

## THE CHT2 PROJECT: DIACHRONIC 3D RECONSTRUCTION OF HISTORIC SITES

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### ABSTRACT:

Digital modelling archaeological and architectural monuments in their current state and in their presumed past aspect has been recognized not only as a way for explaining to the public the genesis of a historical site, but also as an effective tool for research. The search for historical sources, their proper analysis and interdisciplinary relationship between technological disciplines and the humanities are fundamental for obtaining reliable hypothetical reconstructions. This paper presents an experimental activity 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. Its goal is to develop time-varying 3D products, from landscape to architectural scale, deals with the implementation of the methodology on one of the case studies: the late Roman circus of Milan, built in the era when the city was the capital of the Western Roman Empire (286–402 A.D.). The work presented here covers one of the cases in which the physical evidences have now been almost entirely disappeared. The diachronic 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. Such heterogeneous sources have been first georeferenced and then properly integrated according to the methodology defined in the framework of the CHT2 project, to hypothesize a reliable reconstruction of the area in different historical periods.

### 1. INTRODUCTION

In the past decades, 3D reconstruction has progressively become a tool for showing archaeological and architectural monuments in their current state, presumed past aspect and to predict their future evolution. The 3D representations through time can be useful in order to study and preserve the memory of Cultural Heritage and to plan maintenance and promotion of the historical sites. Given these premises, it must be underlined that there are cases in which the three-dimensional diachronic reconstruction is particularly complex. There are several reasons for this: i) the nearly total absence of remains to be surveyed; ii) one or more periods of artefact's time life with a little historical documentation; iii) uncertainty of sources; iv) difficulty to correlate documents and data to a three-dimensional representation. In some cases, in the literature (Guidi and Russo, 2011; Micoli et al., 2013) diachronic reconstruction of an archaeological structure started with the three dimensional survey of the current state of the monument and from 'reading the traces' of different restorations, along with a suitable philological research.

This paper presents an experimental activity defined by the project Cultural Heritage Through Time - CHT<sup>2</sup> (<http://cht2-project.eu>), funded in the framework of the Joint Programming Initiative on Cultural Heritage (JPI-CH) of the European Commission. Its goal is to develop time-varying 3D products, from landscape to architectural scale, to envisage and analyse lost scenarios or visualize changes due to anthropic activities or intervention, pollution, wars, earthquakes or other natural hazards. The main aim of the CHT2 project is to merge heterogeneous information and expertise to deliver enhanced four-dimensional (4D) digital products of heritage sites. CHT<sup>2</sup> is working on the full integration of the temporal dimension, its management and visualization, for studying and analysing Cultural Heritage structures and landscapes through time. The proposed methodology for the whole project described in (Rodríguez-González et al., 2017), suggests different ways to reconstruct the diachronic life of an historical object, monument or landscape.

As far as the case presented in this paper is concerned, given the limited detectable findings, the work began with an in-depth philological analysis from the collection of historical and archival data. It is also based on the integration of different contribution in the area started from the beginning of 2000 (Fischer, 2004; Guidi et al., 2008; Pletinckx et al., 2000).

### 2. CASE STUDY – THE CIRCUS OF MILAN

#### 2.1 Brief historical profile

In the 286 AD Milan became the capital of the Western Roman Empire, under the emperor Maximian. During the imperial period, up to 402 AD, the area has been modified by the construction of major buildings such as the imperial palace, the circus and the defensive walls (Mirabella Roberti, 1984; Sena Chiesa, 1990; Calderini, 1965; Caporosso, 1990).

The Circus was the open-air venue for chariot and horseraces; or rather, the place dedicated to the celebration of the Emperor's greatness and for this reason it was generally located near the Imperial Palace (Humphrey, 1986). The Milan's circus was also adjacent to the defensive walls with which shared the western part. This particular location has probably resulted in a number of peculiarities, such as the absence of the Arc of Triumph on the apex of the curve. Although the circus of Milan was one of the most important of the empire, today only few traces are still visible: a tower of the city walls, a tower of the Carceres reused as a bell tower (formerly belonging to the Monastero Maggiore), and some sections of the walls or foundations in the private properties nearby, sometimes hidden in their interiors or in the basements (De Capitani D'arzago, 1939; Blockley et al. 2012; Fedeli, 2015). Historical sources report the existence of the circus until the Lombard's era. From that period, as happened to other monuments in Milan, the materials of the roman structures were used in other buildings construction.

#### 2.2 Previous archaeological studies on the area

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

The area of the circus includes the Church of San Maurizio, whose nucleus is of early Christian origin and was built in the form we know today at the beginning of '500. Nowadays, unfortunately, only small portions of the monument remain visible and a lot of historical documentation has been lost in a fire during World War II. In the '60s of last century, the area of the complex was used as headquarters of the Archaeological Museum of the Municipality of Milan (Civico Museo Archeologico di Milano) that still takes care to preserve the memory of the various eras represented in this part of town. The rest of the area occupied by the ancient Roman Circus is instead almost entirely occupied by residential buildings (Capponi, 1998) and small remains of the circus are still visible in the basements of modern buildings in that area. Many questions are still open about the building's elevation and its relation to the surrounding area: the imperial palace and the town fortification walls.

### 3. THE METHODOLOGICAL APPROACH

In some cases (Guidi and Russo, 2011; Micoli et al., 2013), diachronic reconstruction of a monumental complex started with the three-dimensional survey of the actual state of the monument and from investigating the traces of different phases of the building, along with a suitable philological research. In the case of the Roman circus of Milan, given the limited detectable findings, the work began with an in-depth philological research started from historical and archival data. All the different kind of sources (texts, maps, drawings, archaeological reports and restrictions decrees, photographs) have been integrated to hypothesize a reconstruction of the monument, by referencing such documents to that specific location of the city.

#### 3.1 Bibliographic sources, historical drownings and maps

The research started from the investigation of the bibliography related to the study of the monument. This was useful for gathering all the information available about the researches and the excavations done during the past centuries.

Especially important for the study of the monument was the book of De Capitani D'Arzago, an archaeologist who has thoroughly studied the Roman circus of Milan in the late '30s of the last century. His studies confirmed the existence, location and essential size of it, thanks to the discovery of the parallel walls, some portion of the foundations and a large part of the curve. Another important book is the one by Humphrey, in which many Roman circuses, among which there is also the circus of Milan, were investigated. Thanks to this information, it was possible to interpret the missing parts of the monument, comparing the shape to others from the same period. This research is fundamental when analysing and reconstructing an ancient building that is no longer visible.

Another step of the work was the collection of maps, drawings and images concerning the various topics covered in the research. Drawings and historical paintings are fundamental to get information no longer available today.

This kind of approach was useful to have typological indications and to validate the reconstructive hypotheses proposed by scholars. In our case, we have found sources regarding: i) domus of pre-imperial era; ii) Roman circuses built in the Empire in the same period; iii) monasteries of the Benedictine order. Unfortunately, in the case of Milan only poor graphical representations of the involved monuments were available, with reference to their active period. As far as more recent times are

concerned, all the drawings of survey campaigns carried out in the area have been collected.

Since many buildings destroyed by bombing during the WW2 were rebuilt, in the post war period the excavations for the foundations of modern buildings have, in some cases, revealed archaeological findings that sometimes were used as basement for the analysed building itself. In other cases, like for example in correspondence to new roads or other unbuilt areas, such findings were simply covered underground. In some cases, notes and sketches made during old excavations revealed crucial pieces of information for defining the structure of the monument.

Then a deep iconographic research was carried out collecting also different maps from various periods that can highlight the urban structure of the area. About 60 city maps representing different historical periods from the Renaissance to the present days have been identified at the Civica Raccolta delle Stampe Achille Bertarelli and analysed to study the evolution of the urban area.

#### 3.2 Photographic documentation

Another type of data taken into account are the photographs taken mainly during the after-WW2 excavations, as for example those shown in Figure 1. Images of artefacts and structures inside the urban area, taken from different points of view and sometimes referred to two or more different periods of their life, are a valuable support for the three-dimensional reconstruction process. Specifically, a research in the photographic archive at the Superintendence's office was made regarding to the area of interest. About one thousand images were found and about 100 of them have been selected. This selection regards artefacts visible during construction projects (e.g. the metro, new skyscrapers) or inspections of the superintendent. These images are a valuable documentary heritage because many artefacts are no longer visible, embedded in the foundations of modern buildings.



Figure 1 Images of excavations in the '50s, showing the remains of some parts of the walls of the circus found in private houses (courtesy of the Archaeological Museum of Milan)

#### 3.3 Archaeological restrictions decrees

Starting from a detailed map of the circus made in the late '30 of the last century, the work was to verify the accurate position of all the remains of the circus walls and its connected structures. This part of the work dealt also with a capillary search, in connection with the inspectors of the Superintendence of Milan, of all the street numbers of the actual buildings where the remains are still visible in the basements. During this search, it was also stated that all the private houses interested by archaeological findings are under restrictions but, given the period in which these restrictions were defined, most of them are brief and unclear. Hence, it was difficult to identify the single structures, their position and their extension, and this required a huge archival work.

All areas subjected to archaeological restrictions have been screened along with the superintendent, in order to assess the actual presence of remains, their state of conservation and the opportunity to do a three-dimensional survey.

### 3.4 3D survey

The 3D survey of all the selected remains is a crucial stage for generating a reliable starting point for the reconstruction. Depending on the conditions of operation, such 3D digitization is being made with both SFM photogrammetry or laser scanning depending on the available conditions of lighting, working space, etc. The monument portions detected, suitably georeferenced, are used to validate the archaeological excavations of the past and to give the main constraints over which the three-dimensional reconstruction is being progressively generated.

In addition to the validation of historical plans, the three-dimensional portions are fundamental as elements of proportion, in relation to the examples of the same type of monument highlighted by other sources, to define the trend elevation of the building, typically the most critical parameter in the reconstruction of any ancient building not existing anymore. The survey work started first on an unrestricted area, belonging to the Archaeological Museum of Milan which was a supporting partner in the CHT2 project. The first two components of the circus that have been digitized are: i) the so-called “square tower”, originally belonging to the carceres of the circus and nowadays used as bell tower of the church dedicated to San Maurizio; ii) the so-called “polygonal tower”, part of the defensive walls of the city. The two buildings were surveyed with both laser scanning, using a Faro Focus 3D scanner, and photogrammetry with a Panasonic DMC GH4 with a 12mm lens and a Canon 5D MkII with a 20mm F 2.8 lens.



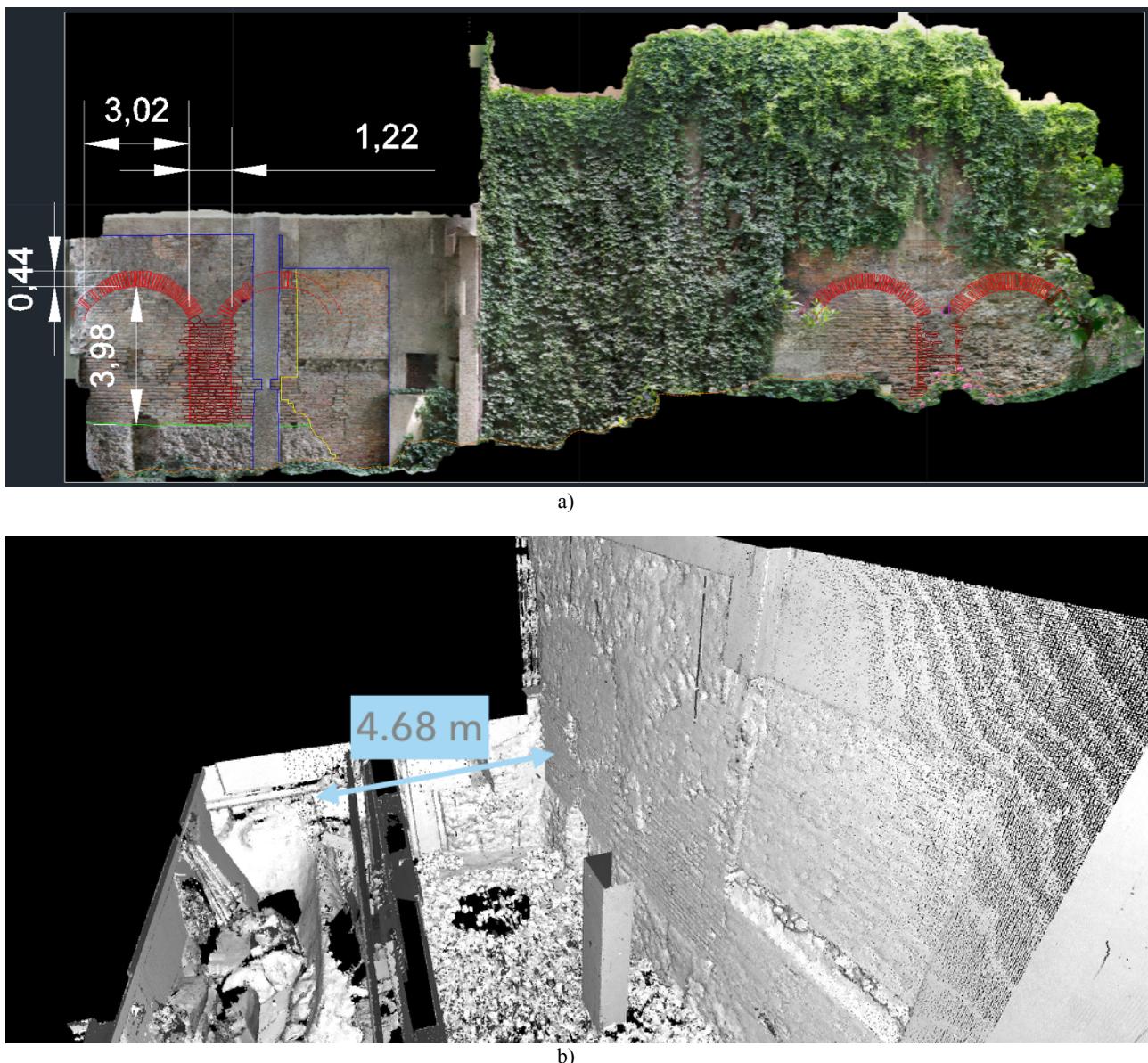


Figure 3. Documentation of main portion of the circus outer wall still standing: a) orthoimage, providing the measurement of the arches supporting the audience seats; b) laser scan including a small remain of the small inner wall found in a private basement, providing the height of the wall remains in this point of the structure, and its distance from the inner one.

Another useful contribution has been given by a significant part of the outer circus wall, nowadays belonging to the garden of a private condominium in Milan, Via Vigna, 1, and a smaller remain of the inner wall, also called podium wall. It corresponds on one side to the limit of the circus racetrack, and on the other side to the lower limit of the cavea. This latter portion of the foundations and inner wall are inside the cellar of the mentioned condominium.

The external wall was surveyed using both photogrammetry, with a NEX 6 camera coupled with a 24mm F 1.8 Zeiss lens and laser scanning, using a Faro Focus 3D 120 device.

The small portion of the podium wall was surveyed with the Faro laser scanner only, connecting the inside to outside through a set of redundant scans taken from several positions along the path from the cellars to the exterior garden, as shown in Figure 2.

These surveys were important for measuring several crucial geometric elements, needed for creating the 3D reconstruction: i) the height of the remains of the outer wall of the circus in this

zone, corresponding to 7m. However, several sources state that this is not the whole height of the circus. This information is confirmed by other measurement taken at the curved end of the circus, on the side opposite to the carceres, that resulted 8,40 m; ii) the height of the traces of the arches, visible on the inner side of the exterior wall, that identify the starting point of the vaults, located at  $3.98+0.44=4.42$ m (Figure 3a); iii) the periodicity of the arches representing the traces of the vaults in the exterior wall, equal to  $3,02+1,22=4,24$ m (Figure 3a); iv) the precise distance between the inner and the outer wall (4.68m) shown in Figure 3b. This latter information, together with the inclinations of the seating tiers, that according the bibliographic sources in other circuses of the same period is  $45^\circ$  (Humphreys, 1970), allowed us to calculate the positioning of the tiered seats with maximum likelihood, as shown in Figure 4.

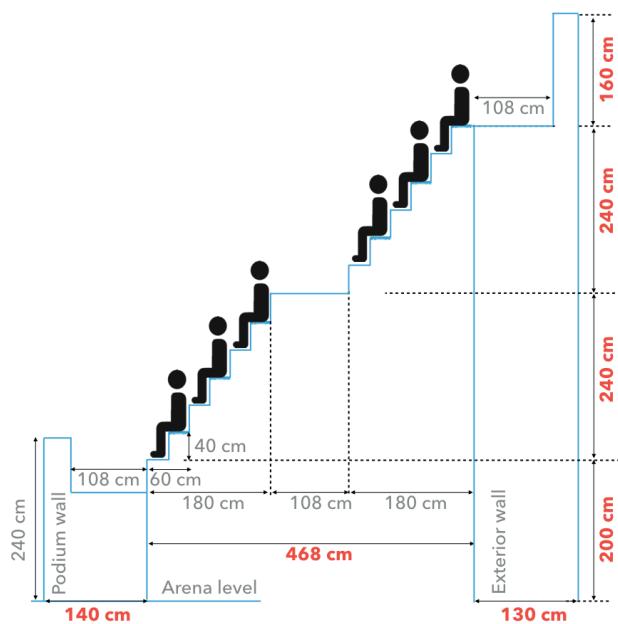


Figure 4. Hypothetical cross-section of the circus showing distribution of seats with a subdivision between different social classes according to the measurements coming out from the laser scanning campaign. In red the measurements taken on the field.

As already suggested in the literature (Mirabella Roberti, 1984) the typical subdivision of the crowd in social classes would lead to the hypothesis of two orders of three seats, with 30 cm for seating and 30 for the feet as shown in Figure 4. This would give a total of 6 rows of seats divided in two orders, separated by a space, with the double function of walking lane for reaching the seats, and separation between the nobles, typically placed closer to the race track, and those of the plebeians, in the upper zone. An element that might seem peculiar in this reconstruction is the positioning of each seat on a plane different than that of the feet, which would be more economical. However, the arrangement shown in Figure 4 was typical of late Roman circuses, like the Circus of Maxentius in Rome, belonging to the same period. In addition, the latter seat organization would give a smaller inclination of the whole area. As a matter of fact, a single large area of 60 cm for the seat of the lower person and for the feet of the upper person would lead to an increase in height of 40 cm, corresponding to the minimum height for a seat with respect to the floor level. This would give an angle of  $37^\circ$ , not compliant with the various considerations in the literature and to the global height of the outer wall. Contrarily, the seat organization shown in Figure 4 would give an inclination of 56 degrees on each order, and, considering the central walking lane, a global height increase of 4.80 m for 4.68 m of distance, corresponding to an average angle of  $44^\circ$ .

This reconstruction fits also better with the global height of around 9 meters of the exterior structure. The sources give a 2m height of the planking level of the first (the lower) row of seats, corresponding to the height of the podium wall shown in Figure 4. This height, plus the 4.80 meters needed for accommodating the 6 rows of seats, gives a height of 6.80 meters of the last (the upper) seat. Behind the shoulder of the upper row of seats a small wall is expected, with a height not lower than 1.6m for preventing accidental falls of the crowd from the upper level of seats. This gives a total height of 8.40m from the arena level, that is coherent with the measurement found in another area of the circus.

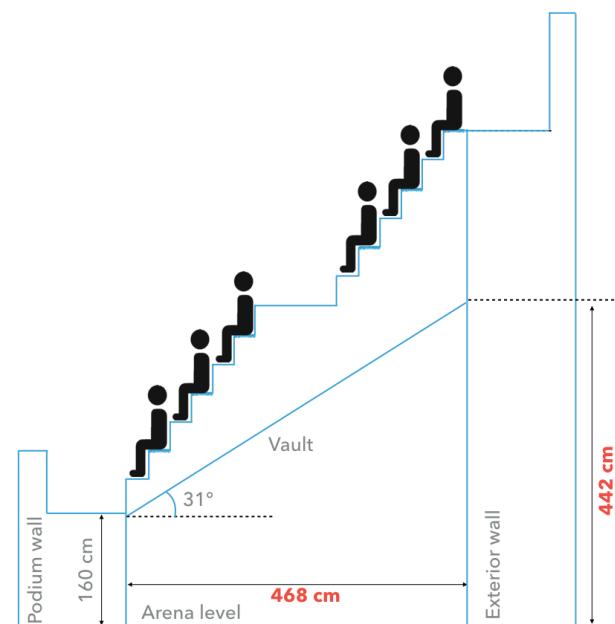


Figure 5. Hypothetical inclination of the vault.

A second element that could be measured is referred to the structure of the arches connecting the outer wall to the podium wall. They are segmental arch 3.02 m wide, reaching a height of 4.42m from the foundations, as shown in Figure 3a and represented schematically on the right side of Figure 5. It is not clear where the vault intersects the podium wall since only very small portions of it are nowadays still available. Presumably the connection should be close to the top of it on the interior side of the podium wall for limiting the slope of the vault. This defines a lower end of the vault at 1.60 m from the foundation level, arriving to 4.42m from the foundation level, corresponding to a vertical difference of  $4.42-1.60=2.82$ m. Such displacement, on a horizontal distance of 4.68 m defines an angle of  $31^\circ$  with respect of the horizontal line, as indicated in Figure 5.

#### 4. GEOREFERENCING AND HARMONIZATION OF THE DIFFERENT SOURCES

All the data collected are crucial for hypothesising and reconstructing the circus. In order to have a shared basis from which starting, a GIS platform was used (ArcMAP).

The first step was georeferencing the most important survey of the past, represented by the hypothetical map of the circus made in the late '30s (De Capitani, 1939) using the 3D technologies available at that time. Even if no precise measurement of the underground remains with respect of the modern city were made, this map represents anyway a reasonable starting point for the following reconstruction phases. The first step was therefore the orientation of the De Capitani map with respect to the cadastral map provided by the municipality of Milan.

The drawing was georeferenced using a Helmert transformation, using the profiles of some recognizable modern buildings visible also on the De Capitani map. The remains of the circus highlighted on the map were then transformed from raster to vector drawings with AutoCAD, in order to have them as curves to be used for extruding a 3D/4D reconstruction of the circus.



Figure 6. Georeferenced representation of the circus maps corresponding to different periods in time: a) De Capitani's map indicating the different information about the walls of the circus excavated or guessed; b) Mirabella Roberti's update highlighting the different paths of the river, before (light blue) and after the intervention (dark blue) for building the circus.

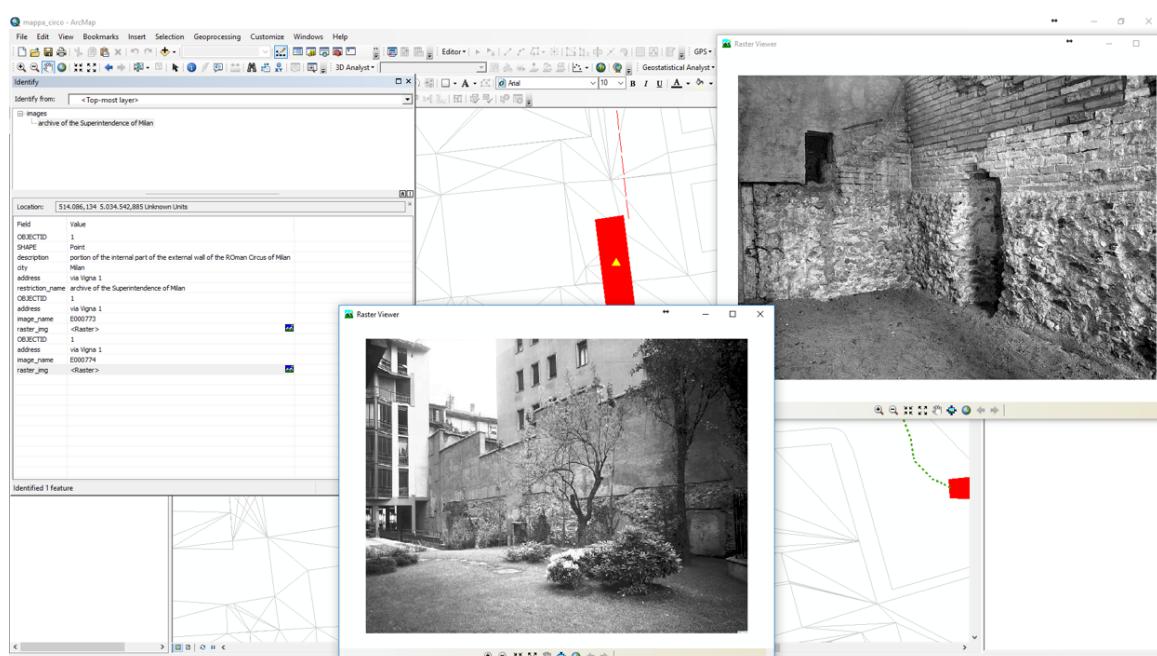


Figure 7. Geo Data Base for associating each piece of information such as historical images, reports or new 3D models originated by laser scanning and photogrammetry, in the same georeferenced platform.

The map of Mirabella Roberti, who updated in the '80s the one from De Capitani, was then georeferenced and vectorised, along with other information about the hypothesised ancient city during the emperor Augustus and Maximian (i.e. before and after the circus construction), to underline the changes in the topography of the city after some huge interventions occurred in the historical phase before the building of the circus. The most important regarded the change of the course of the river Seveso which used to flow in the area where, during Maximian, the circus and the new city walls were built. The route of the river was diverted to make space for the construction of the circus just beside the imperial palace and follows the itinerary of the new city walls, as can be clearly recognized comparing the two plans. The only excavated portion of the imperial palace is the one coloured in green in Figure 6b.

To this georeferenced map was then connected a geodatabase that includes all the information collected during the archival review (Figure 7). The field of the tables were chosen from the excel file in which all the researches done were organized. To each portion of wall identified, the information about excavations, documentation, decrees and images were connected.

## 5. DISCUSSION AND CONCLUSIONS

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 (Rodríguez-González et al., 2017) for integrating the different sources of non-uniform data. In addition, the surveys described above, georeferenced to the topographic network of the city helped to identify the accurate positioning of the building and to obtain precise measurements of the shape and length of the structures. By merging such data related with the current state on the monument with the vast archival material collected until now, a rearrangement of the historical representations was made, like for example the normalization of historical plans in a uniform scale. From such integrated base of information, a 4D reconstruction is ongoing, together with the archaeologists, in order to better identify the proper reconstruction of the ancient building and all the changes that affected the area from the late roman period until the present time.

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## REFERENCES

Blocley, p., Cecchini, N., Pagani, C., 2012. L'area archeologica del monastero Maggiore di Milano, nuova lettura alla luce delle recenti indagini. Civico Museo Archeologico, Milano.

Blocley, P., Caporusso, D., Cecchini, N., Ceresa Mori, A., Miazzo, L., Pagani, C., Provenzali, A., 2013. L'area del Monastero Maggiore in epoca romana. Editore Comune di Milano - Civico Museo Archeologico, Milano.

Calderini, A., 1965. Milano romana. Edito da Istituto Ortopedico 'Gaetano Pini', Milano, pp. 43-142.

Caporusso, D., 1990. Alcuni elementi per la topografia di Milano in età romana. In *Felix temporis reparatio: atti del Convegno archeologico internazionale Milano capitale dell'Impero Romano*, Milan, Italy, pp. 46-60.

Caporusso, D., Donati, M.T., Masseroli, S., Tibiletti, T., 2014. Immagini di Mediolanum, Archeologia e storia di Milano dal V secolo a.C. - V secolo d.C. Civico Museo Archeologico, Milano.

Capponi, C., (edited by), 1998. San Maurizio al Monastero Maggiore in Milano. Silvana Editoriale, Cinisello Balsamo (MI).

Colombo, A., 1928. Milano preromana, romana e barbarica. Famiglia Meneghina Editrice, Milano, pp. 101-144.

De Capitani D'Arzago, A., 1939. Il circo romano. Casa Editrice Ceschina, Milano.

Fedeli, A.M., (edited by), 2015. Milano archeologica. I luoghi di Milano Antica. Edizioni Et, Milano.

Frischer, B., 2004. Mission and Recent Projects of the UCLA Cultural Virtual Reality Laboratory. *Actes du Colloq. Virtual Retrōsp. 2003* 65–74.

Guidi, G., Frischer, B., Lucenti, I., Donno, J., Russo, M., 2008. Virtualizing ancient Imperial Rome: from Gismondi's physical model to a new virtual reality application. *Int. J. Digit. Cult. Electron. Tour.* 1, 240–252. doi:10.1504/IJDCET.2008.021410

Guidi, G., Russo, M., 2011. Diachronic 3D reconstruction for lost Cultural Heritage. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Trento, Italy, Vol. XXXVIII-5/W16, pp. 371-376.

Humphrey, J.H., 1986. Roman Circuses: Arenas for Chariot Racing. B. T. Batsford Ltd, London, pp. 18-53; 579-638; 687-691.

Micoli, L.L., Gonizzi Barsanti, S., Guidi, G., 2017. Interdisciplinary Data Fusion for Diachronic 3D Reconstruction of Historic Sites. *ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* XLII-2/W3, 489–494. doi:10.5194/isprs-archives-XLII-2-W3-489-2017

Micoli, L.L., Guidi, G., Angheloddu, D., Russo, M., 2013. A multidisciplinary approach to 3D survey and reconstruction of historical buildings, in: *2013 Digital Heritage International Congress (DigitalHeritage)*. IEEE, USA, pp. 241–248.

Mirabella Roberti, M., 1984. Milano romana. Rusconi immagini, Santarcangelo di Romagna (RN), pp. 8-40, 63-68, 78-84.

Pletinckx, D., Callebaut, D., Killebrew, A.E., Silberman, N.A., 2000. Virtual-Reality Heritage Presentation at Ename. *IEEE Multimed.* 7, 45–48. doi:10.1109/93.848427

Rodríguez-González, 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: analysing our legacy through time. In: 3DARCH 2017, ISPRS, Nafplio, Greece.

Sena Chiesa, G. (edited by), 1990. Milano capitale dell'impero romano: 286-402 d.C., Silvana Editoriale, Milano.