

3D data integration for the digital reconstruction of cultural heritage monuments

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Abstract. The ancient city centers often contain traces of monuments almost completely disappeared, whose few remains are hidden by modern buildings. This is the case for many monumental buildings of the Roman period in Italian cities, that have almost disappeared over time being gradually dismantled for the reusing their construction materials, leaving space to a dense urbanization. Knowledge of such monuments is often approximate and based on historical memories of various kinds. In such situations, three-dimensional surveys and digital 3D modelling reconstructions can be of great support for scientific-archaeological research and for providing a scientifically supported image of cultural heritage sites.

This paper shows the work on the emblematic example of the late Roman Circus of Milan, an impressive monument of about 450x85 meters, built when Mediolanum used to be capital of the Western Roman Empire (286-402 A.D). This fact is nowadays almost unknown to most citizens of Milan. The diachronic reconstruction approach is used in order to show the monument in his current state and in his presumed past aspect. The reconstruction is based on a proper mix of quantitative data originated by 3D surveys at present time, and historical sources like ancient maps, drawings, archaeological reports, archaeological restrictions decrees and old photographs. In this panorama, the georeferenced acquired data of the remains play a key role in order to validate the previous reconstruction of the building and to define some fixed points to hypothesize a reliable reconstruction of the area in different historical periods. The experimental activity is defined by the project Cultural Heritage Through Time - CHT2 (<http://cht2-project.eu>), funded in the framework of the Joint Programming Initiative on Cultural Heritage (JPI-CH) of the European Commission.

1. Introduction

For research purposes, documentation needs, preservation and conservation issues in the Cultural Heritage field, it is fundamental to appropriately record, document and survey artefacts and sites: indeed, an accurate and complete 3D digital documentation is a prerequisite for further analyses and interpretations. This digital representation is also important to properly communicate our Heritage to the public, often coupled with a 4D reconstruction, highlighting the real shape of a monument compared with what is still visible nowadays. This type of reconstructions can be based only on archival data but several works [1-4] have shown that a serious reconstruction work should start from the accurate digitization of the existing remains coupled with a deepen research of other sources of information. However, there are cases where the three-dimensional diachronic reconstruction is particularly complex, due to: i) the nearly total absence of remains to be surveyed; ii) few documentation on one or more periods of artefact's time life; iii) uncertainty of sources; iv) difficulty to correlate documents and data to a three-dimensional representation.

This paper presents a work done on the Late Roman Circus of Milan that, given the limited detectable findings, began with an in-depth philological analysis from the collection of historical and archival data, integrating the different contribution in the area started from the early 1939 [5-8]. The case study covers the south-west area of the city center of Milan that corresponds to the Roman Circus area [6, 9], where it is possible to see several traces of the different historical periods from ancient times until the densely urbanized structure of the present days. The Circus was the open-air venue for chariot and horseraces and also the place dedicated to the celebration of the Emperor's greatness and for this reason it was generally located near the Imperial Palace [10]. Archaeological studies were conducted



mostly at the beginning of the '900 and after World War II, during the reconstruction of some private and public buildings, when it was possible to see the archaeological remains. Nowadays, only small portions of the monument remain visible and a lot of historical documentation has been lost during World War II. Starting from the '60s of last century, the northern area, corresponding to the to the complex of the Monastero Maggiore, was used as headquarter of the Archaeological Museum of the Municipality of Milan (Civico Museo Archeologico di Milano). The rest of the area is instead almost entirely occupied by residential buildings [11-12] and only some portion of circus remains is still visible in the basements.

2. Investigation methods

This work, given the limited detectable findings, began with an in-depth philological research started from historical and archival data that have been integrated to hypothesize a reconstruction of the monument, by referencing such documents to that specific location of the city.

One of the first step was a deep bibliographic research to collect information about the studies and the excavations done during the past centuries on the Milan's Circus and also on the others circuses of the same period to understand the design rules for that kind of monument [5, 10]. Another step of the work was the collection of historical maps and drawings showing the knowledge of the area and the extreme urbanistic changes during the centuries. In the Figure 1a) and 1b) for example it is possible to see how the northern area of the circus, converted into the ecclesiastical complex of the major monastery starting from VIII century BC, in the 19th century underwent a major transformation due to the opening of a new road axis of Via Bernardino Luini.



Figure 1. Detail of two historical maps in which the urban change in the 19th century is visible:
a) 1837/1860, G. Pozzi; b) 1877, C. Fenghi (Courtesy of Archivio delle Stampe Bertarelli).

At the beginning of the activity an agreement was signed between the CHT2 project and the Milan Superintendence in order to obtain the permission to study the monument and to access to all the documents stored into the archive. Thanks to this, a long research was done taking into account: pictures, drawings, old digs diaries and archaeological constrain decrees.

The area of study, for example, was severely damaged during the II world war, and as a result of this, in the 50s and 60s, many buildings were demolished and rebuilt. During these works, some finds emerged and were subsequently removed, incorporated into new structures or covered and today they are no longer visible (Figure 2). Even for these peculiar reasons the analysis of the historical documents is particularly relevant.



Figure 2. Photographs of the remains during the excavation of private buildings reconstruction after the WWII, actually not more visible: (a) Via Brisa 1951; (b) Via Medici-Circo (courtesy of Soprintendenza Archeologica di Milano).

3. Inspections and surveys

Parallel to the archival research, a capillary inspection was carried out in all the buildings in the area where the circus was expected to be. Thanks to this, it was possible to make a first check on the quantity and positions of the remains compared to the historical maps. In figure 3 it is possible to see a map of the circus with some portion filled in red corresponding to remains considered visible at that time [8], the overlapping portions filled with the red cross-hatching highlight the areas where currently there is nothing visible and detectable. As it can be noticed, there are large areas where historical information deviates from the real situation. Based on the obtained results of the inspection, the following activities were planned: i) comprehensive three-dimensional survey of all the remains currently accessible with different technologies depending on their peculiarities and the needs of study; ii) topographic survey of the area in order to correctly georeference each portion of the monument.



Figure 3. The map shows the state of the art of the survey campaign: cross-hatching in red the areas in which the archival data gave information of remains but now nothing is visible, in green the acquired data, in light blue the building not yet accessible.

3.1. 3D survey

The 3D survey regarded the data acquisition of all the archaeological remains still visible in the area. Different techniques were used: ToF, Phase Shift laser scanners, mobile mapping and photogrammetry, depending on the condition of the walls and the aim of the survey.

Laser scanning was used to acquire the geometric and dimensional information of the remains, maintaining a standard deviation lower than 3mm and a spatial resolution at least at 1cm. For the exterior parts a Faro Focus 3D 120 and LEICA HDS7000 were used.

While for the most of the inner parts and the connections to the exterior, in order to have the needed data for the georeferencing work, the hand-held mobile laser scanning GeoSLAM ZEB-REVO was used [13, 14]. This instrument is a portable mobile mapping system (MMS) consisting of a 2D time-of-flight laser range scanner rigidly coupled to an inertial measurement unit (IMU) mounted on a motor drive; the data are combined by a 3D simultaneous localization and mapping (SLAM) algorithm is used to combine the 2D laser scan data with the IMU data to generate accurate 3D point clouds. The data is captured by simply walking through the area of interest drastically reducing the time consuming scanner set-ups and data registration associated with traditional terrestrial laser scanning methods. This aspect is relevant because of some peculiar aspect of the survey: i) most remains are located in rooms and basements of private properties, often prestigious residences with problems related to privacy and security issues; ii) long and complex paths to go from the rest to the outdoor road position useful for georeferencing; iii) the need for a short time work, both in the acquisition step, to stay as short as possible in residences, both in the post-processing step to minimize the alignment time.

A photogrammetric SfM/IM survey, was performed only in some cases, where it is particularly important to enrich the geometric data with color information of the texture in order to be able to better read the wall traces. It is the case for example of the wall of Via Vigna/Via Morigi, one of the few developed in height, where it is possible to analyze some structural issues and the stratigraphy of the monument, as well explained in a previous paper of the same authors [15].



Figure 4. The 3D textured model of the Via Morigi wall, from a photogrammetric survey realized by images captured with a Sony NEX 6 camera coupled with a 24mm F 1.8 Zeiss lens.

3.2. Topographic survey

To place all the remains in the same georeferenced system, a topographic survey with differential GPS was performed using 13 natural points for the exterior part of each portion of remains surveyed.

This step was a crucial stage for generating a reliable starting point for the reconstruction, allowing also to obtain georeferenced data and to correct some information about the monument that are uncertain as for example the total length of the circus. The two archival maps [5, 6] collecting the results of the excavations and used as basis for the reconstruction, show a difference in length of quite 10 m (Figure 5). With the results of the survey it will be possible to give a conclusive and correct data, that will be useful also for the Superintendence.



Figure 5. Map of the 13 GPS station on the circus area.

4. Results and future works

The knowledge of the Milan circus presents, as with many ancient monuments, some aspects still doubtful or unaddressed and in the specific of our case study there are three crucial issues. The first of these is the actual extension of the monument which, according to different historical sources, is indicated as 460 or 470 meters. Since in the North the carceres position is unequivocally identified by the tower conserved in the archaeological museum area it is fundamental to identify the correct position of the circus curve which, as visible from the geo-referenced historical maps shown in figure 6 (a), is not certain.

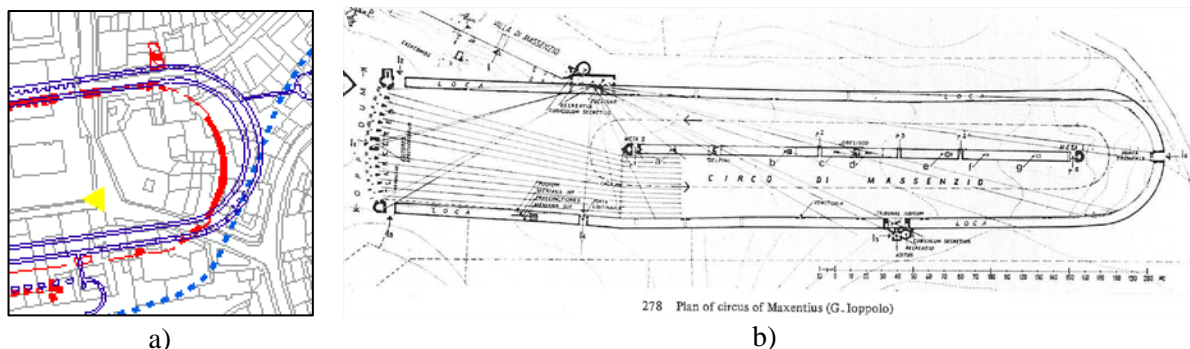


Figure 6. Two imaging showing critical aspect of knowledge on the Milan circus: a) vector drawing of the archival maps showing the difference in length of the circus; b) the plan of the circus of Maxentium in Rome showing as in late roman circuses the walls were angled based on race rules.

An important contribute on this matter was given by the survey of the part of the wall belonging to the aps of the circus in the southern area. These impressive remains are the higher still visible of the monument, developed in four floors in a private house discovered during some restructuration works in the '80. The 3D georeferenced survey realized will allow to right positioning the curve and calculate the building length (Figure 7 (a) and (b)).

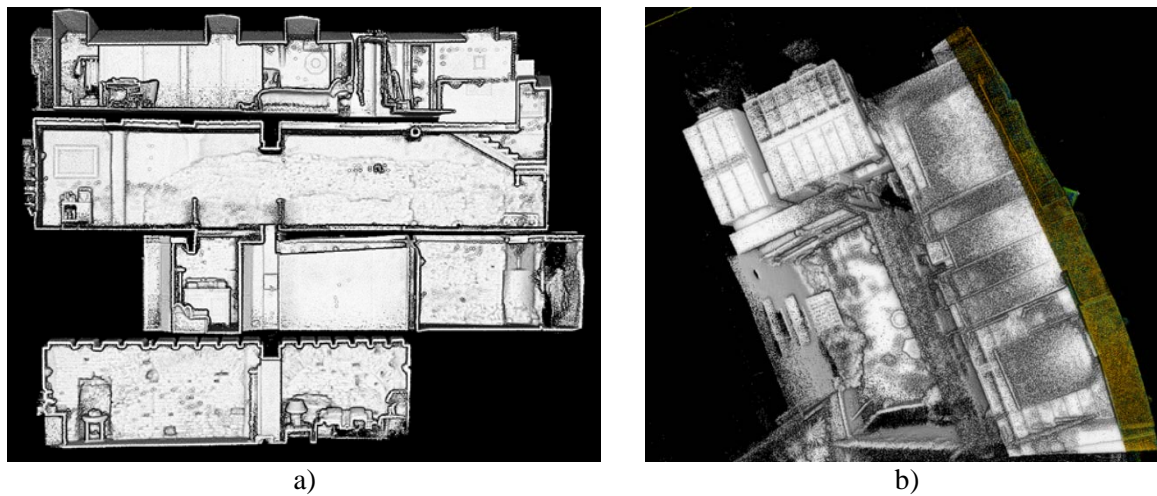


Figure 7. The points of cloud of survey inside the private apartment of the remains of the apse of the Circus: (a) the extension of the wall along the 4 different floor of the apartment; (b) the curvature shape of the remains.

Another critical aspect is the orientation of the walls that in the circuses of the late Roman Empire, as evidenced by the studies of Humphrey [10] were not straight and parallel but had angles in order to allow all competitors to make an equal path and to avoid accidents. In the case of the Milan circus, due to the small remains and their distribution, the orientation of the walls to date is not certain and the studies of Mirabella Roberti have indicated plausible but not totally verified angles.

Thanks to the 3D capillary survey of all the remains and their georeferencing we will be able to perform an integrated reading of all the single portions, small and large, and to identify the actual course of the walls.

Finally, some doubts remain with respect to structural questions related to the support of the cavea. The recent survey provides us with new elements of analysis as we have been able to identify and acquire in the western area a site in which a large portion of the internal wall towards the arena and a small portion of the corresponding external wall are present. The remains of Via Cappuccio (figure 8 (a) and (b)), similarly to what has been previously at Via Vigna, this allows measurements to be made between the two walls and to make some hypotheses about the structures.

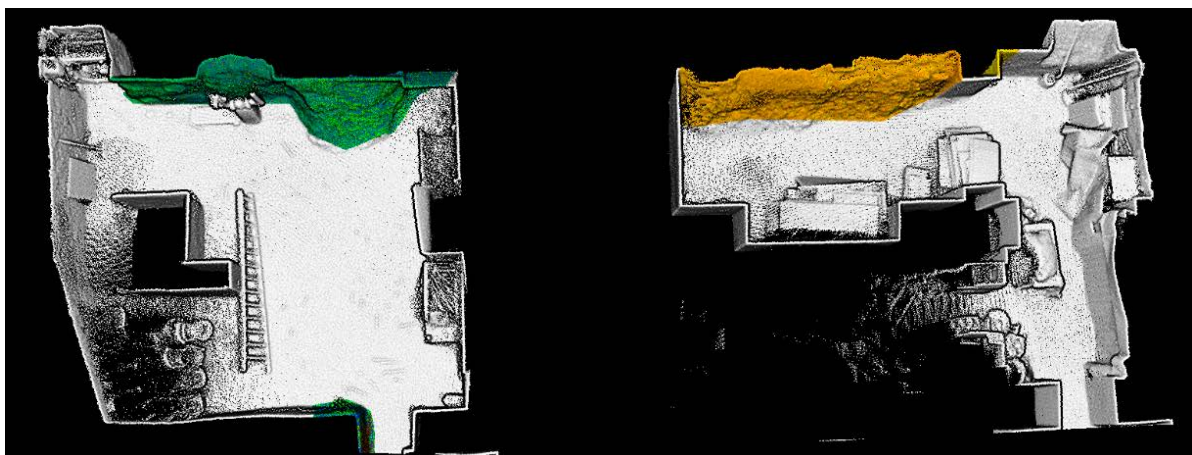


Figure 8. The survey in via Cappuccio where the portions of the two walls internal and external are visible (highlighted in green in the image).

All the data collected are crucial for hypothesizing and reconstructing the circus. In order to have a shared basis from which starting, it was decided to create a GIS platform (ArcMAP) to which a geodatabase will be connected to include all the information collected during the archival review and the surveys, in accordance also with the inspectors of the Superintendence.

On the basis of this georeferenced map, the reconstruction of the shape of the monument as it was, started as well described in [15], and will be updated with the results of the late 3D and GPS surveys. In this way, the reconstruction, done with the archaeologists in order to have a correct interpretation of the data, will be as much correct as possible.

5. Conclusion

The integration of the heterogeneous data collected will permit to provide a realistic reconstruction of a monument that is not visible anymore.

The so-called 4D reconstruction is usually intended as the process for obtaining the shape of real objects and its changes along a temporal dimension. This is based on a methodology [4] for integrating the different sources of non-uniform data. On the one hand the surveys georeferenced to the topographic network of the city, will help to identify the accurate positioning of the building and to obtaining precise measurements of the shape and length of the structures. By merging such data related with the current state of the monument with the archival material collected, a rearrangement of the historical representations will be made, like for example the normalization of historical plans in a uniform scale.

This reconstruction will be useful, not only for conservation and research purposes but also to let the citizens of Milan aware of the treasure hidden in their city and of their past.

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7. References

- [1] Guidi, G.; Russo, M.; Angheluddu, D. 3D Survey and Virtual Reconstruction of archaeological sites. *Digit. Appl. Archaeol. Cult. Herit.* 2014, 1, 55–69, doi:10.1016/j.daach.2014.01.001
- [2] Micoli, L. L.; Guidi, G.; Angheluddu, D.; Russo, M. A multidisciplinary approach to 3D survey and reconstruction of historical buildings. In 2013 Digital Heritage International Congress (DigitalHeritage); IEEE: USA, 2013; pp. 241–248.
- [3] Guidi, G.; Russo, M. Diachronic representation of ancient buildings: studies on the “San Giovanni in Conca” Basilica in Milan. *Disegnare Con* 2009, 2, 69–80.
- [4] Rodríguez-Gonzálvez, P.; Muñoz-Nieto, A. L.; Del Pozo, S.; Sanchez-Aparicio, L. J.; Gonzalez-Aguilera, D.; Micoli, L. L.; Gonizzi Barsanti, S.; Guidi, G.; Mills, J.; Fieber, K.; Haynes, I.; Hejmanowska, B. 4D Reconstruction and visualization of Cultural Heritage: analyzing our legacy through time. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* 2017, XLII-2/W3, 609–616, doi:10.5194/isprs-archives-XLII-2-W3-609-2017.
- [5] De Capitani d’Arzago, A. *Il circo romano*; De Capitani d’Arzago, A., Calderini, A., Eds.; Ricerche della Commissione per la forma urbis Mediolani / Istituto di studi romani, Sezione lombarda; Ceschina, 1939;

- [6] Mirabella Roberti, M. *Milano romana*; Rusconi: Sant’Arcangelo di Romagna, 1984; ISBN 88-18-33964-8.
- [7] Blockley, P.; Caporusso, D. *Area del Monastero Maggiore in epoca romana / [testi di Paul Blockley ... et al.]*; Archeologia a Milano; Civico Museo archeologico: Milano, 2013; ISBN 978-88-97568-08-7.
- [8] Caporusso, D.; Donati, M. T.; Masseroli, S.; Tibietti, T. *Immagini di Mediolanum - Archeologia e storia di Milano dal V secolo a.C. al V secolo d.C.*; Civico Museo Archeologico di Milano: Milano, 2014; ISBN 978-88-97568-00-1.
- [9] Sena Chiesa, G. *Milano capitale dell’impero romano: 286-402 d.C.*; Silvana Editoriale: Milano, 1990; ISBN 978-88-366-0276-6.
- [10] Humphrey, J. H. *Roman Circuses: Arenas for Chariot Racing*; University of California Press: Berkeley and Los Angeles, 1986; ISBN 978-0-520-04921-5.
- [11] Fedeli, A. *Milano Archeologia. I luoghi della Milano antica*; Fondazione Cariplo: Milano, 2015; ISBN 978-88-86752-69-5.
- [12] Capponi, C.; Ambrosini, A. *San Maurizio al Monastero Maggiore in Milano: guida storico artistica*; Silvana Editoriale: Cinisello Balsamo, Milano, 1998; ISBN 88-8215-095-X.
- [13] Farella, E.M., 3D mapping of underground environments with a hand-held laser scanner, *Proc. SIFET Congress, Lecce, June 2016*
- [14] Nocerino, E., Menna, F., Remondino, F., Toschi, I., Rodríguez-Gonzálvez, P., Investigation of indoor and outdoor performance of two portable mobile mapping systems, in: *Remondino, F., Shortis, M.R. (Eds.), Videometrics, Range Imaging, and Applications XIV; 103320I. International Society for Optics and Photonics, Munich, Germany, p. 103320I*
- [15] Guidi, G.; Gonizzi Barsanti, S.; Micoli, L.L.; Malik, U.S. Accurate Reconstruction of the Roman Circus in Milan by Georeferencing Heterogeneous Data Sources with GIS. *Geosciences* 2017, 7, 91.