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Virtual Systems in the Information Society

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Conference Proceedings



**2012 18th International Conference on
Virtual Systems and Multimedia (VSMM)**

Proceedings of the

VSMM 2012

Virtual Systems in the Information Society

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Editors

Gabriele Guidi

Alonzo C. Addison



**POLITECNICO
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Game engine for Cultural Heritage

New Opportunities in the Relation Between Simplified Models and Database

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Abstract — Game engines can be regarded as powerful tools in the Cultural Heritage domain, not just as dissemination tools, but for managing the urban context in real time. This case-study is based on the ongoing project of Pietrabuona Castle (Pescia, Italy). It is an interesting example of a stratified historical centre, the conservation and promotion of which might benefit from using a new, integrated survey and alphanumeric data management tool. The method used to survey this medieval fortification had to provide both local institutions and researchers with an interactive tool encompassing several features of Cultural Heritage: from technical (decay, maintenance, environmental risks, etc.) to cultural (urban standard, historical understanding, immaterial features). Due to the cross-disciplinary nature of the ongoing project, we decided to share some major points of our investigation with the scientific community, in particular those concerning our procedure: the opportunity to use interactive applications to display themes of urban settlements as 3D models, based on a survey by laser scanner.

Keywords- *Game engine, 3D laser scanner, urban survey, simplified models, UV mapping, normal mapping, 3D GIS.*

I. INTRODUCTION

In recent years, some research projects have been focused on 3D urban information systems [1]. More often than not, they gave a substantial contribution to the scientific community, but failed to tackle all the problems of a 3D interactive displaying of information about urban settlements¹: in particular, when having to manage models based on massive laser scans.

The three main areas that impact on the problem of interaction in the design of historical towns are:

- Accuracy of the survey,

- Optimisation of the 3D model,
- Ergonomics of the relation between database and real-time application.

From the surveyor's perspective, it is important to provide an accurate digital overview of the shapes, colours, materials and decay of such heritage, reflecting the balance between the scale of representation and the level of accuracy in the sampling used in the survey. The amount of information provided by complete data acquisition (GPS, topography, laser scanner, photogrammetry, etc.) is huge and needs to be carefully "filtered" for interactive exploration through real-time applications. As data-acquisition professionals, our priority is to monitor all the steps in the "filtering" process, in particular the geometrical error introduced in the modelling process by the transition from laser scanner to game engine. Earlier studies [2] showed that using point-cloud models only, in an interactive investigation, can cause problems: firstly, an altered perception of the surveyed objects, and, secondly, the practical aspect of relating an unstructured representation to a database. An interesting opportunity was provided by converting the discrete representation (point cloud) into a continuous model (polygonal surface), whereby the survey could embrace a wider range of applications. But how should a dense mesh be simplified to really improve the reading/survey of an urban complex? The modelling process, from the single building to the whole historic settlement, has to do with cultural requirements, which the architectural representation aims at. From this perspective, we believe that, in such projects, priority should be given to a preliminary step, the so-called "semantic reading", where the implicit hierarchy of the building's parts are identified [3]. The design of the modelling steps should reflect these aspects when dense point clouds need to be converted into low-poly meshes: in other words, the development of a structured mesh must reflect the information provided by the survey of the building. The role of textures in the optimisation process prior to interactive visualisation is as an essential step in such procedure, in terms of data compression as well as a new way to represent or manage an urban context. In such area of research, the performance of a game engine does not only have to do with its ability to visualise a scanned town or environment in real time, but also

¹ We refer to the experiences of: University of Brescia / Gexcel Ltd., (Giorgio Vassena), *Architectonic 3D laser survey with scanning: visualization and management of large datasets using Gexcel R3*; DIAPReM (Marcello Balzani): *3D databases from laser scanner for the management, protection and preservation of cultural heritage*; Pisa CNR, Visual and High Performance Computing Laboratory (Roberto Scopigno).

We would like to thank Caripit Foundation and the Bank of Pescia, without whose support this research would not have been possible.

with the option to interactively explore the many features as in a cross-examination².

II. PURPOSES

Following an extensive preliminary step with a view to understanding the state of the art in 3D-GIS, we thought that a game engine could be the right solution to bring together the many aspects involved in the representation of the urban built heritage. In order to pool all such data (assets) into one ‘package’, we split the main objective into the following steps:

- Develop a reverse-modelling procedure for proper conversion of the unstructured point cloud from a whole settlement (discontinuous model) into a

structured network of polygons (continuous model).

- Proper mapping of low-resolution models within a reference system (u,v) as an appropriate canvas to draw different themes on (not only for shade-related textures).
- Methods for building databases of qualitative information about the urban environment [4].
- Arrangement of an integrated model and database-management system, to draw themes straight onto 3D models in real-time applications.

As to data acquisition, since the beginning of such research work (settlements of Pescia, Aramo, Sorana and Pietrabuona), we have opted for an extensive use of laser scanners for our

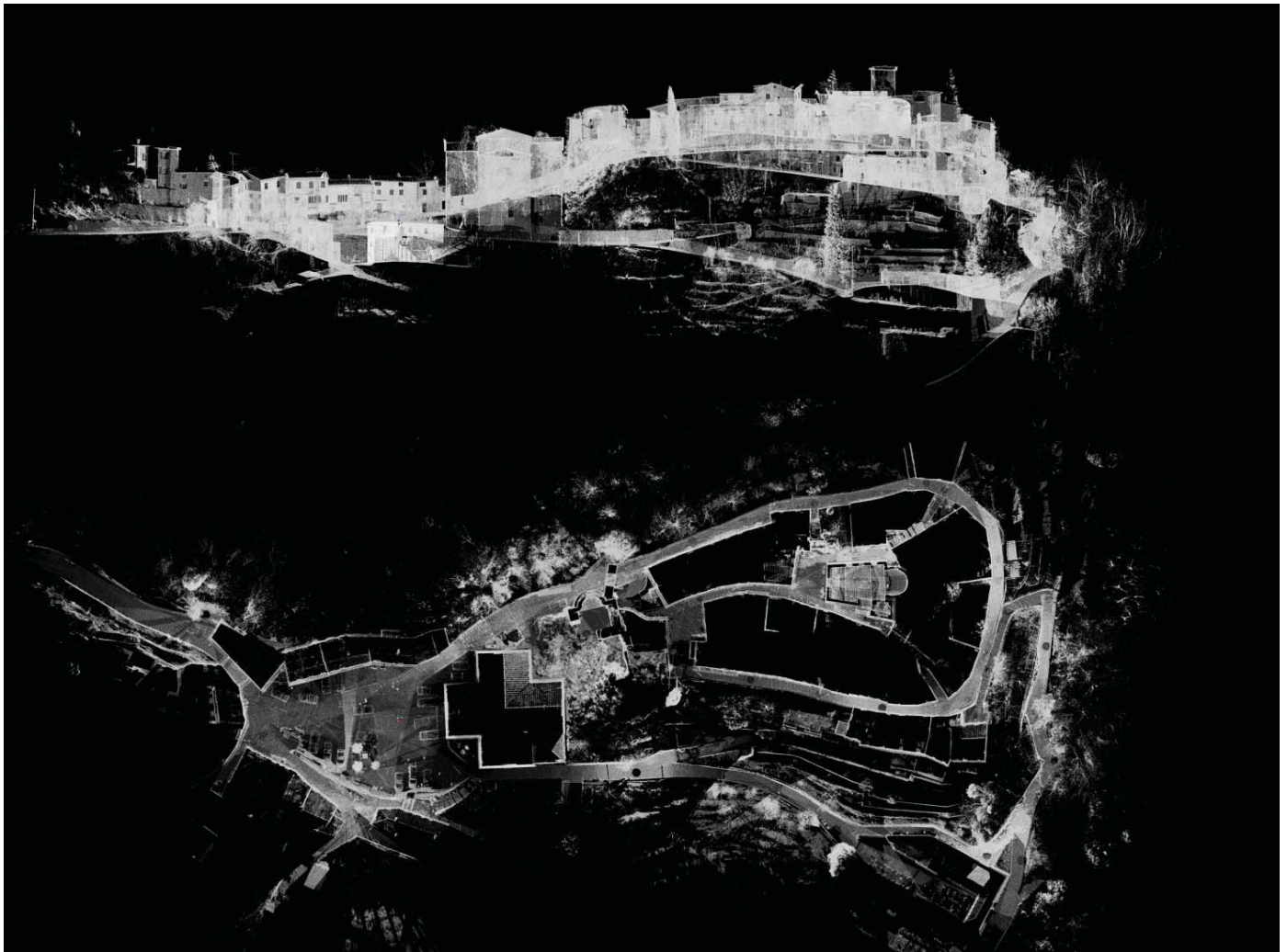


Figure 1. Point cloud model of Pietrabuona.

² In this case, the purpose of game engines is not to develop training or advertising applications; here, our approach is very far from that of “serious games” as it is focused on the documentation and interactive management of major features of historic towns.

surveys. To overcome any constraints in the management and visualisation of point clouds, it would be advisable to build high-poly models, which can be more easily understood by unskilled or untrained staff. Before heavy 3D meshes can be placed in interactive environments, they need to be converted

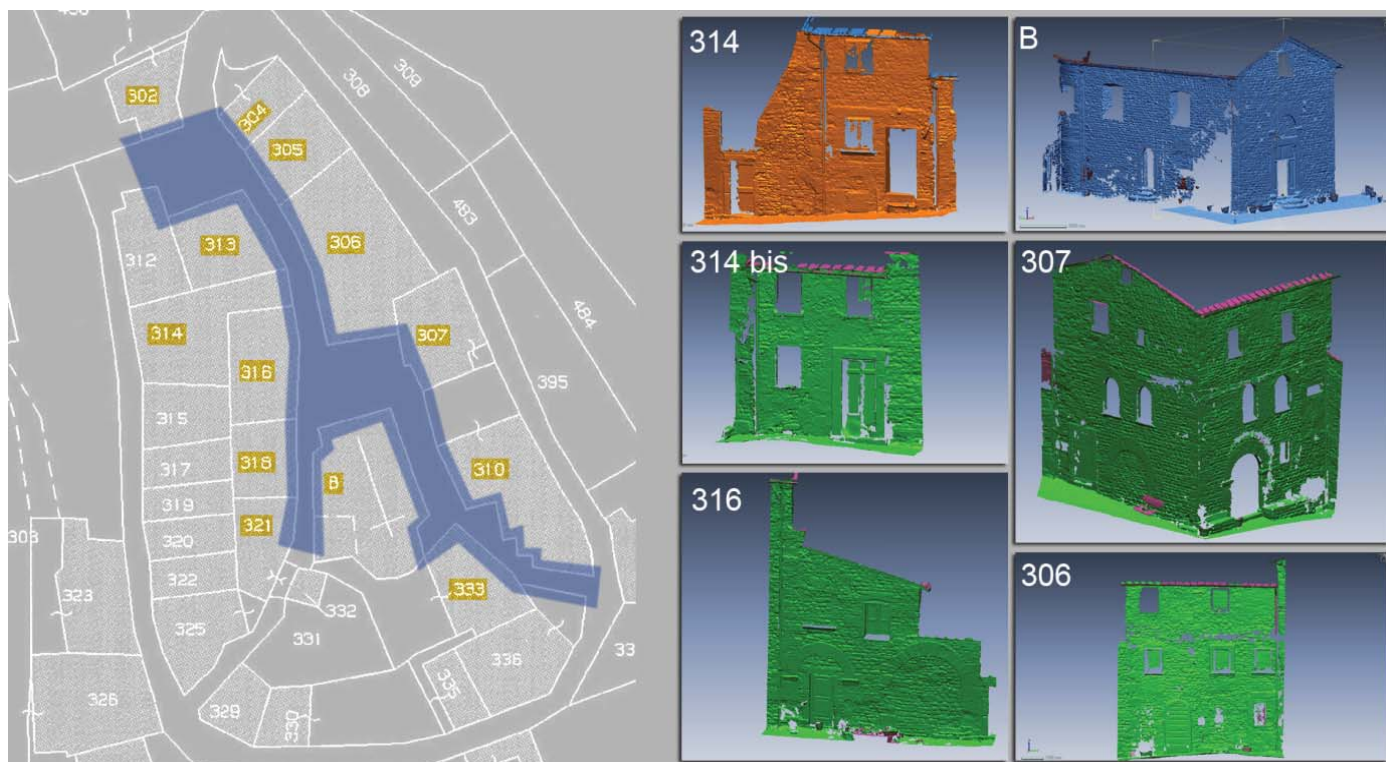


Figure 2. Planning of the exportation phase.

into low-poly models, which can be easily viewed on ordinary computers, smart phones, tablet computers, etc., although not with any scientific reliability. Generally, low-poly models are the result of a substantial automatic geometrical decimation process, that, unless kept under control, may “damage” the metrical reliability of the meshes, even when reduction is based on advanced algorithms [5].

The kind of optimisation we propose is focussed on image-based geometric processing techniques: a method that uses (u,v) reference systems for storing apparent colour and normal maps from dense meshes. These RGB images improve the appearance of low-poly models on coarse meshes, because the three components of any normal vector belonging to the high density mesh is encoded in the three components of a bitmap [6].

The main purpose of this research work involves the use of (u,v) reference systems as a base for the application of different sets of images, not just for improving the quality of the shading but more generally to show and blend different thematic maps together (in the Unity 3D game engine, these maps can be interactively turned on and off)³.

III. PIETRABUONA’S CASE STUDY

The procedure developed for the fortification of Pietrabuona⁴ (Figure 1) begins by planning how to export the sets of point clouds into the mesh-processing applications.

When exporting huge amounts of data, as in the case of an urban context surveyed through more than one hundred panoramic scans⁵, the process should be split into multiple, appropriate steps. In this case, we decided to use the cadastral identification codes as reference for a progressive exportation of .PTX files. The purpose of this process is to enter appropriate amounts of data in the reverse-modelling application in a way that will make the meshing process easier.

No model associated with a façade (based on cadastral classification, Figure 2) should exceed the max limit of 4 million polygons when converted into a mesh triangle (Figure 3); in addition, when building a 3D digital urban model, the average edge length of the mesh triangle should also be carefully taken into account. Such quantity should be consistent in all models and should not exceed that of the sampling used in the survey. In this case, we decided to use a

³ Unity 3D game engine, because this application supports advanced real-time rendering techniques, such as deferred rendering, light mapping, linear space lighting, HDR, screen space ambient occlusion (SSAO), occlusion culling, batching, providing a high level of visual quality, which can be especially noticed in the reconstruction of photorealistic environments.

⁴ The examples herein have been drawn from “Rilievo e documentazione del borgo murato di Pietrabuona (Pescia – Pistoia)”. Reference: n° 1.12.03 SDISMERLATEN10. Funding Institution: Università degli Studi di Firenze. Timeline: from 1/1/2010, to 31/12/2012. Leading researcher: Prof. Alessandro Merlo. This line of research was started by Prof. Alessandro Merlo, who set up the investigation team in 2007; the general project is called: “Rilievo e documentazione dei nuclei insediativi minori della Svizzera Pesciatina”.

⁵ The survey was carried out through a Faro Photon 80 based on phase-shift technology.

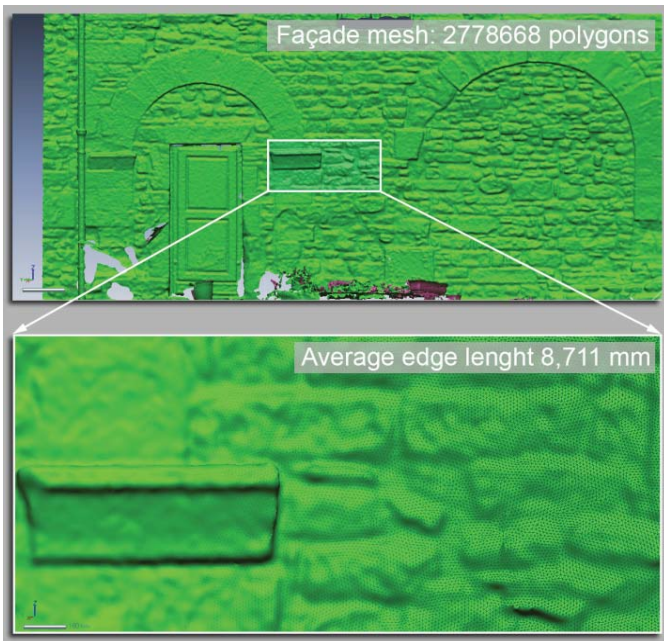


Figure 3. The aims of the pipeline are to keep the high-poly mesh of every facade lower than 4 million polygons and an average length of the triangles edges close to the sampling distance of the scanner.

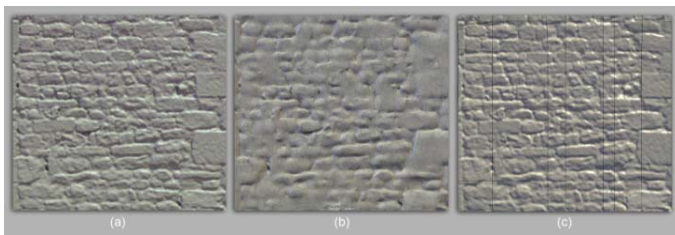


Figure 5. Rendering comparison of a facade. (a) High-poly model, 430055 triangles, (b) mid-poly model, 193458 triangles, (c) low-poly model with normal map applied, 756 polygons.

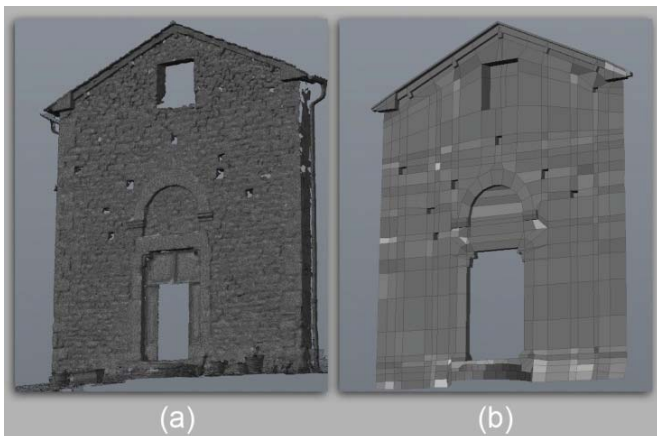


Figure 6. (a) non structured high-poly model. (b) structured low resolution quad-dominant model.

one-centimetre length, as it provided a good balance between the scanner's accuracy and the max number of polygons that

could be managed by the hardware and software used herein⁶.

Once converted into high-poly models, point clouds contain a lot of topological errors (folded, dangling, crossing or non-manifold faces, etc.), which are corrected by our automatic global re-meshing tools [7]. This feature provides an isotropic mesh, whereby the lengths of every edge within the model become approximately the same; in addition, all of the smaller gaps are automatically filled, without any manually-intensive operation. In the case of urban centres, the typical occlusion effect exhibits recurring traits (no roofs, incomplete documentation of windows, cantilever, etc.) that cannot be completed by the modelling tools in mesh-processing applications. As a matter of fact, because of the large number of gaps that can be found in such surveys, a different approach needs to be taken, one that is not based on traditional bridging tools or "gap-filling" features; the typically medieval "boxy" shape of Pietrabuona cannot be completed by such tools, which produce unsuitably rounded blob surfaces. This is why we opted for a different approach where the gaps were replenished by direct modelling application, since the error built in any automatic or semi-automatic gap-filling tools would have impaired the quality of the survey. In this case, we will use a high-poly mesh merely as a template for the following operations: retopology and baking (or render-to-texture). By retopology, we mean a technique whereby a coarse mesh made of quadrilateral (quad) polygons and triangles is used to rebuild the shape outlined by the high-poly mesh.

Generally speaking, software developed for the entertainment industry does have dedicated retopology tools [8]: the latest solutions provide semiautomatic quad dominant re-meshing⁷ [9], but it cannot always be used when processing data from urban surveys due to the massive amount of occlusion effects. In fact, quad dominant re-meshing needs "waterproof" meshes without topological errors, and such models are very hard to come by in this area of investigation. The first step in the retopology process tries to find the greatest deviation between a simple plane and a dense mesh (Figure 4).

The classic approach to the design of a simplified 3D model involves the use of a 2D wire-frame model; horizontal sections are used for extrusions, followed by Boolean operations to produce the doors and windows, and so on. The models resulting from the relevant sections of a building are a simplified, mediated version of the high-poly mesh that could usually be produced through a topographic campaign, without a laser-scanner survey.

As we mentioned before, here we are trying to produce a structured mesh that reflects the semantic reading of the building; the measurements of the edges of such coarse mesh should be planned by the user based on the results of the mesh-to-mesh deviation analysis shown in Figure 4c. Once the areas

⁶ Mesh-processing application: Inus Rapidform XOR3. Entertainment application: Luxology Modo. Photogrammetry application: EOS System Photomodeler.

⁷ Quad dominant means that the retopology technique provides a low-resolution version of the original model, largely consisting of loops of quadrilateral polygons; the word 'dominant' suggests that the original mesh can hardly be wrapped without using triangles or n-gons, depending on the chosen software solution.



Figure 7. Photogrammetry application provides tools aimed at finding all the parameters of the camera when the photo was taken, starting from a set of homologous points (a) related with the corresponding ones acquired by means of laser scanner survey. The model of the camera (b) can be exported to other modeling packages where it can be used for reprojecting the image on the simplified mesh.

of greatest deviation have been located, relevant measurements for the following modelling processes and the areas that will require special care during the retopology process may be selected. The colours on the model in Figure 4c intuitively suggest what size the minimum edge of the coarse mesh should be (about 15 cm); in addition, the areas in which just a few planar polygons are enough to properly document the building's shape can be located as well. The main vertical walls (Figure 4c) deviate from a simple vertical plane in the range 2.5 cm as an absolute value. Such deviation is compatible with the max acceptable limit that results in good-quality shading, using standard mapping instead of real geometry (Figure 5).

In the last few years, virtually all 3D packages for the entertainment industry have developed their own way of wrapping dense triangle meshes in structured quadrangular meshes (Figure 6), such as, for instance: automatic reconstruction after interactive drawing of a curve, mesh-to-

mesh constraints, interactive drawing of loops of quadrangles, etc.. The most convenient aspect of having such optimised models (optimised, not just simplified) is that they can be easily mapped in the (u,v) reference system; actually, reverse-modelling applications can automatically map a 3D geometry in the 2D (u,v) system for colour-mapping purposes, but, regrettably enough, they create lots of islands [10] which eventually need to be pixel-edited, a quite annoying process usually employed for raster images.

Once the structured mesh has been built, the second step is projecting it in the (u,v) reference system, using one of several tools. The double purpose of such process is to make the points from the 3D shape match their 2D counterparts on a one-to-one basis; as mentioned before, islands should be avoided as they may cause problems along the seams, i.e. along the sequence of consecutive edges used for cutting the “waterproof” boundary representation and then unwrapping it in the (u,v) system.

For proper mapping of the apparent colour of the facades, we opt for an integrated technique based on photogrammetry and 3D modelling applications. The former provide high-quality camera re-sectioning, which means finding the internal and external settings of the camera when photographing the object (Figure 7). Once the location of the camera relative to the model of the façade has been found, the UV mapped version of the structured mesh may be used for the baking of the apparent colour: a render-to-texture solution in which the central projection of an image may be converted into a (u,v) system (Figure 7); the file format in which the vector describing the camera's settings may be exported is .FBX. The second baking process aims at encoding the normal vectors of the high-poly model into the same UV map used for storing the apparent colour. As explained above, the potential of this 2D reference system does not just lie in the shading and appearance of the models, but in the fact it can easily store different kinds of data from analyses conducted by professionals and experts (Figure 8).



Figure 4. (a) high resolution model of a façade, (b) superposition between a simple plane and the mesh, (c) mapped colors highlighting the deviation between the vertical polygon and the scanned façade.

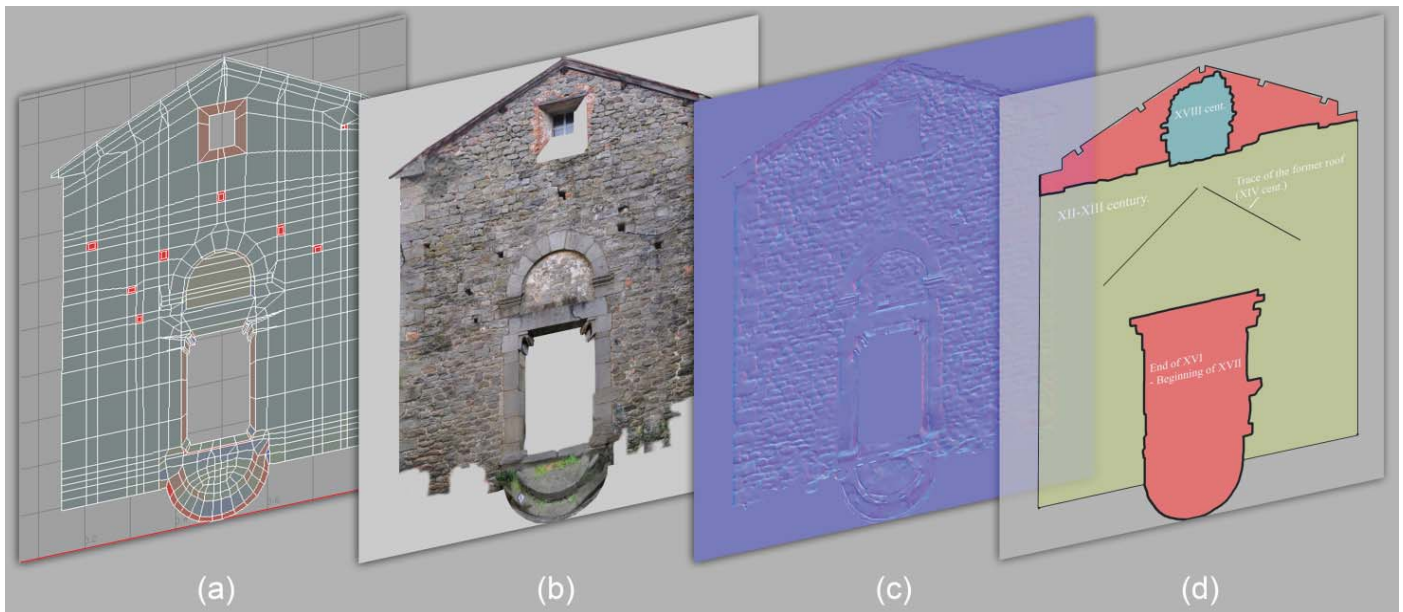


Figure 8. (a) mapped mesh with highlighted in red the parts where polygons in (u,v) are smaller than the corresponding in 3D. (b) Apparent color map. (c) normal map. The u,v reference system provides an useful template for the storage of other kind of information related to quantitative and qualitative aspects of the built heritage. (d) example of a thematics map congruent with the others texture.

IV. CONCLUSIONS

The methodology implemented in the case-study of Pietrabuona is the result of many steps, carried out as multiple packages and selected as those that offered the highest quality of representation and the best control over any error introduced in the low-poly models for 3D-GIS applications. The level of reliability of such representation can be estimated in quantitative terms through reverse-modelling applications, without having to use empirical processes that are assumedly inappropriate in any scientific documentation.

Game engines seem to be a consistent achievement, compared with the options currently provided by the many 3D-GIS prototypes. For the specific purpose of this Research Unity, 3D applications, which provide a high degree of interactivity between users and objects⁸, can be used for an easy management of different kinds of assets (optimised models, normal and colour maps, themes, etc.) the purpose of which is to represent, in a 3D interactive space, the results of specific queries about information stored in database. In such procedure, our research team implements (from the survey to the interactive 3D application) an alternative use of the textures, not just to realistically simulate the urban

environment, but, more generally, to represent the features and state of preservation of the built heritage.

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⁸ One of the many distinctive features of Unity 3D is its ability to visualise models with different levels of detail (LOD): from a low-resolution global model of an entire village to an extremely detailed "subjective point of view" of portions of it. Because of the wide range of possibilities provided by Unity 3D to define GUIs (graphic user interface) through which the user can control the application, functional and user-friendly ergonomic interfaces may be designed. Finally, the programme may be used to develop dedicated tools (within the application) to fulfil specific requirements, such as interactive measurements and sections right on to the 3D scene.

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