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DIGITAL SEGUSIO: FROM MODELS GENERATION TO URBAN RECONSTRUCTION

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Abstract:

The reconstructive study of the urban arrangement of Susa in the 4th century arose from the intention to exploit some resources derived from local studies, and survey activities, fulfilled by innovative methods from which the modelling of architectural heritage (AH) and virtual reconstructions are derived. The digital Segusio presented in this paper is the result of intensive discussion and exchange of data and information during the urban landscape documentation activities, and due to the technology of virtual model generation, making it possible to recreate the charm of an ancient landscape. The land survey has been accomplished using aerial and terrestrial acquisition systems, mainly through digital photogrammetry from UAV (Unmanned Aerial Vehicle) and terrestrial laser scanning. Results obtained from both the methods have been integrated into the medium scale geographical data from the regional map repository, and some processing and visualization supported by GIS (Geographical Information System) has been achieved. Subsequently, with the help of accurate and detailed DEM (Digital Elevation Model) and other architectural scale models related to the ancient heritage, this ancient landscape was modelled. The integration of the history of this city with digital and multimedia resources will be offered to the public in the city museum housed in the restored castle of Maria Adelaide (Savoy dynasty, 11th century), which stands in the place where the acropolis of the city of Susa lay in ancient times.

Key words: digital archaeology, 3D models, 3D survey, GIS, cultural landscape, 3D reconstruction

1. Premise and aims

The history of the valley and the city of Susa in the Celtic and Roman periods is extensively mentioned in different literature, especially literature related to archaeological investigations, which is a scientific proof of the interest in the land's history and its heritage.

The ancient remains are partly well-preserved, but a unified and organic transposition of this important story told through modern multimedia has not yet been made. Such tools are currently recognized as feasible means to bring the stories from the past before a wider audience, and perhaps specifically in school age.

The innovative tools and the significant advances that have radically changed and expanded the descriptive potential of traditional metric survey techniques are now more adaptable to the evolving framework of needs, featured by a rapid specialization in many fields of application.

The reconstruction of an ancient scene begins with an accurate account of all the evidences gathered from the study of materials and documentary sources.

Besides, when the relationship between the natural environment and the landscape is significant (but now the belief that it is a relevant factor in any context is shared), it should be possible to relate the objects of historical and archaeological interest with the natural component of the landscape. For example, it is often essential to compare positions with orography and hydrography, or anthropogenic factors, including the complexity of roads that are fundamental networks, above all in mountain contexts or piedmont areas.

The use of tools that allow the geographical information management (GIS) is primarily a means to represent data derived from studies of the ancient buildings, and is simultaneously useful to allow the assessments of supposed reconstructions of the overall ancient scenario, natural and anthropogenic. Only after accomplishing these steps, the land and the built heritage models become tools of communication and education, which are the typical functions of a virtual reconstruction of ancient environments.

This paper reports the development of a study that started from a set of known information about the city of Susa and continued with the adoption of innovative survey systems, terrestrial laser scanning and aerial and terrestrial photogrammetry, for the documentation of archaeological preserved emergencies in relation to urban and natural territory. The spatial multiscale information managed with GIS tools in a single geographical reference system has enabled to achieve,

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in different phases, the ancient hypothetical configuration to the 3D virtual reconstruction.

2. Segusio and the Alps: from Celts to the 4th century A.D.

Over the centuries, the arc of the Alps marked history and tended to establish two different worlds, in contact with each other, but still carrying separate stories: the Celtic world in the north, the Greek-Roman world in the south.

Crossing the Alps in the past was much less easy than it is today: in the western corner of the Alps, at the end of the Aosta and Susa valleys, a series of important passes were open; this is doubly interesting because they enabled direct contact with both the French plains and the Rhine valley.

Segusio (today: Susa, near Turin, Italy) is located on the far west edge of the Po Valley, where the climb towards the passes of Mont Cenis and the Montgenevre starts. The present paper concerns this city of Celtic origin (Fig. 1).

Segusio is an auspicious name since it is related to a Celtic root word meaning "Victory". The Celts choice, accomplished when they settled in Segusio, was decisive: at a stroke, the new settlement was on the edge of the plain and controlled the two crossings.

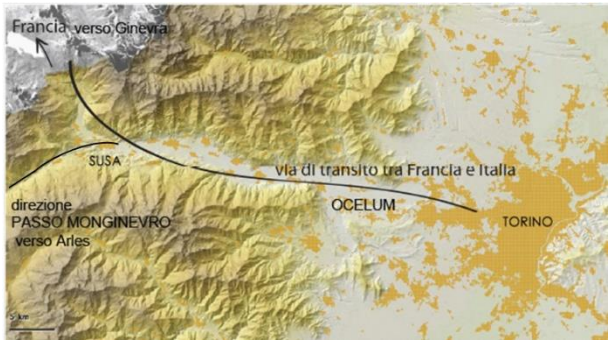


Figure 1: Segusio, a key point to two passes in the Alps: the Mont Cenis to the north, and the Monginevro to the south.

(a)

(b)

(c)

(d)

Figure 2: The Arch of Augustus: a) An excerpt of an input image showing targets on the attic; b) Laser scanning model; c) Photogrammetric model of the attic; d) Integrated photogrammetric and laser scanning model of the Arch.

We know nothing concrete about Celtic Segusio, however we do know perfectly, the time when Segusio came under the influence of Rome.

The Arch of Augustus is an imposing and a very well preserved monument describing this particular moment. The arch was built in the year 8 B.C., as a testimony to the agreement arranged between the Celtic king named Cozio and Emperor Augustus (Figs. 2 and 3).

In this Romanization phase, the first settlement of the Roman Segusio was established. Unfortunately, the evidence from the ruins is very limited, but a typical Roman urban arrangement, with temples and monuments and without any town walls could be assumed (Mercando, 1993; Barello, 2007, 2008).

During an imprecise period but dated somewhere around 275 A.D., the "first Susa" was violently swept away by one of the first Barbarian invasions that descended through the passes and was directed towards the rich Po valley.

The location of Segusio was too strategic to be abandoned; corresponding to a hub of the two major crossings. Therefore, a “second Segusio” developed presumably in about ten years, not as an open city but as a heavily fortified urban settlement (Dezzani & Patria 2009, 2010).

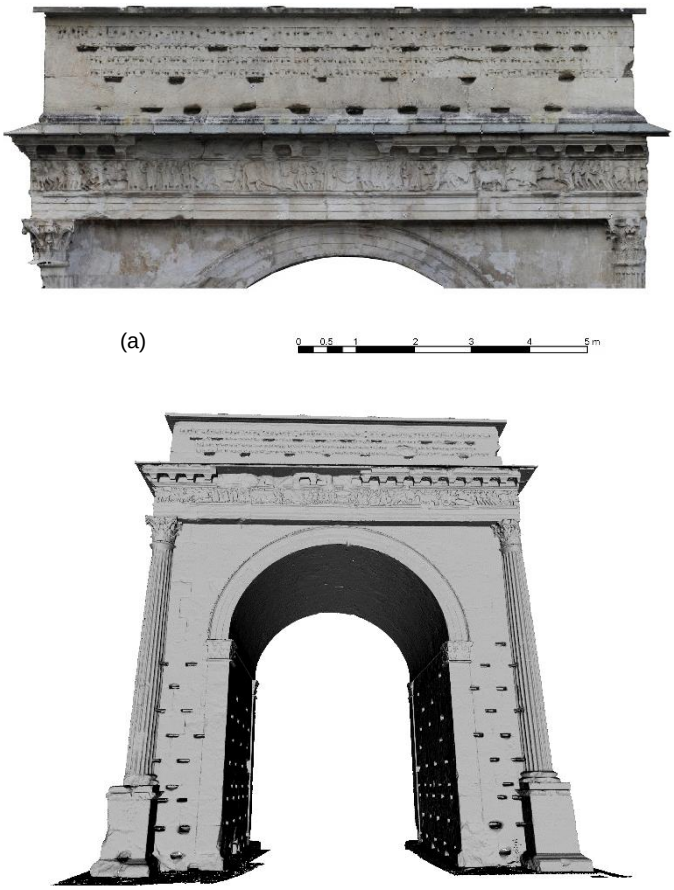


Figure 3: The Arch of Augustus: a) Highly detailed orthophoto (pixel size 1 mm) concerning the frieze and the attic: the frieze illustrates the pacification of the Celtic and Roman worlds; b) A view of the geometric model. (The 3D model is a result of the cooperation between the DIRECT team from Politecnico di Torino and 3D Optical Metrology (3DOM) unit, FBK, Trento).

This second Segusio is the one that has been digitally reconstructed. More precisely, the attempt is to revive the Segusio from 355 A.D. In that year, Emperor Julian passed through this land when he was going to Gaul, in order to counter the continued threat of the Germans. The historian Ammianus Marcellinus was traveling with the emperor, and he left a description of Segusio defining it as a fortified city.

The Segusio town walls are an important example of the 3rd century military architecture. However, they are not an isolated case since most of the Roman cities located on the axis Rhine/Rhone/Mediterranean were in fact equipped with walls. The cities or other involved settlements were about 140 in number, among them 55 are very relevant (Boudeau, 2009) (Fig. 4).

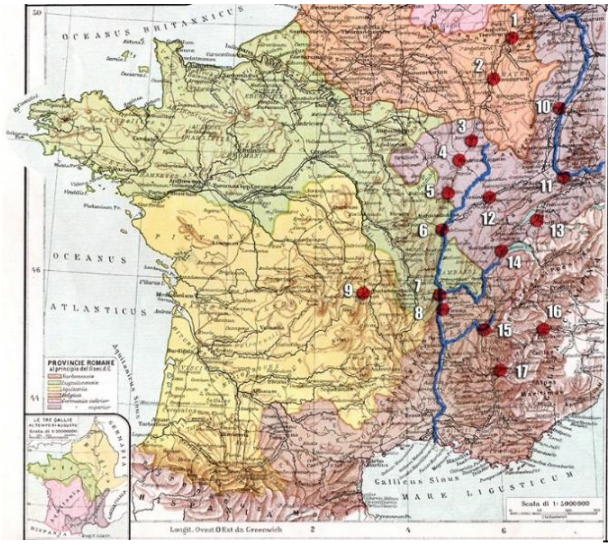


Figure 4: The fortified cities of Gaul in the 4th century: the Rhine and Rhone (Boudeau, 2009).

All these cities are currently located in the territory of France: among them Segusio is the only one now in Italy. This fact is not surprising since, during the Roman Empire, the administrative boundary between Gaul and Italy was in fact some 30 km downstream from Susa.

Another aspect makes the town walls of Segusio interesting: in almost all French cities, the boundary walls have been destroyed or mutilated during the 19th century, enabling the expansion of urban centers.

Susa, instead, preserves the traces of town walls almost clearly; it was, therefore, possible to achieve an extended survey and a consequent reconstruction of their appearance.

Undoubtedly, the walls of Segusio were built quickly, with the aim to defend the population against invaders.

However, the construction must have been a huge and complex challenge, as some supposed technical data related to the walls clarify:

- Length of the town wall: about 1250 m.
- Area included in the city walls: approximately 67 200 m2.
- Number of city gates: 4
- Average height of the walls: about 12 m (from ancient ground level).

- Estimated number of towers: 28 (from ancient ground level).
- Estimated volume of the walls (stones, reused materials, bricks): about 67 000 m3.
- Volume of handled ground for foundations: approximately 50 000 m3.
- Estimated time for the construction: 4-5 years.
- Employed labor force: from 200 to 500 men.
- Population hosted by the walled city: 1200-1500 inhabitants.

The so-called Porta Savoia, on the west side of the walls, is particularly imposing; it was built on the model of the Aurelian Walls in Rome. Its original estimated height of 27 m, probably makes this city gate the tallest building in the 4th century A.D. between the Alps and Rome.

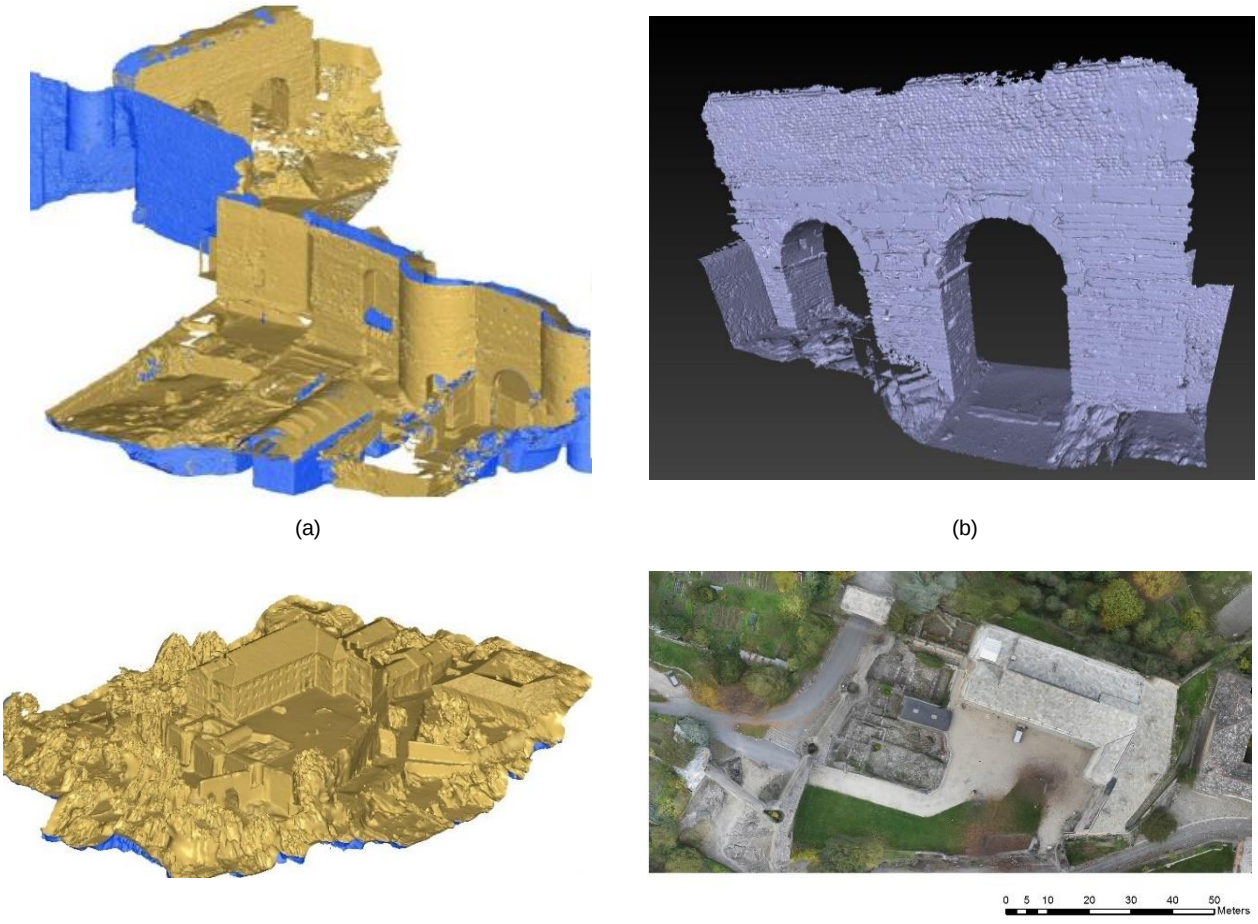
The dimensional data speculated for Segusio are consistent with the latest research and analyses dedicated to the late antique fortifications in Gaul. That confirms they are a homogeneous set of experiences and accomplishments (Heijmans, 2006; Bachrach, 2010).

3. Landscape and heritage reality based modelling

The new survey technologies offered by geomatics allow users (in a rather accessible way) to acquire terrestrial and aerial data compatible with each other, so the integration is possible.

The low altitude of UAV flights is particularly significant in the field of ancient and architectural heritage located in urban contexts. This ability added to the chance of describing an object from different points of view, aerial and terrestrial ones, is a topical issue in the architectural and landscape survey and modelling since this operation makes it possible to analyse the objects in a more detailed and complete way, helping the phase of knowledge, comparison and monitoring.

The ancient architectural heritage (AH) of Susa has undergone a wide campaign of surveys in the recent past, via terrestrial techniques (photogrammetry and laser scanning) and aerial methods by the use of UAV photogrammetry, with the aim of documenting and thus enhancing the knowledge of a little-known heritage (Aicardi et al., 2015).



(a) (b) (c) (d)

Figure 5: Multiscale models concerning the Acropolis of Susa and its buildings: a) Lidar high detailed model of the archaeological area of the Acropolis (Praetorium excavation, arches of the aqueduct, preserved city walls); b) Very high detailed model of arches of the aqueduct (Terzago, 2014); c) UAV model of the complete acropolis; d) Orthophoto of the Acropolis.

Those acquisition activities have considered the integration of multi-sensor methods, and the first data processing consisted in the data registration and geo-referencing in the global reference system; this step has been performed using the vertices of the network measured with GPS/GNSS techniques.

The photogrammetric survey by UAV has been fulfilled with a Hexakopter of Mikrokopter (multi rotor system) equipped with a Sony Nex 5 digital camera.

To cover the subject of the trial areas were designed and executed several flights: the entire archaeological site of the Acropolis until the area of the amphitheater has had its flying height above ground equal to 70 m and the amphitheater area equal to 30 m, executed during several flights.

The product of UAV photogrammetry consists of a set of images from which it is possible to extract point clouds, 3D textured models, Digital Surface Model (DSM) and orthophoto. The data processing techniques are mainly automated by an image matching approach (Kersten & Lindstaedt, 2012; Remondino, Spera, Nocerino, Menna, & Nex, 2014).

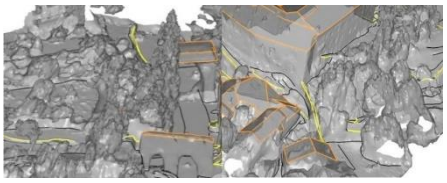
The automation is derived from the use of the Structure-from-Motion (SfM) method that allows users to estimate the 3D position of points represented in multiple images, and reconstruct the geometry of the represented object (*structure*) and the photo acquisitions (*motion*), even when the camera calibration parameters are not available.

Moreover, the LiDAR (Light Detection and Ranging) technology is well-established for applications in the field of cultural heritage, in the knowledge and documentation phases, allowing experts to gain a lot of information on both simple and articulated surfaces with a high precision and quality.

The LiDAR survey has been achieved by means of a Faro Focus 3D, which has a measuring range from 0.6 m up to 130 m; moreover, it measures up to 976 000 points/s and is equipped with an integrated camera. The acquisition involved the Acropolis emergencies, the amphitheater and the Arch of Augustus, which was detected both from the ground and from an aerial work platform in order to obtain more detailed information on the frieze (Fig. 2a, c).

The 3D models provided different resolutions and consequently helped in relating the vast multiscale information content (Fig. 5).

These 3D models have been integrated in order to obtain a more complete description of the objects investigated, allowing multiple representations useful for several purposes: 2D and 3D representation of objects and areas, extraction of orthophotos, DEM extraction from DSM, DEM/DSM integration in regional scale.



(a)

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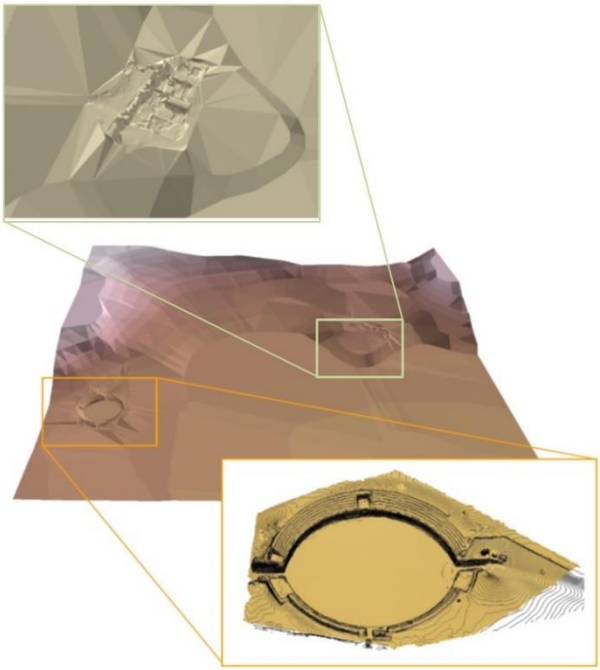

(d)

Figure 6: Data at different scales implemented within a GIS structure in order to connect multiple needs: a) Studies for break-line extraction from the UAV model; b) UAV model (30 m flying height) of the amphitheater (Capacchione, 2014); c) Topographical datasets derived from the UAV model and structured with the aim of urban digital map updating (Carnino, 2015); d) Fusion of UAV models in the regional DTM, visualized as a TIN (triangulated irregular network).

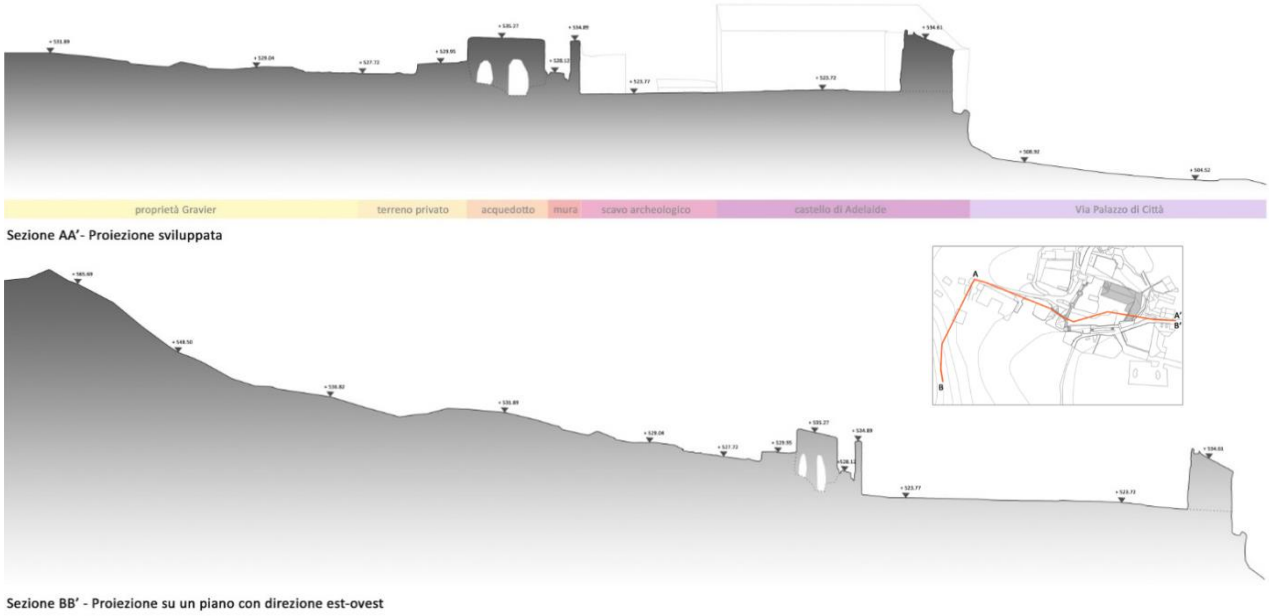

Figure 7: Section profiles, accomplished by GIS tools, aimed to study the path of water flow connected with the aqueduct arches.

The opportunity to compare with each other the different models into a larger regional model, to judge levels and their differencies into a single reference system, assumed heights and assess alignment of buildings is particularly important as a corollary to the archaeological studies and investigations on the urban form.

This is the reason why the data at different scales have been finally implemented within a GIS structure in order to connect multiple needs (Fig. 6 a-d). The set of images of Figure 6 explains these aims and related results. Raster datasets (orthophotos, DEM, DSM) and vectorial data (surfaces, breaklines, levelling points) contribute, each with its own informative power, to the increase in the scenario of useful knowledge needed for the reconstruction of the ancient landscape (allowing the generation of profiles as in Figure 7).

4. A didactic project for a 3D city model of Susa

Recently, the modern city of Susa has been the subject of a further training project that has, as its objective, the creation of an urban model of the current city, with today's tools that enable the creation of 3D city models (Carta, 2015).

To add to the recently available dense data on the Acropolis and the city areas affected by the archaeological remains that had been the subject of targeted flights using photogrammetric UAV, the need to have a good altitude record of streets and buildings concerning the entire area of the ancient city was compounded.

A classic photogrammetric approach has been chosen: this allows experts to obtain more detailed data and better information on elevation profiles of roadways and on the volume of buildings. For this purpose, some frames of a recently fulfilled regional aircraft flight were used (the regional orthophotomap have been published by Piedmont mapping agency in 2010) (Fig. 9c).

Consequently, the use of *CityEngine* software (ESRI) allowed us to obtain a model of the modern city (Fig. 9 b-f), limited to the area corresponding to the walled Segusio, so that the combined vision of this product lead to the reconstruction of the model of ancient Susa (Fig. 8), facilitating the observer's understanding in relation to the current situation.

This kind of software is used in various fields, especially in urban planning and design, for the reconstruction of urban areas through procedural modeling. It began as a GIS environment expansion project, to respond to the need of quick and inexpensive creation of whole city spaces while avoiding the modeling of each building,

Figure 8: "Carta topografica che comprende i forti della Brunetta e di Santa Maria, la citta' di Susa unitamente ai villaggi, e borgate di Monpantero, Venaux, Giaglione, Gravere, Meana, fabbriche, e terreni, monti, valli, ripe, fiumi, torrenti roggie, strade (a0004481)", undated, early 19th century. http://www.igmi.org/prodotti/cartografia

and managing to keep a control on model appearance and software behaviour in the creation of the entire scenario.

Although the method of creating a 3D city model is a very different modelling approach compared to other methods based on the derivation of surfaces from innovative survey methods (such as photogrammetry and laser scanning), it still shares the cartographic reference system (Pilouk, 1996; Zlatanova, Rahman, & Pilouk, 2002).

However, the 3D city model approach is even far from the realistic models such as the ones presented in Section 3, as well as the ones based on software that aim to display scenarios as realistically as possible. Actually these softwares do not support the mapping coordinates yet; Autodesk Maya has been used to generate the Segusio model in the 4th century, since it is one of the most suitable software for this purpose.

The images of Figure 9 show the workflow.

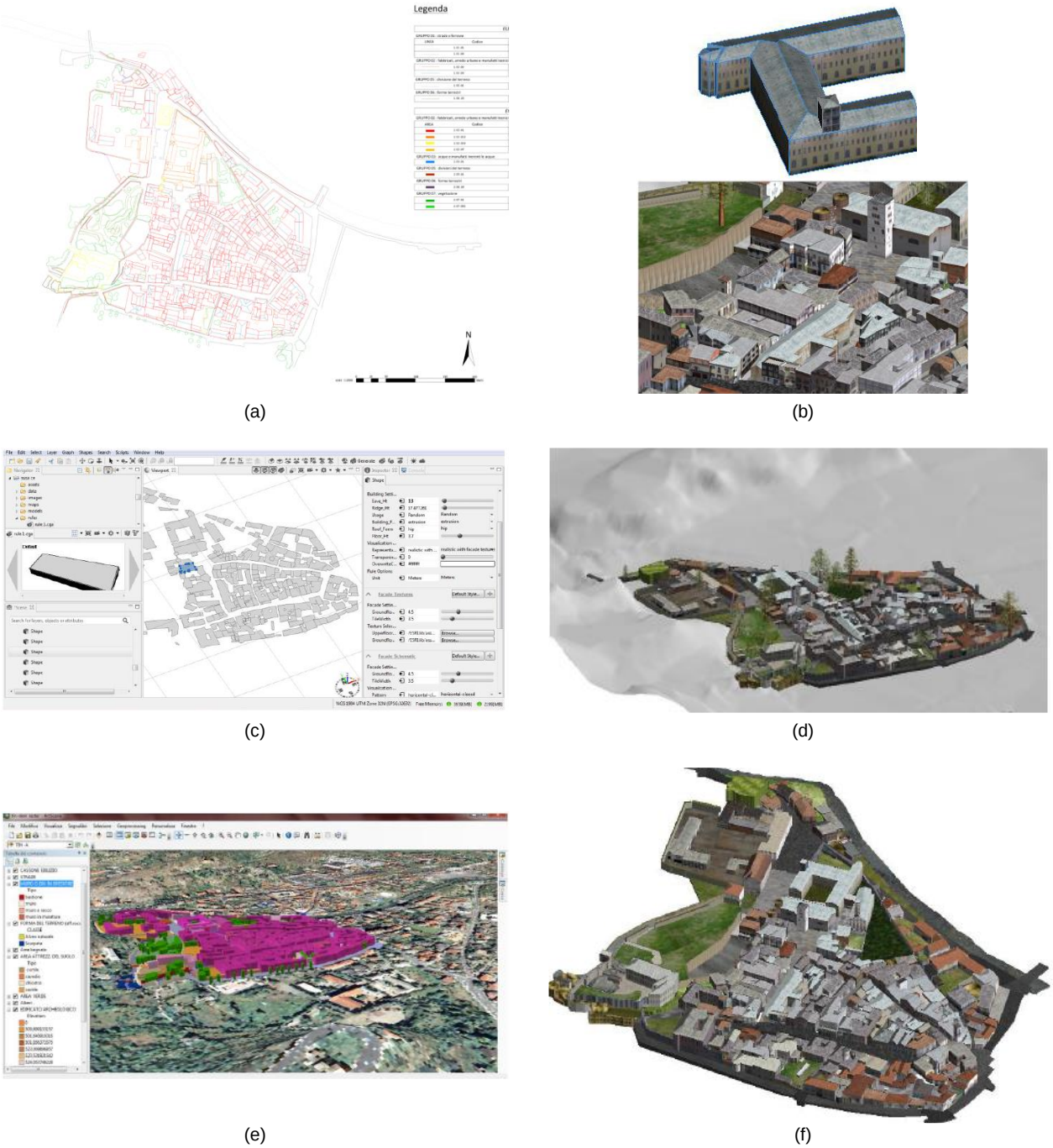

Figure 9: The workflow of the 3D city model of Segusio: a) 3D plotting using classic photogrammetric approach; b) Screen shot of the setting the 3D modeling work in CityEngine for the walled city; c) Bird-eye view of the superimposition of parametric building models on the regional orthophoto; d) Examples of texturing some buildings; e,f) 3D views of the central city model.

5. Modelling the types of towns and walls

One of the most critical aspects in the study of reconstruction of monuments and ancient cities is the need to assume the shape and consistency of public and private buildings, especially their configuration in elevation, and the compositional aspects of fronts.

Very often what appears deleted has just changed the shape. This is the case with Roman cities such as Segusio. Segusio preserves what is considered the presumed original plan of the Roman city, enclosed by walls that are partially visible in the current urban configuration.

Despite the objective lack of direct material sources, inevitable in the contexts in which the urban continuity has succeeded over the centuries up to the present configuration, the graphic reconstruction was inspired by the representations and descriptions handed down by historical figures who had seen directly the chosen scene (as Ammianus), and of course from the available literature of studies, research, and insights.

Given the scarceness of authentic data, the accomplished virtual reconstruction, does not claim to be a true representation of a bygone era, but rather wants to be credible in the general overview and in some of its structural parts.

We therefore believe that the reconstruction model created (an image is shown in Fig. 10a) shows a credible idea of how the city must have appeared in 355 A.D.

It was a small town of about 1500/2000 inhabitants (Fig. 10a), including the Cardo and Decumanus as main streets, but with an additional artery (14) that connected the two major ports: Port Savoy (1) and Porta Piemonte (2).

The city then had a regular frame, but not squared with the Castrum area (7) and the Arch of Augustus (9) that dominates from the imposing fortress.

A back door also allowed citizens to exit to the arena (6), located outside the walls in a natural depression. The city wall was surrounded, to the north by the river Dora (12), to the east by the river Cenischia (3), and to the south by the ditch (4).

This characteristic shape of a triangle, obtained from a previous reduction of the town center that has been enclosed within the walls, has created large areas of defense in front of the walls, where the enemy could easily be hit from above.

The housing model are modules suitable for one or two families, of 1-2 storey at most, with some typical Roman structures, (with porches and the roof covered with tile

(a)

(b)

(c)

Figure 10: The reconstructive model of Segusio: a) Plan of the buildings and urban elements; b) Slight ascent to the castle/acropolis with the Cozio heeron on the right; c) Aqueduct with arches connected with the city walls' reconstructed model.

Roman) and others are more like Gallic type homes, or rather Gallo-Roman, with the roof covered with stones or straw alternatively.

During the construction of walls, the old forum had been left outside the wall itself (11); such space therefore has been chosen to be an arcaded square that would serve as a new forum, where the area in front of the current cathedral was built in the Middle Ages; which, however, remains a square till today (Barello, 2011).

In the reconstructive city model, some workshops or atelier have been assumed near the entrances to the city, imagining it as the ideal place to do business.

Ammianus, following the Emperor Julian in the winter 355 A.D., described a view of the outside of the walls in front of the now called Porta Savoia (Fig. 11), citing the presence of the ancient tomb of King Cozio (10), who built the Arch dedicated to Augustus. The reconstruction of King Cozio's tomb (11) comes after the data entered by the historian (Brecciaroli Taborelli, 1994), while for Porta Savoia, references are taken from some Cesare Bertea (1866–1941) studies (Mercando, 1993).

In places where the reconstructive model of the walled city shows preserved buildings, such as the aqueduct arches, the representation is definitely very realistic since the laser model is involved. A relevant reference to represent important buildings and ancient structures that still exist have been the Theatrum Sabaudiae, a historical map dated towards the end of the 17th century that reports figurative images of the cities of Piedmont, targeted as partly realistic and partly aimed at emphasizing the magnificence of the court of Savoy (Blaeu, 1682).

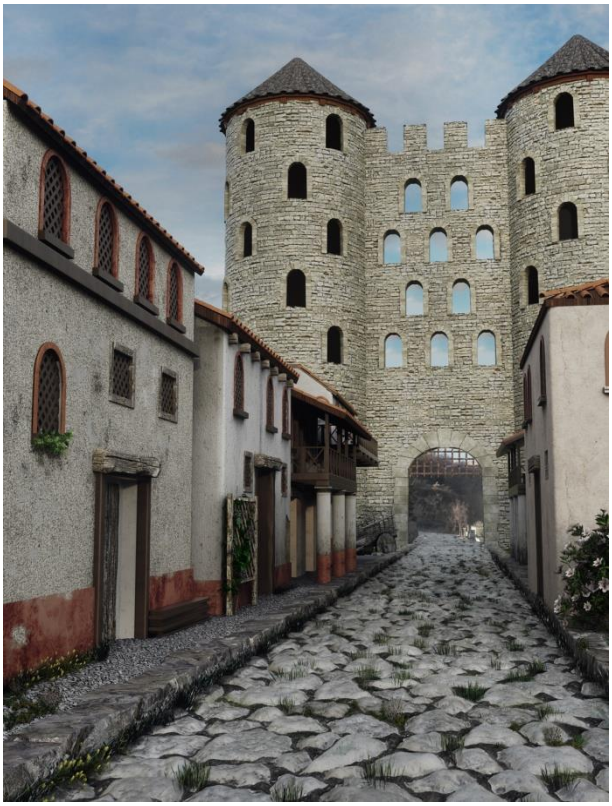

Figure 11. Reconstructive model of Porta Savoia inspired by Cesare Bertea studies and samples of residential buildings (Mercando, 1993).

In cases such as the Arch of Augustus (Fig. 12), starting from the laser survey model, a possible completion of the decorations was inspired by the studies of Cesare Bertea and Luigi Rossini (1790 – 1857) and all studies recently dedicated to Porta Savoia analysis (Mercando, 1993), while for residential buildings, reference was made to studies already being tackled.

Figure 12. Reconstructed model of the Arch of Augustus: on the left the laser survey model; on the right the model inspired by Cesare Bertea and Luigi Rossini's studies (Mercando, 1993).

6. The use of the model in the museological context

The image in Figure 10a, which is a bird's eye view of the city as we imagine it in the 4th century, will be projected in the museum of Susa on a wall of 6 m x 3 m size, using a wall printing technique to ensure it is an immersive enjoyment experience for the visitor.

This technique allows visitors to pull the image easily and place it on other historical representations of the territory, which are in the same museum room, and ensures that the viewer can find uniformity, while running his gaze from one wall to another.

A topical issue is to make approachable the tools of land representation and management, which are GIS-based, with the tools for documentation and sharing of information regarding cultural heritage.

The integration of the functions of representation and analysis of spatial data in GIS with the level of geometric-semantic specialization, useful to represent the complexity of cultural assets, is closely required (Costamagna & Spanò, 2013).

Lately, there has been a development of standards for interoperability both in geography and in cultural heritage, with the first steps having been taken towards their integration. Indeed, the standards in spatial information provide limited representation scales (1:100, OGC CityGML) and the considered semantic values are not suitable. The second (and in particular the CIDOC

Conceptual Reference Model (CRM) ontology) are born from documentation of museum objects (Noardo, 2016; Le Boeuf, Doerr, Ore, & Stead, 2013).

7. Conclusions

We believe that this project will demonstrate the valuable possibility of using heterogeneous tools of investigation, analysis and representation of a territory and of the built heritage, developed within different scientific communities, enabling to group the study outcomes into products that communicate ancient scenarios in some detail.

The use of the results from historical research, as well as those from the non-standard photogrammetric surveys (e.g. with UAV) and terrestrial laser scanning, along with the management of geographic data in GIS and even virtual reconstruction tools (Maya – Autodesk) have made it possible to coordinate the pieces of certain knowledge and those hypothesized in a single "picture" of the whole city.

In recent years, the use of material and published sources, even from ancient or historical sources, combined with the use of new technologies has provided the opportunity to present reconstructed scenarios adhering to scientific studies, which are easily accessible to a wider audience (Ampliato Briones & Gimena Córdoba, 2014; Piñas Azpitarte, 2012). This certainly facilitates the spread of sensitivity about cultural heritage and in general, about the heritage of the past, which could be useful for conservation and protection purposes.

The development that we propose for the future, and that we have already presented to local authorities, is to coordinate the different multi-temporal scenarios. Since in Susa Valley, there are archaeological remains from the Bronze Age, the Roman period (pertaining to the current project), the Middle Ages and of course others from later periods, the next stage is the reconstruction of different eras/scenarios, while also investigating the reasons for the subsequent transformations.

Acknowledgements

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The city of Susa and the architect Maria Pia Dal Bianco (castle restoration and setting up of the Civic Museum designer), who participated actively in the initiative's success.

The DIRECT team (working in the field of advanced technologies, 3D Metric survey, for the on going education of students from the areas of Architecture and Engineering in relation to the promotion and protection of the territory and built heritage) participated in the survey campaign and data processing in 2013, and above all Elisabetta Donadio. We would also like to thank Dr. Enrico Maggi –PhD in Arch.– who has deepened the study and the graphic representation of the walls of Segusio.

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