IMMERSIVE APPIAN WAY HEALTH INFRASTRUCTURE: HUMAN CENTRIC DIGITAL TWIN (THE PAAA ARCHEOLOGICAL PARK OF THE APPIAN WAY 12KM STATE-OWN SECTION, UNESCO CANDIDATURE)

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ABSTRACT:

From Rome to Benevento, the Appian Way (Via Appia Antica) was born as a military road, 'Regina Viarum'. In 312 b.C., consul Appio Claudio extended the infrastructure for 132 miles to Capua. Many transformations and integration occurred across the centuries, resulting in a unique multi-stratified world heritage (landscape, architecture, archaeological remains and tombs along the military way). In the 19th century, Luigi Canina conceived the Appian Way as an outdoor museum, realizing a first state-own section along the 12km here surveyed and described. This year, the Ministry of Culture (MIC) has launched the UNESCO nomination for the road. The article discusses aspects of the mass digitization undertaken by the Parco Archeologico dell'Appia Antica (PAAA, the Archaeological Park of the Appian Way). The aim is to build a Digital Twin of the infrastructure supporting knowledge enhancement, preservation, design, communication and fruition. A virtual space where digital technologies and eXtended Reality are the digital arms of the contemporary Vitruvian humanistic mission and vision of the PAAA Appian Way as a source of wealth and healthiness for all the users and visitors.

1. INTRODUCTION

1.1 The Appian Way Digital Twin as a human-centric digital Vitruvian-multi-XaRm to decode a multi-stratified cultural heritage addressing multi-purpose activities

The PAAA Appian Way Digital Twin (DT) is conceived as a human centric Vitruvian multi-XaRm to embed multi-stratified tangible and intangible values documenting the landscape, infrastructure remains, architectures and archaeological artefacts for operators, professionals, museum curators, citizens as local users and tourists.
Multi-sensors (such as Mobile Mapping Systems, Terrestrial Laser Scanning, and Photogrammetry combining fisheye images with Spherical 360° video frames), multi-temporal and multi-scale digitization of such complex sites play a crucial role in the assessment of environmental sustainability, addressing maintenance, management, preservation, design, data dissemination and fruition. The paper describes the overall vision of undertaking massive multi-sensor digitization with high accuracy and resolution for experts, operators, museum curators, and visitors, building a methodological framework from the data acquisition to the 3D data processing and management to data sharing. The result is a DT supporting knowledge growth by sharing models, shifting from CAD to multi-scale informative models, as GIS, HBIM object-based models linking information and vocabularies on materials and construction techniques documented by the 3D models. Particularly a 3D-textured model as a multi-stratified immersive heritage environment (landscape, infrastructure, architectures, archaeological artefacts, unmovable and movable remains) has been achieved. High Resolution informative models feed immersive design project and eXtended Reality (XR) experiences. The DT human-centric vision aims to support a better sustainable future, addressing documentation, conservation, slow mobility design, rising awareness and health. The Appian Way Heritage empower the 'health infrastructure' concept of slow mobility as active transportation fruition and social well-being with the progressive growth of knowledge content sharing and re-use by communities by interactive webXR (Figure 1).

Figure 1. The human centric Appian Way Digital Twin concept.

2. THE MULTI-STRATIFIED APPIA ANTICA ARCHAEOLOGICAL PARK (PAAA)

The Appian Way length reported by historical sources is about 360 Roman miles (540 km) from Rome to Brindisi, mostly made with different layers on which large paving stones rested (*Basoli*) (Quilici, 2004). Since ancient times the first miles between Rome and the lost Bovillae have focused on the attraction of Roman aristocracy to compete for the most prestigious villas, temples

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and sanctuaries of primary importance. Scholars have given special attention to the Appian Way, from the Caetani foundations to the famous letter from Raphael and Baldassarre Castiglione to Leo X at the Grand Tourn Way (Oliva, 2022). In 1852, Pope Pius IX inaugurated the Appian Way archaeological open-air museum by Luigi Canina, Rome's Commissioner of Antiquities. The planting of cypresses and pinus carried out at the beginning of the 20th century by Antonio Muñoz, inspector of the Royal Superintendence of Monuments, will permanently change the landscape of the first miles of the consular road (Capuano et al., 2017, 152-168). The reconstruction after the Second World War radically changed the relationship between the city and the countryside, jeopardizing the conservation of those values recognized as a common heritage until a few years earlier (Asor Rosa and Rossi, 2013). Starting from those years, the battles of Antonio Cederna, Italo Insolera and Vittoria Calzolari expanded the protection of the archaeological context to the urban and territorial dimension, linking the preservation of the historical landscape to the safeguard of the Roman countryside (Cassetti, 2006; Quilici, 2022). These instances led to the establishment of the Appia Antica Regional Park (1988) and the Appia Antica Archaeological Park (2016). The Archaeological Park is an autonomous museum institute of the Ministry of Culture (MiC). It is devoted to protecting the cultural heritage and coordinating the valorization of the Appian Way. The MiC interest in the Appian Way was further underlined by the launch of the first candidacy promoted and coordinated directly by the Ministry for the inscription in the UNESCO World Heritage List as a ‘serial site’ of the integral route of the Appian Way from Rome to Brindisi, including the Trajan Way.

3. APPIA REGINA VIARUM PROJECT ‘VALORIZATION AND SYSTEMIZATION OF THE PATH ALONG THE ANCIENT ROMAN ROUTE’: THE SURVEY PURPOSES

On September 23, 2015, the Appia Regina Viarum project ‘Valorization and systemization of the path along the ancient Roman route’ was presented in the villa of Capo di Bove in Rome (FSC 2014-2020, CIPE Resolution 3, May 1 2016, EUR 20 million, MIC and regions). The goal is to recover the original route of the Appian Way to allow – through ‘slow’ tourist mobility – making the cultural heritage (historical centres, monuments, landscape and archaeological areas) along the roads accessible and enjoyable.
Above all, the attention to cultural tourism aims to revitalize the territories which the Roman road crosses. A significant financial allocation was donated to the peripheral institutes of the MiC to carry out research and projects to rehabilitate the archaeological areas. The cognitive approach is fundamental for valorizing a system that is still partially unknown despite its two-thousand-year fame. Furthermore, the advanced survey technologies allow the analysis of well-known and frequented contexts, such as the Appian Way parts located within the territory of the Roman Archaeological Park.
The project envisages the development of an experimental interactive platform for remote dissemination (augmented, mixed and virtual Reality). Interactive totems will be placed inside the Park to explore portions of the territory and famous finds.
This survey is the virtual backbone to which other data could be connected, such as field research (i.e. ground penetrating radar and ICT), information from archaeological excavations and restorations financed by the National Recovery and Resilience Plan (PNRR, Jubilee 2025, Caput Mundi Project for the enhancement of the archaeological, tourist and cultural heritage of Rome and Lazio) and the National Plan for Complementary investments to the PNRR (PNC, Intervention n. 8 “UBS. From the city to the Roman countryside" intended for major cultural attractions), digitization of historical documents and images, virtual reconstructions for immersive devices (i.e. video mapping, augmented Reality, eXtended Reality, geotag).

4. THE MULTI-SENSORS SURVEYING

A multi-sensor strategy was adopted for the survey of the Appian Way according to the different goals of the documentation and digitization project (Figure 2). In particular, the survey had three main goals:
- Overall documentation at 1:100 scale of the Appian way from Capo di Bove and Frattocchie (approximately 12km). The final products expected from this survey were: a set of panels (scale 1:100) of the Roman road and a 2D GIS system aiming at the documentation and management of the different elements constituting the road and the nearby green areas;
- Detailed documentation at 1:50 scale of a set of areas along the Appian way in correspondence with the main monuments along the road and with the parts showing the original Roman paving. The final product expected was a set of detailed cross-sections for the selected areas (20) between Via di Fioranello and Frattocchie;
- A comprehensive record of the Roman pavement between Via di Fioranello and Frattocchie was produced, which resulted in a highly detailed orthophoto with a pixel size of 5.0 mm

A multi-sensor approach was devised by integrating Mobile Mapping techniques with static Terrestrial Laser Scanning (as discussed in section 3.1) for creating comprehensive layouts, 2D GIS (scale of 1:100) and cross-sections (scale of 1:50). Then, a photogrammetric strategy combining both frame and 360° images was used for the generation of a detailed orthophoto of the Roman paving.

Figure 2. The Appian Way team and multi-sensors digitization.

4.1 Multi-sensor surveying and mass data acquisition at the scale 1:100 and 1:50

For the comprehensive documentation of the Appian Way and the production of CAD plans and GIS (scale 1:100), the survey was based on Mobile Mapping System to give a continuous geometric frame, integrated by TLS focuses along the 11.7km, and by a high-resolution photogrammetric section (0-4km) to support the first design project. The choice of a MMS was connected with the high productivity of this survey strategy and the achievable level of details in the geometric restitution that those typologies of instruments can achieve (Sammartano and Spanò, 2018). In particular, an handheld system was selected for this task (i.e., GeoSLAM ZEB Horizon) because, compared to other car-based solutions, it allows a higher flexibility and a more complete survey of all the monuments facing the Appian Way. Indeed, with a handed instrument the operator can walk all around them and complexly scan them. To prevent drift effects (El-Sheimy, 1999) the entire road was divided into branches of 200 m length approximately and along each branch a set of Control Points (approximately 10 per branch) were measured with a GNSS receiver in RTK model.
As mentioned before, the terrestrial laser scanning acquisition was selected for detailed documentation (1:50) of areas in correspondence of the main monuments (Figure 3), archaeological artefacts, and areas with the original Roman

paving (*Basolato*). Corresponding with each selected area, 2 to 5 scans were acquired with TLS laser Faro Focus X130 (around n.100 focus square areas, 50mx50m). A set of at least three targets was measured in RTK to provide the scans georeferencing. The Faro Focus TLS clouds have been integrated with the MMS ones and managed to extract different entities with different accuracies, as in the case of the infrastructures (as the railways and over passages crossing the Appian Way), landscape-vegetation along all the Appian Way sections and the geometric entities (carriage wage, architecture, artefacts), where not covered by the Orthophoto (0-4 km), as illustrated below (Figure 4).

Figure 3. Example of point cloud acquired for detailed artefacts and monument documentation (scale 1:50).

Comparison between static point clouds and the MMS ones showed some differences in planimetry (up to some centimetres) that can be associated with three different elements: i) accuracy of RTK measurements (approximately ± 2.0 cm); ii) the lack of suitable geometry in some areas of the Appian way that may determine some minor drifts effects; iii) geometry of GCP used for the georeferencing of the TLS data.
Altimetric differences between the two datasets are generally below 2.0-3.0 cm. Finally, it is worth mentioning that TLS data are used only to produce 100 cross-sections and related focus areas on the transversal cross-section.

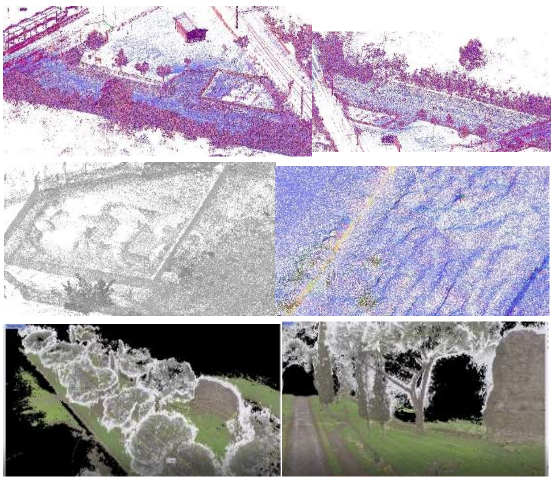
a.
b.
c.


Figure 4. Details of the cloud points: a. MMS Geoslam ZEB in the urban-infrastructural context; b. Faro Focus 3D in correspondence of the 100 sections (square aresa of ~50 m each side); c. merged clouds of the landscape context.

4.2 The survey of the paving from combined cameras: the Orthophotos

One of the project's goal was to survey the pavement of the Appia Way in the stretch spanning approximately 4.0 km from Via di Fioranello to Frattocchie. The photogrammetric acquisition was planned to accomplish a detailed mapping on the existing paving (i.e. *Basolato*), the '*Crepidines'* and '*Macere'* (5.0 mm of Ground Sampling Distance) (Figure 5). Due to the vicinity of the airport to the city (Ciampino airport is on the border along the Appian Way, less than 500 m distance) and the requested resolution of the final orthophoto product, a ground acquisition was planned instead of a UAV acquisition. The ground acquisition was carried out by integrating two different systems. The first one is a ground acquisition with a non-metric DSLR camera (Nikon D610) mounted on top of a system of masts allowing shooting images at the height of 3.0 m with an home-made backpack. Due to the limited acquisition distance, the camera was equipped with a full-frame fisheye lens system. This choice aimed to reduce the total number of images acquired and provide a larger field of view to allow higher overlap between consecutive images. A single person walking along the road can operate the masts systems. A ball head at the top of the masts allows for mounting and adjusting the camera's inclination. The camera was set with an inclination of approximately 50°.

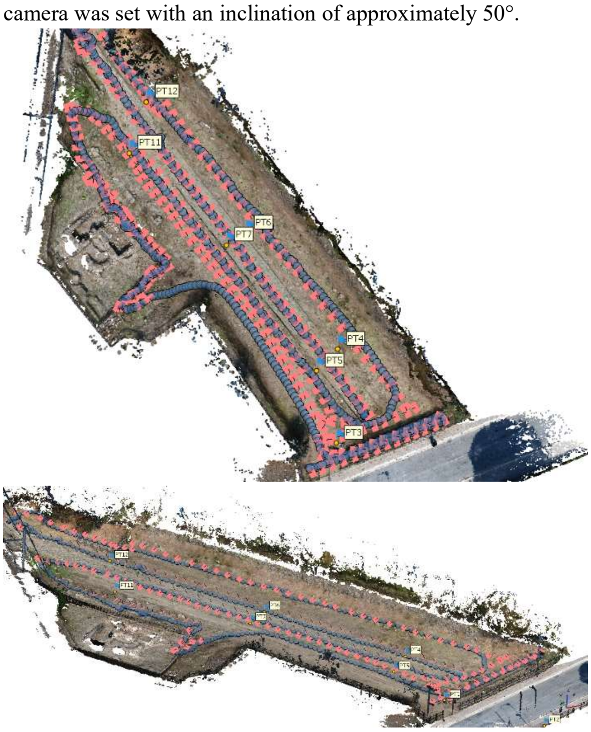


Figure 5. Example of dense point cloud obtained from combined fisheye (in red) and 360° (in blue) cameras reconstruction.

By doing this, the operator captures the ground to a distance of 5 meters in front for a width of 10 meters. Above those distances, the GSD is no longer meeting the requested requirements. Therefore, the acquisition was carried out by acquiring a set of two, and for some areas three, strips with an effective side overlap (i.e., an area with GSD lover than 1.0 mm) of 60% and an effective front overlap of 80%. The second one instead was based on 360° video frames. Video acquisition with 360° (spherical) cameras is becoming increasingly popular for photogrammetric applications for the opportunity to capture the entire scene around the user and provide overlap between consecutive frames. In addition, the wider field of view of the camera can provide a stronger configuration of the image block than the one obtained by using only images acquired as a set of consecutive strips on the top of the musts system. For the acquisition, an Insta360 OneX2 camera was used to capture a

5.7k video. The entire area was divided into portions of approximately 200 m distance to manage the acquisition better. The video was recorded in those areas forming at least one closed loop. Ground Control Points were distributed approximately 30 m on both sides of the road and were measured with the GNSS technique using an RTK acquisition scheme. Images, which were acquired with the mast system (approximately 6200 photos) and acquired with the 360° camera (around 15000 images), were processed in a combined adjustment (Lichti, 2020). The final average residual on GCPs is ±2.2 cm, while on C.P.s, it is ±2.8 cm. Once the images were oriented, a standard photogrammetric workflow was followed, creating a DTM and a final orthophoto (Figure 6). Only images acquired with the Nikon D610 were used to create the Orthophoto to guarantee a uniform GSD.

a.
b.
c.


Figure 6. Example of the Orthophoto of the paving: obtained Orthophoto (red boundaries) overlaid to current cartography (a) and two details of the paving (b-c).

5. FROM CAD TO GIS: ORGANISING THE APPIAN WAY PORTOFOLIO

5.1. CAD portfolio sections (n. 117 sections, 100m length, variable width 15m÷35m)

After the data acquisition phase, the point clouds were processed two-dimensionally and three-dimensionally with a dual purpose: i) create a single document available to the various professionals and experts who could interact with the Appia Antica Park, such as institutional operators, designers, but also those who deal with maintenance and cost computation; ii) import the documentation on the GIS platform to make an interactive drawing. All the elements on the point cloud were represented by closed polylines (to be managed as polygons in the GIS environment and support Area, Perimeters and other computations), divided into different layers based on the element type and associated with a solid background hatch. The subdivision of the elements into layers has also allowed the assignment of colors and types of lines in such a way as to generate an abacus of the elements that be graphically distinguishable. The representation of this stretch of the Appian Way (12km) has imposed a subdivision in the representation, compatibly with the chosen scale (1:100) and the available print formats, but with the challenge of making the immediate identification of a geographical point within of the portfolio. The entire length of the street was then divided into 100m sections to generate 117 portions. The key-plans, rigorously repeated and progressive on each page, allow immediate identification through reference points (road intersections) and geographical coordinates indicated on each work (Figure 7).

5.2. GIS data management and vocabulary toward HBIM and XR common sharable 'Information'

All the entities digitalized in the 1:50 scale have been managed as closed self-consistent polygons inherited from the cartographic specifications. This step made it possible to build a GIS that would support the PAAA for managing maintenance, design, and preservation and for the metric-cost computation during the procurement of green maintenance. It is the case of the mowing areas or the management of archaeological units, as the still preserved *Basolato* Roman paving (Figure 8, top). Object-based restitution is the basis for object modelling, as illustrated hereafter; it will be the base for the HBIM infrastructure following the HBIM first output of the Claudius-Anio Novus Aqueduct (Banfi et al., 2022). An external DataBase (D.B.) conceived as a vocabulary of the Appian Way to be shared among GIS, HBIM, and eXtended Reality for touristic purposes, has been undertaken under the PAAA coordination. It is progressively enriched with the description of materials, construction techniques, and historical construction phases (and restoration phases) (Figure 8, bottom). Born to manage the common 'I' connecting HBIM and GIS, the D.B. has been developed to enrich the personalized parameters (as in the case of the Stratigraph Units of the Claudius Aqueduct and Cecilia Metella Mausoleum HBIM). The result is to support synchronic and diachronic comparisons among different constructions and restoration phases across the centuries in the overall PAAA extension, which will be shared to visitors through the X.R. platforms (Brumana and Quilici, 2023).

GIS entity management, catalogation and vocabulary (sample):

Sections of 'Pavimentum', paved surface ***('Basolato')*** still visible (**Tot. N.122 entities,** 6.400mq AREA)

Carriage paved Pave': (**Tot n.165 portions**, 30.000mq AREA)

"Margines" or "Crepidines": the two lateral bands up to the state domain borders, ~14 meters from the carriage side. Hewn stones stuck vertically into the ground to contain the lateral thrust (**more than n. 1900** portions classified, 3.400mq AREA).

Macére: state-domain Appian Way border dry walls (**Tot n.1200 portions**, 56.700 mq AREA)

Archaeological artefact, Unmovable objects, **Tot n.325 entities**, 15.000 mq AREA

Archaeological artefact, Movable objects: Scattered stone /marble elements: **Tot n.2436 entities,** 1.575 mq AREA.

Green areas to be mowed (ordinary maintenance and extraordinary maintenance to free the green areas from brambles that overcame the carriage and sidewalk): **221.769,5 mq AREA,** (~ brambles 29.388 mq AREA).

Tall trees: Domestic Pine (Pinus Pinea) and Cypress (Cupressus sempervirens)**: Tot N.569 entities.**

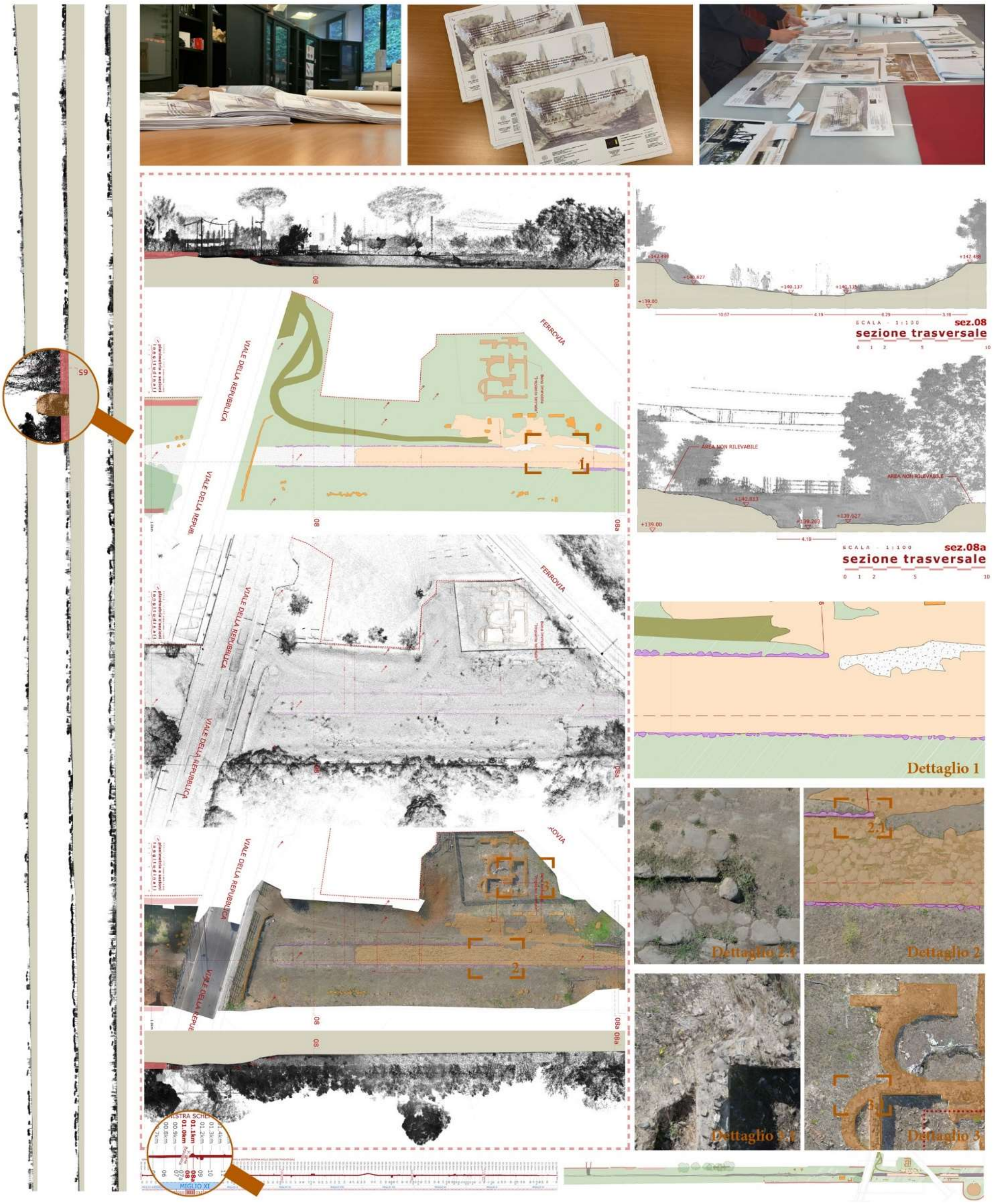
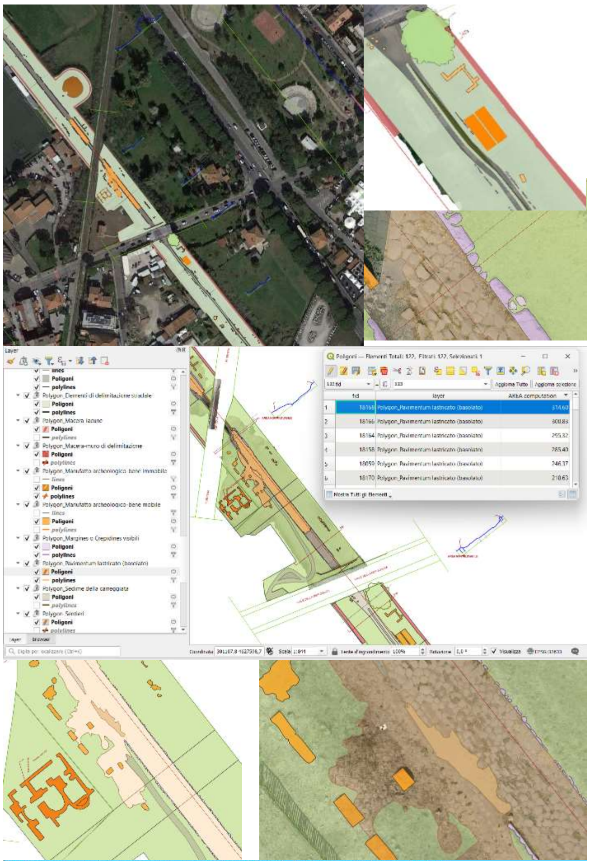


Figure 7. The Appian Way n.3 Portfolio CAD volumes from Frattocchie to Capo di Bove assembled (0-4km, 4-8km, 8-12 km), with a total of 240 panels (top). The 11,7km section has been subdivided into n.117 panels, 100m length (leaving variable their height correspondent to the carriage width 15m÷35m): it supports A0+ layout plotting at the scale 1:100, and n.3 A3 portable Portfolio volumes). A grid section schema guides users extractions with the progressive kilometer of each section panel and the transversal sections with UTM and geographic coordinates (bottom). Here the series generated on Section n.010 (Via Della Repubblica, 01km-01.1km): ‘010’, the geometric CAD polygonal restitution; ‘010a’, the environmental survey with the clouds coming from TLS, MMS (and Photogrammetry) complementary to the CAD drawing to support the 2D design projects; ‘0010b’, the Orthophoto (so far funded for the 0-4 km section). The longitudinal section with the view fronts section along the 11.7km with the ’Macere’ walls in red and the vegetation fronts (left). The 100m planimetric views and details (centre). The transversal sections 08/08a on the 120 focuses (right).



The Appian Way state own section - Capo di Bove (Roma) - Frattocchie di Marino - 11,7 km Appian Way Vocabulary - Information, Infrastructures, Materials and Construction Techniques (HBIM, GIS, XR)							
Entities - Type (ENG)	Entities -Type - Italian (or Latin) Words	ID-CODE	N.	Construction Tecnique	Materials	Picture	Short description
Carriagewage	Carreggiata	IC		Appia Way Infrastructure Layers (Foundation, Sedime, Pavimentum-Paved Surface)			The central carriageable area (mantle and sedime) of ancient 'carreggiata' dedicated to the passage of the wages;
Carriagewage	Pavimentum	IB		The paved surface (Basolato) with the original or reconstructed pavement of the roadway, made with polygonal plates of leucithitic lava (basoli) still visible;	Basolato		Pavimentum-Paved Surface
	Pavimentum			reconstructed pavement (i.e. the carriage signs are transversal to the road direction)	Basolato		Pavimentum-Paved Surface
"Margines" or "Crepidines"	"Margines" or "Crepidines"	ICS		Crepidines hewn stones stuck vertically into the ground that mark the roadway and contain the lateral thrust	Crepidines hewn stones stuck		The areas of the 2 sidewalks (Crepidines) extend in a band of about 14 meters from the carriage side at the 2 left and right bands.
"Macére"	"Macére"	IM		Stretcher bond Brick pattern made only using stretchers, with the joins on each course centred above and below by half a brick.	Masonry dry wall		2 lateral masonry wall designed and built up to limiting the state domain border by Arch. Luigi Canina (1851-1855)
Canina Luigi Arch.	Canina Luigi Arch.						Design "Project of Arrangement of the Via Appia Antica as an archaeological pass (1851-1855)"
Landscape Infrastructure		LPP		Domestic Pine (Pinus Pinea)			
Landscape Infrastructure		LCS		Cypress (Cupressus sempervirens)			

Figure 8. The PAAA APPIAN WAY GIS data management: polygon entities layers from the geometric restitution with metric computations (Area) and Orthophoto tiles (top). The Vocabulary (bottom), courtesy of ABC-Lab GIcarus.

6. 3D IMMERSIVE MULTI-STRATIFIED APPIA: EMPOWERING DESIGN AND FRUITION

6.1 3D environment: landscape, infrastructure, vegetation, archeological sites and artefacts, and remains:

A full immersive 3D landscape representation of the Appian Way has been achieved by managing all the 3D models within pure modellers (i.e. Rhinoceros McNeel ©), (Figure 9).
It has been addressed to support the preservation and design project phases (Preliminary, Definitive, Executive Design, November 2022) as shown in Figure 10.

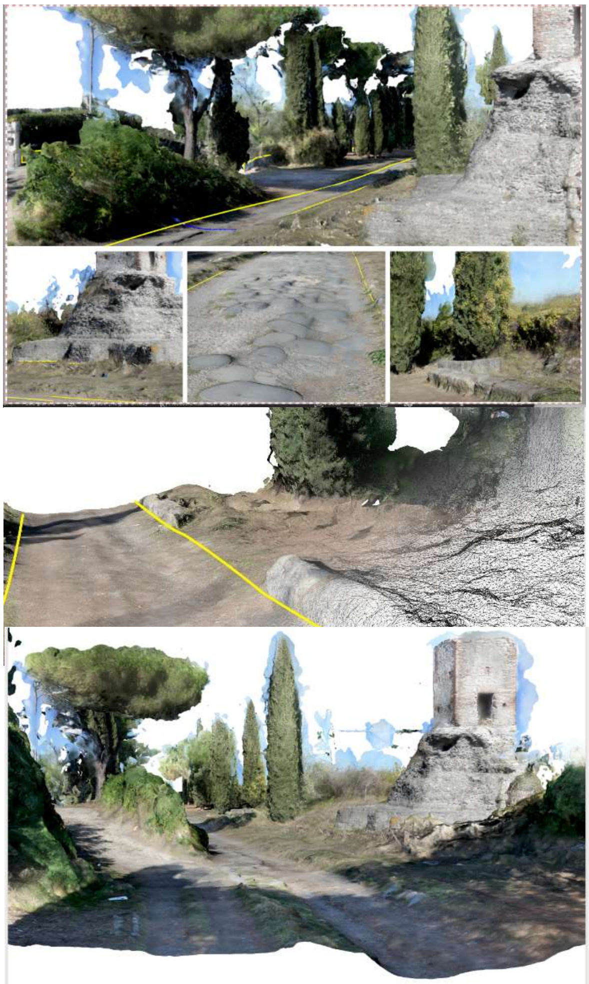


Figure 9. The immersive 3D model representation of the multi-stratified Appian Way landscape, vegetation, infrastructure, *Basolato* and *Crepidines*, architectures, archaeological artefacts, and remains, courtesy of ABC-Lab GIcarus.

Figure 10. A detail of a preliminary design concept of the slow mobility with 3D view representation reconstruction. The design model has been previously integrated by multiple copies of a sample tree and replaced with the immersive one (courtesy of PAAA Parco Archeologico dell'Appia Antica, AXA Architectural Studio).

The 3D immersive model has been obtained by merging all the 3D data, notably: i) the 3D entities (as the longitudinal section and the carriage-wage line with discontinuity respect to the '*Crepidines'*): the 3D line shows the altimetric ascendent volcanic geomorphology of the Appian Way with an altitude difference of 106.08 m along the 11,7km); ii) the 3D entities extracted from the TLS and MMS (as the movable archaeological sites and artefacts); iii) the 3D Textured Objects models coming from the Photogrammetry including the 3D vegetation, where present; iv) the cloud points to complete the 3D perspectives views to support impact analysis of the design of the services or planning the re-vegetation. The project involved also the Appia Antica Regional Park, different municipalities and the most active associations in the area. Thanks to its institutional economic and managerial autonomy, the PAAA has agreements and conventions with these institutions to manage the rich cultural heritage and extensive green areas.

6.2 A 3D digital framework for the design of services to improve accessibility

The 3D immersive model usability is linked to defining the basic knowledge framework for the Park's heritage preservation. It also support the design of the creation of services and infrastructures to improve accessibility. Agreements with public and private bodies to recover areas and infrastructures will be undertaken for the management and dissemination through sites and social channels. The 3D context model documentation represents the multi-stratified section 010 with landscape, infrastructural, architectural and archaeological components. Figure 11 shows the 3D textured model (OBJ) in correspondence with the junction of the Appian Way with the Viale della Repubblica, and the railway infrastructure: it is the result of the integration of the OBJ with the 3D features, as the Carriagewage lines along the 12 km, *Basolato* Roman paving, the sidewalks with the Crepidines and Macere remains, the longitudinal and cross sections and the focus of the archeologic thermal area.

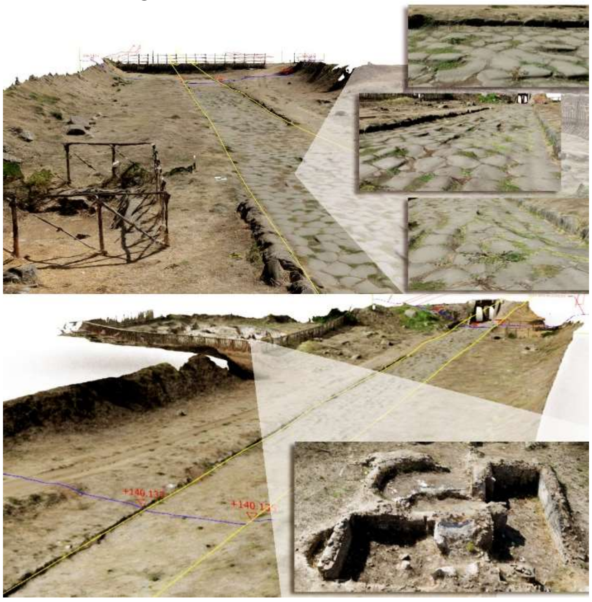


Figure 11. The 3D context OBJ textured model and all the features extracted (courtesy of ABC-Lab GIcarus).

The funding of the Appia Regina Viarum project will be used for the rehabilitation of the miles excluded from this intervention between the boundary of the municipal territory of Rome and the conjunction with the via Appia Nuova (S.S. 7) in the locality of Frattocchie in the municipality of Marino (R.M.). Finally, it will be possible to complete the large open-air museum created by Luigi Canina in the 19th century, preserving and adapting it to the current needs for safe use. The PAAA coordinated the project presented by AKA studio (Federica Caccavale, Alessandro Casadei and Paolo Pineschi) (Figure 12).

Figure 12. The use of 3D context model as a background for the design project of the slow mobility in correspondence of the junction of the Appian Way with the Via della Repubblica and the Railway infrastructures. New trees, re-vegetation, and green regeneration actions have been planned too (courtesy of ABC-Lab GIcarus, PAAA, AXA Architectural Studio).

7. HEALTH INFRASTRUCTURE BOOSTED BY THE APPIAN WAY AS A SOURCE OF WEALTH

7.1 From slow mobility toward active and health infrastructure micro-mobility in a sustainable future

Slow mobility concept is turning toward ‘active mobility’ concept as a source of health: innovative ways to get around reducing congestion and carbon emissions, supporting a sustainable economy, and building greener, more resilient communities. Micro-mobility trends started to appear five-plus years ago, mainly from tech companies in Silicon Valley and the U.S. Physiological markers of traffic-related stress during active travel suggest innovative approaches to health mobility issues (Bigazzi, 2022). Active travel (walking and bicycling) and micro-mobility are personal-use vehicles ranging from bikes to electric scooters and emerging human-electric hybrid vehicles such as e-bikes (Bardutz et al., 2022). Current research focuses on practical bicycle and pedestrian travel analysis and modelling (speed and route choices, facility and network design, comfort and safety, energy expenditure, air pollution uptake, and more), as the React Lab, a group of researchers dedicated to finding ways to make our transportation systems more effective, sustainable, equitable, and healthy with the guiding values of integrity, rigor, creativity, and empathy (React Lab web site).

7.2 Interactive web-based XR platform: eXtended Reality as a source of wealth by cultural heritage contents fruition

Starting from this concept the PAAA addressing this concept to the Appian Way valorization, coupling slow mobility with multi-stratified culture fruition as a source of wealth with the support of eXtended Reality. The virtual backbone of digitalization has aimed to form the basis for the development of virtual reconstructions for immersive devices (video mapping, augmented Reality, geotag, etc.), progressively integrating the richness of textured multi-layered 3D models. It can be enriched with historical and current information and documents, to support a virtual use of the multi-layered Appian Way, built on the immersive digital twin (Banfi et al., 2019; Banfi, 2021). Landscape, architectural and archaeological values will augment the experience of the Appian Way's slow mobility. A web-based XR interactive platform implemented within the ABC-lab GIcarus at the Villa dei Quintili started collecting models, sculptures to be navigated interactively by the visitors: it can be remotely and on-site accessible by smartphone as well as other devices (headsets, oculus, wearable devices) in the PAAA exhibition outdoor and indoor spaces. An experiment on the use of the DT textured model with the GIS information is feeding a web 3D immersive XR experience. It will be added to the Appian Way visits, reaching the public, physically and remotely, raising awareness of the multi-stratified historical richness (Figure 13).

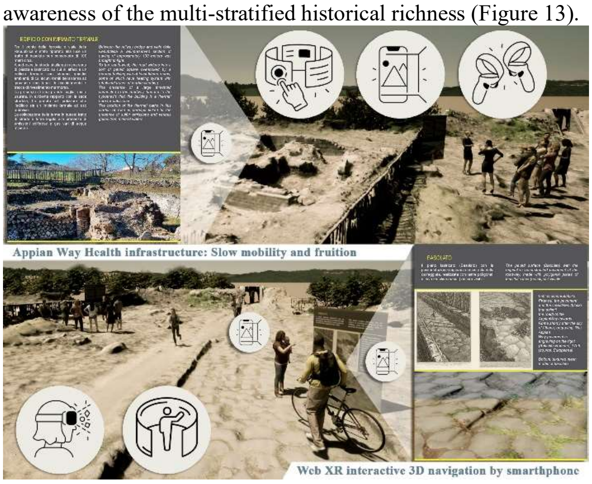


Figure 13. The work-in-progress web eXtended Reality interactive platform, remotely accessible by smartphone during the visit and with headsets in the PAAA exhibition spaces (courtesy of ABC-Lab GIcarus).

8. CONCLUSIONS

The Digital Twin of the PAAA and Appian Way are conceived as an updatable system made by a set of constantly growing data, information models and tools that will be tailored to the maintenance, conservation, design and fruition purposes within a human-centric vision in the construction of a sustainable future and use of cultural heritage and growth of well-being. Surveying documentation and digitization is the common wire to design sustainable intervention as the on-course slow mobility, preserving the past, raising awareness for an informed society, and increasing social well-being through cultural heritage.

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