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Hypotesis on Transcribing Historical Sources to Represent the Evolution of Geo-cultural Landscapes: Natural Environment, Settlements, and Hazards

The paper proposes a methodology for the analysis and representation of Geo-Cultural Landscapes. These are contexts where resources, risks, and culture structurally coexist, defining a territory's identity through the age-old dialectic between natural dynamics and human activity. The research focuses on the Acque Albule Basin (Lazio), an exemplary model characterised by the co-presence of significant natural resources and considerable geological hazards, such as karst phenomena and subsidence. The aim is to reconstruct the diachronic transformations of this complex territorial model through a systematic and holistic reading of figurative historical sources (pre-geodetic cartography from the 16th-18th centuries), overcoming the limitations of sectoral approaches. The method articulates a critical process of transcribing and vector-redrawing historical cartographic information within a digital environment. Through in-depth philological analysis, data extracted from four significant pre-geodetic maps were translated into a new Map of Represented Land Use (Carta dell'Uso del Territorio Rappresentato - CUTR). The alphanumeric data is visualised in a series of mappings, which synthesise the process of representing the past and the place as it is today; their interrogation can reveal surviving identity traits, potentially aiding in identifying environmental risk scenarios. In this context, the study aims to present the results of a procedural approach designed to construct information into new, valuable mappings. This approach, for the first time, enables a comprehensive utilisation of what was only partially represented across the various figurative historical sources.

Keywords:
Geo-cultural Landscape; Digital Transcription; Cartography; Acque Albule Basin

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"The impulse to draw maps and charts is a fundamental and immortal human instinct. Where would we be without them? [...]".
Brottom, G. (2012). *La storia del mondo in dodici mappe*. Milano: Feltrinelli, p. 22

1. INTRODUCTION

Territories are complex entities, the result of a centuries-old and ceaseless dialectic between anthropogenic factors and natural dynamics. Consequently, the present state of a place is the outcome of both visible and invisible processes, whose root causes lie in historical stratification and in the relationships established over time between humans and the environment.
This research focuses on the investigation and representation of Geo-Cultural Landscapes, understood as a specific classification of contexts where resources, risks, and culture structurally coexist. This construct identifies territorial changes as the result of the combination of anthropogenic processes, resource exploitation, and the necessity to control geological-natural risks, moving beyond the traditional definition of a cultural landscape. In this sense, natural-cultural resources and geological-natural risks become the key cognitive elements for understanding these dynamic processes (fig. 1).
This paper presents a method for understanding and identifying such contexts through the interpretation of historical data found in past representations. The representation of a territory stems from the need to impose order and structure upon the seemingly boundless space of the known world.
The act of representing equates to knowing, and the process of identification unfolds through re-interpreting historical representations and translating the data into a new informational synthesis.
The central thesis guiding this research is that, for every territorial model, its identity is determined by its own unique model of transformations. The proposed methodology therefore experiments with a holistic reading, in stark contrast to sectoral approaches. The research contributes to the scientific field that approaches the 'Time of Places' – the sequence of transformations and permanences – from a systematic and dynamic perspective.

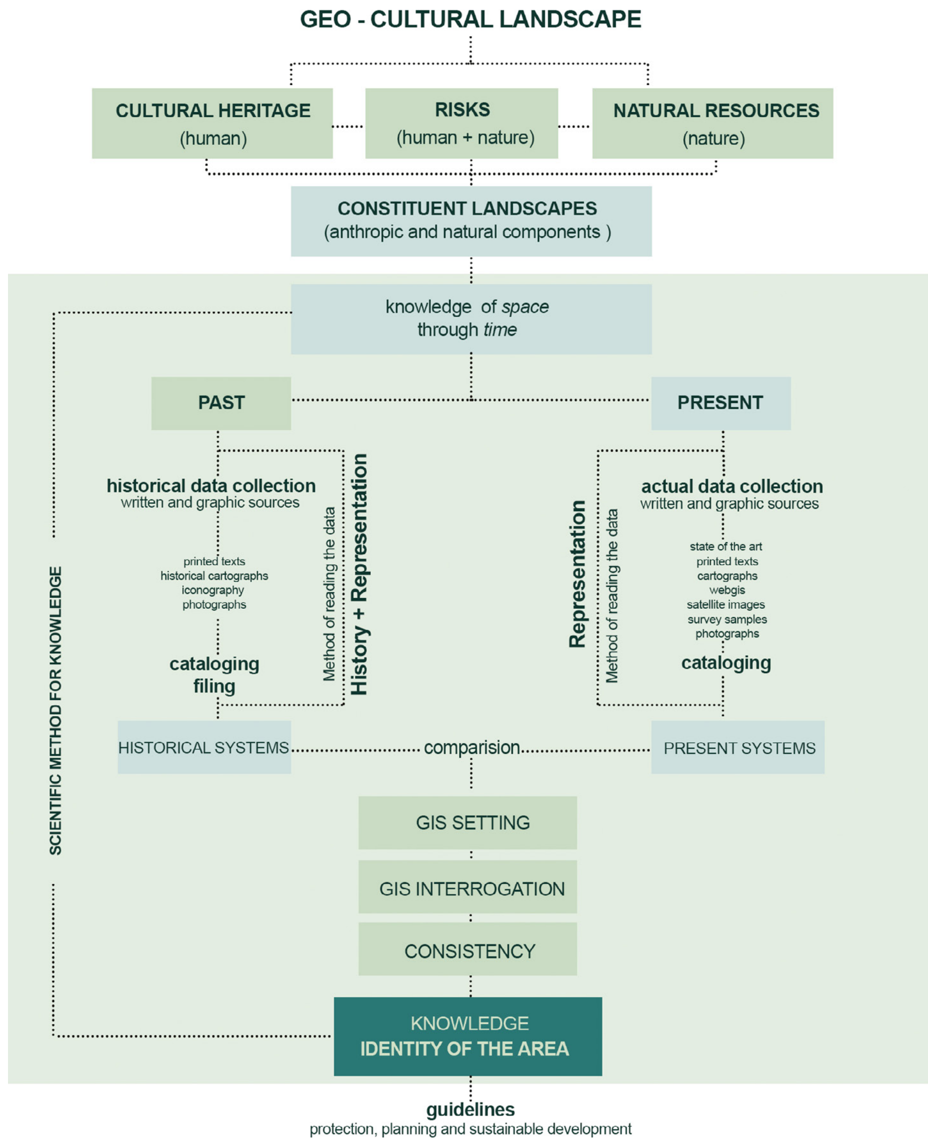

Fig. 1 - Diagram on the concept of geo-cultural landscape.

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The objective is to identify the transformations that have altered the use and perception of the heritage, understood as the entire Complex Territorial-Cultural Model. These transformations result in "remnants" – both material and immaterial – which constitute the identity and memory of a place. The related study of images, from historical maps to satellite imagery, can yield an exemplary informational model of the dialogic relationship between the natural and human-modified landscape, revealing the causes of transformation processes and the alternation between settlement and abandonment over time.
In central Italy, the Acque Albule Basin has been identified as a model that fully embodies the characteristics of a geo-cultural landscape. Indeed, the area is characterised by particular geological settings, with significant natural resources (specifically travertine, *Lapis Tiburtinus*, and sulphurous thermal springs) but also a notable presence of hazards (karst phenomena and subsidence). The case study is located within the Bagni di Tivoli plain, situated between the Castel Giubileo hills (west), the Sabina area (north), the Tivoli mountains (east), and the Alban hills (south).
Following a thorough philological analysis, based on re-examining analog, pre-geodetic, and geodetic cartographic views, the extracted information was translated into a digital environment to construct a geodatabase of digital historical systems. This is organised within a GIS environment according to a new Map of Represented Land Use (*Carta dell'Uso del Territorio Rappresentato - CUTR*).
In this context, the aim is to present the results of a procedural approach intended to construct information into new, valuable mappings. This approach, for the first time, enables a comprehensive utilisation of what was only partially represented in the various figurative historical sources, whose informational potential remains unexpressed to this day (fig. 2).
This essay confines itself to the qualitative description of the scenarios and outlines the path undertaken and currently in progress for the validation of the models.

2. UNDERSTANDING THE NATURAL-CULTURAL LANDSCAPE: REGULATORY FRAMEWORKS AND METHODOLOGICAL APPROACHES

The recent emphasis on landscape quality as a strategic foundation for national development, as enshrined in documents like the *Carta Nazionale del Paesaggio* (National Landscape Charter, 2018), has made the adoption of more rigorous and integrated analysis and monitoring methodologies indispensable. The objective is not merely to catalogue elements, but to understand the landscape as a dynamic natural-cultural model, the result of centuries of interaction between human activities and natural dynamics.
In this context, the systematisation of knowledge between regulatory proposals and operational practices in terms of landscape protection and prevention becomes necessary. Directives for reducing land consumption and landscape protection instruments necessitate a systematisation of knowledge. The *Valutazione Storico Ambientale* (VASA - Historical Environmental Assessment) emerges as a key procedure, aimed at inscribing an area in the *Registro Nazionale dei Paesaggi Rurali Storici* (National Register of Historical Rural Landscapes). Although specific to rural contexts, the VASA provides a crucial conceptual framework for recognising complex landscape models. It requires an assessment of a place's significance, defined by three fundamental parameters: Persistence, Integrity, and Uniqueness.

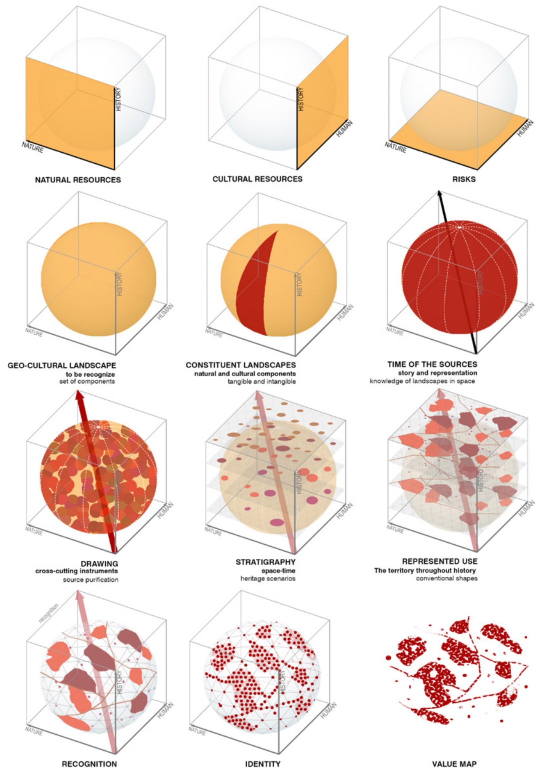

Fig. 2 - Procedural diagram of the research approach: from the geo-cultural landscape to value maps.

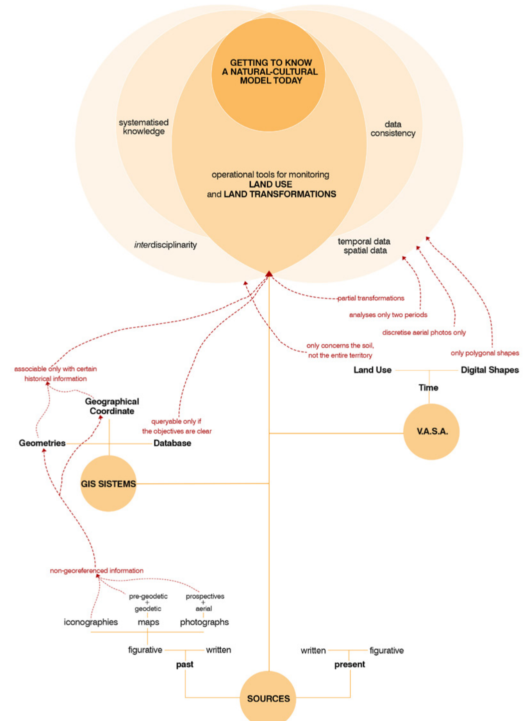

Fig. 3 - State of the art. The limitations found in current methods used for understanding the territory are shown in red.

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The *Carta Nazionale del Paesaggio* represents a strategic policy document that guides the integration of landscape themes into education and planning. The *Registro Nazionale dei Paesaggi Rurali Storici* is fully operational and continuously evolving, with the *Osservatorio Nazionale del Paesaggio Rurale* (National Observatory for the Rural Landscape) managing data analysis and classification for the recognition of persistence and integrity values (fig. 3).
In the realm of relational data representation and management, and specifically concerning GIS in relation to historical sources, GIS environments represent the optimal setting for associating geometric forms, databases, and geographical coordinates, establishing them as central to territorial analysis. However, their use is not without critical issues, generating a 'utility paradox': the enormous quantity of data (from orthophotos to intangible elements) risks transforming these systems into 'crowded containers', slowing down analysis and management. This is compounded by the non-correspondence of information within different institutional databases, for instance, regarding built heritage data (fig. 4).

The methodological challenge attempted here involves using figurative historical sources for diachronic reconstruction, considering historical maps, iconographic sources, and aerial photographs. The first, pre-geodetic maps, undergo deformations that compromise their readability during the re-projection process, hindering analysis at the territorial scale; the second, while having holistic potential, remain partially unexpressed as they are rarely systematically integrated graphically within GIS; the third, aerial photographs, constitute the most utilised historical source, thanks to their metric properties which facilitate georeferencing.
A sound methodological approach lies in the interdisciplinary integration of data for environmental risk prevention. Philological research proves essential for extracting information from ancient documents and reconstructing past events, such as subsidence phenomena and sinkholes. The relevant literature highlights a lack of a unified perception of the territory, where anthropogenic development often ignores distributed environmental hazards.

Fig. 4 - Comparison between the OpenStreetMap 3D building database (left) and ESRI (right). The number, footprint, and heights of the buildings are different.

It is important to recall that the effort to combat land consumption is based on systematic, high-precision annual monitoring conducted by ISPRA (SNPA), through the annual report "Land Consumption, Territorial Dynamics, and Ecosystem Services." This data quantifies soil sealing and its impact, providing the knowledge base for policies. See, for example, the land consumption atlas published by ISPRA.
Although a definitive national framework law is still lacking, action is articulated on two fronts: the adoption of regional laws setting targets for zero net land consumption, and the establishment of the National Fund for Combating Land Consumption, which actively finances interventions for the renaturalisation of degraded soils.
It is emphasised that a full 're-cognition' of the natural-cultural model requires overcoming technical limitations and adopting a methodological approach that systematically links data on vulnerability, persistence, and integrity, thereby transforming the fragmented mosaic of conservation actions into a unified strategy for valorisation and prevention.

3. A DYNAMIC LANDSCAPE: THE ACQUE ALBULE BASIN

The Acque Albule Basin is located between Rome and Tivoli and represents a significant natural-cultural model whose history is inextricably linked to the exploitation of resources such as water and travertine, and to the local morphology. Several sub-landscapes are also identified within it, such as: urban, industrial, rural, and the archaeological-monumental landscapes of Villa Adriana and Villa d'Este. The co-presence of these elements alongside hydrogeological risk makes the site an ideal field of investigation for testing a systematic approach and the re-representation of dynamic processes (fig. 5).
The Acque Albule Basin is situated in the middle Aniene Valley between the carbonate ridges and the volcanic area of the Colli Albani, thus representing a unique and intensely dynamic geological and hydrogeological laboratory. Its history is shaped by the complex interaction between active tectonics and uninterrupted hydrothermal upwelling, creating a continuously evolving landscape evidenced by historical maps.

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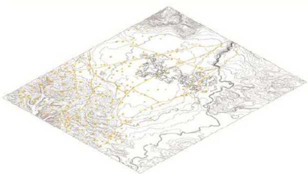
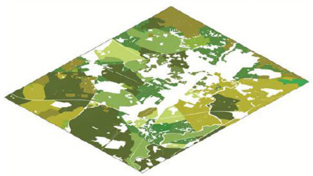
CONSTITUENT ACTUAL LANDSCAPES	TIME	TRACES OF HISTORICAL LANDSCAPES	
		artifacts	ecofacts
urban landscape 	discontinuous	/	old town centre
preexistence landscape 	interrupted	/	archeological traces archeological streets
rural landscape 	continuous	cultivated filds	game reserve historical estate
⬆ UPPER LAYERS OF THE SOIL ⬆		⬇ DEEP LAYERS OF THE SOIL ⬇	
stone landscape 	cyclic	quarries	forni di calce Casale del Barco Casale Bernini Vapor train Guidonia ...
water landscape 	continuous	Anienre river moats sulfurous lakes (lago delle Colonnelle, lago della Regina) drain lakes (lago dei Tartari)	cisterns drainage canals acqueducts thermal baths Villa D Este Villa Adriana Hydroelectric central paper fabric ....

Fig. 5 - The elements that make up the landscape of the Acque Albule Basin above and below ground.

The hydrogeological system is characterised by two main aquifers: a deep one within the carbonate bedrock (the thermal feeder) and a shallow one within the travertine deposit. Studies highlight that the shallow aquifer receives recharge primarily through lateral overflow from the adjacent ridges and through the upwelling (siphoning) of thermal fluids from below, corresponding to structural discontinuities.
However, the area is constantly subject to delicate risk management. The intense historical and modern quarrying activity for travertine requires de-watering (artificial lowering of the water table), which, combined with tectonic movements and the dissolution of the substrate, can trigger subsidence phenomena and the formation of sinkholes. Geological and satellite monitoring is crucial for understanding and mitigating ground deformation dynamics in this intensively utilised and geologically reactive landscape (figs. 6-7).

4. READING THE ACQUE ALBULE BASIN: DRAWING AS AN ENVIRONMENT FOR REFLECTION

The interpretation of the geo-cultural landscape characterising the case study began with the systematisation of the available figurative historical sources. These were organised into three macro-categories – pre-geodetic maps, geodetic maps, and cadastral maps – and analysed to determine which type provided the best ratio between the quantity and quality of information on the landscape of the Acque Albule Basin. The choice fell upon pre-geodetic topographic maps produced between the 16th and 18th centuries because they are rich in historical information and describe a sufficiently long yet recent enough time span. This allows for both the recognition of long-term identity traits and the ability to find their traces in the current landscape. Generally, historical sources belonging to this category share common features – such as a N-S orientation rotated to a horizontal position, a broad territorial frame, the presence of orographic and hydrographic indications, and the representation of settlements and main rural buildings – but they differ in the abundance of graphical information concerning secondary elements such as minor rural buildings, secondary road networks, and land use for agricultural and extractive activi-

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ties. Based on the analysis objectives, four significant maps were selected:

- The *Mappa della campagna romana al tempo di Paolo III* by Eufrosino della Volpaia, 1547.
- The *Tavola esatta dell'antico Latio e nova Campagna di Roma* by Innocenzo Mattei, 1666.
- The map *Territorii Tiburtini. Veteris et novi descriptio* by Athanasius Kircher, 1671.
- The *Diocesis et Agri Tiburtini Topographia. Nunc primum trigonometrice delineata et veteribus viis villis ceterisque antiquis monumentis adornata* by Diego De Revillas, 1739.

It is emphasised that in environments characterised by subtly expressed elements, the role of drawing becomes fundamental for the phases of representing a territory characterised by geo-cultural transformations which must account for systems of elements defined by both human and natural actions. The process includes the phase of designing the vectorial representation of historical systems, through an initial delineation of the case study and the definition of the investigation scale. The perimeter of the study area (Acque Albule Basin) was not established by urban planning conventions, but by a gradual cognitive process based on the philological analysis of the sources. The area was defined by including all elements – morphology, pedology, mineral resources, and hydrography – that share the same History.

The analysis of figurative sources at different scales (both regional and specific to the Tibur area) identified the 'triangle' Rome-Acque Albule-Tivoli. On the current map, this was verified and defined by geomorphological elements – such as the travertine deposit at the centre, the elevation of the Acque Albule geomorphological basin at 70m above sea level, the course of the Aniene river – and by protected areas. The nominal scale for the entire vectorisation project is suggested by the IGM topographic base, namely 1:25,000.

This paper presents the methodological approach by showcasing the processing of data read and transcribed from the *Mappa della campagna romana al tempo di Paolo III* by Eufrosino della Volpaia (1547). Following an initial phase of creating a glossary of the symbols present in the historical source, a search for correspondences on IGM maps and satellite orthophotos was conducted; the former provided topo-

Fig. 6 - Mapping of sinkholes present in the travertine quarry area (ISPRA database) in relation to the inhabited settlement (ESRI database).

Fig. 7 - The Acque Albule Basin. From top: 3D morphology of the territory; 3D morphology with orthophotos; land use (Corine Land Cover Europe 2000 database); land use and 3D building fabric (ESRI database).

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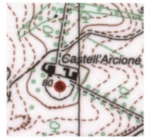
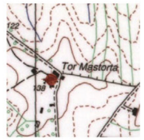
1.1.1.3 - isolated building							
HISTORICAL SOURCE REPRESENTATION					IGM REPRESENTATION		ORTHOPHOTO
id	DESCRIPTION	HISTORICAL INFORMATION SIGNS	DEGREE	CURRENT STATUS	1931-36-49 serie25v	1996-2000 serie 25db-25	Google Map
1	farmhouse, castle, estate or hunting reserve		1 2 **3**	PRESERVED **MODIFIED** TRACE DISAPPEARED			
2	farmhouse, castle, estate or hunting reserve		1 2 **3**	**PRESERVED** MODIFIED TRACE DISAPPEARED			
3	farmhouse, castle, estate or hunting reserve		1 2 **3**	**PRESERVED** MODIFIED TRACE DISAPPEARED			
4	punctual settlement		1 **2** 3	PRESERVED MODIFIED **TRACE** DISAPPEARED			
5	punctual settlement		1 **2** 3	PRESERVED MODIFIED TRACE **DISAPPEARED**			
6	farmhouse, castle, estate or hunting reserve		1 2 **3**	**PRESERVED** MODIFIED TRACE DISAPPEARED			

Fig. 8 - An example of the historical entities found in Eufrosino della Volpaia's pre-geodetic map, reclassified according to the CUTR nomenclature.

graphic and toponymic verification, while the latter were used to assess the state of preservation/transformation of each element. This procedure proved to be iterative, as the identification of a new element often challenged previous recognitions, but it allowed for an assessment of the degree of precision of the correspondence (rated on a scale from 1 to 3) and the level of transformation the element has undergone within the geo-cultural landscape (fig. 8).

5. THE PAST IN THE PRESENT. TOWARDS A METHODOLOGY FOR THE VECTOR REDRAWING OF HISTORICAL SYSTEMS IN ARCHIVES

The redrawing of historical systems depicted in historical sources into new digital maps is a complex process, as it requires the transcription between images created using different techniques, functions, and points of view. The transition from historical cartography to numerical-digital cartography follows a path where the level of subjectivity of what is represented progressively varies, and the roles of the creator and the reader also change. The latter is dynamically involved in cartographic consultation – consider both generalist platforms like Google Earth, Bing, Open Street Map, and specialised tools such as webGIS, or online tools for their creation and management like ArcGIS Scene Viewer – being able to intervene on aspects such as the point of view, the graphic style, and the informational layers (fig. 9).
Furthermore, the creation of thematic maps, such as Land Use Maps (*Carte di Uso del Suolo - CUS*), requires the composition of specific legends and their pairing with the most suitable geometric primitives – points, lines, polygons – for the numerical-digital representation of the elements. To this end, an iconic legend of the elements identified in the map by Eufrosino della Volpaia was created, broken down according to the geometric primitives and the classes adopted for interpreting the geo-cultural landscape. This was subsequently converted into a legend composed solely of graphical codes, organised according to the land use classes represented in the historical sources (fig. 10).
The transition from drawn cartography to digital cartography requires the definition of clear topological rules, valid both for the CAD (Computer-Aided

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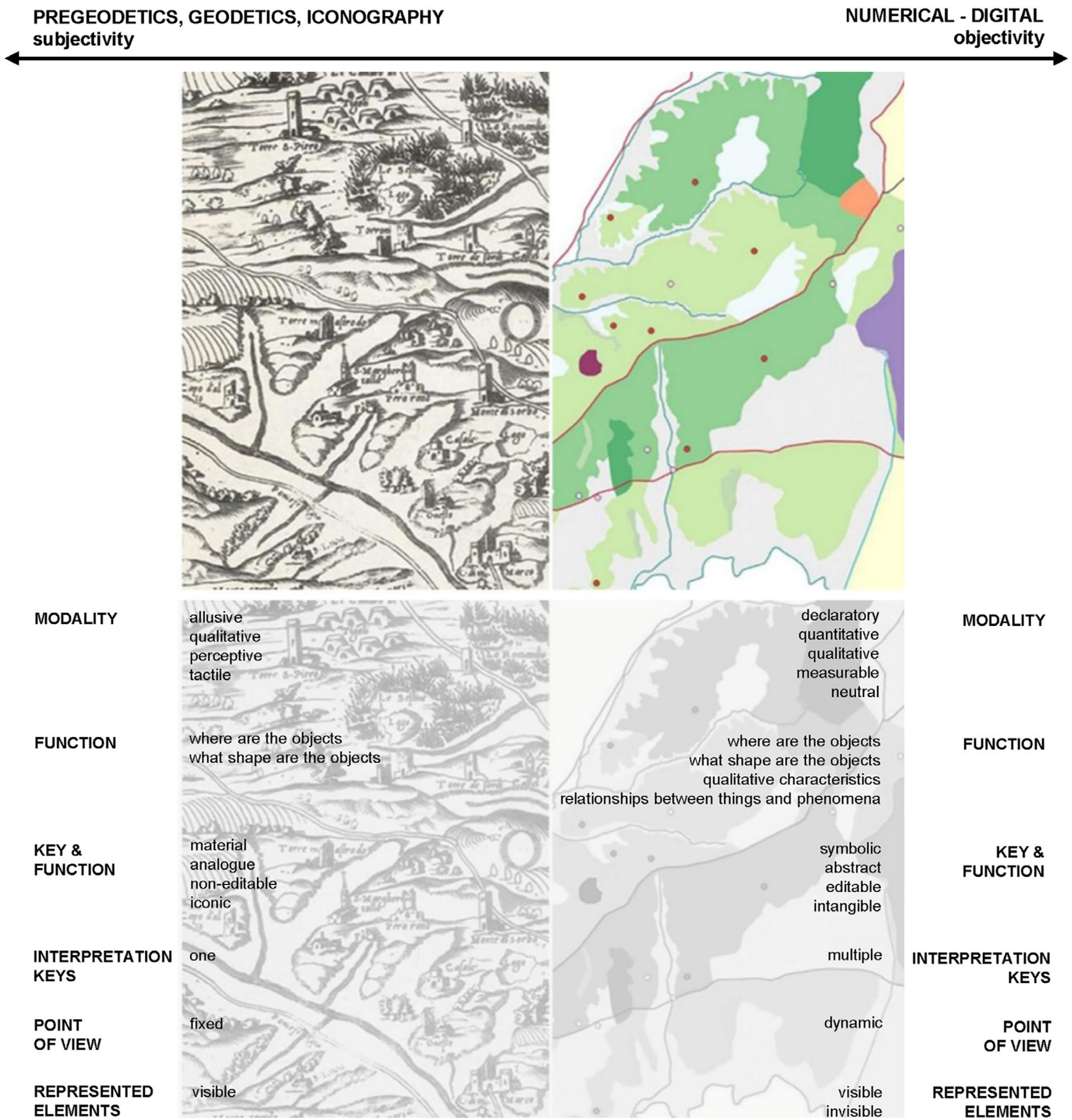

Fig. 9 - Differences between iconography, pre-geodetic and geodetic cartography and digital cartography.

Design) redrawing presented here and for the transposition into a GIS (Geographic Information System) environment and the subsequent construction of a queryable, dynamic geodatabase.
The CAD redrawing was structured in layers corresponding to the identified land use classes, integrated by assigning a numerical code and a colour to each represented entity. Furthermore, the geographic reference system (Datum WGS 84, EPSG Code 32633 - UTM Zone 33N) and the topological rules for the geometric entities were defined:

- Areas (Polygons): Vectorised as closed two-dimensional shapes, they must be adjacent and non-intersecting.
- Linear features (Lines): Vectorised as one-dimensional shapes, they can constitute a boundary or cross a polygon if they do not alter its identity. An exception is established for contour lines, key elements of morphology, which must be able to visually “interfere” with all geometries, disregarding the land use they cross.
- Point features (Points): Vectorised as dimensionless shapes, they overlay polygonal forms without altering their values.

The graphical codes, topological rules, and classes were applied to the redrawing of information from the 1547 map and subsequently transcribed onto the IGM cartographic base. This operation highlighted the criticality of transposition posed by polygonal geometries which, referring to natural or semi-natural landscape components, proved particularly complex to delineate. To manage this issue, a three-phase process was adopted: to establish initial correspondences between the ancient and the modern, significant point landmarks are connected through triangulations that circumscribe the areas; to control the extent of the areas, a system of alignments was used; finally, to define the area boundaries, the orography is considered (figs. 11-13).

6. INITIAL RESULTS OF THE REPRESENTATION: ANALYSIS OF PRE-GEODETIC SOURCES AND REPRESENTED SYSTEMS

The accuracy of the redrawing is directly linked to the consistency between the analogue signs of the histo-

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rical sources and the levels of detail in the Map of Represented Land Use (CUTR). The process of "recognition" is not linear, as pre-geodetic maps, often lacking scale or legend, require subjective interpretation and interdisciplinary comparison. Below is a summary of some historical scenarios emerging from the redrawing of the four studied pre-geodetic maps:

- 1547 *Mappa della campagna romana al tempo di Paolo III* (Eufrosino della Volpaia): Describes an active rural context where the plain is characterised by heterogeneous agricultural areas, arable land, and olive groves. The central Acque Albule area is a hunting reserve, meadows, and pastures, with toponymy (*Le Testine*) already indicating the presence of limestone deposits. Industrial/artisanal settlements (lime kilns) and a road network (*Via Tiburtina*) connecting Rome to Tivoli and Montecelio are present.
- 1666 *Tavola esatta dell'antico Latio e nova Campagna di Roma* (Innocenzo Mattei): The scenario is similar, but with less precise communication due to a higher percentage of uncharacterised area. Toponyms are crucial to compensate for the schematic representation. The first figurative testimony of extractive activity (travertine) emerges in the *Le Fosse* area ("Pietra Tibur"), while notes on the sulphurous nature of the Acque Albule confirm the karst-related hazards.
- 1671 *Territorii Tiburtini. Veteris et novi descriptio* (Athanasius Kircher): Despite the partial coverage, the author enriches the information with notes providing a geomorphological, botanical, and archaeological picture. Geology is narrated both as a "presence" (layer of *testina*) and as a "utilised resource" (active quarry). Channels for water regulation indicate productive use (extraction and cultivation) of previously marshy areas.
- •1739 *Diocesis et Agri Tiburtini Topographia. Nunc primum trigonometrice delineata et veteribus viis villis ceterisque antiquis monumentis adornata* (Diego De Revillas): The map is more oriented towards highlighting roads, cities, and monuments. Extractive activity is now well distinguishable, with the *Le Fosse* areas converted into an active latomia and the emergence of diffe-

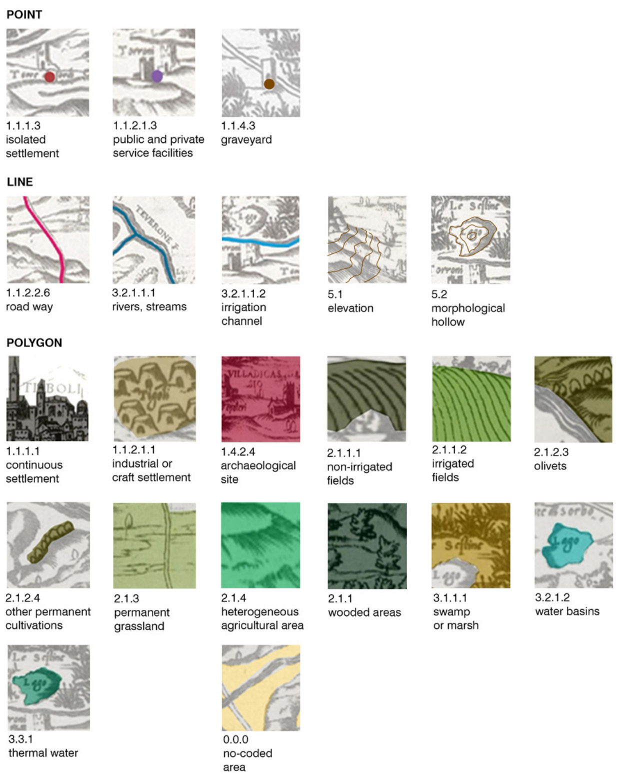

Fig. 10 - Comparison between the legend of the codes identified in the historical cartography of Eufrosino della Volpaia and its transposition for vectorisation, according to the CUTR nomenclature.

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rent types of quarries (ancient and recent) in the *Barco* area. The natural environment is described by the dominant presence of water (Aniene river, lakes, sulphurous springs), with agricultural areas concentrated near water and olive groves on the hills.

This reading of the sources as representations of historical systems can be further broken down into three sub-systems: the natural environment system, understood as the set of resources and risks; the semi-natural environment system, comprising cultivated areas; and the anthropogenic environment system, composed of settlements and extractive sites. Comparing these sub-systems at different moments allows for extrapolating considerations on their evolution:

- Natural Environment (Resources & Risks): The key element is water, distributed linearly (rivers and ditches) and areally (marshes and lake basins). Subsurface resources emerge through the polygons of travertine deposits, thermal basins, and the presence of ancient baths, which exploited the sulphurous upwellings.
- Semi-Natural Environment (Cultivation): In the 1547 map (where graphical codes almost entirely cover the analogue base), arable land and crops act as a connective tissue between anthropogenic and natural elements. Conversely, the eloquent synthesis of De Revillas's map (1739) accentuates the centrality of anthropogenic and natural elements, relegating the cultivated landscape to information with a quantity inversely proportional to its reliability, though still traceable in the historical persistence of olive groves.
- Anthropogenic Environment (Settlements & Quarries): Settlements appear as point geometries (served by the road network) or as polygons (archaeological areas or extractive areas). It is significant to note how the extents of extractive areas, as early as the 18th century, often coincide with the outcrop of the carbonate bedrock.

The vector redrawing phase, although complex due to the non-standardised nature of pre-geodetic sources, has allowed for the reconstruction of the fundamental identity scenarios of the Acque Albule Basin, creating the georeferenced database necessary for subsequent GIS implementation and the dynamic assessment of relationships and transformations. Furthermore, the overlay of historical systems, stratified over three centuries, allows for perceiving the substance of the place and the ways of living in it.

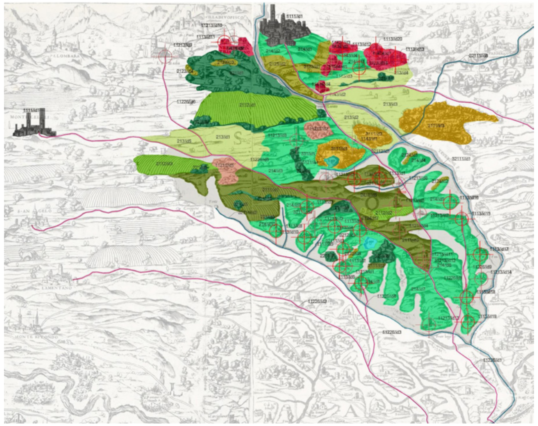

Fig. 11 - Redrawing of the cartography by Eufrosino della Volpaia according to the CUTR nomenclature.

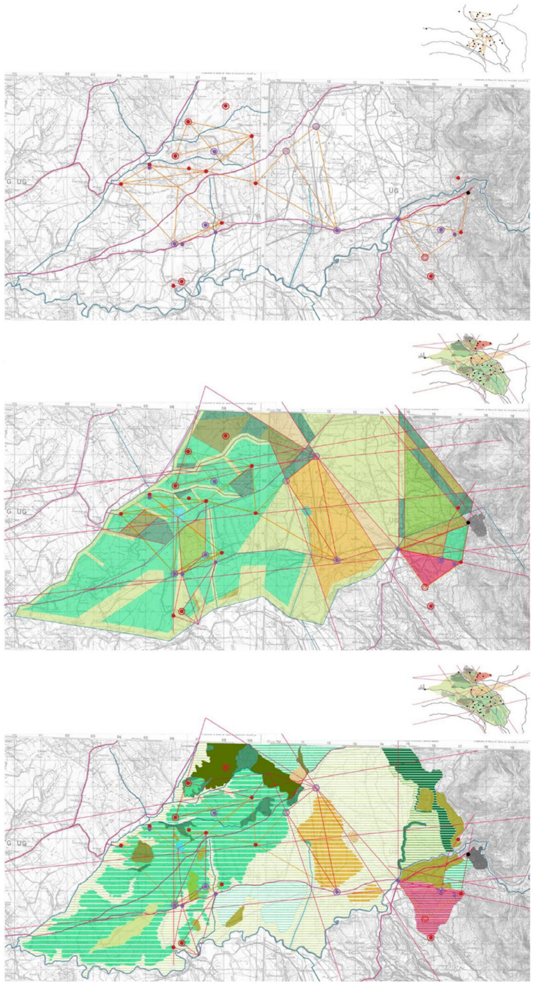

Fig. 12 - The procedure for digitally transcribing Eufrosino della Volpaia's cartography on IGM data. Eufrosino's redrawings are on the upper right corner.

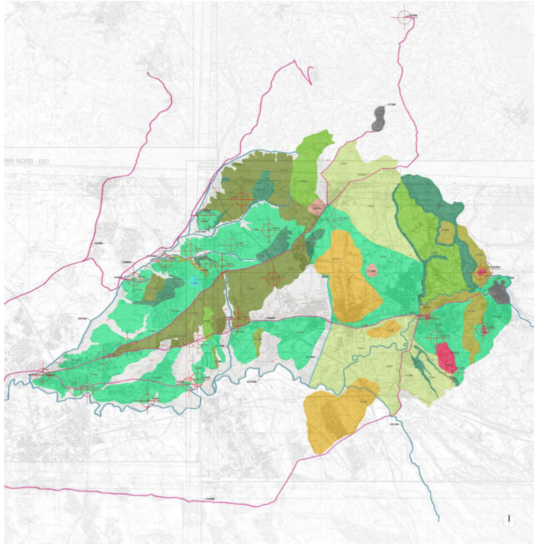

Fig. 13 - Georeferenced redrawing on IGM data of the cartography by Eufrosino della Volpaia according to the CUTR nomenclature.

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7. CONCLUSIONS AND FUTURE DIRECTIONS: METHODOLOGICAL INNOVATION AND THE NEW ONTOLOGY OF REPRESENTATION

The fundamental innovation of this research lies in placing the graphic sciences at the centre of the spatial analysis process, defining Drawing as the critical method for creating new representations that carry information. The project's aim, focused on creating a GIS for the Map of Represented Land Use (CUTR), goes beyond the mere archiving of historical data, positioning itself prospectively as a processing environment that ensures a visualisation coherent with spatial analyses between the environments (natural, semi-natural, and anthropogenic) from a systemic perspective.
The effectiveness of the process is demonstrated by the production of the transcriptions, which materialises the transition from drawn historical cartography to numerical cartography. This conversion required rigorous work in defining topological rules and the relationships between geometric primitives, necessary to transform analogue sources into interoperable data series. The focus was on the dependency of these rules on the types of sources, the scale, and, particularly, on the perceptual and communicative objective of the summary mappings.
The Acque Albule Basin case study has validated the concept that the act of re-cognition is indispensable for territorial management, as only the systematic rereading of the past can identify compromised equilibria and inform project and planning decisions.
The developed methodology is conceived to be replicable in other complex territorial contexts, contributing significantly to the future of representation and the graphic sciences applied to environmental risk monitoring.
The proposed approach does not exhaust the research questions but opens a programme for further investigation aimed at (1) the quantitative validation of the results and (2) integration with the new paradigms of GeoAI, Geospatial Artificial Intelligence. Specifically, to achieve an overall quantitative validation of the pre-geodetic map transcription process (1), the aim is to define the criteria for quantifying two control parameters, one referring to geometric properties, the other to informational quality:

- The margin of error, evaluated through the Root Mean Square Error (RMSE): a numerical datum expressed in metres, referring to the georeferencing and reprojection process of the historical sources, would allow for a metric validation of the effectiveness of their repositioning—currently assessed in qualitative terms—and would define the spatial limits of each historical system.
- The source reliability index: a numerical datum expressed as an absolute value, derived from the ratio between the extent of areas to which a land use could be attributed and the extent of "unrecognised" or entirely indeterminate areas in the historical source. This quantifiable data is crucial for establishing a degree of scientific confidence for each source and for the historical systems that can be identified within it. This index would also allow for the comparison of different sources, guiding the critical reading of the results.

The adoption of these validation criteria would transform the analysis from a descriptive form to a statistical plane, enabling the execution of vector comparisons, calculations, and quantitative and percentage-based comparisons between sources from different eras. This approach will provide a solid numerical basis for activating interdisciplinary comparisons with data from geological analyses and risk assessments.
These research directions aim to make the proposed knowledge protocol a fully defined, quantitatively validated model, ready for the subsequent phase of (2) integrating artificial intelligence algorithms aimed at activating GeoAI processes. This refers to the automatic analysis of historical graphic sources, the provision of citizen services, and predictive analysis.
Indeed, the application of Artificial Intelligence (AI) in Geographic Information Systems (GIS) for reading the territory is a rapidly expanding field that is revolutionising the way geographical and spatial data are generally analysed and managed. GeoAI leverages machine learning and deep learning algorithms to analyse vast volumes of geospatial data – cartography, data collected via UAVs, GPS data, and satellite imagery – in a faster and more precise manner than traditional methods, automating part of the land interpretation process.
With specific reference to the proposed methodology, three potential research developments are envisaged concerning data extraction, the creation of more accessible citizen and tourism services, and the provision of real-time predictive analysis. In particular, Artificial Intelligence can be implemented within existing systems with different objectives: the automatic analysis, detection, segmentation, and annotation of historical maps, significantly accelerating the initial phases of the proposed methodology; the development of mobile applications that combine geospatial data, GPS location, and Augmented Reality (AR) technologies for landscape recognition and the overlay of information derived from the analysis of historical sources, cultural heritage assets, and services present in the user's surrounding territory; environmental monitoring and sustainable planning through real-time analysis for identifying imminent or future risks and optimising land use by evaluating multiple alternative scenarios.
In summary, it is believed that AI has the potential to transform territorial analysis, shifting from static mapping to a dynamic and predictive system capable of supporting sustainability and efficiency in land management, while simultaneously integrating information from historical sources that remain underutilised.

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