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KNOWLEDGE AND VALORIZATION OF HISTORICAL SITES THROUGH LOW-COST, GAMING SENSORS AND H-BIM MODELS. THE CASE STUDY OF LITERNUM

1. Introduction and related works

The development of digital technologies for metric acquisition has had a significant impact on the field of representation and visualization, providing inedited scenarios for knowledge, documentation and preservation of Cultural Heritage. Nowadays, the increasing use of laser scanning technology and digital photogrammetry for 3D reality-based digital documentation and reconstruction allows a deeper understanding of heritage sites and artifacts, by the accurate recording of shapes, geometries and colorimetric information. The integration of several geomatics techniques for the 3D documentation of cultural heritage (Remondino 2011; Fiorillo *et al.* 2013; Remondino, Campana 2014) is getting more and more a common practice, especially in the field of archaeology. However, in order to apply these tools and techniques in as many sites as possible, some researches (Pollefeys *et al.* 2003; Izadi *et al.* 2011; Nguyen, Izadi, Lovell 2012) are experimenting with the use of instruments that are cheaper but equally reliable and accurate. This way, it is also possible to solve problems related to the cost of the metric and colorimetric data acquisitions.

Another important aspect related to digital survey is the increased use of interoperable information parametric models, often identified with acronyms such as BIM (Building Information Modeling) or HBIM (Heritage Building Information Modeling). This term is related to interoperable information models applied to buildings of particular historical-architectural value. These models are especially interesting because they have two main advantages. First of all, they are parametric models: they depend in their geometric definition on one or more parameters, which are interconnected. Changing the value of these parameters, the models change and are updated in real time. Secondly, it is possible to associate to these models a heterogeneous set of information (metrics, formal, historical, stratigraphic, on the state of preservation, on the performance characteristics of materials, etc.). These features make these models particularly interesting and useful for historical reconstruction and restoration projects. For this reason, an interesting area of research that is spreading in recent years (Fai *et al.* 2011; Apollonio, Gaiani, Zheng 2012; Hichri *et al.* 2013) is the interaction and integration of different digital models: the numerical models for points, the numerical models for surfaces and the parametric models.

2. The archaeological site

The experimentation was conducted on the Roman forum of the ancient colony of Liternum, in Campania, Italy (Fig. 1). The establishment of the civium Romanorum colony of Liternum was approved towards the end of 197 BC as part of an extensive program of colonies wanted by Scipio in Southern Italy. In fact, Liternum was established at the mouth of the river Liternus, from which it takes its name, on a tuff bank in a gritty and marshy area. As in all the colonies of the Roman era, a forum was founded in Liternum near the river, since 194 BC. It covers an area of ca. 10,300 m² where several public structures are present. Subjected to various events, the archaeological site of the forum is now in ruins. It is under the protection of a Commission that established an archaeological park. However, abandonment and neglect are threatening its survival.

3. Reality-based 3D survey

In order to produce a 3D reality-based model of the heritage site, multiple surveying techniques were employed:

1) Aerial photogrammetric survey to obtain a complete environmental point cloud geo-referencing the data;
2) Terrestrial photogrammetric survey to fill any voids and acquire a detailed point cloud;

Fig. 1 – Archaeological site of Liternum, aerial view.

Fig. 2 – Archaeological site of Liternum, orthophoto: photogrammetric survey.

3) 3D laser scanner survey of some details carried out by a low-cost, consumer-level hand-held RGB-D sensor in order to compare the results.

3.1 *Photogrammetric survey*

Some ground control measurements evenly distributed over the forum's area guaranteed the reliability of the entire workflow. 8 high contrast and well-distinguishable targets were placed on the corners of the rectangle in which the archaeological area is included. The objective was to use them as Ground Control Points (GCPs) for the aerial as well as for the terrestrial photogrammetric surveys.

The complete environmental image-based 3D point cloud of the archaeological site was obtained using a commercial Unmanned Aerial Vehicle (UAV) such as DJI Phantom 4. In order to acquire data concerning the whole forum, 3 flights were planned in relation to the battery duration. In the first flight, the camera was set in a nadiral position, the Phantom flew in autonomous way and the flight height has been established at 25 m above the ground. 137 horizontal images were acquired and an average Ground Sample Distance (GSD) of 5 mm was obtained. In the second flight, the camera was set with a mean angle from the horizontal of about 45° and the flight height has been established at 10 m above the ground. 126 oblique images were acquired at a distance from the object of about 10 m so an average GSD of 3 mm was obtained.

To survey the ruins of the unique column, the UAV flew in assisted way. The preselected trajectory in order to obtain an accurate 3D model has been to orbit around the object to survey. Shoots were taken using an intervalometer set at a 4-second interval. Both vertical and oblique images – with a mean angle from the vertical of about 30° – were acquired around the column. A mean GSD of less than 1.5 mm was obtained and about 50 photos were acquired to guarantee a proper coverage.

A terrestrial photogrammetric survey was carried out to integrate the data missing in the previous aerial survey and to improve the color information for the final texturing of the 3D digital models. Using a Canon 1300D and a Zoom-Canon 18-55 lens set at 24 mm view, a mean GSD of less than 4 mm was planned maintaining an average distance of 10 m from the object. A mean overlap of about 70% was chosen, acquiring 457 images of the theatre and adjacent structures.

The processing of the acquired images followed the standard photogrammetric pipeline (Fig. 2).

3.2 *3D live scan survey*

The Roman forum of Liternum was an opportunity to test a new and low-cost approach for the 3D reconstruction of archaeological ruins. The methodology is based on an inexpensive RGB-D sensor, for example the Microsoft Kinect, used in the gaming world.

The device has characteristics such as to enable, when scanning the object framed by built-in cameras, a simultaneous view of the reconstruction in real time, making it possible for the user to intervene immediately and adapt the path of the sensor in order to obtain a complete model. The output that a Kinect returns is a point cloud, like photogrammetry or a traditional laser scanner. This point cloud combines the color values to the spatial information of each scanned points. This is possible thanks to the presence of two sensors integrated into the case:

– an RGB camera: up to 640×480 @ 30 fps, 1280×960 @ 12 fps;
– a depth sensor: up to 320×240 @ 30 fps.

Based on these features, the experiment was conducted using an RGB-D device for the survey of the ruins of one of the pillars of the substructure of

Fig. 3 – RGB-D scan survey: colorimetric information (right) and depth map (left).

the Roman theater of Liternum. Since the sensor requires, for its operation, a constant power supply in addition to a connection to a laptop, the device has been connected to an uninterruptible power supply via an IEC / SCHUKO cable of suitable voltage. In this way, the system becomes transportable and usable for a time interval appropriate for the acquisition of small elements. In reason of the limitations associated with the illumination of the captured scene, the survey was carried out in diffuse natural light condition (cloudy sky). The definition of the trajectory to be followed with Kinect for the pillar survey took into account an important factor. A well-known problem of Simultaneous Localization and Mapping (SLAM)-based reconstruction methods is loop closure. If the user makes a 360° turn, the final estimated position of the sensor will be off by a few degrees, and objects that become visible again will not coincide with the first observation. As a result, gaps or ghost objects appear. So, to avoid this problem, the device has been used by turning around the masonry block, from the top downwards, and scanned with a zig-zag pattern. 1 scan, divided into 32 depth frame, has been recorded (Fig. 3).

3.3 *Data evaluation*

The complete photogrammetric model, deriving from the integration between the aerial and the terrestrial ones, was obtained by scaling and georeferencing operations. The aerial datum includes Global Navigation Satellite System (GNSS) information acquired during every single shoot so the related model is referred to the UTM/WGS84 reference system. In order to improve the metric scale, the satellite data processing, which provided a sub-centimeter accuracy, have been integrated with the reference points (targets) which were distributed over the area and measured in the field.

Then, the photogrammetric model was combined and compared with the RGB-D scan data. As expected, the major problem was that, due to unavoidable inaccuracies in camera tracking (drift), the generated model is slightly deformed. The correction of the geometric drift was made by warping the model according to the set of geo-referenced landmarks in a separate postprocessing step. In this way, it was possible to compensate and remove global deformations for drift and bring the reconstruction into the coordinate system of the geo-referenced model.

In terms of resolution and accuracy, the quality of the Kinect reconstruction is comparable with the offline photogrammetry model. The metric precision of two acquisitions differs by ca. 3 mm.

However, in terms of texture resolution, the achieved reconstructions cannot compete with the quality of less inexpensive high-resolution instruments.

After the data integration, a phase of overall modeling was conducted.

The first step consisted in a manual cleaning of noise and vegetation. The merged point cloud was decimated at 5 cm sampling step, providing a final point cloud of about 22 million points. A polygonal mesh model was generated using the Poisson surface reconstruction algorithm. A final mesh model of about 14 million of triangles was obtained. After editing the mesh model, the last step consisted in texture mapping, using the images acquired for the photogrammetric survey.

4. Parametric reconstructive modeling

4.1 *Historical sources*

The most reliable historical sources (Chianese 1924; Ciancio Rossetto, Pisani Sartorio 2002; Tosi 2003; Sear 2006) converge on the same hypothetical reconstruction of the Roman forum of the ancient Liternum. The Imperial Age encompasses the years of greatest splendor of the colony: the founding of the forum that was the heart of public life and of *ars ludica*, dates back to this era. The forum (92×112 m) presented a tetrastyle capitolium (194 BC) located on a high podium, in a central position. Then, there was a basilica, located in the southern part of the capitolium. It consisted of a nave with columns and was founded in the late Republican Age. A theater is located to the N, founded during the imperial years. Various taverns were arranged on the other three sides of the square. The three sides showed all arcades. The access axis of the Forum was located along the longitudinal direction and in almost symmetrical position. The accesses were underlined by monumental portals.

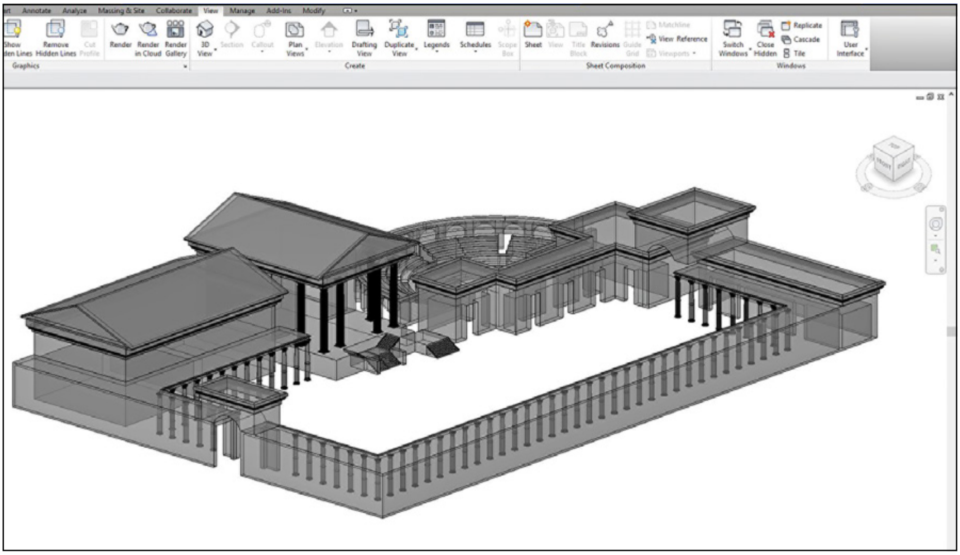

Fig. 4 – HBIM reconstruction model.

4.2 *3D reconstruction*

As specified, parametric digital models (HBIM) are becoming increasingly popular in the field of archaeological reconstruction due to their potential.

A goal of the research is to investigate the various forms and shapes that make up the historical architecture of a Roman forum. On the one hand, there are the most frequent forms in the building (such as walls, beams, columns, slabs, etc.), which are based on simple geometries; on the opposite side, there are elements with prevailing sculptural character that have function of decoration, hardly attributable to regular geometries. However, these sculptural elements are characteristic forms of the architectural classical orders. So, while being declined in the most diverse facets, they are almost always attributable to rules and proportions that facilitate the conversion into parametric models.

The experimentation was done in the Autodesk environment using Revit software (Fig. 4). The Revit working environment, having the ability to manage and view in the same file both the point cloud and the 3D model, allows you to check in real time the correspondence between the two models.

Leaving aside the parametric modeling of simpler elements (walls, slabs, pillars) for which there are already encoded families of parametric objects into modeling software, the test made by taking the only Corinthian column, remained almost entirely on archaeological site, as the main geometric reference, is illustrated in detail below.

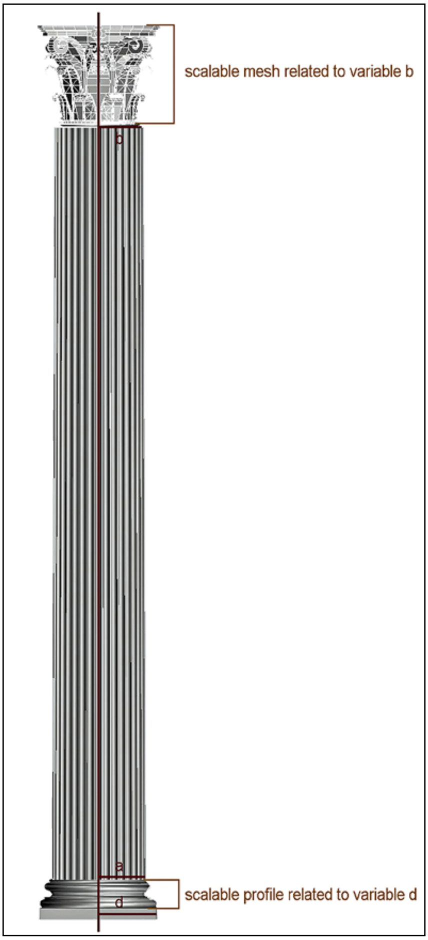

Fig. 5 – HBIM model of the Corinthian column: geometries and variables.

The reference parametric model is composed of three types of objects: a first variable parametric object that is the shaft of the column; parametric objects that are proportionate (in this case, the profile of the attic base and the circumference of the column's base); objects related to numerical models of mesh type subject only to the change of scale.

Once defined the basic parametric model, the definition of the input values, extracted from the point cloud, has been investigated. Among these, there are the four vertices of the square plinth from which the diameter of the circumference derives. Once defined the basic polygon (the plinth), some geometries and some variables will automatically be reconstructed. The center of the polygon coincides with the center of the column on which the vertical axis is set. This is the axis of revolution (vertical plane) of the column profile. The variables are: the basic radius "d", the radius of the *imus scapus* of the shaft "a" and the scale factor of the basic profile designed on the vertical plane. To model the shaft, once the base radius is determined, the Z coordinate is required. It is calculated as the distance between the *imus scapus* and *summus scapus*. The value of the radius to *summus scapus* determines the scale ratio of the capital.

The capital is a mesh suitably integrated in the missing parts on the basis of classical architecture books. The mesh has been scaled according to the radius of *summus scapus* and bound according to the axis of the column for the X,Y position and at the highest point of the *summus scapus* for the Z position (Fig. 5).

In accordance with the BIM methodology, every element has been associated with a number of information arising from the survey and historical research. In this way, the final model is enriched with several information: geometric dimensions, material, text documents, CAAD reconstruction hypotheses, drawings, photos, etc.

5. Conclusions

This experiment demonstrates that it is possible to pursue new ways in relation to the various problems of interaction between the digital data obtained with 3D shape acquisition techniques and how to process and manage new HBIM models. Compared to the first point, it was experimented with the use of cheaper sensors that have shown a good degree of accuracy and reliability. The integration of detection techniques is always necessary in order to achieve the most satisfactory result.

In reference to the spread of parametric models for the historical architecture, research shows that a careful reading of the geometric elements that make up a historical architecture allows to identify the basic geometric elements that can be more easily translated and managed in the BIM environment.

Valeria Cera
Università degli Studi di Napoli "Federico II"
Dipartimento di Architettura
valeria.cera@unina.it

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ABSTRACT

The paper presents the results of an interdisciplinary project related to the 3D documentation, dissemination and valorisation of archaeological sites. The project has two goals: to test a novel and economic pipeline for the acquisition of survey data, and to promote the study and appreciation of archaeological areas, among public and scientists, using the HBIM workflow. The 3D survey of archaeological sites is still an expensive and time-consuming task. In this project, a low-cost approach to 3D survey is presented and compared to a standard photogrammetry pipeline based on high-resolution photographs. The pipeline is based on a consumer-level hand-held RGB-D sensor as Microsoft Kinect. The quality of the digitized raw 3D models is evaluated by comparing them to a photogrammetry-based reconstruction and then the acquired data is elaborated in software BIM in order to create a semantically enriched model of the archaeological site. This method has been verified on the archaeological park of Liternum (Campania, Italy), a Roman forum that includes a capitolium, a theatre, a basilica and some others commercial spaces. Using a reflex camera for the photogrammetric survey, it was compared to the Kinect acquisition. In this way, we obtained a 3D model that is imported in a BIM software such as Autodesk Revit. Every element is modelled as a parametric object so the final model is enriched with additional information: geometric dimensions, material, text documents, CAAD reconstruction hypotheses, drawings, photos, etc. These methods allowed us to better understand the site, perform analyses, see interpretative processes, communicate historical information and promote the heritage location.