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THE WALLED CITY OF VERONA. INTEGRATED SURVEY SYSTEMS FOR THE ENHANCEMENT AND PROMOTION OF VERONA'S CITY WALLS

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ABSTRACT:

The present study concerns the digital documentation of the city wall of Verona. The "Verona Città Murata" project began in 2015 thanks to the research agreement between the Municipality of Verona (UNESCO office) and the Department of Civil Engineering and Architecture of the University of Pavia. The project stems from the request to develop tools to document the site's conservation to initiate timely restoration, management, and maintenance studies. Measures for protecting, conserving, and enhancing a comprehensive and impressive cultural and natural heritage, such as the Magistral Walls and the Veronese Park, are complex and multifaceted. The multi-disciplinary aspect and the use of flexible tools to manage the information and analyses obtained during the study phase are fundamental. The research aims to optimize the fortified system's acquisition process by validating integrated survey methods and assessing point cloud data's potential, limitations, and planimetric and elevation accuracy (TLS, MLS, UAVs). On the one hand, the research products are aimed to structure a methodology of valuable representation for the documentation and diagnostic and conservative analysis of the artifact; on the other hand, they will become a helpful tool for the narrative description of Verona's fortifications to disseminate and valorize the fabric of military technology.

1. INTRODUCTION

The urban genesis of the city of Verona can be read through a triad of elements that have defined the limits and space of the city, modifying its morphology according to historical times and social dynamics. (Zorzi, 2019) These urban entities are still closely connected today: the river, the riverbanks, and the walls. The latter cyclically played an important role and were built and extended in periods of splendor for the city, only to fall into ruin in unlucky times and re-emerge by changing their image and function in more favorable seasons. (Zorzi, 2019) Verona is one of those places where it is still possible to read the historical continuity and overlapping of civilizations and epochs, which today can be seen along the route of the city walls. This aspect is further emphasized by the nomination as a UNESCO site decreed during the XXIV Plenary Assembly of the World Heritage Committee Verona (30 November 2000), where the city is defined as an outstanding example of a stronghold that has preserved a considerable number of ancient monuments from the Middle Ages and the Renaissance. (Becherini, 2022) The walls, built for defensive purposes, were enlarged and partly destroyed over the centuries. The construction phases are still partially visible today and bear indelible witness to the city's history. The fortified perimeter was the boundary between the city area and the countryside; the entire defensive route is still clearly legible and incorporated into the city's urban layout, constituting a real filter of urban permeability.

Their current image offers various opportunities for research and investigation through the materials and techniques used in their construction, allowing them to be placed in different historical periods. These marked the main changes in the structure of the fortified walls: the Roman age, the medieval age, the Scaligera age, the Venetian age, and the Austrian age. (Conforti Calcagni, 2008). Today, the Veronese city walls extend along a perimeter of approximately 9.5 kilometers. (Parrinello, Pivetta 2016) It is divided into two zones by the flow of the Adige River, with the right bank of the Adige on a slight slope, while the left bank has a steep terrain culminating in the Castle of San Felice. A large urban park is located along the course of the walls, representing an essential environmental and naturalistic function for the city, constituting an important ecological corridor connecting the Collina di Verona and the Adige. (Figure 1)

The Veronese Magistral Wall represents a system consisting of walls, bastions, doors, towers, walkways, and underground systems, a still-living testimony of the historical stratification and the architectural and monumental importance. (Barbetta, 2018) For years, having lost its defensive function, it was seen as a marginal place that was difficult to use. In particular, the community perceived the southern bastion area as an obstacle

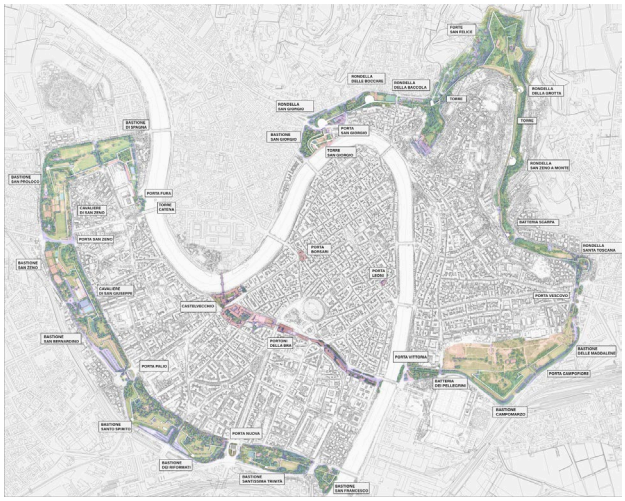

Figure 1.General map of the city of Verona in which it is possible to observe the area of the Fortified Magistral Wall, the research project object, highlighted.

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between the historic center of the city and the area beyond the walls affected by the new building expansion and the growth of urban neighborhoods. (Dell’Amico, Cantea 2022) The administrative strategy initially adopted a destructive perspective, opening some breaches along the walls and causing some damage to the fortified system. During the 1930s, the stretch of the border saw the birth of various sports facilities near the area of the valley, such as the example of the "Lido di Verona", an Olympic swimming pool system, now abandoned, which was built between Bastione di San Bernardino and the Bastion of San Zeno. (Figure 2) During the war, the underground spaces of the fortifications were reused and transformed, with reinforcement interventions in reinforced concrete, into anti-aircraft shelters equipped for civilians and Wehrmacht troops, restoring the original defensive value to the wall system. The park's current management is in the hands of the municipal administration, which is working to systematize a management plan for the entire fortified park through a project that sees the connection of the various specific elements of the walls in a museum visit path. (Figure 3) By putting all the fortified structures present along the path into a system, management difficulties emerge due to a past that has seen the fragmentation of skills and responsibilities in the management of spaces between different departments, districts, companies, and state authorities, including the Superintendency and the State Property and the various voluntary associations that manage and contribute to the maintenance of the environments of some of the monumental gates. From an open dialogue with the UNESCO office of the municipality of Verona, the five-year research agreement was born, coordinated by Professor Sandro Parrinello and Professor Francesca Picchio, which involves the experimental teaching laboratories DAda-LAB and PLAY of the Department of Civil Engineering and Architecture. The project aims to implement a digital documentation plan, structured on different reading scales, of the entire magistral walls aimed at enhancing the park of the walls and dictating the guidelines for the design of a UNESCO management plan that enables the fortified structures to be discovered and reopened to the public employing monitoring and reorganization of the spaces transforming the wall's path in a museum visit. (Figure 4)
The synergistic research action between subjects, institutions, and society is confirmed in the satellite actions of this project aimed at organizing events, conferences, and temporary exhibitions aimed at disseminating and promoting the research documentary corpus. Today’s visit to the walls presents itself with fragmented paths without signs explaining the place's contextualization along the fortified path. The monumental gates, the ramparts, and the washers are not all accessible and equipped to accommodate public visitors. They are singular episodes within the path, disconnected from the rest of the monuments. The project aims to unify the elements within an organic visit by designing a museum system that is a narrative dialogue between place, exhibition, and visitor.

Figure 3. The Can Grande path: along the north-east fortified route, sections of walls alternate with towers from the Scaliger era.

Figure 2. The path inside the Verona Bastion of San Bernardino.

Figure 4. View of the interior of the Rondella delle Boccare. The rondella, like other structures along the city wall, is not accessible to the public today; a redevelopment project is underway to reopen access and visits to citizens.

The different phases into which it is divided deal with the digital documentation, using integrated survey systems, of the fortified system, the development of analysis papers for the typological and diagnostic assessment of the structures, the structuring of an enhancement system by promoting cultural itineraries for the discovery of the fortified route (Parrinello et al., 2023).

2. INTEGRATED DIGITAL SURVEY PROCEDURES FOR DIGITIZING THE FORTIFIED SYSTEM

2.1 The integrated digital survey project for structuring a 3D database of the fortified perimeter

During the first two years, the researchers experimented with a protocol of metric survey and expeditious diagnostic investigation to define a method that could provide a replicable 'rule' along the entire wall path, optimizing data acquisition and processing methods along the approximately 9.5 km of the Veronese defense system.
The wall system was analyzed and divided into macro-portions and punctual elements considering the typological categories of the fortified structures.
The breakdown of the system identified 11 Areas and 121 elements subdivided into portions of walls, gates, roundels, towers, breaches, riders, ravelins, bastions, batteries, and castles. Each element was assigned an alphanumeric recognition code to define a common language for organizing and storing the data within the project.
Taking into account this initial subdivision into macro-areas and point elements, a method of expeditious digital documentation was defined that sees the use of different types of tools chosen based on the following criteria (Figure 5) :
- level of detail required for the representation of the object for the return of 2D vector drawings and high-resolution photo plans;
- the ratio between instrumental acquisition time and area to be surveyed;
- risk conditions and access to structures.

Nowadays, the amount of available 3D datasets has increased exponentially thanks to tools divided on the character of survey operations from the macroscale to the microscale level. (Bertocci et al., 2019)
The evaluation of the type of device for the case study of the walls of Verona was carried out based on the geometries of the elements of the architectural object, which must be readable within the metadata of the point cloud. (La Placa, Doria 2022)
The most influential instrumental characteristics are resolution, precision, acquisition timing, and the points' RGB texture availability. (Tu et Al., 2017)
It was decided to divide the survey actions into :
- documentation of the connective tissue between areas;
- external architectural structures;
- internal architectural structures;
- roofs and coverages.
For the extensive survey of connective tissue, a KAARTA Stencil type mobile laser scanner was used (a range of about 80 meters, about 400,000 points per second, it should be emphasized that the field of view of the instrumental shooting angle is limited. It imposes an angular shooting limit (360° horizontal FOV 30° (from +15° to -15°) vertical FOV) with metric reliability (Accuracy ±30mm ±10mm post-processed). (Dell'Amico, 2021)
Two terrestrial-type laser scanners (FARO Cam Focus S150 and Leica RTC360) were used for the punctual survey of the architectural structures for which the project envisaged an in-depth analysis of the detailed masonry textures. These

Figure 5. Laser scanner acquisition operations along the path of the magisterial walls. For the digitization of the walls, static laser scanning technologies were used, integrated through rapid mobile acquisition procedures.

instruments offer high performance and allow source images to be obtained with a native resolution (3mm/ 10 meters).
On the visible external surface of the perimeter, an equally extensive and complex system made up of interior rooms and underground tunnel is developed in parallel. This system connected the various structures and had a defensive function. Over the past year, the project has been experimenting with the acquisition of indoor environments using a handheld mobile laser scanner (MLS) type Leica Geosystems BLKGO, which is suitable for the expeditious acquisition of indoor environments as it has a declared indoor accuracy of +/- 10 mm - has a minimum range of 0.5 m horizontally and 0.7 m vertically and a maximum range of 25 m.
Non-offensive Mavic mini-type drones were used to acquire the covers and the detailed photogrammetric survey of certain elements. In parallel, a photographic acquisition and photogrammetric survey of the masonry texture was carried out, aimed at the e provision of high-resolution photo-plans and 2D vectorial drawings of the masonry texture, distinguishable in each stone for the reading of masonry apparatuses, the mapping of pathologies.

2.2 Processing and Structure of the 3D Point Cloud Database

The high complexity of the number of elements acquired and the different nature of the data is amplified by the extension of the survey of the inner fortified perimeter.
Hence, there is a strict necessity to define a methodological structure for managing a complex database according to a recording scheme that breaks down the walls into areas and sub-elements. In particular, as the survey campaigns are spread over five years, the database is continuously being implemented.
The data processing phases are subdivided as follows:
Subdivision of records according to the survey campaigns carried out for the acquisition of individual elements, subdivided by external acquisition (TLS and MLS), internal acquisition (TLS and MLS) coverage integration (UAV) (Figure 6):

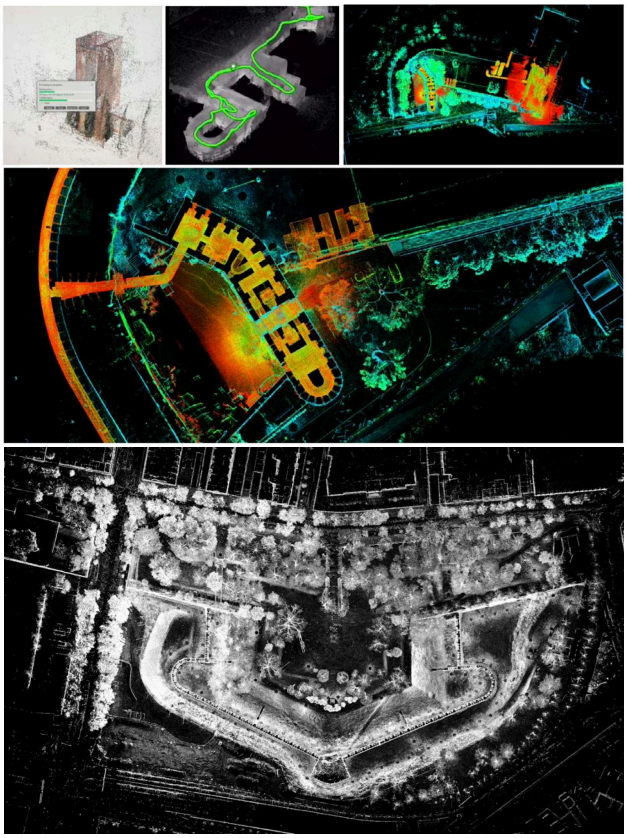

Figure 6. Point cloud data used to process the integrated 3D database of survey data from SLAM, TLS and UAV using the Leica Cyclone software.

- data processing and control of recorded data;
- database implementation covering an entire Area;
- registration control between *Scanworld* groups;
- merging of Area databases into a single database;
- Finalization of the database.

For the registration of individual elements, visual matching systems based on *cloud-to-cloud* algorithms were used using Leica Cyclone Core software. To control the error of each component, closed polygonal around the element being surveyed are foreseen during the acquisition phase; to then be able to proceed with the union and registration blocks between different areas that are contiguous, overlapping zones are distributed along the perimeter and calibrated to guarantee metric cornerstones to verify the union between the areas. (Figure 7) (De Marco, 2019) The decomposition into registration subgroups allows for a database layered in depth layers that allows for the analysis of the relationship between individual areas if the registration *Scanworld* joining them is activated or for in-depth analysis of separate registration *Scanworld* for the study of portions of the boundary confined to a single element. This discretization is fundamental to smooth and facilitate the calculation processes of points for the visualization of the point cloud data.

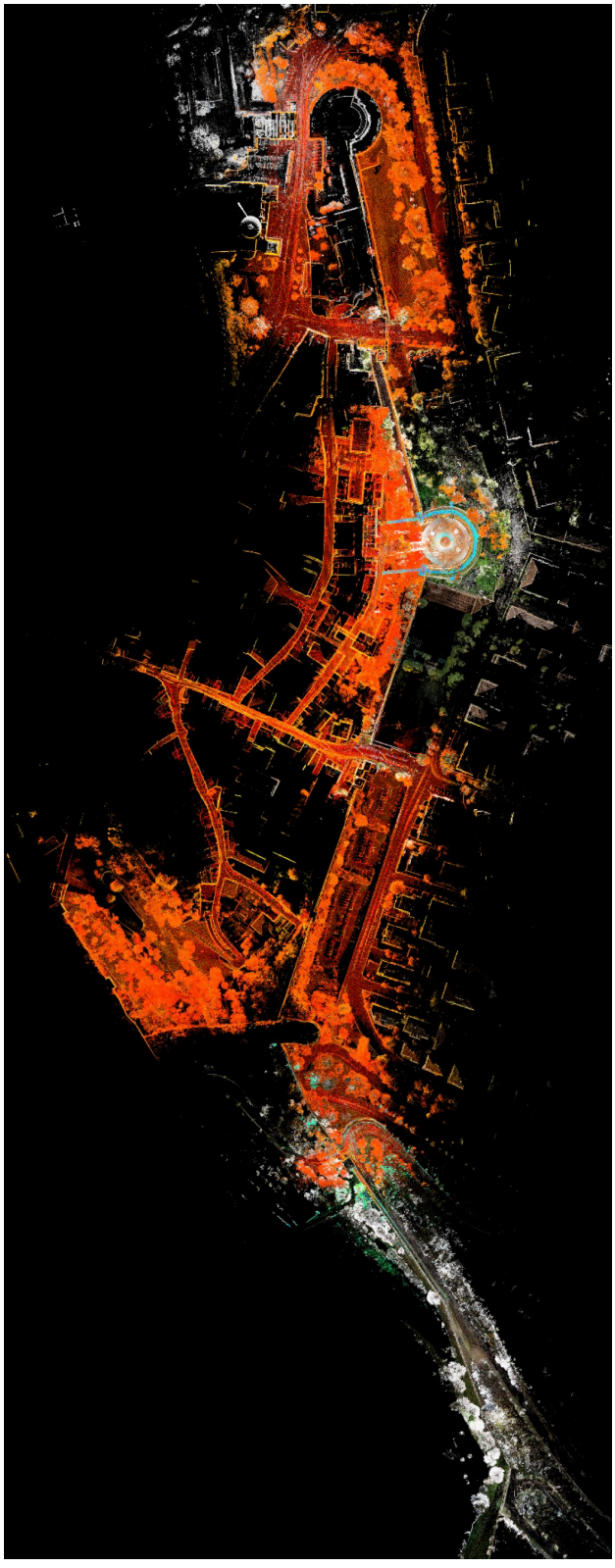

Figure 7. The result of registration between several areas. The portions highlighted in arches correspond to the MLS-type acquisition data used to document the portions that circumscribe and connect the fortified structures.

3. VERONA CITTÀ MURATA 3D DATABASE: DIFFERENT LEVELS OF READING

3.1 Methods of digital representation of the Walls of Verona

The research investigates possible strategies for analyzing and reading digital data for two- and three-dimensional representation to develop a descriptive geometric reference model of the identifying elements of the fortified walls. From the survey conducted with digital technologies, two-dimensional descriptive drawings of environmental sections of the various portions of the fortified walls and a 3D model are elaborated through modelling operations directly from the point cloud in which the morphological complexities of the architectural and naturalistic layout are reproduced. (Figures 8, 9) The model is intended as a tool that combines and synthesizes the components of the fortified system with those of the landscape/environmental system. The production of the digital model will make it possible to structure a representation of valuable methodology for diagnostic and conservation analyses of the artefact. The research also intends to develop a useful model for the narration of the fortified works of Verona for the dissemination and valorization of the work of military engineering. Based on the information derived from the point cloud and its discretization into two-dimensional drawings, the production of the 3D model was started. In particular, the modelling actions were differentiated according to the elements to be produced. The defense system was modelled using NURBS surfaces from the two-dimensional drawings made in the post-production phase. For the three-dimensional representation of the environmental system or the construction of the surfaces describing the terrain morphology, low-poly mesh modelling was used using Blender software. (Figure 10) Thanks to the use of dedicated plug-ins and essential software tools, it was possible to model the orography of the Parco delle Mura with the necessary approximations. The acquired data were translated into an ultra-light three-dimensional model, providing easier handling than the polygonal mesh derived from the photogrammetric survey. This allowed greater freedom in controlling the global model and the information added in the post-production phases to create virtual platforms. (Sanseverino et al., 2022) These will suit the landscape system's planning and management and the fortified system's protection. The model, resulting from the processing of the point cloud data and its discretization, highlights the problems of management, representation, and interpretation of the data of both the greenery and the defensive apparatus, opting for a dual solution:

- About point cloud information, the data were simplified by reducing the total number of points, in favor of better management and reading of the point cloud data during modelling processes;

- About the redesign choices of the model surfaces, a range of formal simplification of the surfaces describing the morphology of the terrain;

- vegetation and architectural elements are modeled, taking account the general morphology of the elements to develop more effective tools for navigation and virtual interaction with the 3D environment.

The development of this type of three-dimensional representation becomes a valuable tool for understanding the evolution of the defense system as a whole through virtual reconstruction and fruition. It will be necessary to work on a different scale to achieve the objectives set by the research and make the model a supporting tool for developing virtual tourism in the city. For punctual museum poles, it will be important to enhance internal

Figure 8. Section of Campofiore Gate, processed from the 3D point cloud survey data.

Figure 9. Section of the Scarpa battery tower, processed from the 3D point cloud survey data.

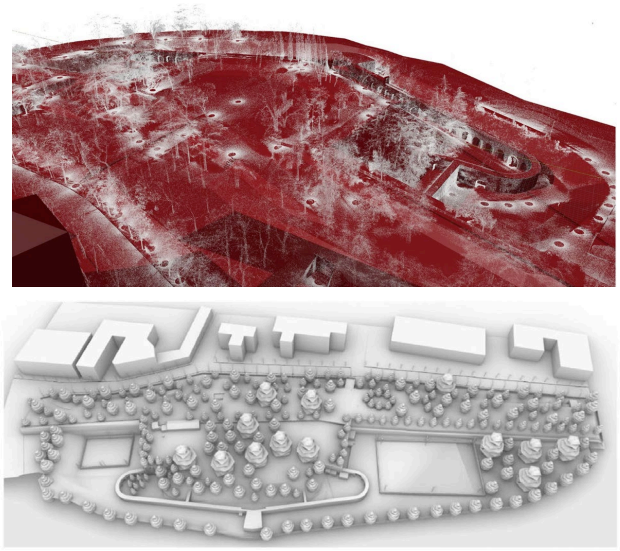

Figure 10. Construction phases of the low-poly model developed by using the Blender software. This process made it possible to obtain an ultra-light model with adequate approximation concerning the data acquired during the documentation campaign.

structures by creating virtual systems based on avatars, serious games, holographic video mapping systems for multimedia

Figure 11. Reading of decay maps through a sheet system linked to drawings.

projection on 3D prints, and sensors for tracking and recording movements within museum spaces. (Picchio, Galasso 2023)

3.2 Systems for the expeditious analysis of degradation pathologies

As part of the research, an expeditious census system was developed by compiling census cards of degradation phenomena directly on-site. The cards were designed ad hoc using Filemaker software, as it allows rapid compilation through mobile systems such as iPads. (Figure 11)

The cards allowed the creation of the diagnostic survey atlases that the laboratory provided to the municipality, supported by the annotation, on the two-dimensional drawings of the main degradation phenomena found. The fields and values were chosen according to the case study and linked to the Italian and European reference standards. In particular, the UNI 11182/2006 standard (ex NorMaL 1/88) and the Illustrated Glossary on the Deterioration of Stones ICOMOS 2008 were used. (Parrinello et al., 2023) This allows the optimization of investigation times by combining the pathology observation phase with photographic documentation, all possible in situ and remotely. The structure of the sheets is composed of several sections:

- Unique code assigned to the portion;

- General map to frame the analyzed portion about the city walls;

- Planimetry for identification of the analyzed portion;

- Location of pathology with ad degradation map applied to the front;

- Type of alteration found;

- Images that can be taken directly on-site by the operator carrying out the analysis;

- Descriptive fields of the alterations and pathologies with specific notes;

- Date of the survey carried out and name of the operator who carried out the analysis, this information is particularly important as the degradation characteristics can vary over time due to many factors. (Parrinello et al., 2023) From the compilation of the sheets, the data is then collected in an atlas that is made available to the municipal technical office for maintenance and cleaning operations.

4. PROMOTION AND DISSEMINATION STRATEGIES

Following the European Union directives on digitizing cultural heritage for the promotion of digital tourism, various strategic actions have been activated to develop digital reconstructions and tools for remote visits, encouraged following the impact and consequences of COVID-19 pandemic has had on the museum sector. In addition to the cultural value, it is essential to emphasize the importance that a digital reconstruction of sites has in preserving the image of those places that risk losing historical and cultural value due to calamitous actions or anthropogenic transformative interventions (Maldonado, 2015). "Knowledge, technique, art" are keywords for implementing digital storytelling to build a collective memory of the cultural and landscape heritage. Narrative planning desired at the funded ratio process must create shared construction contexts to safeguard heritage, guarantee continuity of knowledge, and develop new cultural values, leading to further "narrative landscapes.” (Bertocci et al. 2018)

The project aims to redefine the image of the Verona wall system. To prevent this phenomenon from persisting over time, both scenarios, the fortified one and the naturalistic one, must be rediscovered, highlighted, and enhanced, making necessary tools capable of documenting the state of conservation of the places to start punctual surveys of recovery, management, and maintenance over time.

The actions of protection, preservation, and enhancement of the vast and impressive historical-cultural-naturalistic heritage, such as the one represented by the Veronese magistral walls and the Walls Park, constitute a complex and articulated area that requires a multidisciplinary approach as well as the use of flexible tools to the management of information and analyzes acquired during the survey phase. (Respini, 2018) The first action is to provide the basic methodological information for the documentation strategies of spaces. Secondly, the methodological aspect of representing the three-dimensional model of the fortified systems is treated based on the acquisition by laser systems and digital sensors with an examination of the reading and translation of the digital data of the clouds. The model is used to develop a serious game and application for discovering the wall system.

Survey activities have become a time for highly formative workshops open to researchers, Ph.D. students, and students. (Figure 12) It represents a real opportunity to experience and study architectures, urban fabrics, historical complexes, and landscape systems that are unique and characterized in their educational, professional, and personal development. It also generates products and publications for scientific dissemination. The project for the purpose of scientific dissemination opens up the spaces of the fortifications by using them to design events and exhibition routes. This intention was then declined into a graphic line and designed a brand for the project's recognisability by promoting it by setting up temporary and permanent exhibitions at the city's bastions and gates. a way of reopening spaces for citizens. (Picchio, 2021)

In addition to the graphic line, structures have been designed to display panels that dialogue well with the locations of the various installations. An iron weave, which does not close but filters the vision and is not invasive. They are also versatile structures,

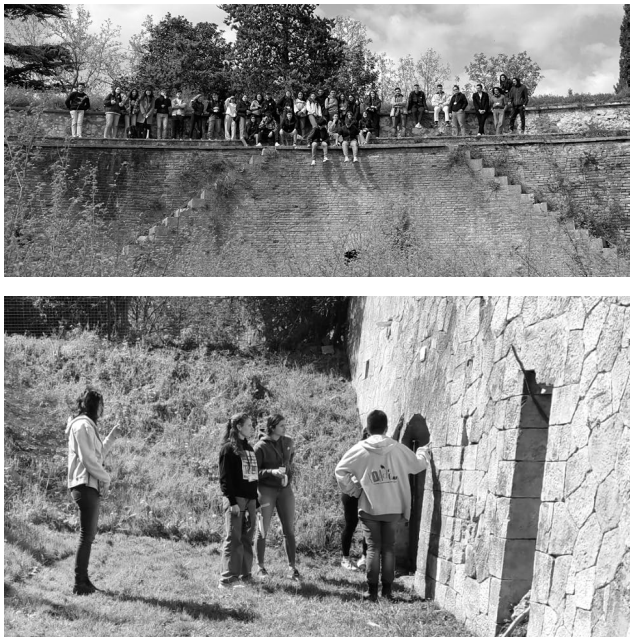

Figure 12. Workshop activity with the students of the course of survey (DICAr, Unipv a.a. 2022-2023)**.**

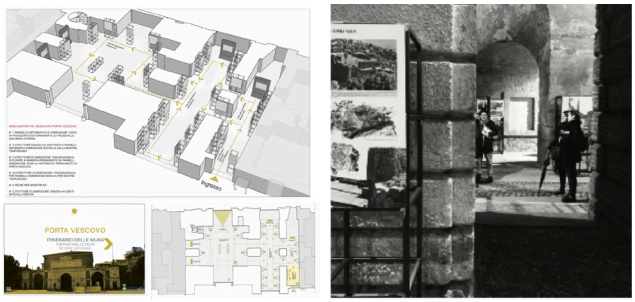

Figure 13. Temporary exhibition project realized in Vescovo Gate. The project provided non-invasive temporary structures and information panels.

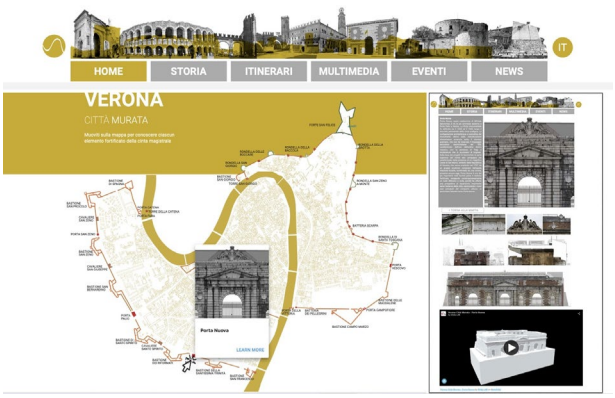

Figure 14. Web site interface development.

designed to be moved according to the needs of the different sites. In all events, the exhibition routes are designed according to the graphic lines of the project. Over the years, efforts have been made to create a recognizable sign. For the museum system as a whole, the project plans to develop applications for virtual tours, which will allow links to the information within the central hub. The idea is to digitally link a specific museum space with an overall system identified by a landscape and urban route. The user can access information in the museum environment through intelligent applications while visiting the external route, and vice versa. He/she can use enhanced content to narrate the museum's urban route. (Picchio, Pettineo 2023)

It will be necessary to work at a different scale to achieve the objectives set by the research and make the model a supporting tool for developing virtual tourism in the city. For the point museums, it will be important to enhance the internal structures by creating virtual systems based on avatars, serious games, holographic video mapping systems for multimedia projection on 3D prints, and sensors for tracking and recording movements within the museum spaces.

For the overall museum system, the implementation of the project is envisaged through the development of applications for virtual tours, which allow connection to the information within the central hub. In parallel, a project website has been designed that collects the results and allows the visit to the Magistral Wall through an interactive map.

An information sheet is associated with each element along the wall's route, accompanied by photos, drawings, and a three-dimensional model. The website was designed in collaboration with the municipality of Verona as an information collector and a remote visit system to promote monumental park knowledge. In addition to data relating to the historical account of the evolution of the magistral wall, all the news converges and the promotion and dissemination events of the UNESCO site.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

Today, the survey is configured as an integrated discipline that uses data from different sources and skills with specific methods and procedures to depict the environments. Therefore, it becomes natural to understand the means that allow us to orient ourselves in this integration of meanings and the means that can translate these complexities into places that can be managed.

To this end, a tool is needed to synthesize the essence's structure and the site using a graphic language, which develops into univocally defined signs and symbols; in a simplified form that uses a handwriting format by also reproducing part of the same logical procedures used in the natural discretization of the phenomenon.

The use of virtual environments for informational purposes is configured as a suitable tool for visual narration: the user, viewing the infographic product, faces the possibility of interacting with multimedia products and learning new information, making it more engaging and stimulating the process of getting to know and visiting the museum. (Tucci et al., 2019) In the cultural field, putting digital works into practice is a means of contact for different interconnecting areas of application: education, institutional, cultural mediation, and tourism. The digital content expands the narrative and descriptive possibilities of the work through the option of using hypertext and hypermedia together. It broadens the capacity of the information potential, favoring readability, contextualization, and narration (Bonacini, 2020).

ACKNOWLEDGMENTS

The Verona Città Murata project is based on a five-year research agreement between the UNESCO office of the municipality of Verona and the Department of Civil Engineering and Architecture (DICAr) of the University of Pavia. The aim of this project is the digital documentation of the perimeter of the fortified city to support the planning of actions for the promotion, development, and restoration of the fortified structures. Since 2018, several survey campaigns have been carried out in which the staff of the DAda-LAB laboratory (DICAr, Unipv) has participated under the scientific coordination of Professor Sandro Parrinello and Professor Francesca Picchio and the technical coordination of Dr. Anna Dell'Amico.

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