Reshaping the Coliseum in Rome: an integrated data capture and modeling method at heritage sites

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Abstract
The paper describes the process of building Internet-transmittable, 3-D digital virtual models of ancient heritage monuments from on-site data, focusing especially on 3-D dimensional data acquisition techniques and color processing methods. Section 1 considers project goals and the attendant problems; Section 2 provides a brief summary of state-of-the-art experience and the technologies adopted by the Authors; Section 3 illustrates the key features of the 3-D color data acquisition methods used as well as the shape and color processing pipeline; Section 4 describes the specific study conducted on single elements and façades of the Coliseum in Rome, while Section 6 outlines future work.

1. Introduction
A major feature of a hypertext multimedia system is that it allows a large variety and quantity of heterogeneous data (3D models, images, photos, drawings, texts, written documents, etc.) to be collated and integrated. In architectural restoration, in particular, the dispersion of such material, along with the lack of user-friendly restitution tools in a traditional storage and registration system have often led to much vital documentation going unheeded. As a large, ordered database of spatial information, a 3D model can be added to and altered over time, provide a more accurate representation of the real life of the monuments than a 2D drawing, and can also be a powerful tool for complementary analyses.

Recent improvements in digital technology in the fields of 3D imaging, 3D data capture and color images, in addition to methods developed at Nub-Lab of the University of Ferrara for combining 3D vector files and color images, can now reliably and accurately digitize the external shape and reflectance of parts, ornaments or whole architectural complexes. The resultant restitution as a 3D digital photorealistic model is suitable for use as a working tool for restoration planning.

The Rome Coliseum is one of the most famous monuments of Roman Antiquity. The survey conducted by the Dipartimento di Rappresentazione e Rilievo of the “La Sapienza” University in Rome and the on-going restoration work, provided our working group with an opportunity to develop a digital data registration and restitution method for large segments of the building, such as the north entrance, and several architectural features i.e. a capital, a base of an ionic column and a decorative frieze in the hypogeum.

The project aims to replace traditional architectural survey documents such as 2D drawings, pictures and texts with 3D digital models, which as well as providing a representation of the object, give other essential information such as: color data, geometric data, historical data, typology of the materials and their age, extent of deterioration, structural data. The study also aims to compare different 3D data capture methods, assessing their suitability as a survey tool for environments like the Coliseum for which no 3-D model exists. In this way, a best-practice methodology could be developed capable of extrapolating and interpolating data from a limited number of sections but also providing a quality scan of an extended surface area, generating a predictable, coherent and manageable final product.

2. Background

2.1. Data acquisition & restitution problems
The survey of the Coliseum carried out between 1827 and 1828 by Henri Labrouste, architect of the Bibliothèque Nationale and the Bibliothèque de Sainte-Geneviève in Paris, is a fine example of the techniques still in use today to survey and represent ancient and modern buildings.
The drawings of Labrouste’s mature years epitomize the classical method developed to translate the real into ideal form, with all its merits and limitations [1]. A real-life building was represented carefully with its irregularities, missing elements, alterations, additions and restoration work. As a survey method it is both didactic - showing building function, stylistic context and, where appropriate, innovative features - as well as analytic, illustrating the state of the structural features and appropriate remedies. Despite its limitations, it has the merit of providing an unbiased documentation of reality [2]. The survey method makes use of three different systems, each with its own representation specifics. These are:

1. The dimensional system
2. Visualization of shape, or modeling
3. Analysis of building structure and construction techniques.

Labrouste’s drawings are of two types, each providing a different reading or codification of the ancient monument in question: the first—orthogonal projections—defined the formal metric values of the work; the second—iconic representations—provide an overall visual perception of the building. In a word, orthogonal views define the space of the object while the iconic views define the object in the space. This method, however, has its limitations. Firstly, there is the problem of the requisite to use cross-sectional views. The ‘measure and draw’ method requires that the three sides of a cross-section be measured (direct survey method) or that triangular measurements of a cross-section be taken (indirect survey method). Reference is always to a vertical or horizontal section. It follows that a building will always be drawn as an ‘extrusion’ from a plane or a ‘projection’ of an elevation, reproducing only planes or sweep representations along a straight-line path and not the actual geometry of the real-life object. When these methods prove inapplicable, representation must be limited to the intersection between the plane of the picture and the object. Secondly, the 2D ‘measure and draw’ system is inflexible and incapable of solving the key problem of illustrating the ‘life’ of a building with its anomalies, special features, overlapping, missing pieces and irregularities that, although hiding its pure form, make it a specific building in a specific context. While the draftsman can reconstruct the shape of a building by plotting flat shapes, planes, polygons, lined surfaces or parts of spheres and quadric surfaces (by means of quadratic polynomials), he is unable to recreate the real-life shape of the building with its out-of-plumb, irregularities, sweep variations, bulges, sags, etc. [3].

2.2. 3D Survey and Representation

2.2.a The 3D range camera technology

Direct 3D data acquisition and restitution technology obviates the inevitable information loss that accompanies traditional 2D survey methods to produce 3D representations. These 3-D technologies can be divided into two broad categories [4], [5].

a. Contact techniques: as the name suggests, this technique entails physical contact with the surface of the object, either manually or with an instrument. Techniques include ruler and plumb line, sophisticated articulation with touch probes, and touch probes with optical spatial detection devices.

b. Non-contact techniques: these exploit existing energy sources or generate an energy source (i.e. ultrasounds or optical radiation) that is directed onto the surface of the object. The energy rebound is measured in a variety of ways, including special cameras and even the naked eye. Today, lasers, optical and ultrasound techniques can exploit coherent radiation propagation properties and generate realistic models of objects and large structures. Techniques can be either:

- Passive systems deriving the coordinates of a given object from the information provided by intensity images, such as photogrammetric systems, or
- Active 3-D vision systems, such as laser scanners and structured light systems in which information inputs are external, i.e. scanning angle, time of flight, or the shape of projected patterns. A 3-D active vision system can measure in a matter of minutes vast amounts of 3D data in the form of accurate 3-D point clouds without the need for prism or reflectors. 3-D range cameras have been built and tested for applications as diverse as space, industry, anthropometry, and finally - more recently - cultural heritage [6], [7].

Clouds of points acquisition is a fundamentally new technology. Unlike 2-D measuring and drawing which entails extrapolation and interpolation of the few points taken into consideration, every point in 3-D clouds of point technology is measured and assessed, with the result that survey accuracy is greatly enhanced [8].

2.2.b. Previous works

Semantic 3-D digital modeling and 3D data acquisition has already been widely used by our group in heritage projects of varying scale. Experience includes:

a. Survey of the façade of the Hearst Memorial Mining Building, University of California at Berkeley (1997) [9].

b. 3D Survey of parts of the atrium of the 8th century Abbey of St. Mary of Pomposa, near Ferrara, using a 3-D Biris scanner (in collaboration with NRC) (1998) [10].

3. Technological features

The project has two main technological features:

- a collection of a 3D range cameras and picture cameras for data acquisition;
- range and color data processing software.

3.1. 3D range cameras

Several 3-D morphological data acquisition techniques were examined for acquisition capability and scale variability:

1. A time-of-flight laser-scanner (CYRAX 2400) was used to scan the north entrance;
2. A Minolta Vivid 700 range camera using technology based on optical triangulation was adopted to survey architectural elements and the frieze.

The Cyrax 2400 has the advantage of high speed and precision over large volumes of view (objects of more than 1x1x1 m), while the Minolta VIVID-700 is best suited for close range study of smaller objects (less than 1x1x1 m.). Both systems are portable and designed to work in difficult environments, making them particularly suitable for architectural applications.

3.1a. The Cyrax 2400 laser scanner

The Cyrax 2400 is a laser scanner that combines pulsed laser with green spot (size <6 mm. from 0-50 meters) with a “time-of-flight” (LIDAR) technique of up to 1000 points per second. The accuracy declared by the manufacturer is 6 mm for each captured and displayed point and 2 mm for modeled surfaces at a distance of 1 to 50 meters [11]. Our tests, carried out under standardized conditions with NubLab statistical data analysis procedures, showed an accuracy better than 2 mm. for plane surfaces on a single point at 1 - 50 meters. Scanning-light laser spot techniques are known to be much less accurate in the event of sudden changes in surface height, rough surfaces or wide reflectance variations (see El-Hakim and Beraldin [12], [13]). The scanner has a maximum field-of-view of 40° X 40° and a specific range up to 50m for each scan. X-Y sample spacing (i.e. resolution) may be set as tightly as 0.5 mm at 50 m range. Table 1 shows some of the specifications of the Cyrax 2400 range camera.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>3D SCANNER - CYRAX 2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions scanner</td>
<td>36.68 x 30.48 x 89.02 cm</td>
</tr>
<tr>
<td>Weight scanner</td>
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</tr>
<tr>
<td>Dimensions electronics</td>
<td>30 x 45.7 x 23 cm</td>
</tr>
<tr>
<td>Weight electronics</td>
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</tr>
<tr>
<td>Single point accuracy</td>
<td>6 mm</td>
</tr>
<tr>
<td>Model surface precision</td>
<td>2 mm</td>
</tr>
<tr>
<td>Experimental Single point accuracy</td>
<td>2 mm</td>
</tr>
<tr>
<td>Field of view</td>
<td>47° x 47°</td>
</tr>
<tr>
<td>Range Recommended</td>
<td>0.5 - 50 m</td>
</tr>
<tr>
<td>Range Maximum</td>
<td>60,100 m</td>
</tr>
<tr>
<td>Spot size</td>
<td>6 mm at distance range of 0 - 60 m</td>
</tr>
<tr>
<td>Scan rate</td>
<td>600 points/second</td>
</tr>
</tbody>
</table>

3.1b The Minolta VIVID-700 laser scanner

The Minolta VIVID-700 is a ultraportable laser-based system, light-stripe triangulation rangefinder, capable of scanning samples ranging in size from 0.7 cm x 0.7 cm to 1.1m x 1.1m, and distances ranging from 0.60 to 2.5 meters. The 400x400 pixel image generated from a videocamera (built-in to the range camera) is automatically re-collimated as a texture-map over the polygon mesh. Scan resolution (x,y,z) as 200x200x256 points (transverse resolution in excess of 4000 3-D points and a measurement discrimination capability of more than 256 levels in range (z)). 3-D image coordinate detection time is 0.6 seconds. Resolution varies with the scanner distance from object and zoom level (e.g. at a distance of 60 cm). The best resolution is on XY axis 0.34 mm and on Z axis 0.11 mm. at 60 cm zoom step 8 (45 mm), the poor resolution on XY axis 5.77 mm at on Z axis 7.23 mm at 250 cm zoom step 1 (9 mm) [14]. Table 2 shows some of the specifications of the Minolta Vivid 700 range camera.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>3D SCANNER - MINOLTA VIVID-700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions scanner</td>
<td>21 x 30.1 x 32.0 cm</td>
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<tr>
<td>Weight scanner</td>
<td>9 kg</td>
</tr>
<tr>
<td>Spot size</td>
<td>0.3 mm - 46 mm</td>
</tr>
<tr>
<td>Resolution of the Digitized Image</td>
<td>400 x 400 (px)</td>
</tr>
<tr>
<td>Resolution (x,y,z)</td>
<td>200 x 200 x 256 pixels</td>
</tr>
<tr>
<td>Absolute accuracy</td>
<td>of range data quoted at 2-3 %</td>
</tr>
<tr>
<td>Tolerance on flat plane</td>
<td>0.5 mm at distance of 45 cm</td>
</tr>
<tr>
<td>Scanned area (x,y,z)</td>
<td>7.5 cm - 110 cm</td>
</tr>
<tr>
<td>Distance to object</td>
<td>60 - 250 cm</td>
</tr>
<tr>
<td>Scanning time</td>
<td>0.6 seconds</td>
</tr>
</tbody>
</table>

3.2. Processing pipeline

Typically the most appropriate 3D survey method for this type of architectural object is a combination of photogrammetric and laser range imaging techniques providing both 3-D shape and reflectance of each surface point [7], [11], [15], [16]. We chose 3-D laser scanners for the external shape and digital photogrammetry to define reflectance.

The processing pipeline consisted of two separate parts:

1. Range processing:
   a. Range image acquisition
   b. Multiview registration
c. Model construction by merging the different data clouds; and subsequently converting points to triangles or points to NURBS surfaces.

2. Color processing:
   a. Fitting the textures onto the geometric 3D model;
   b. Preparing the texture maps: compensating for ambient lighting, discarding pixels affected by shadows or specular reflections, and factoring out the dependence of observer color on surface orientation from the measured intensities;
   c. Texture reduction and definition of Level of Detail

3.2.a. Range processing pipeline

1. Multiview registration

Given the sensor’s limited field-of-view, complex environments might require a large number of views. Each 3-D sensor view provides an ordered set of 3-D points in a camera-centered Cartesian coordinate system. Model reconstruction is obtained by systematic application of this Cartesian coordinate system to every view taken. This process is known as registration and aligns the scans. Both software systems developed for the two 3D laser scanners provide for multi-view registration in two different ways [17]:

a. the Cyrax 2400 laser scanner. Registration comprises two phases: constraining and registration. During constraining, the user identifies objects and surfaces common to the different scenes. Constraints are used in combination to reduce or eliminate the six degrees of freedom (DOF) from the alignment problem. The objects and surfaces include vertices, centerlines, and planes. The method for the determination of rigid transformations between range images takes advantage of so-called cooperative targets (i.e. natural or calibrated features). If the pairings of targets between stations are known, then the rigid transformation linking the different views can be easily computed. Constraints can be weighted according to their level of perceived accuracy. A relatively higher weighted constraint has a correspondingly greater influence on registration. Once all the constraints have been assigned, registration takes place, the CGP constructing and solving a system of equations. The solution is a rigid-body transformation for each scene; when applied to the appropriate scans, all scenes fall within a shared coordinate frame. More than two scenes can be registered at once; this global registration is similar in concept to bundle adjustment, where pair-wise errors are distributed through the system.

b. the Minolta VIVID 700 laser scanner. The VI-S1 software processes data by merging and registering multiple data for integration, smoothing, filling holes and carrying out adaptive and uniform sub-sampling. The software allows multiple scan registration, from the digital pictures saved with the range image using homologous points on pairs of view of the same subject. The intensity values measured by the range sensor are used to constrain the matching of surfaces between views. The labeling of points is then used to identify common portions of surfaces between images to allow for registration. Finally, the algorithm is applied globally to merge multiple scans into a single cloud of points, without overlapping and discontinuities.

Both types of multiview registration software use iterative techniques that correlate standard deviation to digitizer accuracy. An incremental approach may be useful for interactively controlling and validating the acquisition process, but error accumulation may become serious. For this reason, we used an iterative minimization of the least-squares distance between points in different images, performing global minimization of the main deviation to re-balance the errors over all the images of the scene [18]. In the CGP software, this function is called “global registration” and can be performed manually. For the VI-S1 software the algorithm is applied in the merge step.

2. Model construction

The registration of range data from different viewpoints generates large data sets. This raises the issue of how to manage such large amounts of data. A geometric model containing a large number of polygons is required for geometric correctness. However, this often produces a virtual environment that is far too large for real-time interaction or even visualization and walkthroughs. Even high-end computer graphics systems running on the latest, most sophisticated hardware cannot render the geometry of these arbitrarily complex scenes of some 25 frames per second. As a result, a more usable 3-D model must be generated. This requires:

a. Removing redundancy between different views
b. Compressing the model at different Levels Of Details (LOD).

The standard means of constructing an LOD model is to eliminate details and textures and simplify geometry. Care must be taken, however, to maintain good attribute perception. For this reason we used a semantic approach in model construction and segmentation [3]. In addition, for large segments of the models, geometry simplification was carried out in compatibility with NURBS surfaces and with the addition of texture maps, or by applying a hybrid image and geometry-based approach. This was possible in the case of large flat brick or plastered surfaces. Polygon geometry simplification is a function of polygon size or distance from viewer (level of detail, LOD) and results in minimal loss of visual contents. Methods usually consist in either polygon removal with re-triangulation of the resulting hole or the merging or collapsing of several vertices into one vertex [19]. The criteria, or constraints, for either method depends on the desired balance between accuracy and speed and whether the scene topology is to be preserved. De Floriani
et al. provide a comprehensive survey of existing methods
[20].

3.3. b Color processing pipeline

The reflectance of each single point is obtained by mapping
the real-scene image generated by digital photography color
mapping against the geometric model by means of image
perspective techniques (IPT). Weinhaus and Davarjan
review the various texture mapping techniques [21]. Reflect-
tance acquisition and registration on the geometric model
present essentially two problems:

1. Proper geometric fit of the image from the photometric
camera onto the 3D geometric model (2D to 3D transforma-
tion). Lavallée and Szeliski [22] have previously addressed
the problem of finding the 3D-2D projective transformation
of the free-form object. The correct mapping is given by a
projective transform. A wide number of techniques dealing
with the reconstruction of the texture have been developed.

Sato et al. Painstakingly reconstruct the reflectance prop-
erties of real world objects from photographs using the Tor-
rance-Sparrow model [23]. Debevec et al. reconstruct both
the shape and the texture of real world objects from photo-
graphs using a hybrid approach: an initial model is obtained
from photogrammetric modeling based on interactively
specified edge correspondences [24]. Subsequently, the
model is refined using a stereo algorithm to minimize the
error function using a variant of the Newton-Raphson meth-
ods. U. Saccardi et al., on the other hand, adopts the least
squares method [25]. Ofek et al. reconstructs the texture of
objects from a sequence of images [26]. Image registration
is via interactively specified point correspondences, which
are automatically tracked within the sequence. El-Hakim
has proposed a method to define a local texture coordinate
system for each triangle of a 3-D mesh model using a cali-
ibrated camera by warping the original image over the trian-
gle [27]. Neugebauer et al. have presented a texture
reconstruction method for arbitrary shaped objects using
multiple unregistered photographs and a geometry model
represented as a triangulated mesh [28]. Our method is sim-
pler and relies exclusively on commercial software - pro-
vided this contains the necessary algorithms. A-priori
camera calibration is not normally required. However, sur-
faces must be planar-like, which is practically always the
case in a architectural monument. The method is also appli-
cable to both triangulated meshes and NURBS geometry.
The photo shots were straightened using affine transforma-
tion techniques [29] to obtain an orthophotograph. As a
rule, we limited projections where possible. El-Hakim
provides a table of the error sources for visual discontinuities
[27]. The main problem is the distortion inherent in camera
lenses (esp. wide angles). To offset problems with large sur-
faces and close-range camera position, we applied camera
calibration and differential straightening on objects present-
ing deep curvatures. The same projection direction was
again used in Alias/Wavefront to apply the orthophotogra-
phies as projection textures over the model like planar pro-
jection. The end results, even when several images are
collated into a mosaic, are excellent.

2. Definition of the correct reflectance of each pixel and
adjustment of radiometry differences between different
images and across single camera image [30]. Texture color-
ing required:

- Color definition. This was obtained by calibrating the var-
ious profiles and equalizing procedures against a color qual-
ity control target;

- Elimination of all inherent or cast shadows.

Color definition is essential in an outdoor environment
where ideal diffuse illumination and a diffusely reflecting
object are not feasible. All photographs were taken under
strict temperature control conditions to ensure exact chro-
namic reproduction of the sample area. In addition, color
and reflectance reference samples, such as Kodak color
control patches, were used to identify any variations in tem-
perature color. This allows comparison of the dominant col-
ors between the original Kodak patch and the Kodak band
and subsequent software adjustment. Neugebauer et al. &
Schreiber report the causes of different intensity values for
a given surface point as being due to differences in spatial
resolution, non-modeled optical effect (e.g. specular high-
lights), artifacts in the geometry model and registration of
minor inaccuracies. This study was carried out exclusively
on commercial software and color Lab [31], [32], [33].

4. Test procedure & results

Figure 1: Coliseum, Rome, ionic capital on the façade.
Photo taken in July 1999.

4.1. The project

The following architectural and decorative elements were
surveyed:

A) An engraved frieze located in the hypogeum (size:
80x90x10 cm. approx.);
2. a wide expanse of brick or natural travertine stone masonry to be represented with an accuracy of within ± 2 cm (point C)). In this case a CYRAX 2400 laser scanner was used.

4.2. Phasing

Work was carried out in July 1999 with the following schedule:

A - Scans and view registration on site (1 day);
B - Verification of scans and first attempt at building polygonal models (1 day);
C - Complementary scans and view registration on site (1 day);
D - Complete polygonal model construction, polygon to NURBS surfaces conversion, point clouds to NURBS conversion, decimation, texturing (15 days);

4.3. Images collection

For the different objects, the following range images were obtained:

a - Survey of ionic capital: Minolta Vivid 700 scanner - Distance 100 cm – Zoom step 4, resolution (x,y) = 1.25 mm, resolution (z) = 0.61 mm, field of view 25x25 cm approx.; total number of scans: 38, each shot having a maximum of 10.000 3-D points.

b - Survey of ionic column base: Minolta Vivid 700 scanner - Distance 100 cm - Zoom step 4, resolution (x,y) = 1.25 mm, resolution (z) = 0.61 mm, field of view 25x25 cm approx.; total number of scans: 41, each shot having a maximum of 10.000 3-D points.
4.4. Physical & geometric modeling

After re-collimation, 1,860,000 point samples were obtained with the Cyrax scanner and 850,000 points with the Vivid scanner. These underwent standard noise clean-up, removal of irrelevant sequences, homogenization, smoothing, polishing and hole closure. Since the restoration of decorative elements consists largely of cleaning rather than structural modifications, there is no real need for a “manipulatable” 3-D model. A simple 3-D triangular mesh representation is sufficient. Two different freeware software systems, both running under an IRIX SGI Operating System, were chosen for this geometry simplification processing:

a. Jade 2.0 based on the mesh decimation approach. Jade has been designed to provide both increased approximation precision, based on global error management, and multiresolution output. [34], [35].

b. Cosmoworlds 1.03 that supports creation and editing of virtual 3D worlds (VRML), and multiresolution output with a Level Of Detail (LOD) editor. The Polygon Reduction Editor reduces the polygon by: deleting points by curvature, discarding triangles by area, discarding edges by length, merging initial coordinates (clustering) [36].

The final 3-D models have a maximum of 150,000 polygons for a motion frame of 35 frames/seconds on the reference PC (Pentium III 450 Mhz, RAM 256 Mb, Open GL graphic card VRAM 32 Mb)). Model texture was achieved by projection in Alias/Wavefront Studio, version 9.0 modeling software starting from photos taken with a Minolta RD-175 digital camera and a Minolta 800si 24x36 mm. film lenses analogic camera. Orthophotographies were developed from the original photographic images. When necessary mosaicking was performed. The resolution of the digital camera (1528 x 1146 pixels) and the professional Kodak PhotoCD (2632x2048 pixel), gave us a pixel accuracy of more than ± 1 mm. Tables 4, 5, 6 show the position and number of the original shots for each element surveyed.

The masonry work was partly reconstructed with NURBS surface for better performance and made manipulation possible in those surfaces requiring structural restoration work, i.e. rebuilding or integration. An initial DXF format model was reprocessed to make it “manipulatable” using Alias/Wavefront Evalviewer 9.0 software and STL format, which permits the preservation of both clouds of points and 3-D mesh polygons [37]. The computer model of the north entrance presented a typical problem of a scanner providing non-ordered points, or an irregular triangulated mesh. While a simplified version of this mesh might suffice for virtual reality flythrough, it is not useful for most practical architectural applications. Converting it into a segmented, structured, and annotated architectural database is even
harder. However, a highly satisfactory solution was found in an 5.3 IGES format NURBS model which provides a 4 Mb file of the whole of the north entrance, without loss of any geometric data. Texturing has been achieved with the same methods used for the decorative elements. Camera resolution (1528 x 1146 pixels), give us a pixel accuracy ± 4 mm., which is better than the accuracy of the geometrical data. Model restitution followed three different solutions:

1. rendering of the orthogonal or three-quarter views as a real-life photographic representation or as an intensity map (an observer based classification and restitution);
2. IGES 5.3 file format for use in a CAD system [38];
3. VRML '97 file format (ISO/IEC 14772-1:1997) [39] for inclusion of models in a multi-platform system enabling visualization of a 3D database with a simple Web browser, since the files are too large (typically 25-30 Mb with up to 2 Mb of textures in JPEG format, lossless compression) to download over the Internet on a local machine [40], [41].
sites. This article illustrates how these technologies can be put to practical standardized use in a heritage context. Future work will address development and refinement issues, such as:

1. Improvement in texture production to obtain different LOD directly from transformed original photographic shots in order to avoid slow, indirect and inaccurate procedures.

2. Automated polygonal simplification, NURBS conversion and hierarchical construction; implementing LOD on both models and textures.

3. Applying 3-D survey on a wider scale, i.e. an extensive segment of the Coliseum.

4. Refining color survey methods with greater integration and wider data capture.

5. Better integration of laser-scanner time-of-flight and triangulation methods in order to obtain a continuous data flow.

6. Examining ways of using the acquired data on the Internet.

Figure 7: Coliseum, Rome, north entrance. An intensity map of the full 3D model.

6. Acknowledgments


Figure 8: Coliseum, Rome, north entrance. Rendering of full 3D model.

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