

DIGITAL SURVEY OF ANCIENT MOSAICS OF RAVENNA

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ABSTRACT:

The aim of this paper is to show a methodology to ease problems due to the richness and heaviness of files of meshes derived from the digital 3D survey of mosaics, in order to store them in databases that can be accessible via Internet. In particular, the paper illustrates a comparative application of mesh simplification algorithms in order to simplify meshes derived from laser scanners without loss of the required details in 3D reconstructions.

Despite the apparent two-dimensionality of these artefacts, mosaics have generally different levels of geometric complexity. In addition, problems due to occlusions and to the semi-transparency or reflectance of tesserae can effect metric measures obtained from laser scanners, requiring long post-processing operations of the derived meshes. The amount of these operations mainly depends on mosaics characteristics and on the aim of the survey. In order to allow scholars to access via web to 3D data collected in information systems, for example, meshes have to be simplified in order to show different levels of detail according to different and changing communication aims. This paper shows and compares two different approaches to the problem. In order to obtain different models corresponding to pre-defined LODs, a global and a local incremental simplification of triangular meshes are applied to the Master Model. The purpose of preserving feature edges and varying tessellation density is reached testing different algorithms that are available in common modeling packages.

1. INTRODUCTION

During last years, the availability of digital instruments that allow to acquire 3D information and rebuild digital models of artefacts has encouraged their fast widespread in the field of Cultural Heritage. Today the technology and methodology to acquire reality and rebuild replica of it is rather mature and has multiplied very accurate digital surveys and reconstructions. But despite this availability, some aspects still have to be solved, for example, both to define qualitative standards for the acquisition of artefacts and for the post-processing of data that allows to share the results of surveys with different and changing users.

The planning of a digital survey is a very important phase upon which the quality of the results depends. The level of detail of the information to be acquired is, for example, a fundamental aspect that has to be pre-defined and that mainly depends on the characteristics of the object to be modeled and on the purpose of the survey.

In order not to repeat survey campaigns or to exploit the potentials of digital instruments, the actual trend is often to collect the most accurate and detailed information about artefacts and then post-process and, generally, simplify data, to adapt them to different and changing requirements.

These post-processing stages can be very long and often need the intervention of different operators, depending on the geometrical characteristics of artefacts, on the accuracy of the survey and on communication aims.

In this scenario, this paper has the purpose to show the post-processing work that is required in order to simplify digital models of artefacts that have very peculiar characteristics.

The present case study are the mosaics of Ravenna. They are unique artefacts which importance depends both on their

narrative and decorative characteristics, and on their peculiar construction techniques. Because of their communication intents, mosaics are strictly related to the cultural context in which they were built. In some cases, this relationship and changes of narrative intents led to their deep transformations through centuries, that rarely have been documented using graphic representations. Moreover, their degradation and restorations have profoundly changed their aspect through time. As far as their construction systems are concerned, mosaics are unique artefacts that have peculiar geometrical and material characteristics.

These artefacts generally have two levels of geometric complexity: one depends on the geometry of the support on which mosaics are placed (they can lie on semi-planar surfaces, such as walls or floors, or else they can be located upon columns, vaults, etc.) and the other one characterizes the shapes of single tesserae, their micro-scale details, their misalignments, their inclination and location in relationship with mortar.

Although their predominantly 2-Dimensional geometries, mosaics of Ravenna have been surveyed in past decades using different techniques.

In the 60's, for example, during the restoration of the basilicas of Ravenna, restorers and painters were commissioned to carry out accurate surveys of mosaics. In this occasion, both 2-Dimensional drawings and paintings (mosaic cartons) and 3-Dimensional moulds were acquired in order to represent mosaics through the accurate reproduction of their shapes, colours, materials, dimensional characteristics and alignment of tesserae. In some cases colour information was directly painted upon moulds. Most of these surveys are extremely accurate both from a metric and a colour rendering point of view, so that they are considered works of art and are used both for documentation purposes and also as important teaching tools for Institutions dedicated to restoration.

Given the importance and uniqueness of the mosaics of Ravenna within the World Cultural Heritage, in 2007 they have been catalogued (Kniffitz, 2007; Kniffitz, 2009) and information about them have been collected and made accessible to everybody through the Mosaic Data Base promoted and developed by the International Center of Mosaic Documentation CIDM (www.mosaiccidm.it). Thanks to this extremely important work, iconographic, bibliographic, documentary references and information about their construction systems have been collected. But despite this important work, their 3D surveys using digital instruments and procedures still remain single episodes that haven't been translated in a repeatable procedure to be applied to the whole heritage that has already been catalogued.

In order to fill this lack and plan the addition of 3D information to the digital catalog of the mosaics of Ravenna, this paper deals with the problem of the management of their digital surveys. Because of the above mentioned geometrical characteristics of mosaics, and also of problems due, for example, to occlusions and to the semi-transparency (glass, marble, golden or silver leaf metal, etc.) or reflectance of tesserae that can effect metric measures acquired with laser scanners*, their digital 3D survey needs long and very careful application of decimation algorithms in order to simplify meshes without loosing the required level of detail of the information.

Therefore, although triangular mesh simplification is a mature technology, its application to mosaics, highlights problems and suggests solutions.

The goal of this work is to show and compare the application of decimation algortithms that are available in common modeling packages in order to obtain different derived models which correspond to distinct LODs to be used for different purposes. Particular attention has been paid to the quality control of the derived meshes.

2. RELATED WORKS ON SIMPLIFICATION ALGORITHMS AND LODS

Since the original approach based upon the decimation of vertices of meshes (Schroeder at al., 1992), these methodologies have been deeply investigated during the 1990's and have often been related to LODs.

This paragraph is by no means exaustive; it just gives an overview of papers that have surveyed these methodologies and algorithms. An interesting essay about the existing methods is, for example, Heckbert and Garland (Heckbert and Garland, 1997), that described different kinds of geometric entities on which decimation methods can be applied and that classified the available algorithms. But that contribution didn't evaluate the described methods.

Other important essays were Puppo and Scopigno (Puppo and Scopigno, 1997) and Cignoni et al. (Cignoni et al., 1998), which presented a classification, review and comparison among major simplification methods and LODs.

* An interesting contribution that highlights problems involved in this kinds of survey is introduced by Salemi et al. (Salemi et al., 2008). In their contribution, they show problems and results about the acquisition of ancient mosaics using different laser scanners in order to produce both a global model of a wide portion of mosaic and very small models of single tesserae. The paper also shows problems due to the use of laser scanners upon gold leaf and transparent tesserae.

These works were very interesting because they illustrated applications of the presented algorithms in relationship with multiresolution applied to computer graphics.

The technique of simplifying the resolution of geometric objects depending on their visual importance and position in relationship with the viewer was originally proposed by Clarke (Clark, 1976). Since then this has become a standard practice. The characteristics of geometric data structures that allow to improve LOD models have been collected by De Floriani et al. (De Floriani et al., 2004). While Garland (Garland, 1999) surveyed the most notable available algorithms and focused the attention on approaches that recognize hierarchical structures on surfaces.

These essays show the variety of algorithms and methodologies related to simplification of complex meshes in order to allow the use information for different purposes.

This paper has been conceived to test and find the most suitable solution to adopt in order to collect and manage 3D models of mosaics in information systems that can have different and changing users.

3. OVERVIEW OF THE METHOD

The case study of this the present paper is a triangular mesh of a portion of mosaic, derived from laser scanner, which has been submitted to some few cleaning procedures (filling of holes and elimination of abnormal faces, such as, for example, non-manifold, crossing, redundant and twisted ones) in order to have a continuous mesh without instabilities that could compromise the following application of simplification algorithms.

The goal of this work to obtain different meshes from the Master Model with good quality, corresponding to different purposes and LODs, has been achieved testing different simplification algorithms that are available in common modelling packages. For this purpose, PolyWorks®, MeshLab, Rapidform® and Autodesk® Maya® have been used.

The quality control of the simplified mesh depends on many aspects, including the geometrical characteristics of mosaics. The visible surface of mosaics consists in tesserae and mortar.



Figure 1. Fragment of mosaic that has been used to test the methodology. Tesserae are made of glass and their placement relative to the mortar creates occlusions.

Tesserae generally have rather flat upper surfaces (considering the Z axis perpendicular to the main location of the mosaic) and a polygonal boundary edge.

Due to the use of laser scanners on semi-transparent and reflective materials (marble, glass, golden or silver tesserae), these portions of meshes are generally very irregular and noisy, and it is not always easy to recognize and select boundary edges.

Moreover, if tesserae sensibly jut out from the mortar, it is generally difficult to access and survey their lateral surfaces and the mortar ones, because of occlusions.

The result is that most of the errors in measurements are concentrated in these areas.

Furthermore, tesserae and mortar have different geometric characteristics and importance in survey of mosaics; as a matter of fact, mortar is often replaced during restoration and consolidation of mosaics.

In addition, upper surfaces of tesserae are generally wider than mortar ones, that generally have one dimension prevailing over the others.

The consequence of these observations is that meshes can be deeply decimated on upper planar surfaces of tesserae, while in spite of their less importance, mortar surfaces can't be severely decimated because of their narrow cross sections. Therefore, simplification operations must progressively produce variable tessellation densities.

In this paper, two different approaches in incremental decimation of triangular meshes are presented and compared: a global and a local one.

The adopted method can be schematically presented as follows:

1. given an input continuous mesh (M_0);
2. apply different global smoothing algorithms in order to reduce noise and flatten irregularities on upper faces of tesserae;
3. evaluate the best solution for simplification aims and build the Master Model (M_M);
4. **METHOD 1 - Global simplification in order to have 2 LODs:**
 - given the smoothed mesh M_M , apply different global simplification algorithms;
 - evaluate the best solution (among M_1 , M_2) for simplification aims;
5. **METHOD 2 - Local simplification in order to have 2 LODs:**
 - given the smoothed and segmented mesh M_{MS} , apply different local simplification algorithms;
 - evaluate the best solution (among M_1 , M_2) to simplification aims;
6. compare and evaluate the best solution.

4. ADOPTED PROCEDURES

4.1 Global Smoothing

As already mentioned before, the input mesh (M_0) is a continuous triangular mesh which has been post-processed in order to make it robust and stable for following operational steps. The mesh is derived from laser scanner and has 32.000 triangle faces.

The decimation process is preceded by a smoothing phase that has the aim to flatten upper faces of tesserae and smooth mortar surfaces. These latter, in fact, are areas where measurements errors are concentrated; as a consequence, edges and boundaries located in these areas, would probably be the result of errors produced during the alignment of point clouds, so they generally can be eliminated.

At this stage, particular attention has to be payed to the preservation of boundary edges of tesserae.

Different algorithms have been applied, in order to evaluate the most suitable one following different requirements.

The definition of these latter and procedures to evaluate them represent the quality control of the whole process.

These procedures have provided both metric and visual checks in order to compare:

- metric distance between the input mesh M_0 and the smoothed one;
- visual comparison between M_0 and the smoothed one, in order to preserve boundary edges of tesserae;
- visual comparison between M_0 and the smoothed one, in order to increase the flatness of the upper faces of tesserae.

During this preliminary stage, in order not to increase the number of faces of the mesh, the following algorithms have been applied to the model:

MeshLab		
- UnSharpGeom (Laplacian smooth that uses unsharp mask that puts in more evidence ridges and valley variations)	calculates the average position with nearest vertex	fitted on new normals)
- Laplacian (for each vertex it	- Two Steps Smooth (first step: similar normals are averaged together; second step: vertexes are	- Depthsmooth (Laplacian smooth that is constrained to move vertices only along the view direction - in this case, Z)
		- Taubinsmooth
Rapidform®	PolyWorks®	Maya®
- Laplacian weight 0.1 (preserving sharp/marketed edges) - Laplacian weight 0.2 (preserving sharp/marketed edges) - Curvature weight 0.2 (preserving sharp/marketed edges)	- Smooth on Vertices (defining the max dihedral angle between adjacent normal vectors)	- Smooth Linear (increases the number of faces) - Average Vertices

Table 1. Smoothing algorithms used during the preliminary stage.

Metric and visual checks have been performed using both 3D models and 2D cross sections (Figure 2), in order to focus the attention upon critical areas.

As far as the metric distance between the original mesh M_0 and the smoothed ones, the algorithms that preserve the minimum distances are: *RFcurvature0.2*, *PWsmoothonvertices* and *RFlaplacian0.1*.

As far as the visual check of the preservation of boundary edges of tesserae and of the flattening of their upper surfaces, *MLUnSharpGeom* gives the best results, but the smoothed mesh is the most distant from the original one.

Local checks through cross sections have highlighted differences; Figure 2, for example, shows the deviation of the smoothed surfaces from the original one in some critic areas.

In areas 'a' and 'c', for example, the curve related to algorithm *MLUnSharpGeom* shows the most abrupt change of slope and therefore highlights boundary edges of tesserae, but at the same time it gives the maximum error.

This figure also shows the relationship between M_0 and the curves derived using *RFcurvature0.2* and *MYsmoothlinear*. These algorithms generate the most accurate smoothed meshes. Considering that the following simplification operations would have deeply change the shape of the mesh, the *RFcurvature0.2* has been applied on M_0 in order to obtain M_M .

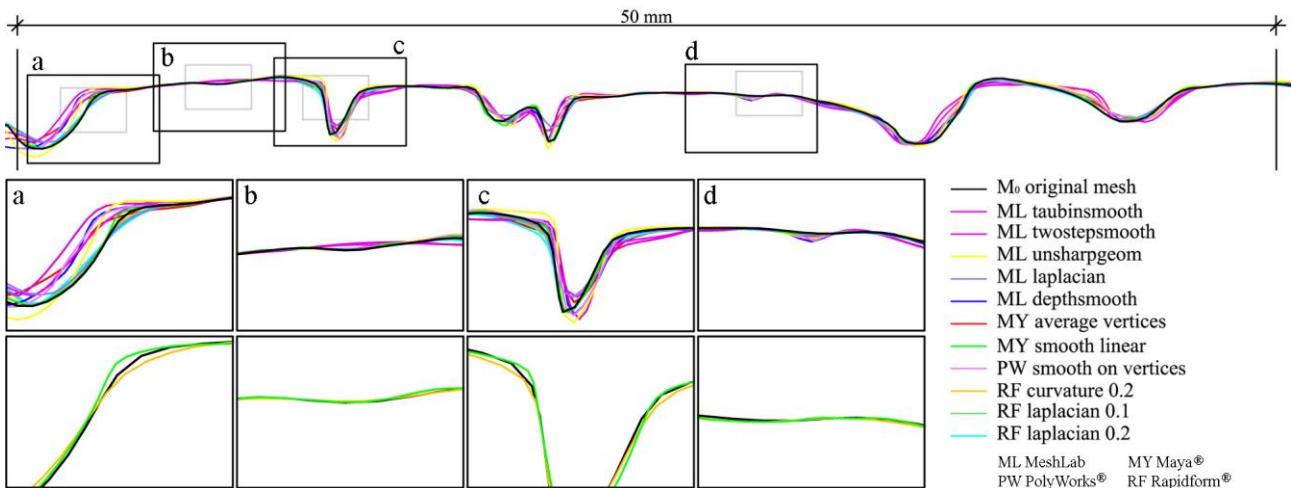


Figure 2. Local checks through cross sections of deviation among the Master Model and the smoothed ones. "a" and "c" areas highlight the behaviour of algorithms near boundary edges of tesserae; "b" and "d" areas show the upper flatness of tesserae. The bottom images show the deviation among MM and RFCurvature0.2 and MYsmoothlinear algorithms.

4.2 Master model and derived models

The smoothed mesh M_M has the same number of faces of the original one M_0 (32.000) and represents the Master Model of the mosaic.

The purpose of the following simplification of the mesh is to reduce its file size in order to allow different uses (e.g., from metric evaluation and measurements on accurate models, to simple visualizations of artefacts), eliminating redundant information when not required. In order to reach this aim, three LODs and derived models were defined:

- LOD₁ - M_1 : mesh faces are reduced to 50% (16.000 faces);
- LOD₂ - M_2 : mesh faces are reduced to 75% (8.000 faces);
- LOD₃ - M_3 : mesh surface is planar and only grafic effects are used in order to simulate reliefs and hollows using normal maps (Figure 3).



Figure 3. A third LOD for simple visualizations can be obtained using graphic effects (normal maps) on textured planes. Left, the textured plane; right, normal maps add details where geometry is simplified.

4.3 Global decimation

The global simplification of mesh M_M has been obtained testing algorithms available in PolyWorks®, MeshLab and Rapidform®. Given our case study and purposes, the most important parameter to be set using PolyWorks® reduction algorithm is the dihedral angle between adjacent normal vectors. If an angle is smaller than this threshold, then the respective faces are considered planar and the mesh is decimated.

Figure 4 -f shows that during the simplification phase using PolyWorks® algorithm, boundary edges of tesserae are preserved and the number of faces on semi-planar upper surfaces are deeply reduced setting the maximum dihedral angle to 180° (LOD₂).

MeshLab quadric edge collapse decimation algorithm allows to force planar simplification but the operator can't modify the parameters that define this constraint. As a consequence, small irregularities (e.g., small incisions on tesserae) can be erased and the mesh acquires an isotropic aspect (Figure 4 - c). Rapidform® algorithm automatically detects boundary and marked edges and allows to preserve them, but, again, the operator can't modify this constraint.

As in the previous smoothing stage, both metric and visual check procedures have been adopted to evaluate the most suitable solution.

As far as the first stage of simplification (LOD₁) is concerned, PolyWorks® algorithms provides the best solution in terms of metric distance and preservation of boundary edges of tesserae, while Rapidform® allows to flatten upper surfaces of tesserae, at the expense of geometric precision.

As far as the second stage of simplification (LOD₂) is concerned, PolyWorks® algorithms provides the best solution in terms of metric distance, while Rapidform® and MeshLab allow to flatten upper surfaces of tesserae and to preserve their boundary edges.

4.4 Local decimation

The local decimation of the M_M mesh requires the automatic selection and segmentation of portions of the mesh.

Given the characteristics of mosaics described in Paragraph 3, this stage has the aim to separate tesserae from mortar using automatic procedures and to apply different and incremental simplification algorithms to selected elements.

For this purpose, the selection tools that use constraints and that are available in the Autodesk® Maya® have been used.

Because of the peculiar geometry of the mesh, in order to limit manual interventions of operators, the most suitable tools to automatically select the upper faces of tesserae and separate them from the rest of the mesh, are the ones that select faces evaluating the angle between normal vector of adjacent faces and the ones that select faces that have a certain distance from a pre-defined plane.

Figure 5 shows the automatic selection of faces and a typical error that can occur when small irregularities are excluded from the selection. In these cases the manual intervention of an operator is required.

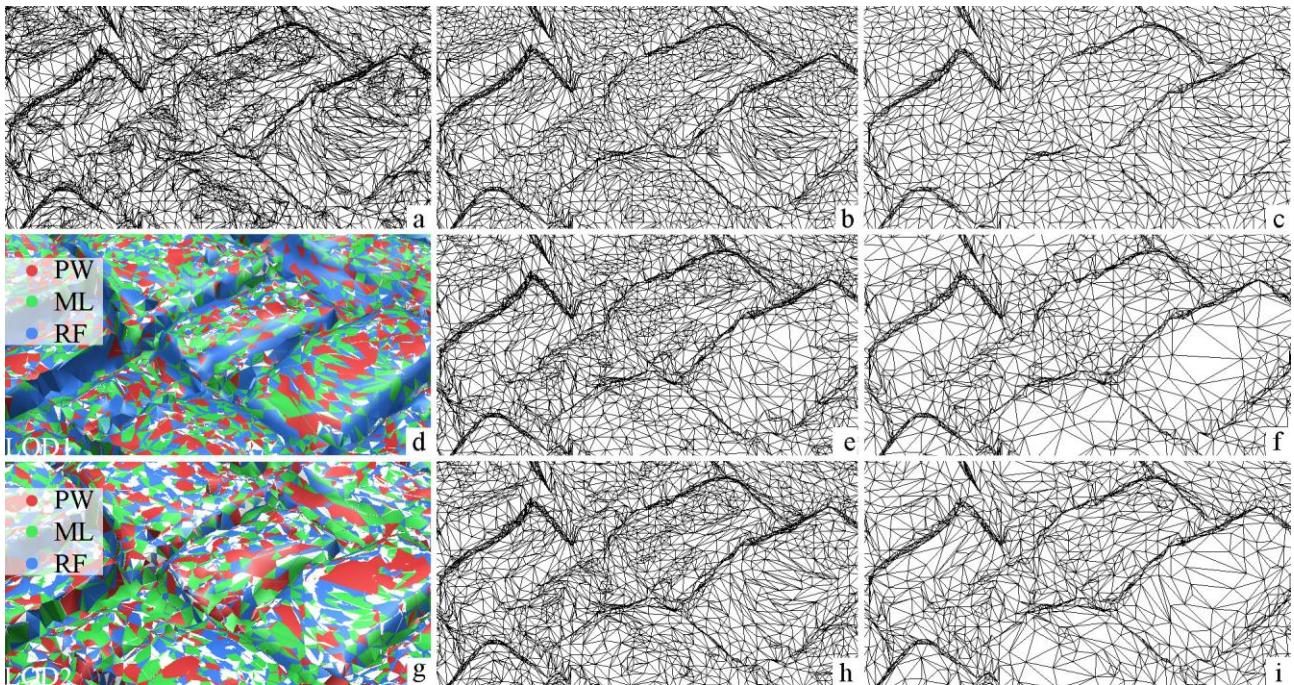


Figure 4. a Master Model M_M ; b and c global mesh decimation (50% and 75% reduction) using MeshLab algorithm; e and f global mesh decimation (50% and 75% reduction) using Polyworks® algorithm; h and i global mesh decimation (50% and 75% reduction) using Radipform ® algorithm; d LOD1 overlap of M_M (white) and M_1 obtained using 3 algorithms; g LOD2 overlap of M_M (white) and M_2 obtained using 3 algorithms.

During the local decimation phase, three procedures have been tested (Figure 6):

PROCEDURE 1

- given the segmented mesh M_{MS} , the Maya® decimation algorithm has been applied both to tesserae and to mortar, in order to obtain two LODs ($M_{1T}, M_{1M}, M_{2T}, M_{2M}$);

PROCEDURE 2

- given the segmented and decimated mesh obtained using Maya M_{1T}, M_{1M} ; the Rapidform® decimation algorithm has been applied both to tesserae and mortar, in order to obtain M_{2T} and M_{2M} ;

PROCEDURE 3

- given the segmented mesh M_{MS} , the Rapidform® decimation algorithm has been applied to tesserae ($M_{1T}: 75\%$); while the Rapidform® smoothing and reduction algorithms have been applied to mortar in order to slightly reduce this portion of mesh ($M_{1M}: \sim 8\%$ reduction).

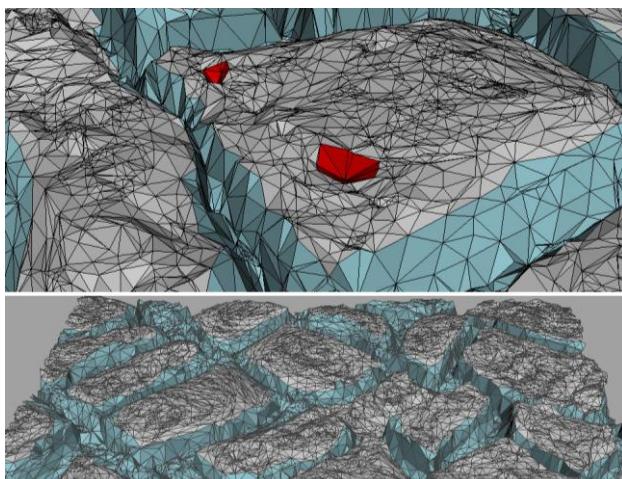


Figure 5. Selection and separation of the mesh.

The results of these tests have then been compared and the best solution for LOD₁ and LOD₂ has been evaluated (Figure 7).

Metric distance between couple of meshes and visual checks of the results have highlighted that the most suitable solution for LOD₁ is the decimation obtained using Maya® (Procedure 1, Fig. 7-b), while the combined use of Maya® and Rapidform® (Procedure 2, Fig. 7-g) is the best solution for the reduction to LOD₂.

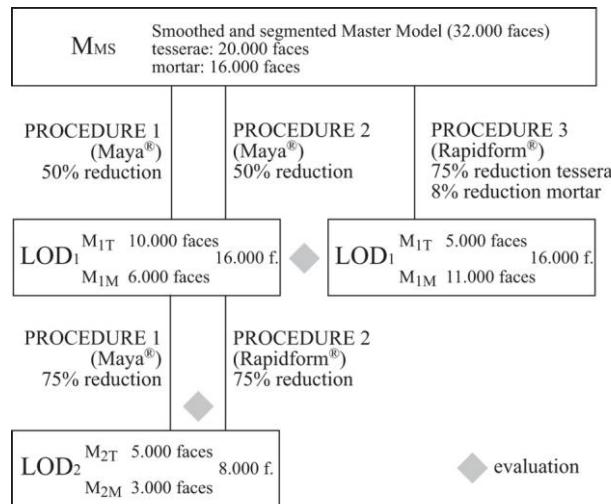


Figure 6. Local decimation procedures.

5. CONCLUSIONS

The present double approach (global and local) to triangle mesh decimation has stressed differences both in procedures and results. Even if local decimation allowed to have a more dense tessellation on mortar surfaces and a more sparse one on

tesserae, this simplification has some limits that depend on the ability of the decimation algorithm to preserve boundary edges. Moreover, the automatic selection of faces aimed at segmentation of the mesh, in some cases, needed the manual intervention of an operator. On the contrary, the global decimation in cases such as the present one, gives the best results. In particular, in the present case study, the Polyworks® algorithm gave the best results in terms of metric accuracy, while Rapidform gave the best results as far as visual simplification of shapes is concerned.

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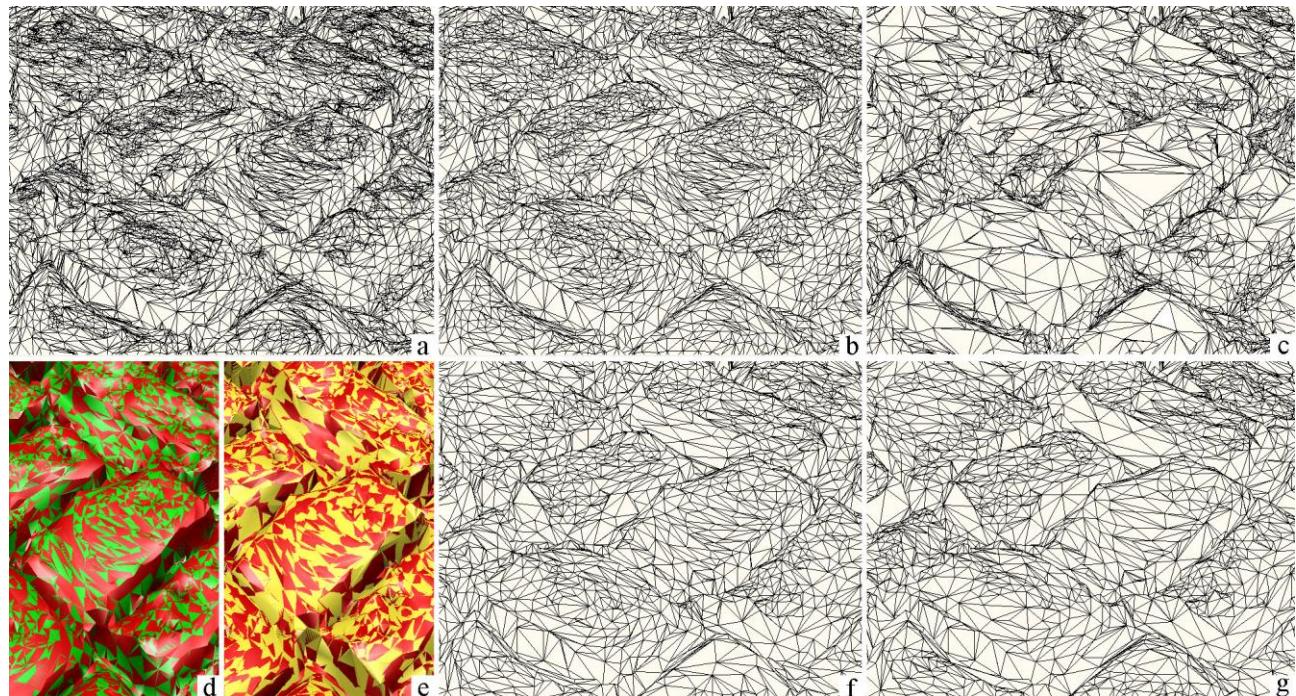


Figure 7. a segmented Master Model M_{MS} ; b LOD1 obtained with Procedure 1; c LOD1 obtained with Procedure 3; f LOD2 obtained with Procedure 1; g LOD2 obtained with Procedure 2; d overlap between the original mesh M_{MS} (red) and M_1 obtained using Procedure 1; e overlap between the original mesh M_{MS} (red) and M_2 obtained using Procedure 2.

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