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DIGITAL TWIN TO MONITOR, UNDERSTAND AND PRESERVE THE COMPLEXITY OF MULTI-SCALE NATURAL, AGRICULTURAL, DESIGNED LANDSCAPES AND ARCHITECTURE: BIODIVERSITY CONSERVATION, TRANSFORMATION AND DECLINE AT VILLA ARCONATI SITE AT CASTELLAZZO OF BOLLATE (MI)

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ABSTRACT:

Digital Twin is conceived as a tool designed to monitor the effects of climate change and human activity on a global scale by integrating Earth Observation with local information. When applied to Cultural Heritage and built environment, this concept requires a detailed analysis to decode the richness of sites and context, highlighting specific local features. This paper aims to contribute to the preservation of the complexity of natural, agricultural, and designed landscapes, including the architectural scale. The case study is the Villa Arconati site in Castellazzo of Bollate, in the metropolitan-peri-urban area of Milan, which is a monumental 16th Century complex, with a significant historical and cultural value and an exceptional green biomass resource in a densely built area. The analysis is carried out at two scales, which complement each other: (i) an environmental-scale study that uses historical maps and the Normalized Difference Vegetation Index (NDVI) analysis from the last two decades to monitor biodiversity transformations and highlight the level of conservation; (ii) a local-scale multi-sensor survey, which uses experimental equipment, such as a spherical camera, to extract 3D vegetation models - referred to historical views - to set conservation criteria of the landscape layout. The multi-temporal-scale analysis helps to define sustainable future management practices (such as FAR and PAS) and raises awareness among the community and the visitors about the importance of preserving both the historical and architectural value and the site's biodiversity [1].

1. INTRODUCTION

1.1 A multi-sensor, multi-temporal Digital Twin: a tool to preserve the richness of multi-scale complex sites.

Digital Twins have emerged as a valuable tool for monitoring the impacts of climate change and human activity on a global scale. They integrate Earth Observation data with local information, allowing researchers to monitor natural systems and human activity in real time. A multi-sensor, multi-temporal and multi-scale approach to digitizing complex sites is crucial for assessing environmental sustainability, including biodiversity conservation and transformation. Digital Twins are born to monitor scenarios under climate change threats and anthropic pressures by using Earth Observation (Bauer et al., 2021). Specifically, when dealing with Cultural Heritage and the built environment, this concept requires a multi-scale analysis that addresses the granularity of sites and contexts to boost punctual local analysis and specificities.

This paper intends to contribute to understand and preserve the complexity of multi-scale natural, agricultural, and designed landscapes, including biodiversity transformation and conservation, to manage phenomena such as decline and decay. The case study is the Villa Arconati site at Castellazzo of Bollate, in the metropolitan-peri-urban area of Milan. Villa Arconati is a monumental 16th Century complex that has a significant historical and cultural value and an exceptional green biomass resource in a highly developed area. This site currently needs a specific methodology to increase its awareness and define sustainable future management. The analysis is carried out at two scale levels.
(i) The environmental-scale multi-temporal framework, which correlates historical maps with the last two decades' Normalized Difference Vegetation Index (NDVI) analysis, obtained from processing EO satellite data (European Space Agency ESA - Copernicus Sentinel-2, and NASA United States Geological Survey USGS Landsat 7). The 20-year time span NDVI, compared with the historical maps, highlighted how the Castellazzo site still works as a hub of biodiversity conservation

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[1] The present work was conceived and written jointly by the four authors with a multidisciplinary contribution of geomatics, EO-driven biodiversity monitoring, innovative multidimensional Digital Twin (Marzia Gabriele and Raffaella Brumana) and landscape preservation and historical garden management (Alberta Cazzani and Carlotta Maria Zerbi). Specifically, MG and RB developed sections 1.1, 3.1, 3.4, 4.2; MG developed section 3.4.1; CMZ section 2.1 and AC sections 3.2 and 4.1. The authors collaborated in the writing of Section 3.3., Section 5, Abstract, Introduction and Conclusions, and for the final revision of the manuscript.

in an area currently characterized by biodiversity loss. The rGEE framework (Aybar et al., 2020) was used to code the overall EO back-end pre-and post-processing, supporting, and structuring this first scale analysis by means of Cloud Computing.

(ii) The local-scale multi-sensor survey, which is carried out with experimental equipment such as a spherical camera, digital camera, and smartphone, captures the richness of the Castellazzo site-designed landscape. This survey develops Digital Twins to compare the past richness - registered by the historical views and its specificity - with the current state of the garden. It immersively raises awareness among the community and the visitors on the importance of the garden also for biodiversity preservation.

The two-scale levels (i and ii) work together as a unique multi-sensor and multi-temporal Digital Twin instrument, to better support and structure multi-scale preservation and mitigation actions, fostered by active learning through conscious fruition. The analysis contributes to define sustainable future management of the site.

A GIS project was created to manage all the information related to the Castellazzo site. The project was structured into groups of macro themes. The base map consisted of the current geographic database of the area (*Data Base Territoriale* or *DBT*), which contained vector thematic layers including Built Environment, Water and Rivers, Agricultural Areas and Green Areas, and Infrastructures. These vector layers were obtained from the Lombardy Region geoportal. Additionally, the project included a regional technical map known as *Carta Tecnica Regionale (CTR)*, which was provided as a raster image at a scale of 1:10.000. To access historical orthophotos, Web Map Services (WMS) were used, which connected to the Regione Lombardia service. Furthermore, the authors (MG and RB) georeferenced the historical maps, which were also included in the project. Finally, a raster containing Remote Sensing (RS) satellite imagery was added to the project. This imagery consisted of NDVI index and True Color RGB images of the area, which were retrieved from the GEE repository through rGEE code.

2. THE VILLA ARCONATI SITE: UNDERSTANDING AND PRESERVING ITS COMPLEXITY

2.1 The Villa Arconati site at Castellazzo of Bollate: the history of a multi-scale-built environment, landscape, historical garden, and architectural Heritage

The extended and articulated historical complex of Villa Arconati in Bollate (a municipality about 12 km North of Milan), often called by the local toponym - the Castellazzo - includes a sumptuous villa and the adjacent gardens, as well as a rural village, agricultural areas and woods which once constituted the hunting ground before of the Arconati, and then of the Sormani and Crivelli families. The large park was connected to extensive areas of heath (to the North), woods (to the East and South) and fields mainly used as arable land, with the presence of mulberry trees for breeding silkworms. The landscape was characterized by the presence of streams and several groundwater springs; the construction of a rich network of canals and ditches made the fields irrigable and more fertile (Cazzani and Giambruno, 1998).The first nucleus of the palace, together with the rural village and the church annexed to it (De Cesare., 1985; Ferrario., 1996), was built by the Marquis Guido Cusani in the second half of the 16th Century. In the 17th Century Count Galeazzo Arconati enlarged the villa and added the rear Italian garden, organized along a wide perspective axis in a W-E direction which, from the main front of the villa, culminated in the monumental Theater of Diana. The villa was also enriched by famous works of art, including an extraordinary archaeological collection with important Roman statues, and by a famous library which for some years also kept Leonardo da Vinci's *Codex Atlanticus* (Beltrami, 1907; Ferrario, 1996; Corain, 2021)

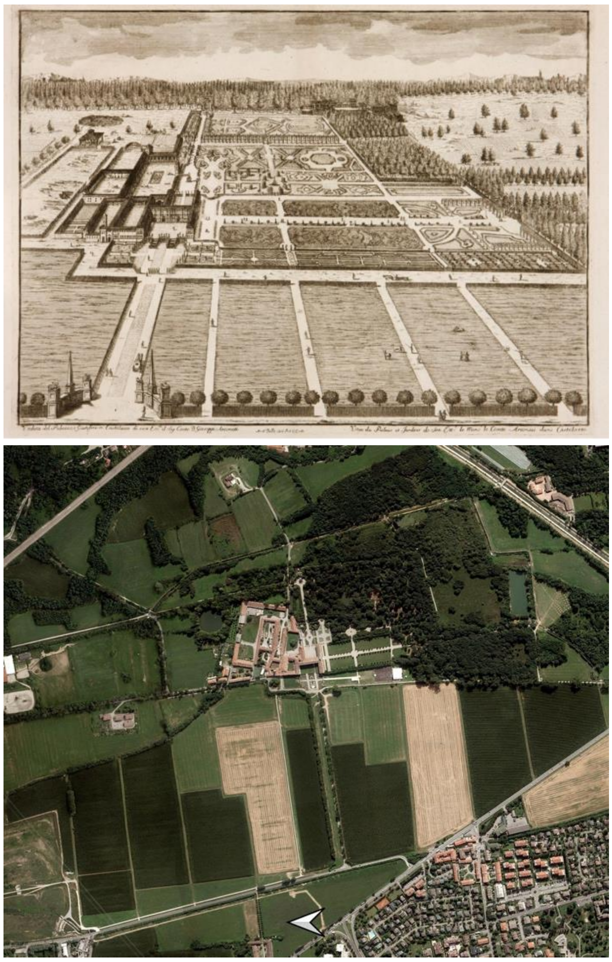

Figure 1. Villa Arconati site: upper, an overview by Marc’Antonio Dal Re, 1743 (Dal Re, 1743); bottom, an extract of the 2017 Orthophoto (source: Lombardy Region Geoportal Web Map Service – WMS). It is possible to observe the high level of permanence of the site historic layout: the access road surrounded by fields, the villa and the connected rural buildings, the formal garden, and woods. This site represents a significant green biomass resource in the metropolitan area of Milan.

Between the end of the 16th Century and the mid-18th Century, the site was further transformed to adapt to the most widespread models in Europe for large residences (hence probably the appellative "the little Versailles" of Milan with which Villa Arconati was indicated in 18th Century tour guides). The S-W wing was added to the villa, while the garden was enriched with three avenues oriented in an N-S direction which led to several “green rooms” delimited by high *espaliers* of regularly pruned *Carpinus betulus* (hornbeam), architectural backdrops, and buildings like a lemon house, fountains, decorative features, *parterres* and groves. The garden also included a *ménagerie*, a fine aviary and hunting woods. All this is well documented by the famous engravings and descriptions of Marc'Antonio Dal Re of 1743 (Figure 1), (Cantù, 1858; Dal Re, 1743; Vercelloni, 1986). During the 19th Century and part of the 20th Century, under the Busca marquises and their heirs Sormani and Crivelli, the villa with garden and the vast estate around it, constituted an important farm complete with rural residences, stables, barns, and rustic buildings located in the large village (Ferrario, 1996). At the end of the 20th Century the site suffered years of decreasing maintenance and then abandonment which caused a severe state of decay. In 2000 a new owner, the Fondazione Augusto Rancilio – FAR, bought the complex and started an important restoration and enhancement plan for the site.

3. THE ENVIRONMENTAL TWIN: A TOOL FOR MONITORING BIODIVERSITY RICHNESS, TRANSFORMATION, CONSERVATION AND DECLINE THROUGH EO-BASED MONITORING IN A MULTI-TEMPORAL FRAMEWORK

3.1 Assessing Biodiversity in a Multi-Temporal Spatial Dimension using a Digital Twin: detecting transformation, conservation, loss, and decline

In 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) implemented a new work program *("Scoping report for a thematic assessment of the underlying causes of biodiversity loss, and the determinants of transformative change and options for achieving the 2050 Vision for Biodiversity transformative change assessment 2019-2030")*, which included a transformative change assessment aimed at understanding the underlying causes of biodiversity loss and identifying factors at both individual and collective levels, such as behavioral, social, cultural, economic, institutional, technical, and technological dimensions. The objective is to bring about transformative change for the conservation, restoration, and sustainable use of biodiversity. Biodiversity loss refers to the decline or disappearance of biological diversity, including the variety of living things and natural patterns in ecosystems, with at least one million species currently in danger of extinction. The assessment takes into consideration the biophysical setting, including hydrology, hydrogeology, topography, hydrometeorology, sensitive ecosystems, and protected areas, and emphasizes the importance of regular regional and subregional assessments.
This study will utilize local area habitat and critical source area maps to determine the most effective measures for enhancing biodiversity with maximum ecological benefit. The analysis will consider various factors, including green areas for cultivation, designed landscapes and parks, water resources and infrastructures, and architectural biodiversity values. Preserving capacities and skills is essential for sharing knowledge with visitors to the park and site as well.

3.2 The complexity of the Villa Arconati - FAR site today

Since the end of the 18th Century, the Castellazzo site has not undergone significant changes, even if the partial abandonment and underuse of the 20th Century have caused the spread of decay and the partial loss of some artifacts, in addition to the overgrowth of the vegetation. The current ownership, the Augusto Rancilio Foundation – FAR, has started important conservation and recovery interventions starting in 2009 and has foreseen the weekly opening to the public, who can thus come to know and admire one of the few Baroque-layout sites still surviving in Lombardy (Corain, 2021). The extensive formal park, covering approximately 5 hectares, in fact, maintains its 18th Century layout clearly legible, with high *espaliers* and plant walls, regularly pruned hornbeams and shaped hedges that structure the layout of the site (Cazzani, 2003). In addition to the sumptuous villa and stables, there are still several other elements of architectural interest: the lemon house, the Theater of Diana with fountains and water features, exedras, flower greenhouses, an icebox and many statues, furnishings, and precious mosaic floors. The portion where the *ménagerie* was historically located is now occupied by a wood mainly of oaks, crossed by straight paths and characterized by the presence of a beautiful aviary, now in a state of decay, but whose restoration is already planned. The main buildings and the garden area are Listed as National Landmark. The entire complex, including over 50 hectares of agricultural and wooded areas and the vast agricultural village (now in a state of abandon), is included in the perimeter of the Groane Regional Park, established in 1976.
It should be highlighted how the territories of northern Milan have been involved, since the beginning of the 20th Century, by a deep transformation: new infrastructures (the Milan-Saronno railway and the Lakes motorway), the expansion of industrial areas – even of great importance such as the Alfa Romeo of Arese – with the consequent abandonment and reduction of agricultural areas, the increasingly intense and extensive urbanization and the deep transformation of the historic landscape, with the loss not only of its structural components (urban and rural clusters, farmhouses, road and hydraulic networks, agricultural layout), but also of natural ones, and an evident reduction of biodiversity. The establishment of the Parco delle Groane had as its primary objective the safeguarding of the residual characteristics of this territory, despite the strong pressures due to the continuous residential, industrial, and commercial expansions of the Milan metropolitan area. In this scenario, the Villa Arconati site is exceptionally unique because, luckily, not only the monumental buildings and the park have been survived, but also the agricultural village and large surrounding agricultural portions, which therefore constitute an extraordinary cultural and landscape resource that deserves to be carefully analyzed and evaluated to highlight its values and potential and to define conservation and management criteria.

3.3 The XIX historic Military map (*Carta Manovra dei Dintorni di Milano, 1878*): the documentation of biodiversity richness, water network, agriculture, cultivation, and designed landscape specificity in a multi-temporal framework.

As stated earlier in the introduction, a GIS has been developed to manage all the available information layers within a multi-temporal framework. This framework includes historical data, current data from the DBT Topographic Data Base, and open data provided by the Lombardy Region as Web Map Services. The open data includes historical orthophotos from 1970 to the present. By combining these information layers with EO data analysis, the GIS can be used to analyze the transformations that have occurred over the centuries and those that are ongoing. Historical Maps have been georeferenced as it is the case of the *Carta Manovra dei Dintorni di Milano*, 1878 (Figure 2).
The data registry of the historical map has been performed with QGIS Georeferencing Tool – Linear transformation pixel residual - resampled with Nearest Neighborhood, by detecting an average of 15-20 homologous points from the DBT and the orthophoto for the Land parcels. As highlighted above, in the Villa Arconati site remains not only the monumental buildings and the adjacent Baroque Garden, but also the rural village and the surrounding agricultural areas, despite being in a zone of very strong human pressure with significant urban expansion in recent decades. The agricultural areas connected to Villa

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Arconati are progressively simplified loosing part of their richness: the historic water network is only partially legible and only minimally functional, the tree-lined row system is lost, and the arable fields has been replaced by meadow crops. The wooded areas, no longer productive, have extended as naturalized areas that were once cultivated, with an evident loss of the historic landscape layout and features, and a reduction of biodiversity.

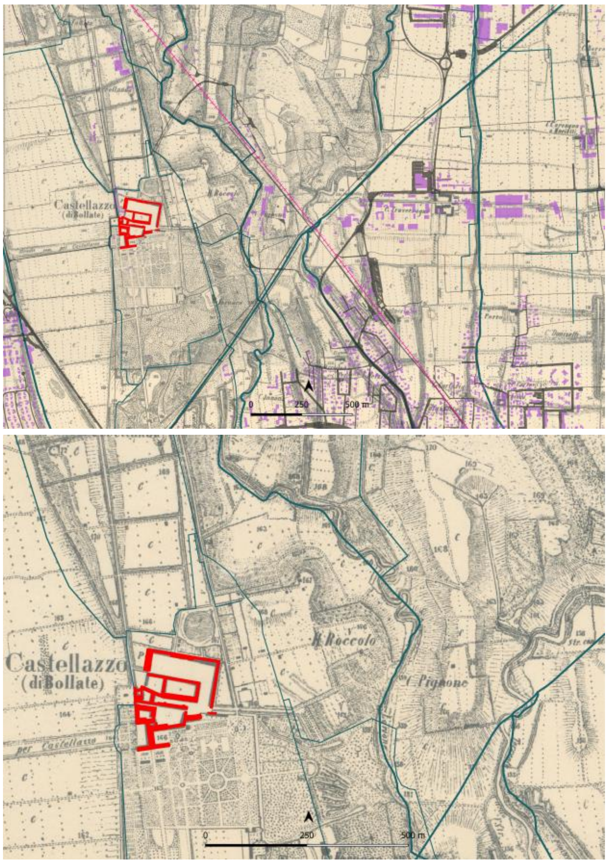

Figure 2. Extract from the *Carta Manovra dei Dintorni di Milano*, 1878, (georeferenced in QGIS 3.22), with superimposed some data from the current Lombardy Region Topographic Database: the natural and artificial water network (blue), the currently built areas (purple), the Castellazzo buildings (red), the railroad (pink), the infrastructure network (gray) (Historical Georeferentiation and Database GIS elaboration, Courtesy of DABCLab-Gicarus, Marzia Gabriele). Upper, the Castellazzo di Bollate area: it is possible to see the high level of permanence of the water network and the intense urbanization. Bottom, a zoom on the Castellazzo site: the level of permanence is higher and there is no sign of modern transformations. It is important to underline that unfortunately the Lombardy Region Topographic Database is not so accurate and, for example, does not represent all the water, landscape, and architectural features of the Castellazzo site still conserved.

The comparison between historic map and the current situation shows this changing and biodiversity loss. Particularly about the water infrastructures it is important to consider that the site was part of an agriculture-designed system with a rich water network made by natural and artificial components. The Nirone river crosses the surrounding area: it is an important river in the built environment history, feeding the Milan City since the Roman period, progressively connected with the Adda River, to all the city thanks to the Navigli Channels (R. Brumana, 2010). In addition, in 1863 it was built the Villoresi channel and the linked *canale scolmatore* (i.e., spillway channel), connected to the Nirone. It is an artificial branch supplying the down-streamed Villa Arconati site to irrigate the agricultural areas, the garden and to feed fountains and theaters, thanks to an artificial *roggia*'s network (i.e., ditch) that runs along the villa borders and across the garden.

3.4 Copernicus, Landsat EO data rGEE backend framework: an automated, coherent, and spatially harmonized methodology to support the study of 20 years of biodiversity evolution.

Starting from research carried out to analyze land degradation indexes and transformations under anthropic pressure and climate change (Gabriele et al., 2022; Gabriele et al., 2023), the subject of holistic analysis of complex heritage, built environment and landscape has been here addressed to investigate the role of Cultural Heritage in biodiversity transformation and conservation. An rGEE code exploited by using Earth Observation (i.e., Copernicus, Landsat) is currently being implemented, pursuing the integration of Google Earth Engine (GEE) and R programming, to spread the EO-derived analysis (i.e., Vegetational Indices, land use and soil sealing semi-automatic classification) into the granularity of Cultural Heritage. The classic approach to EO analysis, before making use of the current advances in Cloud Computing, worked by manually retrieving EO imagery from data hub repositories, not ensuring a proper harmonization of the remote sensing information, and thus, the potential aggregation of it for a comparison over time was limited to the capacity of the local data storage. For these reasons, the very latest innovations in research apply Google Earth Engine (GEE) Cloud computing innovative technologies to the EO domain to efficiently manage petabyte amounts of data for monitoring purposes (Atefi et al., 2022; Crego et al., 2021; Hazaymeh et al., 2022).

The combination of the powerfulness brought by GEE, combined with R coding workflow, bridges the gap between R and the multi-petabyte catalog of remotely sensed data available in GEE (rGEE), pushing toward innovative potentials to support semi-real-time geospatial analysis at an extensive level of applications. In the specificity of the study case, rGEE allowed to exploit the overall potential of Earth Observation (EO) tools to: (i) foster scientific research applied to the earth observation domain, (ii) run mega and petabytes of EO data, (iii) produce a dynamic analysis (i.e., NDVI index, Soil Use maps) on the environmental territorial area of the site, thus, (iv) provide an understanding of the transformations that occurred in the last 20 years in the Arconati site area.

The rGEE code supported the framework of the overall comparison of the transformation across the last centuries, moreover, integrated by historical maps, highlighted the specificity of this site, in terms of the current state of biodiversity conservation, in an area characterized by biodiversity preservation and decline and loss. One of the overall objectives was to define in the coding workflow a coherent methodological framework that could successfully allow a quantitative comparison of the latest 20 years of biodiversity patterns, meanwhile guaranteeing a homogeneous spatial resolution (10mt). The first step was to write and to run the rGEE code to retrieve information for the year 2000, by applying spectral transformation function rgbToHsv() and hsvToRgb() to the 'LANDSAT/LE07/C02/T1_TOA', FilterDate('2000-03-01', '2000-05-30') images, to execute a pan-sharpening. The image change in the spatial resolution must be referred to the Panchromatic band (B8), which allows the

Landsat image to resample the information at a higher resolution (Hi-res gray band = Higher-res color image, by decomposing RGB image in HSV, replacing V values with the High-resolution Panchromatic values, and reconverting it to RGB image). The 10mt-spatial resolution image result derives from the combination of the multispectral image with the panchromatic image (Pansharpening). This means enhancing the geometry of this image, so it has a better resolution geometrically, but the actual spectral resolution stays the same (for 1 pixel of spectral resolution image, 4 pixels of geometric resolution, with the same multispectral value).

The COPERNICUS/S2_SR composite Image for the filter Date('2022-03-01', '2022-05-30') on ImageCollection ('COPERNICUS/S2_SR') was created by using the median composite function method, where the input images are created in a pixel-wise manner by taking the median value (i.e., DN, TOA or reflectance), to not affect the phenology information, from all cloud-free pixels of the image collection. The bands of the median composite image are rescaled with an image scale constant of 1000. The final spatial resolution of the image is 10 mt. This first back-end operation brought to obtain a more geospatial-coherent time comparison of the imagery information retrieved from two different sources (Landsat and Copernicus) (Figure 3).

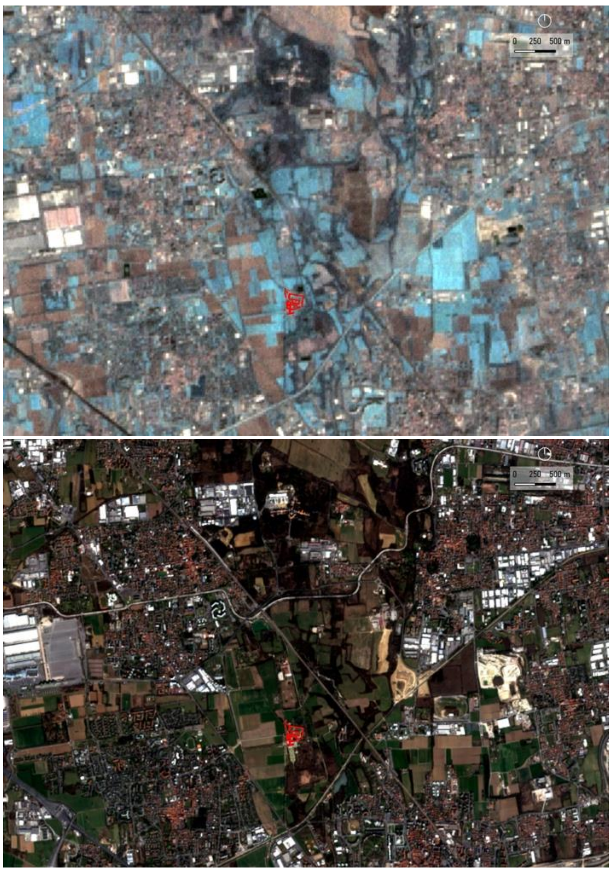

Figure 3. LANDSAT/LE07/C02/T1_TOA – True Color Pansharpened composite FilterDate ('2000-03-01', '2000-05-30'), upper. COPERNICUS/S2_SR – True Color median composite - FilterDate('2022-03-01', '2022-05-30'),bottom. In red, the Castellazzo site.

3.4.1 Normalized Difference Vegetation Index (NDVI) rGEE code for biodiversity monitoring

It allowed to retrieve Normalized Difference Vegetation Index (NDVI) information, to make a comparison of the latest 20 years' time evolution for the studied area, both from Copernicus and Landsat GEE data collections, by using the function filterDate('2022-03-01', '2022-05-30') on ImageCollection ('COPERNICUS/S2_SR') and FilterDate('2000-03-01', '2000-05-30') on ImageCollection ('LANDSAT/LE07/C02/T1_TOA') as shown in Normalized Difference Vegetation Index (NDVI) is a measure of vegetation health and productivity based on the difference between the reflectance of visible and near-infrared (NIR) light by plants. It is calculated using the following formula:

$$NDVI = (NIR - Red) / (NIR + Red) \quad (1)$$

where NIR and Red are the reflectance values of near-infrared and red wavelengths of light, respectively. NDVI values range from -1 to 1, with higher values indicating a greater amount of green vegetation. NDVI values close to -1 typically indicate bare soil or water, while values close to 1 indicate dense, healthy vegetation. NDVI is often used to assess the health and productivity of crops, forests, and other vegetation, as well as to monitor land use and land cover changes. The NDVI was computed by the means of the GEE getNDVI function, returning a normalized difference extracted from (i) the 'COPERNICUS/S2_SR' FilterDate('2022-03-01', '2022-05-30') ("B8", "B4") median composite bands; (ii) 'LANDSAT/LE07/C02/T1_TOA' FilterDate('2000-03-01', '2000-05-30') ("B3", "B4") pan-sharpened bands (Ouzemou, 2018). The 2 images (Figure 4) illustrate on a 25.000 scale territorial frame, the output of the NDVI analysis obtained with the code implemented on the LANDSAT 2000 and COPERNICUS 2022. The comparison of the 2 images highlights the transformation that occurred in the last 20 years of soil sealing, due to the progressive change in land use which favored urbanization, thus, impacting vegetation quality and, consequentially, its biodiversity. This is particularly noteworthy given the two intersecting main infrastructures that form diagonal axes in the study area. The triangle on the right side of the Villa Arconati site and its surroundings highlights the significant impact of altered land use resulting from the decision to expand urbanization into the neighboring districts. This is evident through the decrease in net primary production of vegetation. However, there are limited areas within this triangle that display greater resilience and a lesser decrease in vegetation quality. This can be attributed to the biodiversity preservation efforts that have been implemented due to the cultural significance of the FAR. To further investigate this, the cultivation and transformations that have occurred over time will also be considered. This study serves as a starting point to explore the potential of cultural heritage sites in promoting biodiversity preservation. In the case of the Arconati site, the loss of parcellations has resulted in a decline in cultivation richness in the surrounding area. The soil use classification will be analyzed in more detail in the full paper, with a focus on the importance of on-site ground validation. Additionally, archival research will be conducted to identify the interested parcels on the Teresian and Lombardo Veneto Cadastres to better interpret the past biodiversity richness in terms of cultivation. For further implementation it is advisable to consider the difference between the NDVI datasets calculated by using both the pre-and post-sharpened 'LANDSAT/LE07/C02/T1_TOA input imagery, selecting an algorithm that introduces the least distortion (Beene et al., 2022).

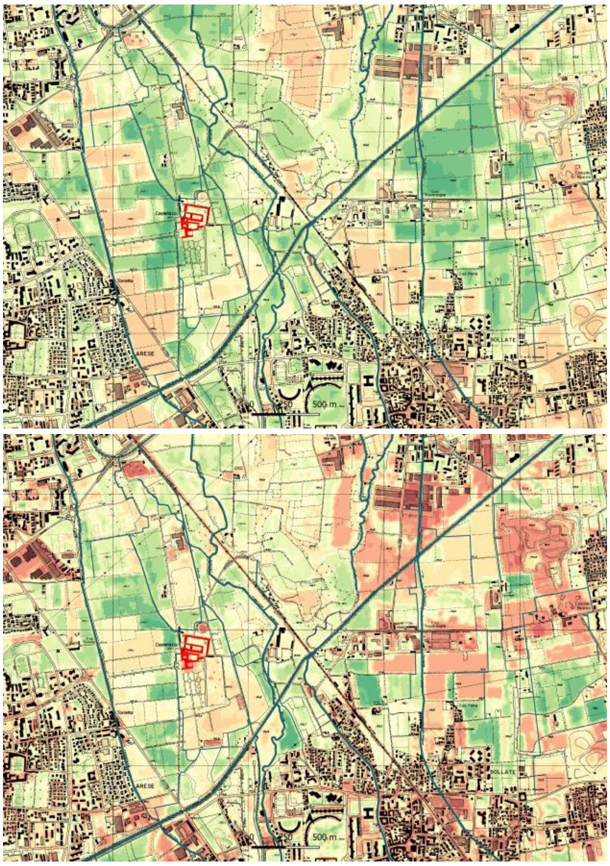

Figure 4. The transformation occurred in the last 22 years: the red gradient of the NDVI index evidences the decreasing of the amount of chlorophyll in the vegetation quality, evidencing biodiversity loss, with the consequent parcel fragmentation resulting from soil sealing and urbanization. Top: ‘LANDSAT/LE07/C02/T1_TOA NDVI – FilterDate ('2000-03-01', '2000-05-30'): bottom: ‘COPERNICUS/S2_SR NDVI FilterDate ('2022-03-01', '2022-05-30').

4. A DIGITAL TWIN TO PRESERVE THE ARCONATI VILLA HISTORIC GARDEN AT THE LOCAL SCALE

4.1 Biodiversity sample of conservation: the designed *carpinate*, the historical perspective views, the water network

The analysis of the historic maps and documents and the use of the NDVI data demonstrates that Villa Arconati site had in the past a richer biodiversity. Among others, two main thematical biodiversity assets have been highlighted (Figure 5): (i) the theme of water network preservation; (ii) the theme of *Citrus* cultivation, shaped green walls, *espaliers* and designed landscape preservation, maintenance, and valorization. The water network includes the fountains and the pond, that were supplied by the Villoresi channel, and the *roggia*’s network that nowadays are empty, even if they are still recognizable. The purpose is to bring back the water system, considering the water scarcity, saving, and reusing the local water resource, by the recovery of the *roggia*’s network, coupled with Nature Based Solutions tanks. About *Citrus* cultivation and shaped green walls (Figure 6) it is important to consider that M. Dal Re (Dal Re, 1743) describes: “Citrus *espaliers* and Citrus pots, green walls, green rooms, tree-lined avenues, green tunnels, shaped trees” and different tree species (*Carpinus betulus, Quercus robur, Ulmus, Aesculus Hippocastanum*), underlining a very significative garden and biodiversity complex. The nowadays abandoned greenhouses will be restored, as well as the *carpinate* (high *espaliers* of regularly pruned *Carpinus betulus*) must be shaped and some *Citrus* trees replanted to restore the historic layout and to increase the biodiversity.

Figure 5. Preservation of two biodiversity themes: water (fountain water was provided by the *roggia*’s network) and vegetation (*Carpinus betulus* and *Citrus limon*).

Figure 6. *“Parte del berso in Castellazzo”* (i.e. *part of the green walls in Castellazzo*), one of the 24 engravings by M. Dal Re, 1743, that document historic biodiversity richness.

4.2 Spherical cameras and 3D vegetation scale addressing biodiversity awareness: 3D immersive digitization and the twin comparison with the historical Dal Re perspective views

In order to aid the conservation and promotion program of the Fondazione Augusto Rancilio - FAR, and to raise awareness about the historical vegetation of the 17th Century Garden and its biodiversity, a 3D digitization of one of the *carpinate* has been attempted. The photogrammetric block, which was created by merging images from 3 different cameras (Canon full sensor, smartphone, and spheric camera RICOH Z1 with fisheye/spherical lens), provides a promising start for further application to other areas of the park and designed landscape.
This survey aims to reveal and evaluate the complexity and level of permanence of the architectural green features to support decisions on conservation and restoration criteria. The ongoing digitization has produced initial results, shown in Figure 7, which will be applied to other portions of the park and the designed landscape. This implementation will also facilitate the monitoring of the green area's evolution and transformation by implementing a classification of soil use and adding index indicators to highlight transformation, conservation, and decline. As the site attracts an average of 400 visitors per weekend, the 3D valorization of the *carpinate* will contribute to

raising awareness about the importance of preserving biodiversity and historical vegetation in cultural heritage sites.
As previously stated, the Arconati historic garden's architectural layout was primarily established using vegetation arranged in regular geometric shapes, as described and illustrated by Marc'Antonio Dal Re (Dal Re, 1743, Figure 6). The digitization of these design projects will gradually reveal their significance, and immersive experiences during visits will increase public awareness of the historical value of this built environment (Cazzani et al., 2020).

Figure 7. From above to the bottom: current view of the main perspective axis of the garden, with hornbeams *espaliers*; the photogrammetric 3D textured image obtained with spheric camera; the photogrammetric processing; a detail of the secondary paths and a detail of the 3D immersive reconstruction of the symmetrical *espaliers*.

5. PERSPECTIVES ON DATA MANAGEMENT ADDRESSING DECISION MAKING, BUILDING CAPACITIES AND AWARENESS RISING

Boosting biodiversity's assessment and data management, will contribute to build capacities in design actions on preserving biodiversity, contributing to reversing the biodiversity decline, boosting ecosystem services, including genetic, taxonomy, carbon sequestration, climate resilience and pollution reduction. Thus, it will equip the next generations with the necessary knowledge, skills, and competencies to promote sustainability within their work practices, achieving the EU biodiversity strategy for 2030 and the EU climate adaptation strategy. The European Commission proposed in 2022 a Council Recommendation on encouraging cooperation in learning for environmental sustainability, including biodiversity learning and teaching, which was accompanied by a competence framework. The topic aims to contribute to the formation, skills development, and awareness raising in the higher education sector, on biodiversity loss, and how this can be addressed, by the means of Nature-based Solutions (NBS). This is fundamental to further implement and upscale NBS, and to mainstream biodiversity, and ecosystem services, including carbon sequestration, climate resilience, pollution reduction, and natural capital in the society and economy. Through education and NBS, the topic contributes to the transformative change necessary to tackle societal challenges, encouraging cooperation in environmental sustainability, including biodiversity learning and teaching. In this spirit, the in-progress research on the Villa Arconati site has been actively supported by the FAR, with the aim to spread the in-progress results and the first outputs of the cutting-edge Cloud Computing EO biodiversity analysis, coupled within the experimental surveying techniques, into the Master of Science Course held by the authors. From the territorial level, using historic maps and digital tools, to the architectural scale detailed surveys it will be possible to define preservation, management and valorization criteria related to the landscape and architectural features and to the biodiversity and ecological aspects. Villa Arconati site represents an opportunity to outline Nature Based Solutions that are compatible with the historic layout and can enrich the current situation, reusing abandoned buildings, introducing new functions, restoring in decay components, increasing the agricultural and productive areas and enhancing the natural and ecological aspects.

6. CONCLUSIONS

By utilizing a range of techniques including historical research, map analysis, detailed surveys, and remote sensing methodologies, a multi-scale Digital Twin was created for the Villa Arconati site. This enabled a better understanding of the site's landscape, biodiversity and architectural richness, underling the level of permanence and transformation to support the future definition of criteria and particularly Natural-Based solutions to conserve, reuse and valorize this Heritage site located in the Milan metropolitan area. A multi-disciplinary approach allowed to consider not only the cultural and artistic values, but also the natural and ecological components that represent a significative resource for this very dense-urbanized area. Particularly, the vegetation and water network biodiversity were studied to identify effective restoration and conservation policy, promoting sustainable management practices, and raising visitor awareness of the site's uniqueness and complexity. The research evaluated changes in biodiversity over time using NDVI monitoring and historical maps and found that the Villa Arconati site played a crucial role in preserving the agricultural areas amid the biodiversity loss observed in the metropolitan region. The study paves the way to further examining soil classification and crop typology using cadastral maps and satellite data at various scales for future research.

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