Integration of Pipelines and Open Issues in Heritage Digitization

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Abstract: In this paper, a series of topics, concerning acquisition, communication, and the analysis of buildings will be discussed. In particular, a strategy aimed at exploiting the visual potentials of reality-based models, will be described inside render engines, real-time applications, as well as their role for the production of conventional drawing for documenting and studying built heritage. This methodology is inspired by pipelines coming from computer-generated imagery (CGI) and the video game industry: areas of research that are progressively showing an increasing interest towards the world of photogrammetry remote sensing, in particular for the new possibilities offered by Structure from Motion (SfM)/Multi View Stereo (MVS) in terms of automatic texturing of complex shapes. Quad-dominant remeshing, displaced subdivision surfaces, and accurate interactive/ automatic parametrization are the main points of this workflow, whose final goal is the achievement of multipurpose models, which are capable to comply with graphic codes of traditional survey, as well as semantic enrichment, and, last but not least, data compression/portability and texture reliability under different lighting conditions.

Keywords: photogrammetry; terrestrial laser scanner; normal mapping; displaced subdivision surfaces; archaeology

1. Introduction

Digitization is a fundamental part of the current scenario of Cultural Heritage documentation and intervention; it grew up and become a protagonist in the script of preservation and valorisation of heritage at risk (Grün et al., 2004), enabling new reading keys to formerly in-depth researched monuments (Bianchini, 2013; Cipriani et al., 2016, Adembri et al., 2014). Nevertheless, several basic issues concerning three-dimensional (3D) model true exploitation are still source of debate, here, in particular, two aspects of these problems will be discussed: the first concerns the pairing of data reliability and the needs of dissemination/interaction, and the second is about the use of digital models as bases for the production of traditional drawings.

The higher the achievable resolution and accuracy, the higher the amount of hardware resources, as well as the software efficiency needed: for this reason, several investigation lines—centred on data portability (Hoppe, 1996, Lee et al., 2000, Gobetti et al., 2012)—3D online streaming and offline visualization of huge 3D models (Potenziani et al., 2015) have been carried out for two decades. After years of applications and progressive implementation inside commercial software belonging to the field of computer-generated imagery (CGI), the duo subdivision surfaces–displacement maps was generally adopted in the field of visual effects as a standard for Level of Detail (LoD) models, due to their scalability, portability, and efficiency. Also, inside game engines, such as Unity, the LoD feature allowed by DirectX 11 opened the possibility to use the tessellation of subdivision surfaces derived from highly detailed meshes from active and passive sensors (Merlo et al., 2013). For these reasons, some years ago, an investigation line started that was focused on the development of specific pipelines on how to convert in the more accurate, automatic and reliable way data from sensors into "displaced subdivision surfaces" (in accord to the terminology from Lee et al., 2000). In this sense, a series of experiments from the world of Cultural Heritage have been conducted (Fantini, 2012; Merlo et al., 2013, Guidi et al., 2016). Other aspects concerning these methods made them increasingly more flexible and reliable: on the one hand, the introduction of OpenEXR (http://www.openexr.com/) as displacement image format, on the other, the development of automatic quad-dominant remeshing tools (Jakob et al., 2015), and last but not least, the increasing automatization and accuracy of mesh parameterization tools (Cipriani et al., 2014).

The ease with which low-resolution quadrilateral meshes can be "sealed" in order to complete models enabling the achievement of constructive solid geometries, CSG, is also undeniable (Fantini, 2009): this issue is fundamental for the true exploitation of digital models as bases for the creation of conventional drawings. In fact, watertight meshes can undergo Boolean operations without problems, allowing for the production of sections on both convex and concave objects, without the need to perform a true slice or modification of the mesh thanks to interactive Booleans that are included in several modelling applications (Maxon Cinema 4D, The Foundry Modo, etc.).

Another issue is the one concerning the role of simplified meshes of "quads" in relation to the semantics that are applied to complex architectural and archaeological surveys. Can a structured mesh—formed by connected and regular sequences of edges in accord to features and curvature flow—facilitate segmentation/partition of a model?

The last topic has to do with the true use of render engines and is deeply connected to the control of the operator on the (u,v) parameter space, in particular it deals with the conversion of apparent colour texture into diffuse colour texture (for Lambertian surfaces), or into a set of textures that are aimed at supplying render engines with proper information concerning complex optical behaviours (for instance mosaic tiles, translucent materials, etc.).

2. Aims of the Study

The purpose of this research on archaeologic and architectural representation is to define a comprehensive pipeline that is capable of converting heavy meshes from active and passive sensors into 3D digital assets that are capable to dialogue with applications aimed at visual realism from the word of CGI/ Visual Effects (VFX). The strategy that is proposed here (Figure 1) focuses on how to produce optimized models: meaning models that are flexible enough to be rendered under different lighting and environmental conditions, which is reliable in relation to physical simulation of light, as well as topologically correct in order to produce two-dimensional (2D) drawing (plans, sections, elevations, etc.). This last aspect is still a matter under investigation, since it requires time-consuming and complex strategies (Martos and Cacheroa, 2015; Tryfona and Georgopoulos, 2016) in order to fit virtual simulacra with standard graphic codes and long-time tradition of archaeological drawings from XVIII and XIX century architects (Jacques and Bonfait 2002). Those examples are still used since they supply scholars and restorers with relevant information about masonries before XX century interventions; however, the charm of those watercolours and engravings require great effort and time to be reproduced by means of the current technological framework, and it could also be considered a sort of empty stylistic exercise (i.e. using non-photorealistic rendering techniques). The outline of work set out in this paper develops a pipeline that integrates the severe use of orthographic projections (architectural drawing codes), and the possibilities that are supplied by render engines (the updated version of manual rendering) in order to achieve true and full exploitation of different surveying techniques.

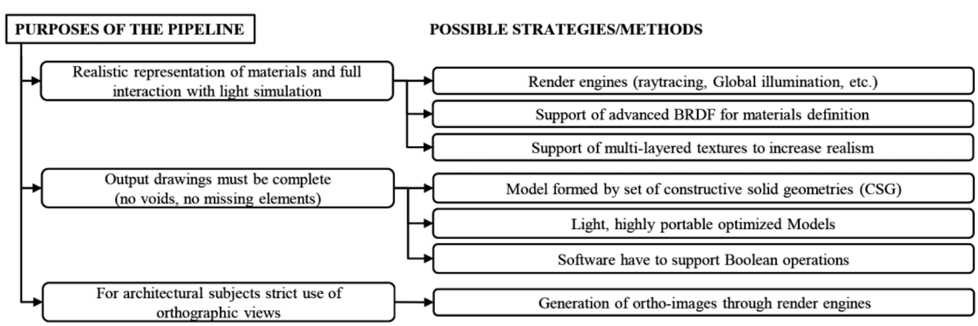

Figure 1. Summary of the purposes and possible strategies.

3. Optimization of Models and Textures

In the field of Visual Effects (VFX) and Computer-generated imagery (CGI), meshes that are formed by triangles are considered very poor in terms of rendering and animation. The main reason is the fact that animation/morphing of virtual characters has to be LoD representations, based on subdivision surfaces (subD), rather than blocked resolution meshes that are made of triangles, or Non-uniform rational B-spline (NURBS) models that present severe topological restrictions (De Rose et al., 1998). Thanks to the achievements in both the fields of mesh parameterization and compression by means of displaced subdivision surfaces, or DSS (Lee et al., 2000), new standards have been achieved in the first decade of this century through the progressive implementation of this variable-level-of-detail representation in the main geometric modelling applications that are addressed to entertainment. The main advantages of the displaced subD are: compression of morphologic detail, high portability, adaptive tessellation, back-face culling (Bunnell, 2005). A strong limitation to an extensive use—in the field of reality-based models for documentation—is that the main subdivision criteria/rule that is implemented in commercial applications, the Catmull-Clark (Catmull and Clark, 1978; De Rose et al., 1998), works more efficiently with quad-dominant meshes, that are far from being a standard in the field of geomatics. The basic idea of subdivision surface is that a mesh M^0 (a polyhedron roughly approximating a shape) can be iteratively subdivided using a refinement scheme, producing a smooth surface that is, in the case of Catmull-Clark approximating scheme, a bi-cubic uniform B-spline. Lee et al. (2000) developed a research line that "merged" the possibility to increase the geometric resolution of a mesh (Figure 2) with the opportunity to modify the position of the vertices belonging to progressively higher resolution mesh using a displacement map (Blinn, 1978).

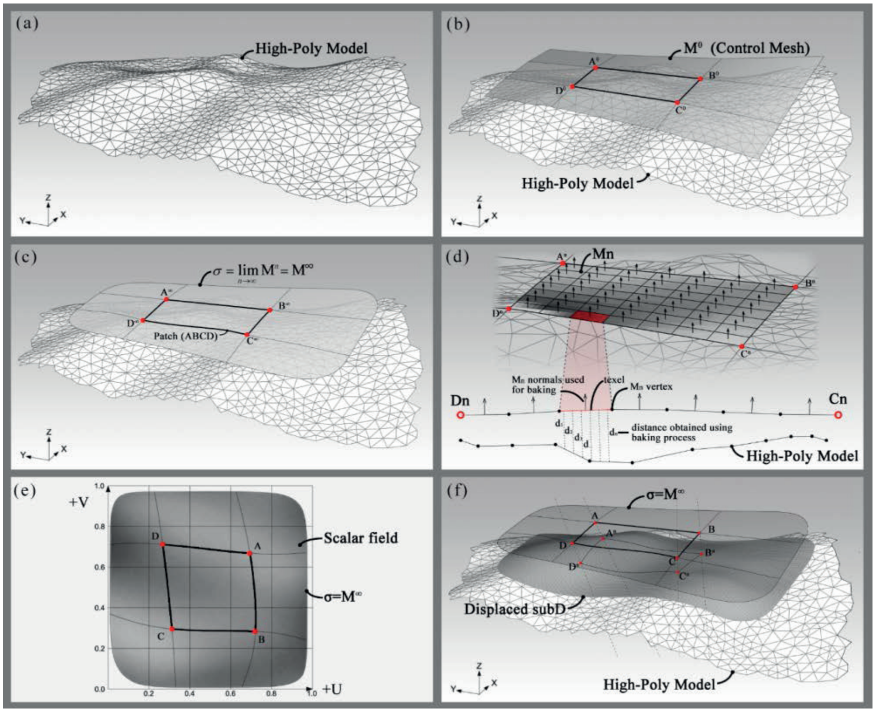

Figure 2. (**a**) high-poly model from active/passive sensor; (**b**) the mesh covered by quadrilateral polygons, M^0; (**c**) M^0 converted into a subdivision surface; (**d**) baking process performed in order to calculate the distances between subdivision surface and high-poly model into a greyscale bitmap; (**e**) parameterization and corresponding scalar field obtained through baking; and, (**f**) the final output is a Level of Detail (LoD) model that fits with the original high-poly mesh.

The last decade has seen further developments and implementation of this techniques, in particular, once High Dynamic Range (HDR) file formats, as the OpenEXR, extended the possibility to store data inside a single displacement map: from 256 "steps" of a 8-bit grayscale to the wider range provided by 16-bit floating-point, 32-bit floating-point, and 32-bit integer pixels (http://www.openexr.com/). Time-consuming manual operations called "re-topology"—in the CGI jargon—have been necessary for years in order to "cover" high-poly meshes that are formed by triangles with quadrilateral polygons, and make them fit with the requirements of subdivision surfaces. Among them, in addition to quad-dominancy, the problem of valence should be mentioned: the continuity of first and second derivatives (C^2) is verified only in points of valence equal to four, namely all of the vertices in which four edges converge. For all the other cases, called "singularities", C^2 cannot be verified and shading discontinuities may appear. This approach can be considered as to be equivalent to reverse-modelling pipelines based on coating, by means of NURBS patches, high level of detail meshes from sensors (Figure 3). The need to escape, or limit, manual "re-topology" (it also requires skilled and experienced polygonal modellers) led to the development of several researches based on the automatic and semi-automatic detection of features and curvature lines on non-structured triangular meshes with the aim to use these morphological hints to obtain quad-dominant meshes (Lai et al., 2008; Jacob et al., 2015). Several entertainment applications, focused on character modelling and organic modelling through mesh sculpting—namely anthropomorphic and phytomorphic assets with smooth flowing shapes and absence of sharp creases—progressively implemented automatic remeshing with quads (e.g., Pixologic ZBrush has Zremesher, The Foundry Modo implements Automatic Retopology Tool, Pillgrim 3D Coat has Auto-Retopo, etc.), other research projects led to stand-alone applications that were aimed at these kind of remeshing (Instant Meshes). In general, the output quad-mesh from these automatic solutions tends to be isotropic, and, in the case of complex shapes (characterized by multi-connected elements), several singularities are produced; in order to get rid of these problems, several tools and parameters are included in such applications (interactive guides, definition of areas with higher detail, general smoothing to be applied before remeshing, etc.), but a final manual completion is, in general, needed (Figure 4). The higher the number of polygons of these final meshes, the higher the time needed to complete them by means of bridges, hole filling, etc.

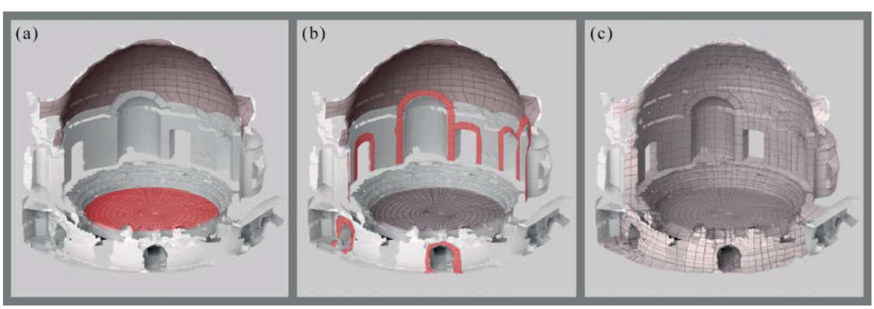

Figure 3. Manual quad-dominant remeshing applied to Heliocaminus's Baths at Hadrian's Villa: (**a**) primary surfaces; (**b**) secondary surfaces; (**c**) the final model obtained by making bridges among bands of polygons.

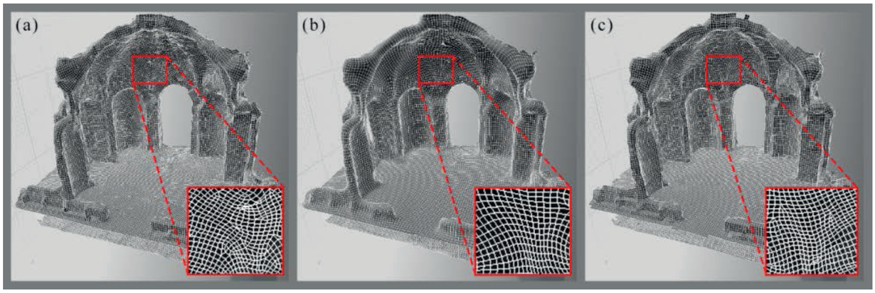

Figure 4. Automatic re-topology tests on the Vestibule of Piazza d'Oro in Tivoli: (a) The Foundry Modo; (b) Pixologic ZBrush; (c) Instant Meshes (ETH, CNR-ISTI, Università dell'Insubria).

In order to establish a correct relation between a quad-mesh and the bitmap that is responsible for the displacement, an adequate parameterization is needed: also, in this case, increasingly more accurate automatic and semi-automatic methods have become widespread in the field of CGI applications (Cipriani et al., 2014). The current state of the art of parameterization includes isometric (length preserving), conformal (angle preserving), and equi-areal (area preserving) solutions to be applied to open or watertight meshes. In this last case, the manual selection of a connected tree of edges needs to be used for braking the connectivity of the mesh inside the parameter space. The possibility to mix different parameterization criteria inside modelling applications allows for the full use of the parameter space, in which colour and other information are encoded (normals, displacement, global illumination solution, occlusion, etc.). A fundamental aspect of the pipeline explained here deals with avoiding automatic parameterization of heavy triangular meshes that leads to poor (*u,v*) layouts and a general waste of pixels, as well as an uncontrolled number of islands (or charts) in the parameter space: a typical feature when working on dense textured meshes from SfM/MVS. Optimized and easy-to perceive 2D versions of quad-meshes, with a correct texel density (with respect to the needed output), is the fundamental step in order to obtain a reliable displaced subdivision surface (Figures 5 and 6). It is safe to say that Structure from Motion (SfM)/ Multi View Syereo (MVS) applications have been inspired by some (*u,v*) checking tools included inside entertainment software to perceive the magnitude of the polygonal stretching amount occurred during the 3D-to-two-dimensional (2D) transformation, fill ratio and overlap ratio. A crucial factor for a correct result, once the displaced subD is completed, is a correct parametrization, as well as a correct resolution of the OpenEXR displacement map, with respect to the original high-density mesh that is made of triangles. The process that leads to this bitmap is called "baking", namely a render-to-texture solution, whose basic functioning is illustrated in Figure 2d: it should be noted that the theoretical subdivision surface σ—the limit surface that is obtained applying infinite times the subdivision criteria—never enters into play during this process. In fact, the calculation of each distance from subD and high-poly model is de facto the deviation from a blocked resolution subD and the high resolution mesh from scanner/photogrammetry. Before launching the calculation (baking), it is fundamental to balance the following factors: the resolution of the original mesh should be matched by the resolution of M^n; the resolution in pixels of the displacement map should match the desired number of polygons (e.g., 4096x4096 pixels can theoretically supply the subD with 16777216 height displacement values). The metric accuracy of displaced subD in the frame of Cultural Heritage applications has already been tested (Guidi and Angheleddu, 2016; Merlo et al., 2013) using deviation tools inside the specific applications. In Figure 7, the results of a test that is conducted on a niche from Piazza d'Oro at Hadrian's Villa are shown, in which the subdivision criteria that are adopted were the proprietary one from the Foundry Modo, and not the classic Catmull-Clark. Then, the role of parameterization is fundamental for a reliable result, but the interest towards optimized and easy-to-perceive 2D versions of meshes provide further opportunities concerning both semantics and the photo-realism of 3D digital assets. If the "pseudo-development" provided by parametrization tools allow an easy interaction between the user and the texture (Cipriani et al., 2015), also an easier and more accurate 2D bitmap editing is possible; for instance, materials like conductors (e.g., gold tesserae of mosaic tiles) need special alpha images in order to specify different bidirectional reflectance distribution function (BRDF) behaviours upon the same mesh (Figure 8).

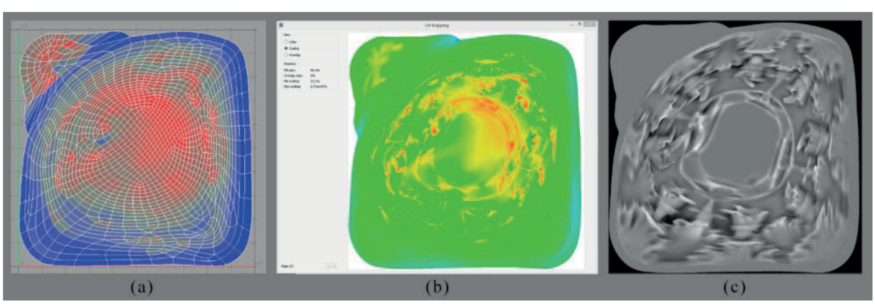

Figure 5. A parametrized subdivision surfaces (subD): (**a**) visualization of parameterization distortions inside a computer-generated imagery (CGI) application; (**b**) an analogous visualization recently included inside a SfM/MVS application; and, (**c**) displacement map storing distances between subD and high-poly mesh: excessive stretching leads to less reliable displaced subD.

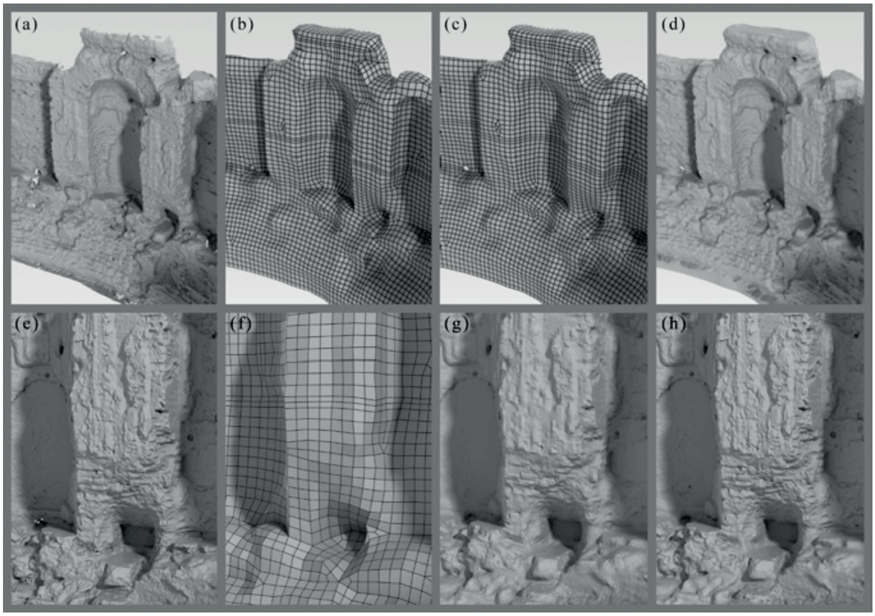

Figure 6. (**a**) high-poly mesh, 42.8 millions of polygons; (**b**) quad-dominant mesh *M*^{0}, 40,956 polygons; (**c**) *M*^{n}, LoD; (**d**) displaced subD, LoD; (**e**) detail of the masonry (high-poly model); (**f**) detail of the coarse mesh, or *M*^{0}; (**g**) increasing of the detail: 78,4330 polygons; and, (**h**) increasing of the detail: 20.8 millions of polygons.

In order to use the full power of render engines—in particular global illumination—on Lambertian surfaces, a shadow attenuation/removal on apparent colour textures is advisable. In fact, once a 3D digital model and the corresponding texture are created, a number of problems arise during the rendering: it is the so-called double shadow effect (DSE), which is due to the excessive pieces of information encoded in colour texture from SfM applications. For this reason, in CGI, they distinguish between apparent colour and diffuse colour: the first is obtained once the frames are re-projected on the model, while the second is the final result of an editing process aimed at removing shadows and other chromatic alterations caused by the interaction with other objects and environment. Focusing on the problem of BRDF diffusive component, several commercial applications facilitate the conversion of apparent colour into diffuse colour (e.g., CrazyBump Software CrazyBump or Rendering Systems ShaderMap). However, those solutions do not always fit with the chromatic reliability that is needed for Cultural Heritage. Neither, academic studies on sharp shadow removal on single pics (Fredembach and Finlayson, 2005; Kumar and Kaur, 2010; Guo et al., 2011) seem to be fitting with the typical problems to solve in architectural representation. In fact, we always try to get rid of sharp shadows in favour of photographic campaigns that are carried out during overcast sky (Martos and Cachero, 2015). Sophisticated shadow removal procedures are based on the knowledge of a more detailed ensemble: the object shape (including its position and orientation), natural, and artificial lighting sources, the exact timing of the photographic campaign and environmental lighting (Debevec et al., 2004); in this way, it is possible to achieve the spatially varying diffuse surface reflectance of a complex scene, with diffuse surfaces that are lit by natural outdoor illumination. The shadow removal technique (Cipriani et al., 2015b) applied in the case studies from Hadrian's Villa are based on two main points: the first is the possibility to have at one's disposal both three-dimensional geometry and the illumination of the scene. This includes the sensor/cameras location, the light source direction, and the observed object geometry, from which a priori knowledge of shadows projection is derived. Both direct and indirect illumination are "baked" and stored inside a grey scale image, saved in OpenEXR format, subjected to specific exposure correction and HDR toning.

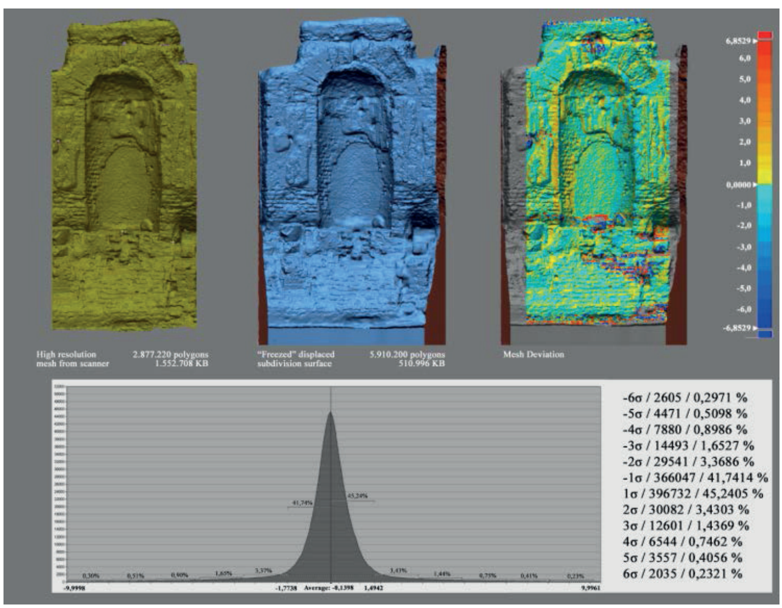

Figure 7. Deviation between the original high-density model from scanner and the corresponding displaced subD model obtained through automatic quad re-meshing (with some minor manual interventions).

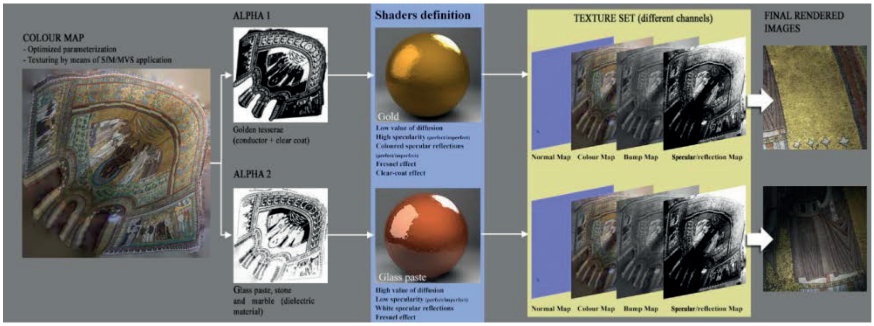

Figure 8. Texturing scheme for San Vitale's apse (Ravenna). The control on mesh parameterization enables the possibility to define different shading behaviours upon the same mesh. In case of poor (*u*,*v*) layouts characterized by high number of islands such possibility is precluded.

This grey scale image, once converted into a conventional one (8-bit per channel), can be used as a mask that is able to "blend" two different textures inside a bitmap-editing application. The two textures are obtained from the same set of images undergone to two different colour calibration using different "hero shots" (Gaiani et al., 2016). The first X-Rite ColorChecker is captured once it is placed on a reference area for bright zones, and the other chart is placed and acquired as a sample for darker areas. The first texture is then correctly exposed for the majority of the subject, while the second is over-exposed, except for deeper shadowed zones. Thanks to the blending provided by the above mentioned HDR map, the diffuse colour texture results are "flat" because it is deprived of shadows. The model in Figure 9a,c with such textures applied do not present too dark areas (DSE) once re-illuminated if compared to those obtained through standard colour processing techniques. On the contrary, other strategies based on tone mapping from HDR images (in this case from RAW image files) tend to produce over-exposed areas on brighter parts of the building, also loosing colour consistency (Figure 9b,d).

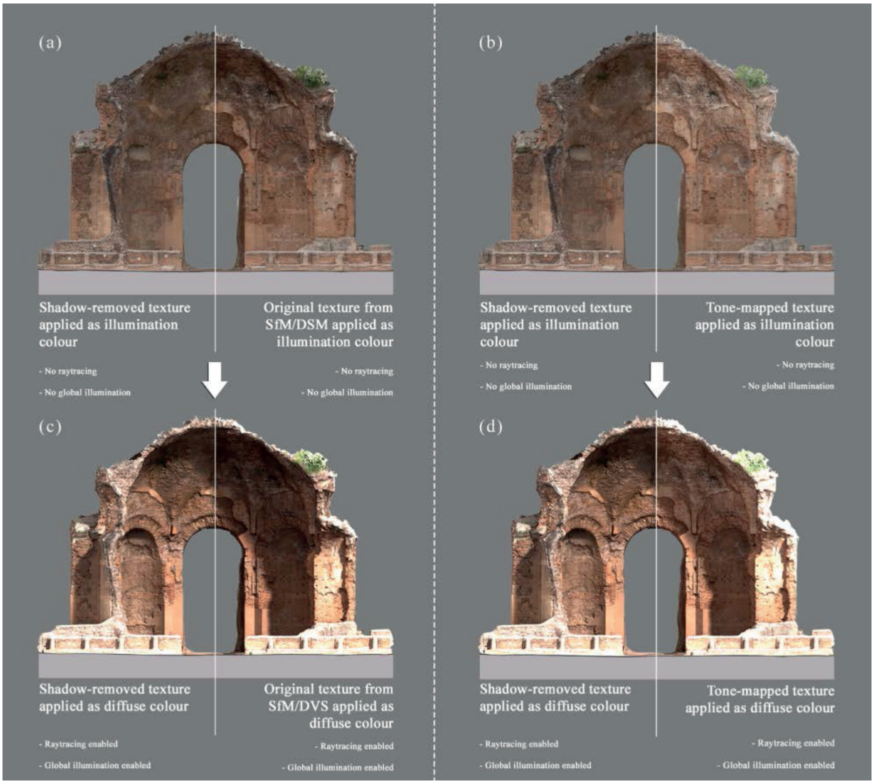

Figure 9. Vestibule of the Piazza d'Oro at Hadrian's Villa. Comparison among textures obtained by means of different pipelines: shadow-removal technique, colour calibration based on chromatic reference (X-Rite Colourchecker, tone mapping.

4. Case Studies

The tests carried out by the research unit are centred on two Italian UNESCO sites: Hadrian's Villa and late Antiquity and Byzantine monuments from Ravenna.

Cases from the pavilions of Hadrian's Villa are presented in order to underline different issues ranging from digitization of optically non-cooperating materials, to the texturing of approximately Lambertian surfaces, and, finally, semantic characterization of the following constructive elements:

- Main masonry: *opus mixtum.*
- Entablatures: travertine, Carrara marble, concrete.
- Columns: serpentine marble, concrete.
- Floor/groundworks: *opus caementicium* traces with footprints of removed elements in opus sectile.

In the case of Maritime Theatre—the Hadrian's personal domus—and the great southern nymphaeum of Piazza d'Oro (a vast multifunctional tricliniar area) archaeologists and architects working on it needed "multi-purpose" 3D model that could be used for the production of drawings (orthographic projections, perspectives, axonometric views), to be compared to archival documentation and historical drawings.

Models had to be specifically designed in order to store and facilitate the visual outputs underlining man-made alterations that occurred during the last centuries (ranging from plundering of archaeological finds to bad or non-intended interventions), and, last but not least, interactive models for enabling virtual anastylosis.

The achievement of multi-scale 3D models, namely LoD representations to be used as tools for virtual anastylosis become than a fundamental issue of the research unit working on both the pavilions of Hadrian's Villa, and on scattered elements once belonging to those buildings, in particular marble entablatures (stored in museums and *antiquaria*).

For the monuments from Ravenna (Arian Baptistery and the Basilica of San Vitale), the main focus was the achievement of a methodology enabling a more efficient BRDF definition for digital models of mosaic surfaces obtained through SfM-DSM pipelines. For these last cases, the problem of topology, as well as image and mesh segmentation, was crucial in order to supply render engines with a detailed modulation of reflectance values.

5. The Proposed Approach

With the aim to solve the problem of how to achieve reliable, multi-purpose models in compliance with the focus of this research, a five-step methodology was developed:

- A first draft point cloud segmentation is carried out manually in order to export toward mesh-processing applications single structural elements of the comprehensive point cloud. Then they are converted into high resolution meshes slightly bigger than the architectural element they represent. The set of independent high definition watertight meshes are achieved through global remeshing (in 3D Systems Geomagic design X) in order to get rid of both topologic and geometric defects (Cipriani et al., 2014). In case of Maritime Theatre or Piazza d'Oro, the list of categories is the following: columns (C), walls (M), entablatures (T) and sectors of floor split into original floor (OF), and simple soil (F). These meshes are aimed at forming a semantic partition on which the optimization and integration process will be carried out through techniques coming from entertainment applications (displaced subD, normal, displacement mapping, etc.).

- After an interdisciplinary discussion phase (with archaeologists, restorers, experts of history of art) a priority list is defined: each part of the complex is evaluated in order to understand its relevance and reliability. Semantics, in case of complex archaeological site/buildings, has to be considered as an all-encompassing tool to deepen the understanding of a building: the model, as well as its parameter space (namely, the way the model is split into (*u,v*) reference space), have to encode and make explicit characters/issues that otherwise could be misinterpreted on the basis of classical treatises. In other terms: strictly formal readings, based on classic orders (*genus*), may be quite far from being complete and reliable. Moreover, elements like floors, as well as portions of masonries, still include relevant formal features, enabling further interpretations, in particular, for removed elements.
- In order to improve the model's portability, reliable and less reliable/erroneous elements are optimized in two different ways. On the one hand, highly detailed models of a building's specific parts (flat elements as floors without specific decorations, ground, restored columns, etc.) have been converted into "low-poly" models, then they were parametrized, and finally, in order to apparently re-establish the original detail, normal maps have been calculated using the typical render-to-texture solutions called baking (Cohen et al., 1998). On the other hand, entablatures, columns, marble elements that are characterized by refined decorations and bass-reliefs, *opus caementicium,* and earthenware regular trails on the floor undergone a quad-dominant re-meshing in order to convert them into displaced subD with OpenEXR texture applied (Lee et al., 2000, Fantini 2012, Guidi and Angheleddu, 2016). Both quad-dominant and low-resolution triangle meshes are converted into Constructive Solid Geometries (CSG). In some cases, depending on special needs of the final model, it can be more advisable to carry out a semantic partition (Cipriani et al., 2014): in that case, it is the summation of a set of meshes that leads to a watertight mesh thanks to specific modelling procedures aimed at supplying continuity (Figures 10 and 11).
- All of the models were then textured using SfM applications since laser scanner and photogrammetric campaigns were carried out at once using a common network formed by ringed automatically detected (RAD) coded targets (Cipriani et al., 2015a).
- For approximately Lambertian surfaces a shadow removal process is carried out (masonry, bricks, mortar); for mosaic tiles an additional segmentation is performed in 2D, using alpha channels in the parameter space in order to apply different shaders to glass paste, golden tiles and stones (Figure 8).

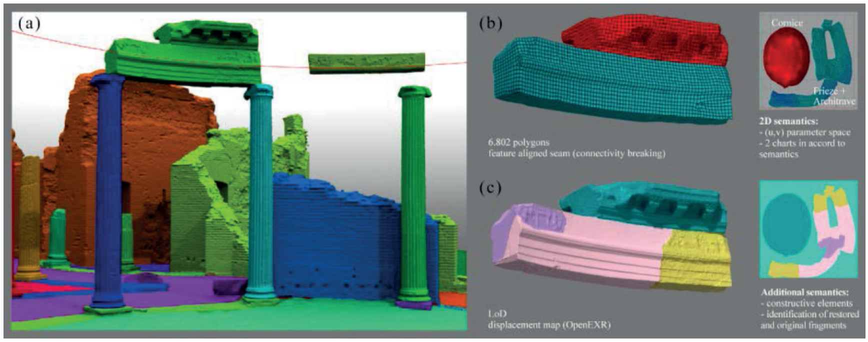

Figure 10. the Maritime Theatre at Hadrian's Villa: (**a**) view of the model showing a detail of the entablature, with a fragment of frieze located in the supposed original position: each colour is associated to an individual mesh and it represents a first draft segmentation; (**b**) the entablature, as well as other parts forming the whole model, are displaced subD made of quads: parametrization can be used as a second segmentation since the two islands are in accord to structural nature of the piece; (**c**) additional segmentation stages can be carried out in order to underline the nature of each fragment included inside a unique piece.

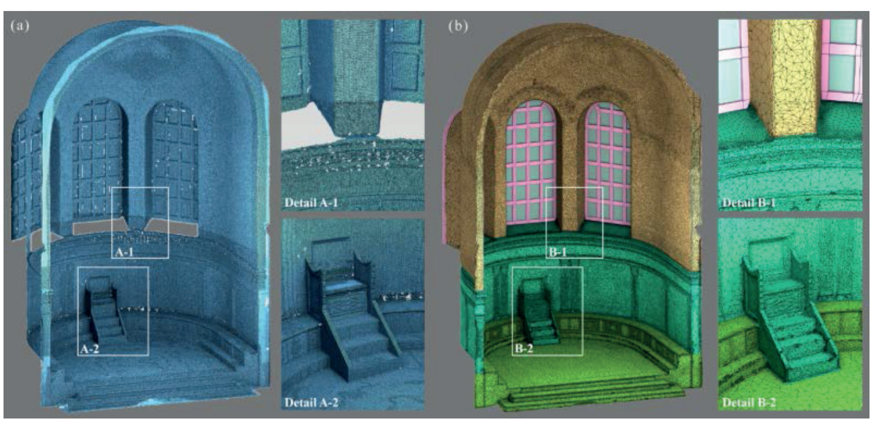

Figure 11. Semantic partition on the San Vitale apse: (**a**) High-poly mesh made of triangles and detail underlining the presence of voids; (**b**) a low-poly meshes made after the semantic partition. A complex task, once working with triangles is the one of following the curvature flow when breaking the connectivity among faces. In these cases quad-dominant meshes are more advisable.

6. Conclusions

The pipeline that is summarized in this paper leads to the achievement of highly compressed meshes, while keeping all of the acquired morphologic detail gathered with sensors of a different nature. The strategy adopted here, underlines the role of displaced subD as one of the most interesting strategies in terms of visual reliability and data compression, even if this representation technique is currently far from being a standard in the field of remote sensing/surveying.

With the only exception of some high-end program belonging to design/mechanical engineering, subdivision surfaces cannot "dialogue" with the current scenario of applications for geomatics, so they have to be "frozen", i.e., blocked at a proper resolution and exported in other formats. At the same time, displaced subD are widely spread among entertainment applications, and from this point of view, their implementation inside mesh processing and reverse modelling applications may facilitate the dialogue with experts of dissemination by means of animations, rendering, as well as game developers who feel more comfortable with such models.

To understand why low resolution quad-dominant meshes are a standard inside entertainment software is food for thought for the community of developers in the field of commercial and open-source applications dedicated to survey.

It will be interesting to see whether or not state of the art applications in surveying will introduce polygonal "quads" in the next few years; moreover, due to the high interest shown by VFX software houses toward automatic quads-remeshing, it is safe to say that in the years ahead, we shall see robust implementations of these algorithms in several applications. In commercial terms, a software house in the field of SfM/MVS, which will introduce special tools that are aimed at facilitating the workflow for the production of 3D digital assets for gaming industry (quad re-meshing, integrated parametrization tools, baking of normals, displacement, etc.) could gain high market shares (avoiding the current practice to import and export data, jumping from an application to another).

A 2D (u,v) reference system that is visually consistent with the corresponding 3D model in (x,y,z) can also open a door for a deeper exploitation of parameter space, seen as an auxiliary to semantic enrichment.

The final models comply with the requirements stated: the visual outputs in suitable for both animations, rendering, and graphic outputs that are useful for documentation, and also in the frame of restoration and maintenance practices (Figures 12–14).

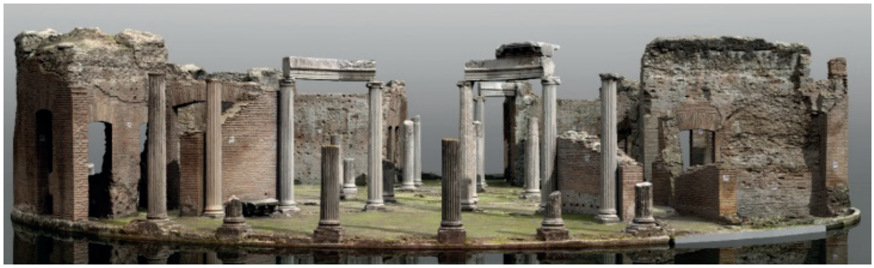

Figure 12. The Maritime theatre digital model obtained through the pipeline exposed in the paper. It can be efficiently used as the base for virtual anastylosis and other studies. Every part of the model is in the form of Constructive Solid Geometries (CSG) and allows sections as well as the production of reliable high-resolution ortho-image.

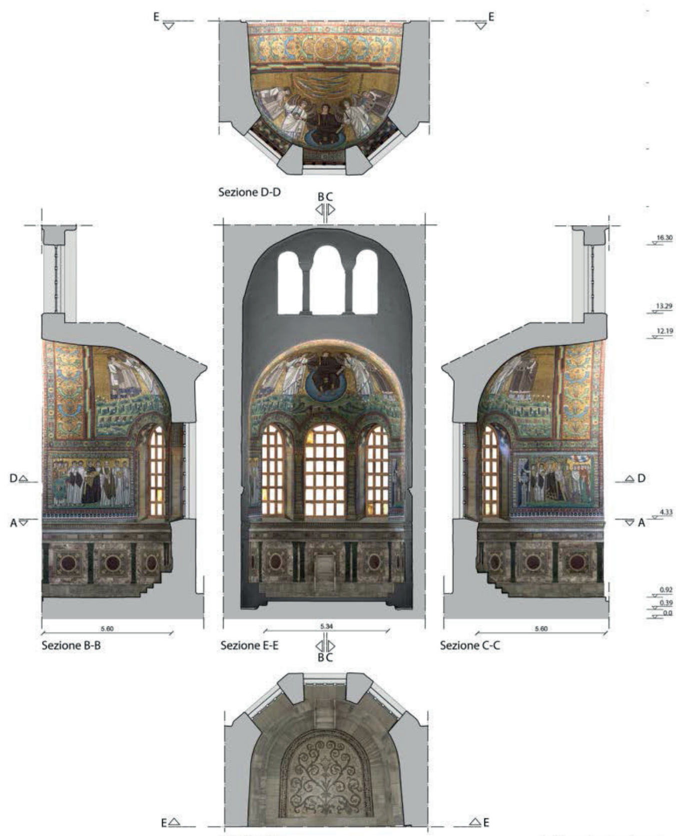

Figure 13. Architectural drawing obtained using the digital model of the apse. The model is also suitable for accurate simulation of light and materials.

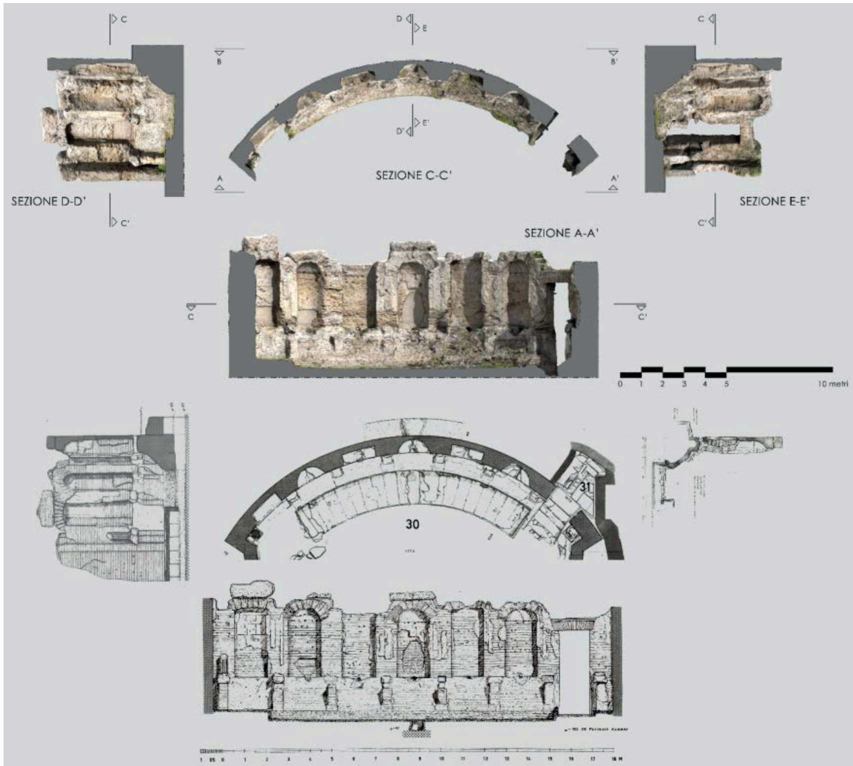

Figure 14. Comparison between orthographic representations of the Southern Nynphaeum at Piazza d'Oro. Displaced subdivision surface model (modelling and texturing by Giacomo Mussoni), traditional survey by Friedrich Ludwig Rakob (1967).

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