DIGITAL SURFACE MODELS FOR ARCHITECTURAL HERITAGE ANALYSIS. THE SURVEY OF THE AQUEDUCT OF "LOS MILAGROS" IN MÉRIDA, SPAIN.

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ABSTRACT:
The documentation of a site such as a Roman aqueduct offers an excellent opportunity for testing the application of software resources and techniques which are usually applied on civil works and modern cartography. The linearity of this monument allows a very structured and systematic information management. We present a graphic documentary work which is part of a bigger project aimed at the consolidation, restoring and illumination of the aqueduct. This work serves as a basis for all of the involved sub-studies regarding lithology, archaeological analysis, rock and fabrics tests, and structural analysis. It also acts as the graphic support for thematic maps related to biological colonisation, vandalic attacks (graffiti) and other pathologies, history of restorations, etc.

The basic support for the survey works was based on widely-experienced topographic and photogrammetric techniques; mainly the use of robotic reflectorless total stations, analytic photogrammetric instruments (Leica SD2000 and Adam MPS2), digital systems, rectification etc. All of these techniques are all well-known among our community, but in this particular case further processes that imply some innovation in the field of Heritage Recording have been our contribution.

Triangular Irregular Networks (TINs) offer very interesting possibilities for deformation analysing, exact volume / mass calculations, material loss evaluations, measuring degrees of metheorissation, real time sectioning, automated slope field graphing, etc. The digital modelling of the building surfaces represents an important qualitative approach to overcome the limitations of wiremeshed models, as those digital models present a true three-dimensional topology that makes the interpretation of the stone limits truly objective.

Beyond the application of the above mentioned quantitative analysis, surface modelling offers new ways to get realistic virtual renderings. Three dimensional views that reveal qualitative aspects, such as texture and the response to different illumination ways, have been other goals of the obtained results.

1. INTRODUCTION

This paper aims at the description of a practical application of some tools offered by computer graphics, which are specific of the field of civil engineering in the context of the analysis of architectonic heritage. Professionals working on the preservation and documentation of heritage recordings very often have to face the problem of the inefficiency of graphic design programmes, when they try to present and manipulate the documented objects. In quite a few occasions, something as simple as achieving partial visualizations, without the presence of any obstacle or occlusion, implies certain problems that make it necessary to make use of strategies which are desproportionally complex in relation to the problem itself (big fragmentation in partial files, complex structures of layers or level with the only aim of differentiating orientations…). This is even more reproachable when, sometimes, this difficulty makes it necessary to do without some useful information, in order to make the visualization more legible.

 The problem of spatial superposition can only be satisfactorily solved by the application of some graphic tools which are not currently found in the most frequently used CAD programmes. In any case, the person doing the drawings must keep in mind that the line-strings he is drafting are, in fact, sides of objects. That is to say, they will have to build topological structures. However, as we all know, when doing restitution one tends to create very complex drawings which look like wire tangles.
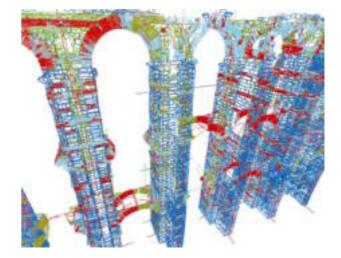

Figure 1. 3-D files of the Aqueduct.

Is it possible to build a topology with these drawings? Some would say so, but, although these "wires" can be spatially organised as well-connected and well-defined entities, this topology must be considered incomplete, as it only allows to distinguish whether a point forms part of a certain linear entity or not. This implies that when an ashlar stone of a monument is drawn as a complex of line strings, it behaves as a cage and we can't even distinguish for sure the inner space from the outer.

The models in which surfaces are interpolated by means of a triangle irregular networks (TINs) or squared grids are very commonly used in the context of aerial Photogrammetry. Also, the so called digital terrain models (DTM) have a wide range of application in the fields of civil engineering, agronomy, environmental studies and so on. Computers' brute force has made these models possible which are now considered to be their most efficient product in the context of digital topographic cartography. So why not try to use them in the field of architecture?

2. HOW?

The DTM are topological idealizations which describe the terrain surface. They are often called digital models of elevation (DEMs) and this leads us to think that, although they are built taking into account the three dimensions, one of them is of bigger relevance in their calculation: the elevation. the reason for this is simply gravity, which gives their universal sense to the concepts of up and down, whereas the position with reference to the other two fundamental axis are, in practice, impossible to distinguish. (Their association to geographic, magnetic, or any other kind of axis is just conventional). From the structural point of view, Gravity obviously also has a peculiar meaning in the field of architecture. However, architecture constantly defies it by making verticality the norm , whereas in nature everything tends to the minimum of potential energy, to the lower possible position, to horizontality. While in a terrain it is very uncommon to find conditions of inverse slope, and almost all the land's surfaces are visible from the eagles point of view, in architecture, the most significant surfaces (façades) are invisible from the aerial point of view. The programmes for terrain modelling make use of this fundamental distinction applying the scheme 3D=2D+1D and they are unable to form continuous models of architectural objects. However, they can be locally used for façades if the direction normal to these surfaces takes the role of privileged direction. This is normally solved in practice by folding down the façade on the horizontal level.

3. AN EXPERIENCE

Los Milafros aquaeduct, in Mérida (Spain), where this trick has been tested, offers a great structural systematism. That's why, as it often happens in the so called linear civil works (roads, trains, canals,…) great advantages can be granted to a system of reference which has three fundamental directions related to this structure. Gravity's direction will be the inevitable axis, whereas the direction of the pillars alignment will be the second one, which we have agreed to called longitudinal axis. The third one could only be the one perpendicular to the two above mentioned. Bearing in mind its form, the aqueduct can be described as a succession of pillars of squared plan linked by arches in three different heights. I the past a horizontal canal was found along the top but it has been destroyed by time. Each pillar can obviously be studied in its four different sides which can be dealt with separately: two on the sides (right and left) a frontal and a back side, which can be identified once we've

established a station increasing sense. The local origin of coordinates have been placed at the centre of each pillar and the two axis described above have been drawn at an integer value of elevation. These axis should serve as hinges to fold each side down on the horizontal level. By doing so we could deal with them as if they were terrains from which we could obtain DEMs.

The turn of each can easily be reversed about the same pivot and the digital skin can be driven back to the erected position.

Figure 2. A pillar face DEM considered as a terrain.

4. HOW IS A SURFACE DIGITAL MODEL MADE?

In a cartographic context, the terrain is modelled from linear and punctual features extracted during the photogrammetric or land surveying. Some of the linear entities represent break lines in the curvature of the land surface, hard variations of the slope, while some others are not noticeable in terms of relief but just lie down on the ground as it occurs with spot elevations and other punctual features. Elevation, shape and type (breakline or random) of all these elements will allow us to figure out the topography of the terrain. Terrain modelling programmes use them also to interpolate a mathematical surface formed by triangles connected by their sides. The programme only needs some rules to handle the graphic entities whether as breaklines or random usually by means of association between behaviour graphic codes (level, colour, style, stroke).

In the architectonic case the something similar can be done in terms of modelling surfaces. By differentiating through graphic codes one could establish those graphic entities which represent disruptions in the curvature of the surface and those that simply lie on it.

In the project of restoration of the aqueduct the criteria for the coding was primarily based on thematic aspects. As a result, to each building material used (granite, quartzite, ceramic, rubble concrete, metal...) corresponded a layer or group of layers. Some thematic layers gathered non-structural features such as paint stains, moss, lichen, oxide or they served to demarcate zones with different degrees of

alteration noticeable. The guidelines for the correct geometric definition of the terrain-like pillar faces were simultaneously defined. This implied that, in addition to the need of digitising features for construct conventional plans of elevation, it was needed the digitisation of random points on the faces of the ashlars to record the roughness of their surface. We also traced line-strings along sharp edges or around the hollows made by the quarrymen's for the rock grab and following the deep heading joints between the stone courses as well.

Once these "topographic" features have been digitised and properly coded for their classification, the computer programme needs to be set up so that it will be able to distinguish which of these groups of layers gather random elements and which others contain breaklines. That's how, once each side of the complete drawing has been folded down, a triangle mesh can be interpolated in very few seconds.

Fig. 3. Triangle mesh model of a pillar face.

5. APPLICATONS OF THESE MODELS.

5.1 Obtaining sections.

Probably one of the most common problem derived from the lack of a surface-topology in the graphic documents obtained by photogrammetric restitution is the difficulty to section these objects. This is specially an obstacle when they present blunt and bulky shapes and their representation with lines is a simplification biased by the point of view of the stereo-plotter operator or draftsman (in fact, in most cases, if the 3D-drawing are shown rotated, the lines no longer make sense and it is difficult to recognize the figures). For example, a bas-relief composed of human figures would be digitized as a few silhouettes and some more linear work defining some features and folds. If we wanted to obtain a section we would have first to decide the position of the cutting plane while doing the

restitution and we would have to go along the section line with the floating mark / pointer, which would often mean a great deal of difficulty.

But once the TIN (triangular irregular network) has been created by means of the drawn elements as a mathematical representation of the surface, it can easily be sectioned along any direction.
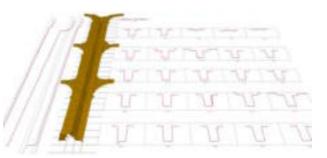

Fig. 4. For each pillar face we obtained horizontal sections at one meter interval and three vertical.

The triangles cover the whole surface so that one can know the third coordinate "elevation" of any desired point so that it is possible to solve intersections between regular surfaces and the network.

We consider that the constructed surface represent a good approach to the true shape of the stone structure better than the line-strings plotted during restitution. The interpolated lattice makes objective the way-of-doing of the operator and makes uniform the merge of sessions done by different people.

5.2 Volume calculations

Volume calculations enclosed by regular figures is a geometric problem which involves a reasonable degree of difficulty. However, the problem when trying to measure volumes of shapes in sculpture figures, or any other irregular shapes (also weathered pieces that have lost their original regularity) becomes almost unsolvable. This difficulty is often work rounded by the simplification or generalisation of the form and assuming the error coming from the method itself.

From the triangular mesh models and through some mathematical processes we can derivate other models of regular square grids, which are very adequate for volume measurement.
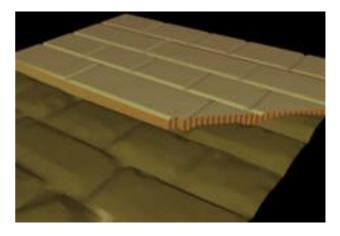

Figure 5. The digital surface model of an ideal reconstruction of the ashlars can be faced to the current estate.

The user, taking into account the unevenness of the surface to be measured and the degree of accuracy desired, will be able to establish the size of the tessella, resulting in a network which could be more or less dense which will adapt to the surfaces of the object quite accurately. Once this lattice has been obtained the software will allow to calculate the approximation of the volume of the original figure as the summation of the partial volumes of prisms whose bases are each one of the grid squares and heights are the average of its four corner elevations.

By applying this technique we could calculate the volume of the loss of matter caused by weathering processes. If it is possible to rebuild (draw) the original shape particular to one piece, we will be able to obtain a digital model of its surface and facing to the model resulting from its current estate, obtained from the restitution, we will be able to obtain the volume between both states (Fig. 5).

5.3 Deformation maps.

One of the main aims of the terrain digital modelling programmes is that of obtaining, in an automatic way, a representation of the relief through contour levels, that is to say, maps of isohyets. These should make reference, in the case of terrains, to a particular altitude origin. If we make this application extensive to a given flat surface, we will be able to obtain a map of isohyets representing how the surfaces differ from that of reference (ideal plan) as if they were elevations of the ground surface. These maps can be drawn with different colours to highlight its expressive power this is an excellent way to represent areas which have been deformed or thrown out of plump.

Figure 6. Colour depth map.

The assessment of the degree of strain on the whole plan and not in isolated spots allows for a more accurate diagnosis of the nature of the cause.

The same technique will allow us to represent any quantitative variable that has relevant spatial distribution. For example, if the elevation is substituted by the degree of humidity in several spots in the façade, we will obtain a map of the humid areas, etc.

5.4 Simulation of shades, ilumination testing.

The surface digital models obtained have been applied to the illumination project of the aqueduct. The triangle mesh reproduces the textural features of the surfaces of the ashlars and above all the combination of the rusticated volumes of their sides and the joints between the ashlars. This makes it possible to emulate the effect of the different ways of illuminating the given monument to enhance the chiaroscuro effect. Ways of illuminating differentiated not only the configuration and nature of light beams (colour, intensity, fuzziness, amplitude) but also by the spatial distribution of any number of sources.

Figure 7. Solar Shadows simulation.

5.5 Creating anaglyphs.

An interesting product derived from the digital surface models are anaglyphic stereograms. These are stereo pairs of images in which each image is shown using a different colour. The two images are overlapped and then viewed using red/green or red/blue glasses (depending on the colours used). This means that the colour channel is used for the stereo separation and therefore the perception of anaglyphs is monochrome (black and white), although colour anaglyphs can be made.
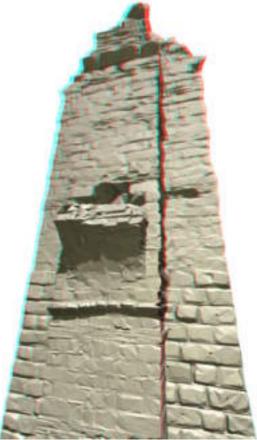

Figure 8. Anaglyphic stereogram. (use red-blue glasses)

As said, anaglyphs can easily be obtained from stereopairs of photographs, but it is also possible to render them from three-dimensional drawings. Some CAD systems like Microstation®, allow the visualisation of stereo-images which can show a realistic three-dimensional simulation of the relief. The interest of these views lies on the fact that they transmit new sensations in the observation of objects and they are, without any doubt a great instrument to call the attention of the public on the heritage assets.

5.6 Realistic visualization, ortho-rectification.

In the field of Cartography, DTM are very often used to obtain ortho-photographs of the terrain. These are achieved by the projective transformation of differential local areas in one or several images with the help of a mathematical frame offered by:

1. That of the lattice work of the DTM.
2. Interior geometry of the camera (lens focal length and the lens distortion parameters) as estimated from the camera Calibration).
3. The exterior orientation parameters of the image: The position vector (3 parameters per image) and orientation (3 parameters per image) of the camera at exposure times.

The objective of differential rectification is the assignment of grey/colour values from the image to each cell of the DTM.

Notice that the need of internal parameters of the camera is an obstacle to the use of conventional or non-calibrated cameras.

The ortho-image is a document which has not only the metric properties of a plan but also the power related to the qualitative information content relative to a photograph. However simple rectification would be more advantageous in financial terms if the object is flat enough. The generation of digital surface models enables the obtaining of orthoimages but, we must say that, in general, it is not very profitable.

5.7 Curvature Maps

Curvature of the surface form is a measure of the rate of change of slopes. This could give us an idea of the distribution of weathered areas. These are zones of the object where edges are getting eroded showing different stages of decay or show a significant loss of high frequency detail.

6. CONCLUSION.

We have widely tested the utility of digital surface models in the context of Architecture and tried to highlight a few possibilities that we have managed. There could be many other applications.

In any case we must admit that the effort needed to get accurate and detailed models my means of restitution of features without thematic meaning (breaklines and random spots), makes them expensive and sometimes unaffordable.

As you all could probably think, all the related possibilities could be better achieved by the surface models obtained with laser scanning devices… well, we must agree. But by this time these machines are not capable to make full-satisfying feature extraction and still need to work in combination with the classic more human-guided Photogrammetry equipment.