet references. Instancing at cluster level is also used to tidy up the file size and obtained good results in terms of band impact for the Montegrotto scenario.

In addition the whole scene-graph has to be re-engineered to optimize *OpenGL* calls and thus maximize performances, with reduced rendering times and load on the GPU. Within the Montegrotto project, materials and other attributes of the modern city have been moved up to the node root and atlas have been used to minimize state changes and avoid unnecessary loads through the web. 3D models can use two or more different bins (reconstruction and interpretation) and can be shown with solid or semi-transparent materials, providing the user with a visual comparison between the ancient and the modern world (Fig. 8).

Figure 7. Reconstruction of Neronian Villa and real-time exploration with vegetation over the web.

Figure 8. Area Scavi and visual comparison with semi-transparent Theatre and its actual ruins over the web.

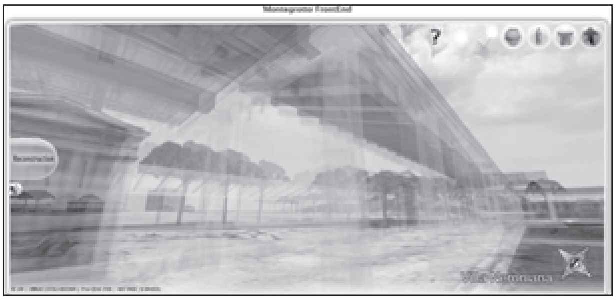

Figure 9. Interpretation layer of the roman Villa on actual landscape with stereo anaglyph over the web.

Online application

The final stage of the workflow includes a web component which can be embedded into a generic web page, such as in the Montegrotto project proposing different and interesting interaction possibilities together with a stand-alone viewer component. Both are able to support remote and/or local content loading with recent support for stereo modes including anaglyph glasses and passive/active stereo where capable.

Other tests have also shown successful integration with multi-touch monitors. Adapting the HUD interface and design opens several possibilities for future development and user realization of 3D content over the web.

Conclusions

We experienced and adopted an adaptable and scalable workflow for the reconstruction of archaeological contexts and their possible outputs to the web. The successful workflow within the Montegrotto project progressed from data generation to a fluid and immersive real-time 3D exploration, over the web or as a stand-alone offline application. This goal was achieved using various steps of modelling, optimization, level of detail and semi-automated tools for advanced scene-graph routing techniques.

Regarding future development, we want to increase the number of the roman models, furthermore we plan an additional investigation into complex 3D model publication: procedural models, huge laser scans cloud points or extensive manual modelling are challenging issues. Automatic model hierarchy development and improved level of detail, together with instancing and atlas, are efficiently supported by efficient paging managers of OpenSceneGraph framework. Automatic octree paging schema also could be used for pointcloud data derived from laser scan surveys. A complete integration of a 3D interface with multi-touch monitors and stereo viewing are also among the goals that we plan to achieve.

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