GEOMATICS FOR KNOWLEDGE AND CONSERVATION OF CULTURAL HERITAGE: THE PRATOLINO PARK CASE STUDY

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ABSTRACT

The project concerns the achievement of multi-resolution and multi-sensor 3D surveys of the main buildings of Pratolino Park, based on laser scanner and photogrammetric technologies, spread to surrounding land and environment and geo-referenced using GNSS.
The case studies presented concern both true architectures as the Chapel by Buontalenti and the Paggeria and other buildings as the Fountain of Jupiter and the giant statue of the Appennino by Jean de Boulogne. These first case studies show the wide range of artefacts present in the Park; each one of them requests appropriate techniques for their surveying and representation because of their different sizes, geometries and materials.
The project gave the chance to define, improve and check the best practices for surveying a wide range of heritage buildings. The drawings and models of the artefacts were used both for research purposes and as a support for conservation projects.

Key words: Geomatics, Survey, Laser scanning, Conservation, Gardens

1. INTRODUCTION

Survey, which has always been considered a tool of knowledge and communication for architecture, has been chosen by Venice Charter too as the essential element for heritage documentation and conservation. Carrying out an accurate direct metric survey for a complex architecture is a long and burdensome task. This is clear in the Pratolino Park, where you can find many examples of irregular and organic structures typical of the Italian 16th-century gardens.
The authors of the previous survey campaigns, carried out around 1985 with traditional techniques, highlighted the inadequacy of those tools, even though they

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followed a rigorous methodology. In fact, these shapes cannot be related to easily identifiable geometric models; therefore, when during the survey recognizable reference points were missing (Dezzi Bardeschi and Zangheri 1988), the adoption of a blurred and evocative drawing technique became essential (Conforti 1987), as sometimes interpretation prevailed over objectivity. In 1985 they already adopted photogrammetric survey for the statue of the Appennino with good results (Ippolito 1988), but the presence of trees and plants allowed surveying only the main elevation. Paradoxically, sometimes the environment hinders the survey of garden architectures, in such an extent that its representation is often omitted.
Instead, the use of automated technologies for survey, in particular laser scanner, means acquiring a huge quantity of non-selected data in a short period of time. This allows measuring complex shapes with the desired sampling resolution, without making a distinction between the scanned object and the environment in which it is inserted. The database obtained is thus proof of the geometry of the object at the moment of survey, which can be compared with similar later surveys to highlight the changes occurred.
On the other hand, surveying means interpreting architecture; therefore, such a survey includes also the detection of the most effective representation techniques for every situation (Balletti et al.2005).

2. THE PRATOLINO PARK

In 1568, the Grand Duke Francesco I de' Medici started the project of the Pratolino Park, the result of the lucky union between the Prince and Bernardo Buontalenti, to which the most talented artists working in Florence at the end of the 16th century contributed.

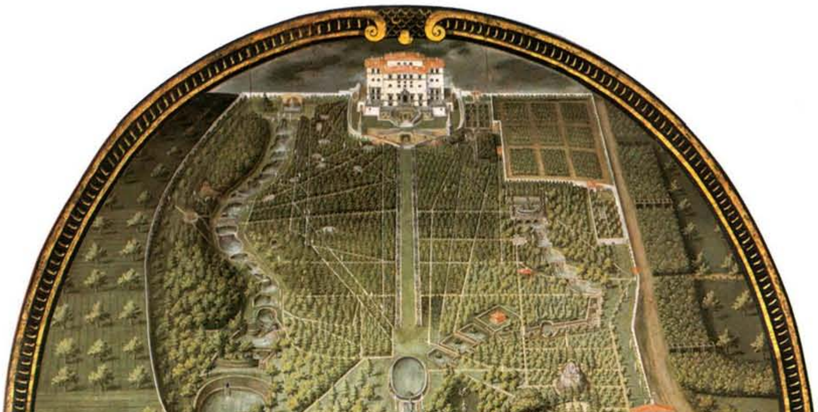

Figure 1. G. Utens, The lower part of Pratolino, 1599. Museo di Firenze com'era, Florence

Pratolino became immediately a milestone for travellers, because of its many wonders. The excellence of this complex originated from its elegant architectures, but above all from the incomparable originality of its water works, water-driven statues, grottoes and fountains. All these mechanisms were driven by hydraulic energy, transforming Pratolino into a spectacular technology exhibition (Battisti 1962). Water was also at the main element of the allegorical meaning of the Park, which had been developed along an axis crossing the whole garden from north to south. The main path started from the Fountain of Jupiter, then moved to the Appennino by Jean de Boulogne up to the Villa, continued along Viale degli zampilli (Fountain Avenue) and ended at the Fontana della Lavandaia (Fountain of the Laundress). In the following centuries, the changes in fashion and the resulting machine deterioration led to the almost total disappearance of the original Pratolino, and the remaining constructions look now like independent works that do not belong to an organic system anymore. The Park then became property of the House of Lorraine and in the 19th century it was purchased by the Demidoff family. In 1969 the already deteriorated complex was auctioned and finally abandoned until 1981, when the Province of Florence bought it (Zangheri 1987, Brunon 2001).

2.1. The Chapel

The Chapel was built in 1580 and is one of the last constructions made in Pratolino by Bernardo Buontalenti. Erected on the margins of the Park behind the Villa on an artificial earthwork mound, it can be reached by climbing up a staircase. It covers a total surface of 300 m^2. Initially delimited by high firs, it is now surrounded by a broadleaf forest.

Figure 2. Cross section of the Chapel. CAD drawing and views from point clouds.

The central-plan building was originally composed of a hexagonal room with a side of 4.20 m, surrounded by an ring-shaped porch of eighteen columns made of *pietra serena* (a grey Tuscan sandstone); four of them were later included in the walls

forming the sacristy. Inside there are some pieces of furniture, among which the wooden stalls and the altar, with a big altarpiece and other decoration elements.
The survey enabled to study the geometry of the dome (Arenga and Velatta 2012), coated with lead sheets and ending with a lantern, for a total height of 15.60 m., which in the previous surveys had been drawn only through patent approximations (Passaniti 2008).

2.2. The façades and garden of the Paggeria

In the original design of the Park, the *Paggeria* (or Pages' lodgings) was part of a complex for the staff and the service activities of the Medici villa, the present garden of which formed the courtyard.

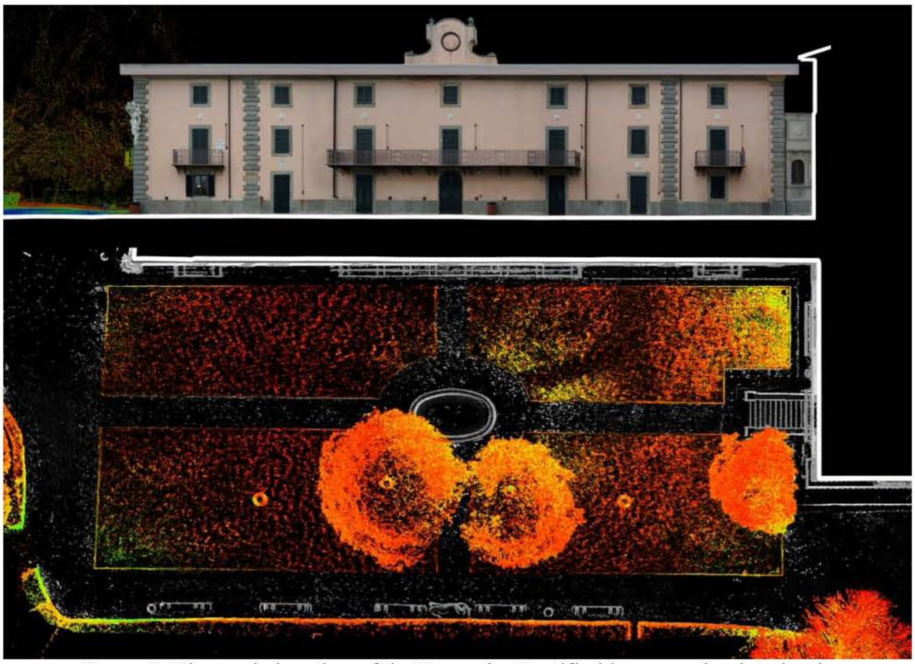

Figure 3. Plan and elevation of the Paggeria. Rectified image and point cloud.

The Demidoff family refurbished the building and transformed it into a villa, adding a new hall perpendicularly to the main body. This latter, divided into three floors, kept essentially the original structure, while the simple façades were reorganised without prejudice: the new iron balconies and the watch on the façade casually combine with both real and fake bas-reliefs. The building overlooks a 57 x 27 m garden including in a geometric layout natural elements and furnishings, among which a central oval marble basin and in particular the original hand and foot of the Appennino statue, replaced during the 1877 renovation works.

2.3. The Fountain of Jupiter

The Fountain of Jupiter was centred on the statue of Jupiter Pluvius by Baccio Bandinelli, later removed and placed in the Boboli gardens in 1834. The Demidoffs gave to the fountain its current aspect, with a modern reinterpretation of the statue of Jupiter. On its side was added a sculpted eagle too, that has no head now, but appeared intact at the time (or reintegrated).

Being in the highest part of the park, the fountain had a precise technical explanation. In fact, the pool acted like a surge tank, a reserve to pressurize the lower pipelines and to operate mechanisms and water works.

The fountain covers an area of approx. 27.00 x 18.50 m, with a difference of altitude of approx. 24.00 m. At the top of a staircase with grass steps, demarcated by kerbstones, there is an oval pool with a brick structure, 12.70 x 8.70 m, 3.50 m. deep. Inside the pool, a double row of pillars holds five vaults on which a stonework mound is laid. The sculptures are placed on top of it. The survey highlighted the hydraulic systems, such as the supply pipe under the central vault, the bottom outlet and the two intake pipes located at different heights (Tucci et al. 2011). It also recorded the deterioration of the last remains of the decoration system made of *spugne* (sponge-like rocks) that can now only be found around the arches.

2.4. The Giant of the Appennino

The giant statue of the Appennino is the most famous and original artefact of the Pratolino Park: the huge “sculpture/architecture” has been transformed and re-invented many times, so we will give here only a brief summary of its story.

The statue was built from 1579 to 1583 by Jean de Boulogne on a foundation structure designed by Buontalenti; originally it was placed inside a huge vaulted rockwork niche and contained several rooms decorated like artificial caves with fountains, paintings, statues and automata. Around 1690 the niche was demolished and Giovan Battista Foggini reorganised the back area and created the statue of the dragon. Some important modifications were carried out in the Romantic age and later by the Demidoff family, but the first studies and restoration in modern sense date back to the eighties (Vezzosi 1990).

Currently, the big statue covers an area of approx. 12 x 14 m (back area excluded) and is 10 m. high, while the base makes it 5 metres higher than the level of the lake.

The survey well documented the condition of the surfaces and the complex relations among the internal spaces that are placed on three non-communicating levels. The lower one (corresponding to the underground structure by Buontalenti) looks like a cave and rises from the level of the lake to the space behind the sculpture. Here there is a small hexagonal room where the vault and walls show the remains of the 17^{th}-century rustic mosaics of stones and shells. In the back of the giant, behind the Foggini’s dragon there is another room, leading to a small vaulted space inside the head, where you can see the remarkable iron structure that holds it.

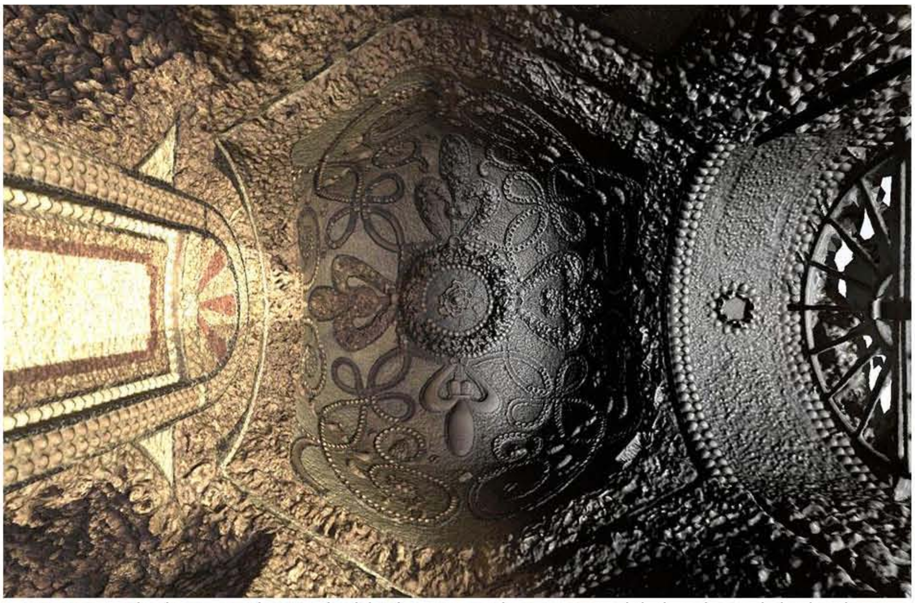

Figure 4. The hexagonal room inside the Appennino. 3-D model showing original colour attributes (on left side).

3. THE SURVEY: PURPOSES, TOOLS AND METHODS. FINAL DRAWINGS

Surveys have been carried out with different purposes and methods. In particular, the surveys on the Chapel and façades of the Paggeria were the subject of the final workshop of the First Training Course in "Geomatics for Conservation of Cultural Heritage" (Tucci et al. 2010, Conti et al. 2010). In compliance with the didactic purpose, the operations carried out (which sometimes exceeded the normal operating needs for such surveys) allowed comparing different techniques and provided all the students with the possibility of testing the available instruments. In the case of the Fountain of Jupiter and the Giant of the Appennino, however, the surveys were ordered by the Property in view of the maintenance works and the June 2011 restoration campaign on the external surface of the giant statue. These two artefacts, characterised by a complex and irregular geometry, were built with rough and carved materials, as well as rockworks encrusted with stalactites, sponge-like rocks and rustic mosaics formed by shells and polychrome lithotypes. These conditions generate several undercuts leaving shadow areas and holes in point clouds. The GeCO laboratory had thus to define specific best practices for the acquisition and modelling of this type of artefacts, later used in the surveys of the Grotta di Cupido (Cupid's grotto) inside the same park and the Grotta degli Animali (Cave of the Animals) in Villa Reale di Castello, which are still under way.

3.1. Topographic and laser scanner survey

We performed a topographic framework within a local reference system for all works, except for the case of the Fountain of Jupiter for its modest size. Targets for range maps alignment and registering were measured using total station. Scans were later modulated by position and number according to the land morphology, construction geometry and limited visibility due to thick vegetation. In some cases, in the same position we carried out many scans at different resolutions to have both a low-resolution environmental survey and a detailed range map of the building. We commonly used a phase-based laser scanner, but in the case of the Giant of the Appennino it was necessary to perform long-distance scans due to the presence of a pond in front of it. We therefore used a time-of-flight scanner with a higher range, which allowed acquiring the chromatic values of the surfaces too. Scanning was always performed during daylight hours and when the park was closed to avoid the presence of visitors who would have become unwanted elements to be eliminated from scans during editing. To acquire the back and the top of the Giant, some scans were performed from an aerial platform.

As each scan position is defined in a scanner coordinate system, for registration it's necessary to know the exact position and orientation of these scanner coordinate systems according to a local or global coordinate system. This can be obtained detecting in every scan at least three correspondences between targets surveyed by total station or any other similar natural points. The whole model is then optimized with an iterative algorithm (Iterative Closest Point). The alignment is followed by the editing of the point cloud (Santana Quintero et al. 2008).

3.2. Integration between rectified images and laser scanning

In the case of the Paggeria, the different geometric and material characteristics of the building (with typical flat façades) proved to be particularly suitable for the representation through rectified images integrated with scans. A survey planning was drawn up to detect the number of images required to represent the elevations in the desired scale, targets and natural points were surveyed topographically, further control points were extracted from the scans carried out for land survey. Images were roto-translated for the image rectification and expressed in the same local reference system used for scanning. As the geometry of some elements, such as the access staircase, could not be represented with rectified images, we integrated the drawings with ortho-images from point clouds.

3.3. Alignment and referencing

Every single topographic survey was performed initially in local reference systems due to the lack of intervisibility between the surveying stations and the distance between the different constructions. The referentiation of a single reference system was obtained by surveying with a GPS some surveying stations and other significant points that were not screened by the thick vegetation.

	Chapel	**Paggeria**	**Fountain of Jupiter**	**Giant of the Appennino**
Acquisition date	March 2010	March 2010	January 2011	May 2011
Number of people involved	9 students + 2 tutors	9 students + 2 tutors	2	7
Acquisition time (days)	2	2	1	3
Total surface (flat projection in m²)	5,400	2,280	500	2,000
Main closed traverses (no.)	1			1
Secondary open traverses (no.)	1	1		1
Traverse stations (no.)	6	2		9
3D laser scanner stations (no.)	25 (12HL-24ML)	6 (ML)	15 (3ML-12HL)	48 resol. m. 0.01 at 10 m
Acquired targets (no.)	47	32	14	35
Acquired space coordinates (no.)	321.778.445	40.779.575	497.077.644	361.698.330
Mean absolute error of alignment	mm 5	mm 3	mm 6	mm 4
Instruments (no., model)	1 Leica Total Station TCR 303; 1 Leica Total Station TCR 705; 1 Leica Laser Scanner HDS 6000; 1 Leica Laser Scanner C10 (Giant of the Appennino) 1 Leica GPS SR530; 1 reflex Nikon D700			
Software	Star-Net (topographic data processing), Leica LGO (GPS data processing), Leica Cyclone (range maps processing), Meshlab (mesh modelling), Geomagic Studio (mesh modelling) Bentley Systems Microstation (vectorialization) Adobe Photoshop (graphic editing)			

3.4. Final deliverables: 2-D drawings and 3-D modelling

While drawing up the final drawings, two aims have been pursued: providing the designers with drawings that comply with the conservation project and fully exploiting the quantity of data acquired with the most suitable representation techniques to describe – briefly but accurately – the geometry, the environmental context and the materials of each artefact.

For the Chapel and the Paggeria we did drawing by means of traditional orthogonal representations in 1:50 scale for architectures and 1:200 scale for general layouts. By using the point cloud of the Chapel we determined the suitable section planes, extracted thin point sections and obtained orthoimages of the building and context. The integration and processing of these images produced both contour lines maps of the whole area and vector drawings of the vertical and horizontal sections of the building.

The nature of the Fountain of Jupiter, characterised by the coexistence of strictly connected natural and artificial elements, suggested the opportunity of executing an overall surface model of the architectural elements, to be used to automatically extract all the desired orthogonal representations. As it was not possible to conceive a single surface model (due to its complexity), in the point cloud we segmented small homogenous portions in terms of morphology and level of detail required for their correct description. In fact, if for natural elements (lawn of the staircase, tree) a brief description of the volumetry is enough, for built parts (pool, statues, etc.) a more accurate definition is required.

Figure 5. Fountain of Jupiter. 3-D surface model of the mound and the statues.

Each single portion was decimated differently according to the planned definition and then triangulated to obtain an overall initial surface formed by 11,334,006 triangles. The following phases involving cleaning and processing gave a final model of 5,815,538 triangles. This model allows obtaining automatically all the desired 2-D representations. The natural environment surrounding the artefact, which is not included in the surface model, was synthetically represented with orthoimages of the point cloud used as the background of the sectional elevations.
In June 2011 a new survey campaign of the giant statue of the Appennino became necessary to carry out the restoration and maintenance works. Besides the complete 3-D representation, we also asked for 2-D drawings in order to compare them with the ones did during the surveys and restoration works carried out in the eighties. On that occasion a reference grid was drawn and used as reference for photos and documents concerning the survey of the artefact complex surface (Pozzana 1988). However, the Giant of the Appennino has different characteristics compared to an architectural artefact, whose representation planes can be generally and easily detected in plans and elevations. Therefore, we needed to obtain the projection planes of the orthogonal views from the pre-existing drawings. This trend proved to be positive for the main elevation, already surveyed through photogrammetry, while it could be applied only by approximation to the other elevations and plans previously surveyed with direct measurements, which showed remarkable deviations compared to the new measures. However, the 2-D representation of the elevations according to prefixed planes with the conventional criteria of the architectural drawing highlights only a tiny part of such a complex artefact, so further drawings were planned.

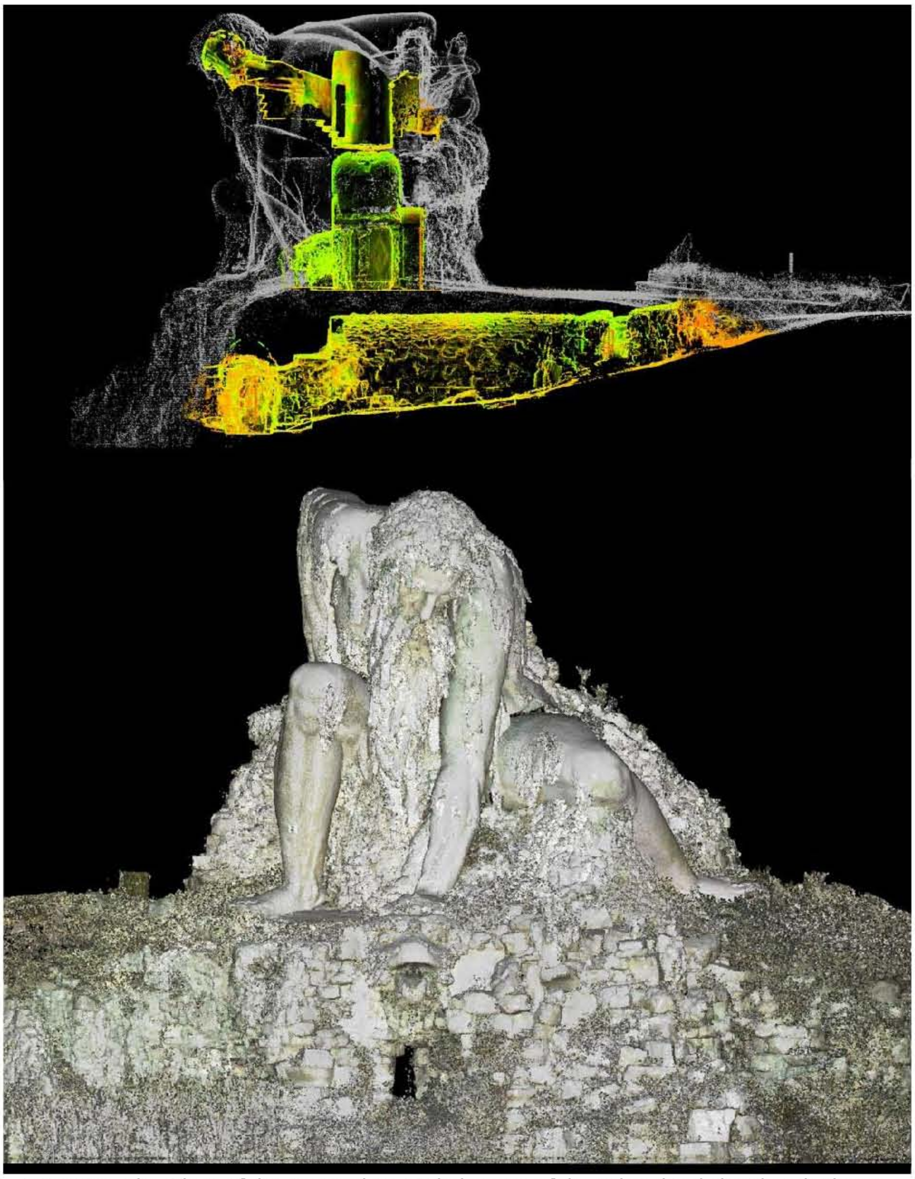

Figure 6. The Giant of the Appennino. Orthoimages of the point cloud showing the inner rooms and the main elevation.

These drawings, by differentiating the representation of the points of the external surfaces from the internal ones, allowed instant representation of the relations among the spaces. In this case too we drew up a surface model (presently only for internal spaces), which allows displaying in real time the geometry and inner articulation, as well as the chromatic values of the surfaces.

Figure 7. A comparison between a photo of the Appenino and the 3-D model (with texture on right)

4. CONCLUSION

The report showed how, by using the Geomatics techniques in an integrated way, it is possible to represent complex and organic shapes with metric precision which otherwise would be difficult to survey through traditional techniques.
However, there is still an open issue: to manage the data obtained suitable IT tools and technical skills are necessary; therefore, it is even more important to detect the most effective ways to communicate the results to non-specialised users too. On the other hand, the best potentialities lie in the production of 3D models that can be used for several functions.
Furthermore, as some in-depth studies have already been carried out on the Pratolino Park within different sectors (history of art, archaeology, botany, etc.), it is possible to use the database holding the surveyed metric data to relate the geometry of the buildings and the environment with the results coming from this multidisciplinary researches.
This way we can link knowledge and dissemination requirements with administrative requirements for better management and conservation of the Park.

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