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# Different approaches to connectivity from the Middle Ages to the present

**Abstract:** The aim of this paper is to discuss three different approaches to reconstructing the connectivity within a given environment over time and in particular from the Middle Ages to the present. The three methods have been applied to three areas in central and northern Italy: a mountainous alpine zone named Feltrino in Veneto region (north-east Italy) (Mascarello 2021), a lowland area between the city of Grosseto and the ancient Roselle (Felicioni 2020), a mountainous marginal region corresponding to Monte Amiata (Paciotti 2021). The common base of this research is the integration and analysis of different kinds of data, in particular historical cartography, in a GIS platform. We opted to use the open-source software Quantum GIS to propose reconstructing the ancient mobility networks. In the present study, we focus on different environmental characteristics, historical sources and analyses processes in order to gain the same objective. This allows involving of much more data and characteristics of the same area rather than applying only one of these methods. Therefore, this way the outcome is a more complete analysis with more plausible results.

**Keywords:** spatial analysis, GIS, connectivity, environment, long-term, landscape archaeology

## Introduction

This paper aims to discuss three different approaches to reconstructing the connectivity within a given environment over time, particularly from the Middle Ages to the present. Three methods were applied to three areas in central and northern Italy: a mountainous alpine zone named Feltrino in the Veneto region (north-east Italy) (Mascarello 2021), a lowland area between the city of Grosseto and the ancient Roselle (Felicioni 2020), and a mountainous marginal region corresponding to Monte Amiata (Paciotti 2021). The latter two zones are in Tuscany (central Italy). The common base of this research is the integration and analysis of different kinds of data in a GIS platform. We opted to use the open-source software Quantum GIS to propose reconstructing the ancient mobility networks. We developed our works by applying different approaches: in Feltrino and Monte Amiata, we focused on simulating the connectivity through GIS algorithms. In particular, we applied "Channels network and drainage basins'' by Pastor Fàbregas Alvarez in 2006, the MADO ("*Modelo de Acumulaciòn del Desplazamiento Optimo desde un origen*", in English "*Optimal Accumulation model of movement from a given origin*", Fàbrega Alvarez 2006, 7-11). This is a simulation of moving accumulation cost based on hydrographical dynamics. It was implemented in 2011 with the study of moving within basins (Llobera *et al.* 2011, 843-851). In 2019, Carlo Citter referred to this research and proposed a method to elaborate a mobility network starting from known points (Citter 2019a, 325-342). The latter is the model for the two research studies conducted in the Feltrino and Monte Amiata. In the Grosseto area, we applied the archaeo-geographic approach, elaborated by the French school (Chouquer 2000; Choquer and Watteaux 2013), based on the comparison between ancient and modern cartography and anthropic and natural elements to detect patterns related to mobility and land use.

Contrary to some, we aim to share our step-by-step analysis, as minor differences can result in varied outcomes, as we find it critical from the perspective of an integrated investigation of the same territory. In the present study, we focus on different environmental characteristics, historical sources and analysis processes in order to gain the same objective. This approach allows for much more data and characteristics of the same area than applying only one of these methods, resulting in a more complete analysis and more plausible results.

## The study of *longue-durée* connectivity in the Alps. The case of Feltrino (Belluno)

In the area of Feltrino, as a first step, we collected all the historical and archaeological information about the analysed territory to select those historical periods that provided more data. Then, we produced maps of the settlements and the areas of archaeological sites. We opted for the Bronze Age, the late Roman period (fourth to sixth centuries), a shorter period within the Middle Ages (twelfth to thirteenth centuries) and the Early Modern Age (fifteenth to seventeenth centuries). We added the natural features that could have influenced human mobility as a second step. In Feltrino, we chose morphology (outlined through the algorithm TPI – Topographic Position Index), hydrography, slope and mountain passes. In case of critical changes in the landscape over time, we created separate maps for every considered period. It is essential to underline that each territory has its specific features, and therefore, when contextualising the sites within the landscape, the parameters and their weights had to be adjusted. All the produced maps were based on the CTR (Carta Tecnica Regionale, scale 1:10000) and the DTM (Digital Terrain Model, scale 1:5000) available on the Geoportale of Veneto (https://idt2.regione.veneto.it/geoportal).

The third step of the process was the creation of cost surfaces by reclassifying map layers and allocating a series of weights, running from 0 (no difficulty) to 70 (maximum difficulty). As the reconstruction of the exact abilities of past people moving through a mountainous environment and what was perceived as inaccessible is ambiguous, we opted not to use the difficulty up to 100. Each variable was weighted according to its individual character and was further enhanced by additional features, such as a Multi Ring Buffer (MRB) around point features representing possible passes, to suggest the algorithm to attract or discourage the crossing. We applied different weights to each ring to encourage the passage. The smallest one was given a 0, while for the largest one, the amount was different in relation to the map: 60 for the passes and 20 for the anthropic attractive points. Oppositely, concerning hydrography, rivers have the highest weight, while the rest of the environment has a low value, to underline the impossibility of going through water without bridges. Finally, in the TPI map, the weights are related to the geomorphological characteristics of the area. In the slope map, weights increase in relation to the rising percentage of the slope. Due to the particular environmental and archaeological character of the different examined periods, cost surfaces were created separately, and a weighted sum of them was constructed in the raster calculator using the following method:

TPI * 0.2 + mountain passes * 0.2 + hydrography * 0.2 + slopes * 0.2 + archaeological sites * 0.2

The resulting maps serve as a base for the creation of cumulative cost surfaces, applying the algorithm '*r.walk.points*', where the starting points were the point layer representing settlements. Arrival points were not considered to calculate the moving costs in every direction around each settlement. These cumulative cost surfaces represent the environment in which path networks ran. The paths were generated by applying another algorithm, '*Channels network and drainage basins*', with settlements as starting points. The inclusion of all the recorded points of interest (archaeological sites and landscape features) resulted in a map showing possible mobility networks for each respective period.

The last step, a *Line Density Analysis,* was inspired by the work of Patricia Murrieta-Flores (Murrieta-Flores 2012, 249-267) and Marcos Llobera (Llobera 2000, 65-84). Through the application of the algorithm '*Line density*' (available in QuantumGIS from version 3.16), networks of corridors of movement with a 100 m radius were created. These corridors represent the density of the paths included in each buffer, defined in relation to geomorphological characteristics. In our opinion, it is better to use short-range buffers for mountainous areas because of the rapid change of altimetry and geomorphological features. Again, a map for each period was produced.

Finally, a comparative analysis was conducted between the *Line Density* maps by summing up the consecutive periods and all created maps to highlight the common corridors. The first approach was used to emphasise continuity and breaks in the hypothetical human mobility networks in the Feltrino between two consecutive periods. The second approach aimed to accentuate *longue-durée* continuity. The comparison between the maps of the four different periods revealed a probable continuity of some of the mobility corridors over time. They are related to paths that climb to glacier circles and pass from settlements and to those that run between villages in the valleys of Feltrino. Even the overlay of the network of the oldest mobility corridors and the contemporary street map shows several overlaps (Fig. 1). This is partially confirmed by the comparisons with Modern Age cartography (in particular, we refer to the *Dissegno del Territorio di Feltre qual per comando dell'Illustrissimo et Eccellentissimo signor C.O.: Lodovico Flagini* of Francesco Grandis, dated to 1713) (Fig. 2) and the information from historical and archaeological sources.

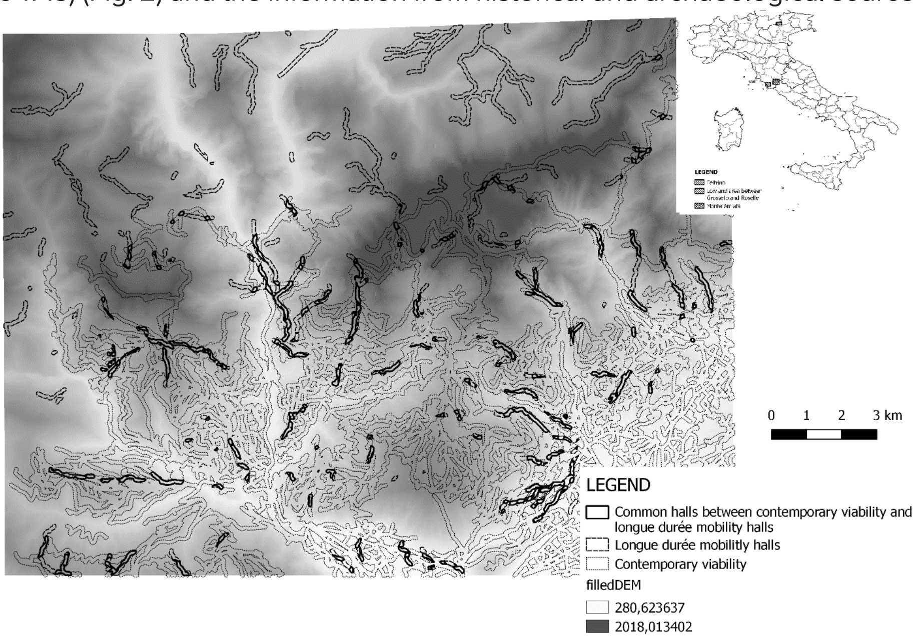


Fig. 1 Contemporary routes in relation to the results of GIS analyses. Dotted lines correspond to contemporary viability; dashed lines represent the longue-durée mobility corridors. Continuous lines draw paths resulting from the intersection between Contemporary routes and the longue-durée mobility (figure by C. Mascarello).


Fig. 2 Continuous lines represent some tracks on the Francesco Grandis' map that could be compared with the Modern Age mobility corridors, indicated by dotted lines. Dashed lines draw the mobility corridors resulting from the comparison between Modern Age elaboration and Francesco Grandis' map (figure by C. Mascarello).

The outcome of this analysis needs further testing. This was conducted partially in Vette Feltrine, though we still need to extend the survey. The main goal now is to re-trace the connectivity network, according to the analyses, and to check the intersections of the route network to test their potential for archaeological predictive modelling. While this approach can be applied to any mountainous environment, the parameters should be calibrated according to the characteristics of the individual areas.

## The archaeogeographical method applied to the long-term connectivity study in southern Tuscany. The case of Grosseto and Roselle.

In the lowland area, we chose to apply the archaeogeographic method developed by the French school (Chouquer and Watteaux 2013) to reconstruct the transformation of the route network over time. The area is about ninety square kilometres between the urban centre of Grosseto and the ancient town of Roselle to the east, while it goes to the mouth of the river Ombrone westwards.

We compared several layers of data. In particular, we uploaded the archaeological sites of previous surveys, the vectorised historical cadastre (*Catasto Leopoldino* dated to 1823-25), the IGM maps and aerial photos (Italian Military Geographical Institute, aerial survey of 1954, 1978 and 2013) into a GIS platform. Then we applied hydrographic and morphological algorithms (Llobera *et al.* 2011, 843-851).

Archaeological data mostly point out the presence of farmsteads, some major sites (Roman villas and villages) and a few pieces of paths. The archeogeographical method in this context is used to highlight the linearity and to compare modern and ancient cartography in order to verify the degree of continuity and/or discontinuity of the routes network over time. The vectorisation of the cadastre allowed us to read the connectivity from a long-term perspective. By pointing at alignments between the route networks and the field patterns, we can argue that the field boundary sometimes witnessed a path's endurance even if the former road was no longer used (Fig. 3).

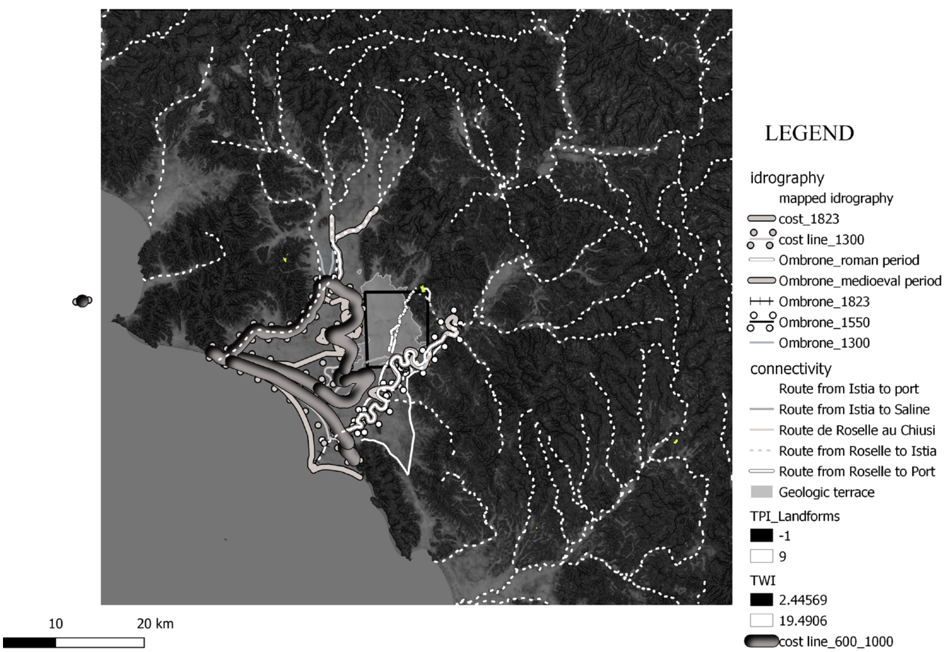


Fig 3. Reconstruction of the hydrographic network and long-term connectivity (300 - 1823) Graphic rendering of TWI and TPI algorithm (figure by authors).

The cartographic analysis was carried out in several steps: the Ximenes Preparatory Charter (we refer to an ancient cartography made by Leonardo Ximenes in 1759) and the Cadastre Map of 1823 were overlain on the IGM aerial survey of 1954, 1978, and 2013. Then, we simply overlaid the route networks resulting from all these maps. Thanks to this contextual overview, we could highlight alignments both related to the route networks and to field patterns. Following that, base maps were created, for which the regional CTR at 25.000 mt was used for hydrographic analysis, and the 10 m cell size DTM (Tarquini S., Nannipieri L. 2017) was used for the analysis of gradients and geomorphological characteristics between flat and hilly areas. Starting from the DTM, the Topographic Position Index was created by applying the SAGA TPI Landform classification algorithm; then the Topographic Wetness Index was made by applying the Saga Wetness Index algorithm. Using the two rasters superimposed on IGM maps and ancient cartography has allowed us to focus on crop marks and anomalies related to the river Ombrone's paleo beds and to the modification of the coastline (Citter 2019a, 325-342; Fig. 4).

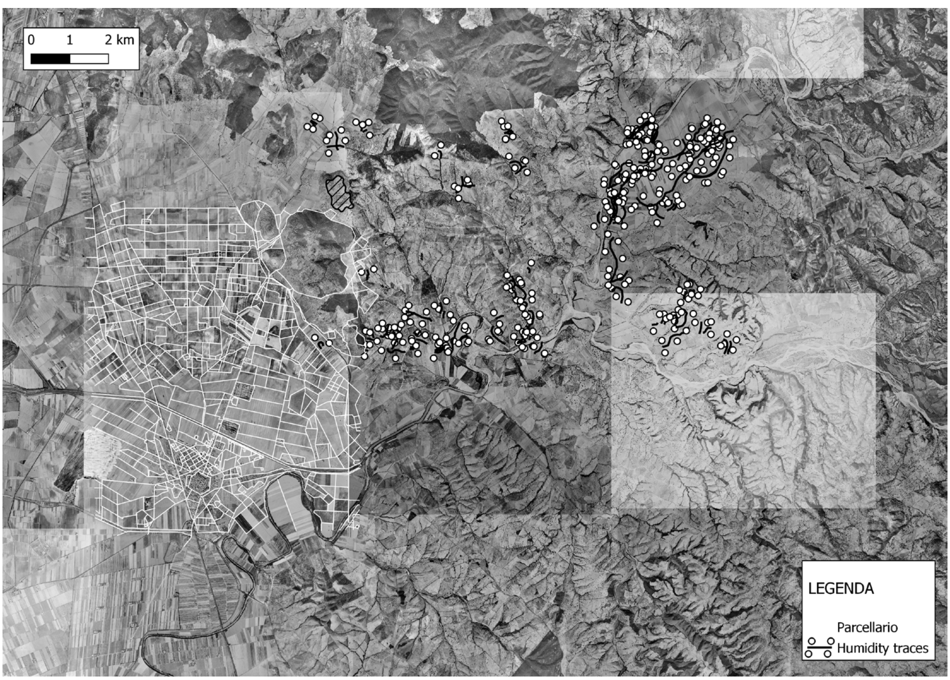


Fig 4. Photoaerial IGM Flight GAI 1954 and Aerial anomalies of parcel and humidity traces (figure by authors).

The overlay of the various layers of information we constructed allowed a more robust hypothesis about the changes of the route networks over time (Arnoldus-Huyzendveld A., Citter C. 2011) In particular, we focused on the connection between the former central place of Roselle and the sea during the Etruscan period (sixth to first century BC), the Middle Ages (seventh to fourteenth century CE) and the Early Modern period (sixteenth to eighteenth century CE).

This research allowed us to estimate that an Etruscan road departed from the town of Roselle in the direction of Grosseto (that was not yet founded) and went straight to the harbour close to the coast of that time. This contradicts previous reconstructions and suggests that the location of Grosseto's foundation could have been due to the existence of a long-lasting road (possibly even already existing before the Etruscans) that intersected another road following the coastline from Rome to Pisa (later rebuilt by the Romans and named via Aurelia).

## Long-term connectivity in the Amiata area. The case of Selvena

The study carried out in southern Tuscany aimed to understand connectivity in an area that includes the Amiata Mountain and the Tuff Area, with Selvena at the centre. This area is considered marginal due to its morphology, but also from an economic point of view. Still, this territory was not always marginal, as in some periods, its resources made it important, particularly its mineral ores, mainly cinnabar, which was extracted from prehistoric times (Brogi *et al.* 2011, 36; Citter 2019b, 50; Farinelli 1996, 39; Leonini & Volante 2005, 549; Volante *et al.* 2019).

This study aims to simulate mobility through algorithms provided by QGIS. The study was focused especially on the pre- and protohistoric periods and the Middle Ages, as the reoccupation of the same places was often recorded, supposing a potential continuity of the mobility network. The hilltops, where many protohistoric settlements used to be, were later reoccupied in the Middle Ages.

At first, we collected data on the study area and uploaded them to the GIS platform to get a larger dataset to work with. The collected data were partially derived from previous archaeological studies, which were supplemented by morphological and hydrological data, historical cartography and the aerial photography of the 1954 GAI aerial survey. This complex data collection allowed the reconstruction of the mobility network and its transformation in the last century, especially from the second half of the twentieth century onwards, when the economic boom changed the Italian landscape (Colusso 2012, 53).

The methodology used combined three different methods: QGIS simulations, cartographic data and field survey data.

The first step was digitising the mobility network from the historical cartographic data and the 1954 GAI aerial survey's aerial photographs, originating from the Tuscany region's WMS service. This step took place at different scales to have both a detailed and a general overview of the study area, to understand better its dynamics (Lock 2009, 78-79).

The next step was to conduct the analysis and the simulation through the QGIS platform. The outcome was a network of paths, most of which still exist today and are partly accessible (Citter, Patacchini 2018, 33; Cross 2012, 1).

The SAGA algorithm TPI Landform Classification was applied to the DTM (Digital Terrain Model). It returns a morphologically accurate raster, that classifies the DTM according to a list of ten morphological positions (Brogiolo, Citter 2018, 602). Then, the algorithm SAGA Wetness Index was applied to the DTM to obtain the TWI (Topographic Wetness Index), which visualises how the hydrology affects the territory (Brogiolo, Citter 2018, 601; Llobera *et al.* , 2011, 844).

The TPI and the TWI were reclassified through the GRASS algorithm r.reclass. It changed the cells' values, allowing them to generate routes where cells with a lower value are easily accessible, while cells with a higher value are difficult to walk through (Citter, 2012, 79).

Using the raster calculator, this base raster was applied to create the *least cost path* analysis (Citter, 2012, 79; Llobera *et al.* , 2011, 844; Lock & Pouncett 2000, 192). The TPI and TWI were weighted so that their sum would return 1. In our case, morphology had a weight of 60%, while hydrology had a value of 40% (Citter & Patacchini 2018, 38; Citter, 2019a, 331). The formula entered was as follows:

TPIreclassified * 0,6 + TWIreclassified * 0,4

We applied the algorithm *r.walk.points* to the *least cost path* get a *cumulative cost surface*. To obtain the latter, it is necessary to process the DTM, the *least cost path* and the vector layers of the considered sites (in our case, first the pre- and protohistoric sites, then the medieval ones). We obtained two *cumulative cost surfaces*, the first for the pre- and protohistoric sites and the other for the medieval ones (Verhagen 2013, 383). To these rasters, we applied the SAGA algorithm *Channel Network & Drainage Basins*. With this algorithm, it was possible to perform mobility simulations in this area. The values 7, 6 and 5 were entered as thresholds. By this method, three networks of paths were obtained, of which the most intricate and complex were those with the lowest threshold values (5 and 6). The value 7 resulted in less redundant paths. The paths obtained according to the algorithm whose setting is 7 are easily accessible and connect the sites in relation to the characteristics of this territory (Citter & Patacchini 2018, 33; Citter 2019a, 331; Fiz & Orengo, 2007, 316; Zakšek et al 2007, 309).

Two field surveys tested the paths generated by these algorithms to verify their credibility. The first followed the path that connected Abbadia San Salvatore, Selvena and Sovana, which took three days. The second survey verified the route between Castell'Azzara, Selvena and Montevitozzo, and it took five days.

The comparison between the simulated paths, the historical cartography and the data from the survey showed that the simulated routes do not properly follow the modern road system, which would have made us think about a possible continuity of the use of the same paths over time. However, it has been noted that some paths overlap the limits of cadastral parcels. The overlaps are not always perfect, and we must consider the errors when the maps were drawn up and the fact that the algorithms do not consider the fact that some of the land could be in use. Therefore, keeping in mind these odds, the paths were redrawn to be more realistic (Fig. 5). We can think that the cadastral limits in some cases may have been some ancient routes no longer in use when the map was drafted.

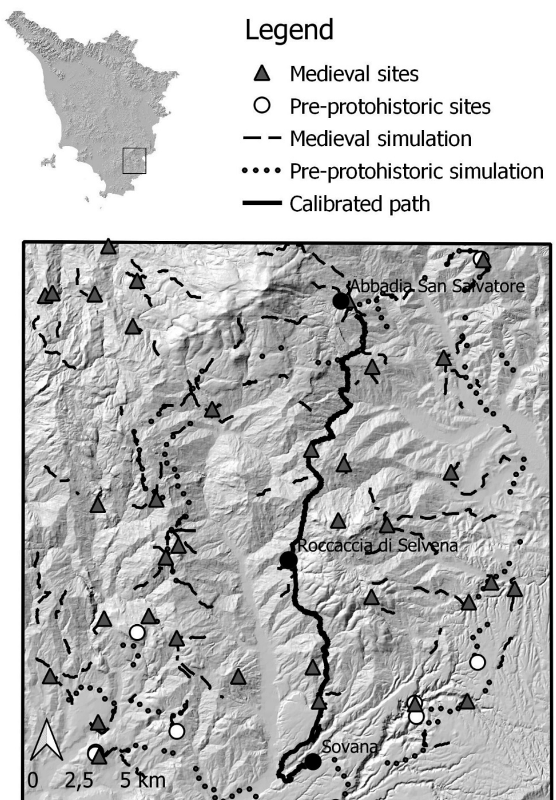


Fig 5. The case study of Monte Amiata. Simulated routes by GIS for the pre- and protohistoric and the medieval periods, and the final result redrawn after the surface survey (black line) (figure by authors).

## Conclusions

The three described methodologies had a common goal: the reconstruction of ancient mobility networks and their development over time. Some of the procedures were similar as well. However, each method was designed to analyse a specific context. The archaeogeographical approach is more profitable in the lowlands than in mountainous areas, where the other two proposed methodologies proved to work better. These last ones have been applied and modified in relation to the differences between the studied areas and the available historical and archaeological sources. In an integrated study of a more geomorphologically complex region, applying all these methodologies allows a more complete analysis and a more accurate reconstruction of the continuities and breaks, as well as the origins of the contemporary local mobility network.

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