“Free rides” in the LBA Argive Plain, Greece: applying FOSS to investigating communication paths in archaeological research

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http://dx.doi.org/10.15496/publikation-xxxx

"Free rides" in the LBA Argive Plain, Greece. Applying FOSS to investigating communication paths in archaeological research

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Abstract

This paper aims to demonstrate the level to which Free and Open-Source Software (FOSS) can be used for spatial analyses and, more specifically, Least-Cost-Path-Analysis (LCPA). To do this, ground-truthed routes which connected major Mycenaean hubs in the Argolid, such as Mycenae and Tiryns, were compared to generated least-cost-paths (LCPs) using both the FOSS platform QGIS and the proprietary software ArcGIS. There were two available options to generate LCPs in QGIS and one in ArcGIS. Different routes were produced in all three cases with the ones generated in QGIS appearing to be following the contours of the landscape and being closer to the surveyed paths. In the end the study shows that advanced spatial analyses can be conducted by employing FOSS. Additionally, thanks to their transparency and the provided tools being easy to understand, the methodologies are reliably replicable and reproducible, resulting in making the archaeological landscapes accessible to all. The research carried out for this paper falls under the SETinSTONE project, funded by an ERC consolidator grant (nbr 646667), under the direction of prof. Ann Brysbaert, and conducted at Leiden University (The Netherlands).

Keywords: QGIS; Least-Cost-Path-Analysis; Free and Open-Source Software; Argolid, Greece; Late Bronze Age

Introduction

The Argolid, in the north-eastern Peloponnese, is a diverse landscape with high mountains, steep slopes, gullies, and ravines, but also very fertile plains. Roads connecting the Late Bronze Age (LBA) sites of Mycenae, Tiryns, Midea, Nemea, Corinth among other locations (see now Brysbaert and Vikatou 2022), must have played a crucial role in the development and the dominance of what is known today as the Mycenaean civilization; best known for the impressive and monumental architecture of its citadels as well as the tholos tombs in its immediate surroundings (e.g. Fitzsimons 2011; Iakovidis 1983; Mylonas 1966). These cyclopean-style structures appear to have been erected at key-point locations (Mason 2007), often close to quarries or areas of favourable terrain for transporting large boulders between desired locations (Brysbaert 2018). These constructions were not limited only to the citadels and the large bee-hive tombs but also appear in various places outside the city walls, in the form of bridges, culverts, and retaining walls along the extensive road network which expands over large parts of the Argolid and up to the north until

Corinth (Hope Simpson and Hagel 2006; Jansen 2002; Lavery 1995). In 1884, Steffen was the first to depict the visible remains of the Mycenaean highways and the structures outside the walls of Mycenae on a detailed map (Figure 1). Since then, several scholars have conducted thorough research and surveys in order to clarify those identified routes, record their length, find other routes, and interpret their use whether seen in a localized settlement context or over a larger regional reach (Iakovidis et al. 2003; Jansen 2002; Lavery 1995; Mylonas 1966; Brysbaert and Vikatou 2022). Therefore, the Mycenaean road network constitutes an excellent case study for spatial analyses for which modern devices and GIS software are used, hence leading to a better understanding of the latter's capabilities and limitations.

The paper's focus is mainly a methodological one while the archaeological findings of the research on roads and their econometric calculations have been discussed elsewhere (Brysbaert 2022; Brysbaert 2023; Brysbaert and Vikatou 2022). Therefore, this study demonstrates how GIS analysis using only Free and Open-Source Software (FOSS) complemented fieldwork surveying, which constitutes the core of understanding the spatial distribution and correlation of important sites in the Argolid. GIS analysis included recording GPS points during fieldwork, reconstructing the potential courses of ancient routes, and ultimately generating maps exhibiting these paths and their connection to archaeological remains. This aids in obtaining a better understanding of the relation between the roads and the settlements since they are accurately plotted in georeferenced satellite images. An essential requirement is for the roads to have been previously surveyed and published in order to compare the accuracy of those surveys to the one recorded using a GPS device as we carried out. Furthermore, tests in Least Cost Path Analysis (LCPA) were computed in both proprietary and FOSS GIS to compare the two platforms in terms of intuitiveness and reliability. Therefore, this paper demonstrates that GIS

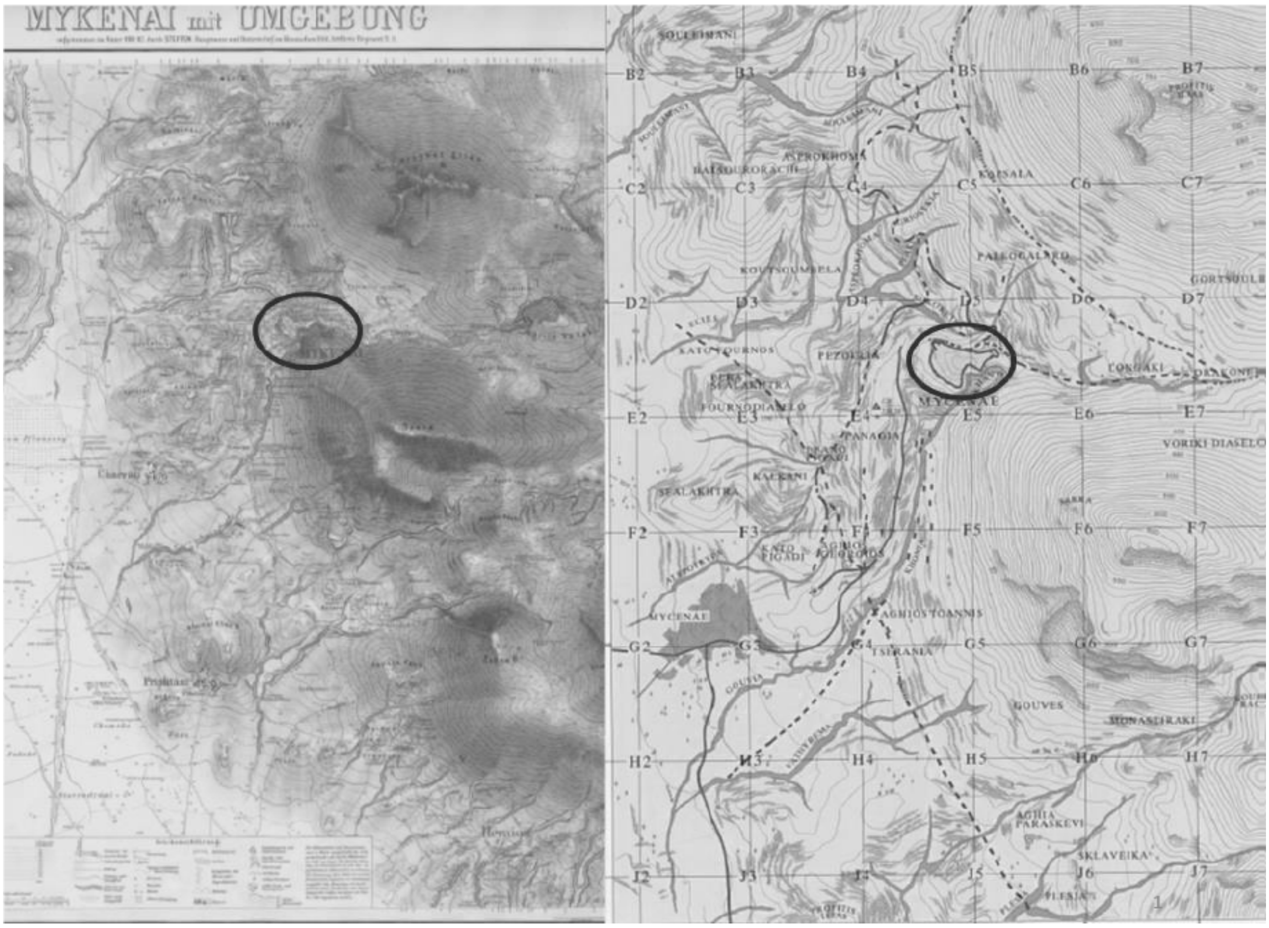

Figure 1. Maps of the region of Mycenae indicating the location of the citadel in the circle. Left: adapted (from Steffen 1884: Map 1); Right: adapted from Iakovidis et al. 2003: Map The Roads. Image generated by Ann Brysbaert and Irene Vikatou.

analysis using only FOSS can produce reliable results which complement fieldwork research. In previous projects, the author AB, used non-proprietary software to execute photogrammetry, hence familiarising herself with the advantages as well as the limitations of FOSS more generally. This is briefly described below.

Background to the use of FOSS for SETinSTONE

Few landscapes have been so intensively modified over time than that of the Argolid (Greece) since at least the Early Bronze Age and certainly in the Mycenaean Late Bronze Age (c. 1600-1100 BCE). The ERC-funded project, SETinSTONE, investigates if and how monumental building activities undertaken there may have impacted on the social, economic, and political structures of the Mycenaean polities in this period, and how people responded to changes in these structures. The overall project investigates (1) the minimum levels of human and material resources input in the prolonged building efforts present in this region between c. 1300-1200 BCE, and what happened to these resources; (2) what subsistence strategies and other activities people were undertaking in this period, and what resources they had at their disposal, and (3) whether there was 'misuse of these workforces' and if there was, how this may have contributed to the Mycenaean collapse; and how this local Mycenaean phenomenon related to societal 'collapse' in other regions of Greece and the East Mediterranean which also suffered major setbacks even though they did not undertake major building programmes. Beyond these goals, mobility and access to resources, for agricultural and building activities, were thus crucial factors in daily life for most people. This subproject investigated and assessed the important usability of past infrastructure and routes to transport resources between the region's major hubs (Brysbaert et al. 2020; Brysbaert and Vikatou 2022).

3. Methodology

3.1Planning, Decision-making, and workflow

FOSS usage was prompted by the ERC requirements and our follow-up thinking and testing for Open Access (OA) purposes beyond the pure publication of results. As such, our research enhances and advocates total FOSS usage, whenever possible, as well as publishing OA to anyone who is willing to persevere in taking available hard/software to new levels. We believe that such an approach makes this landscape even more accessible to all.

Currently, two of the most popular GIS platforms are ArcGIS and QGIS. The former is a proprietary software which has been dominating spatial analysis in archaeology since the 2000s (e.g. Bevan and Conolly 2002; Papantoniou and Kyriakou 2018; Tartaron et al. 2006). The latter- is a FOSS system which was introduced in 2009 and has gained field in becoming more widely and commonly used both by professionals and students. Its compatibility with all Operating Systems (OS) and the integration of other FOSS GIS software such as GRASS and OSGeo4W has contributed to making QGIS one of the most user-friendly GIS platforms to work with, offering an intuitive environment and a variety of tools for all kinds of spatial analyses.

For the roads project, we based our work solely on published information which we wanted to check in the field by revisiting the points of interest while recording them digitally. Hence, we collected all available detailed published maps and started comparing the modern versus the ancient roads in the Argolid, while focusing specifically on the Mycenaean roads. Once useful maps were identified and features recognized on these, road walking was initiated to verify the published features by recording waypoints (N, E, H) using a GPS app and subsequently processing them in QGIS.

Using QGIS, the Mycenaean centres and the road network of the Argolid were plotted in Google Maps satellite images, used as basemaps. Consecutively, Least-Cost-Paths (LCPs) were computed between Mycenae and Tiryns in order to compare the generated trajectories to the actual surviving Mycenaean road remains, and thus obtain a clearer understanding of the practicality of the GIS software usage. Based on our constantly improving strategy towards higher precision we worked with freely available DEMs of 12.5 × 12.5 m resolution, provided by the Alaska Satellite Facility which collaborates with NASA and EARTHDATA (https://www.asf.alaska.edu/). We then created LCPs for all connecting dots, be these mortuary features, quarries, or any other published manipulated feature in the landscape. Producing LCPs was carried out for several reasons: first, to see which routes LCPA produces and, second, to check whether these LCPs are indeed optimal routes to get from A to B. The generated LCPs are compared with the walks we carried out in the landscape while checking efficiency, attractors, and restraints along these routes. Lastly, in addition to LCPA, we imported our recorded GPS points into Google Earth Pro to demonstrate, in a 3D context, where people walked, communicated, and exchanged knowledge, ideas, skills, materials and produce. We believe that placing people's action in a more 3D view would bring us closer to understanding past people's interaction patterns themselves.

To ensure the efficiency and accuracy of the collected data we followed the following procedures. Instead of using written forms which would have taken up much more time (see experiment by Austin 2014 for onsite digital data recording), and which would be rather impractical in the field while walking (strong winds, occasional rain), we gathered higher speed in recording data via apps. This way, we did not make the types of mistakes that occur in copying over forms into digital means. Instead, the mobile data could be downloaded straight into the computer and, when processed and checked on the same day, any minor errors were corrected immediately by two people when the data was entered into the spread-sheets. We avoided using a database because of the relatively small volume of the collected data and flexibility of spread-sheets. The initial version was very complex and was subsequently reduced to no more than 5-7 columns in MS Excel spread-sheet pages that involved all measured points and lines. During the subsequent data processing these were linked to the images taken by a separate digital camera. The work we did required 3-5 m accuracy, and 99% of our data falls within this range. Finally, in line with the funder's requirements of Open Access, Data Management Plans and accessible archived data after project completion, these data sets can easily be uploaded and their management process automated (see Austin 2014: 14).

3.2 Devices

During fieldwork, waypoints were recorded using a GPS app, GPS Essentials v. 4.4.27, which can be downloaded for free on a smartphone equipped with an embedded GPS, which is a mandatory requirement for the application to make the recording. Connection to the internet via mobile data is not necessary. However, its availability is recommended in order to check, via Google Maps, the correct location that needs to be investigated and recorded. The documented waypoints consisted of x, y, z, coordinates, with a deviation of ±3 m using the World Grid WGS84. Subsequently, the waypoints can be exported separately or all at once, as .kml files to a computer with the installed GIS software for further processing. For this study, a DELL laptop (Intel core i7, CPU at 2,60 Hz, and RAM memory 32 GB) was used since it was crucial to generate preliminary maps while being on fieldwork so that, if needed, additional data could be collected, or gaps could be filled in while still on location. Therefore, access to a

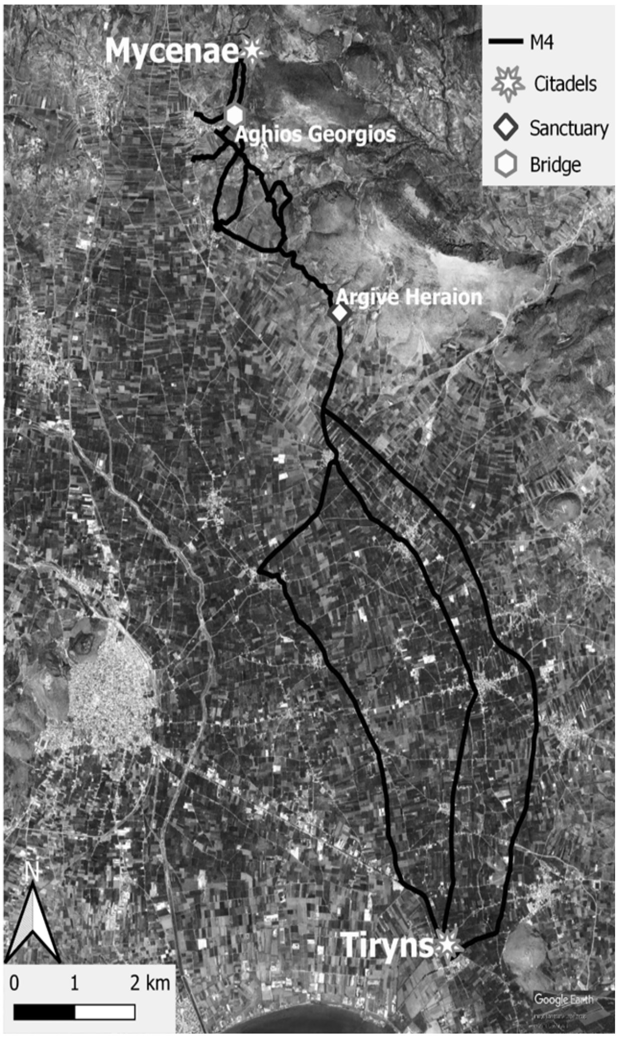

Figure 2. 2D rendering of all possible ancient routes connecting Mycenae to Tiryns. Image generated by Irene Vikatou and Ann Brysbaert in QGIS 3.4 using Google Maps as a basemap.

Figure 3.3D rendering of parts of all the alternative ancient routes leading from Mycenae to the later Argive Heraion, clearly indicating the topographical variety along the trajectory. Image created in Google Earth Pro by Irene Vikatou and Ann Brysbaert.

desktop was not available but the advantage of data processing during fieldwork by a laptop compensates the lack of efficiency provided by desktops. Pictures were shot using a Nikon D7200 DSLR camera, correlating to each recorded waypoint, in order to have a visualization of the landscape from various angles.

The largest advantages in using mobile technology, e.g. smartphones, laptops, and cameras for the road study are:

1. it provides up-to-date online maps, accessible on the phone, of the region in sufficiently large resolution to find the walking tracks we aim for. Those tracks are identified and subsequently ground-truthed because they connect major settlements while passing by known and published archaeological sites and remains;

2. the data is easily collected via the app for GPS coordinates that show us our topographical trajectory in detail, one of the main issues in this study;

3. it allows us, while recording the GPS coordinates, to write instant comments, irrespective of length, that may reflect observations made on the spot and reflections triggered by other features later on and by reviewing the photographs taken;

4. the GPS coordinates hold a time stamp which helps in recovering and matching the photographic records that are collected alongside the GPS data as digital cameras also have a time stamp (see also Austin 2014: 21);

5. all data collected can be embedded in freely downloadable Google Maps via QGIS or Google Earth Pro, and these show, both in 2D and 3D, the trajectory carried out in as much detail as wanted in visual images (Figures 2-3).

The maps which we used as the basis for our work, (e.g. Steffen's 1884) themselves are not digitized, but for our needs, this was not absolutely necessary.

Only minor disadvantages in employing electronic devices and software were encountered during our work so far. These range from issues in visualisation to data accuracy. There will also be a loss of data when turning 3D captured data into 2D images and even 3D images are still shown most often on a 2D screen. This logically affects maps too. The ±3 m deviation when recording coordinates in the field using the mobile device is compensated by their low cost compared to the highly accurate but expensive GPS devices (up to a few thousand euros). Furthermore, computing LCPA is hardly affected by that deviation since the accuracy of the analysis depends more on the DEM's resolution, rather than the recorded points which could have been selected even on Google Maps without ever visiting the site. Finally, practical matters such as screen glare in the sun are easily solved by using the highest brightness level of the mobile device. It is useful to remind the reader here that the core of our interest lies in the course of the road/path trajectories and what laid along these, and in the events, processes, and practices through which these roads came into existence.

3.3 FOSS

The Mycenaean centres of the Argolid and the road network with its architectural remains (tholos tombs, bridges, culverts, and the later Argive Heraion sanctuary), were plotted into Google Maps, provided as basemaps, through QGIS Long Term Release (LTR) version, 3.4. Multiple layers were subsequently generated exhibiting each time the necessary feature, for example recorded routes, tholos tombs, quarries etc. All layers were generated in the Greek grid GGRSS87, EPSG 2100. The EU-funded Copernicus project (https://www.copernicus.eu/en) and the OpenTopoMap (https://opentopomap.org) constitute two more websites which provide free downloadable maps demonstrating different features of land coverage. In the former case, the user can download the Corine land cover maps (https://land.copernicus.eu/pan-european/corine-land-cover) which demonstrate the current land use in Europe. For the Argolid in particular, this is mainly agricultural. When used as a basemap in QGIS and by overlaying the plotted Mycenaean road network, it is observed that a large proportion of the ancient routes runs currently through cultivated land (Figure 5). This means that in the majority of cases physical remains of the ancient road do not exist. Therefore, we use the architectural archaeological remains e.g. bridges, tholos tombs, chamber tomb cemeteries, quarries to try and reconstruct the route. The OpenTopoMap alternatively, offers a variety of topographic maps demonstrating the contour lines of a region. Subsequently, that was particularly helpful in calculating the gradience fluctuation of the ancient roads in relation to the contours by overlaying the plotted routes over the contour-line maps (see Brysbaert 2023, for road cost calculations on this basis).

At a final stage, LCPs were generated. The QGIS LTR v. 3.4 provides an LCP tool which runs the analysis in three quick and simple steps. However, for our research, the LCPs were computed using the r. tools provided by the integrated GIS software GRASS 7. More specifically, the r.slope.aspect tool generates raster maps of slope using the DEM raster (https://grass.osgeo.org/grass70/manuals/r.slope.aspect.html). Then, the r.walk tool employs the Aitken 1977/Langmuir 1984 formula, which complements Naismith's rule for walking times, to generate a raster map demonstrating the anisotropic cumulative cost movement between a start and an end point. Dijkstra's algorithm computes the minimum cumulative costs, providing the best solution. For higher accuracy, the "knight's movement" parameter, which takes into account 16 neighbouring cells instead of 8, is implemented. The cost values represent time (https://grass.osgeo.org/grass72/manuals/r.walk.html). Finally, by using the r.drain tool a LCP is generated connecting the two points of interest (https://grass.osgeo.org/grass72/manuals/r.drain.html). The used DEM raster

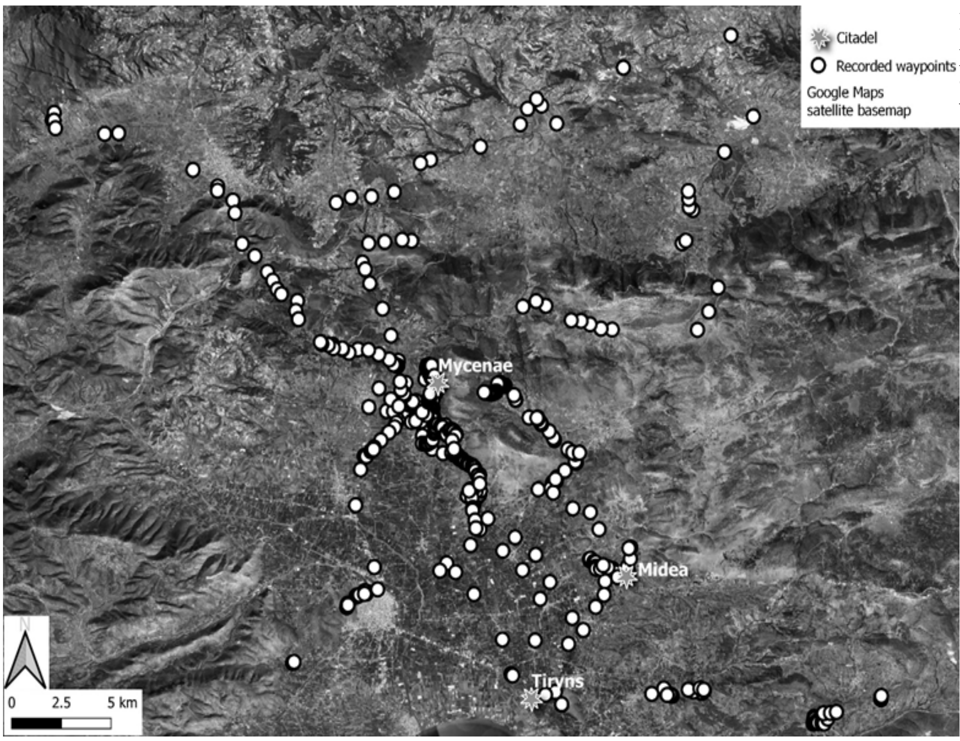

Figure 4. Imported recorded points in QGIS 3.4 using Google satellite maps as basemap. Image generated in QGIS 3.4 by Irene Vikatou and Ann Brysbaert..

of 12.5 × 12.5 m resolution was downloaded for free by the UAF-Alaska Satellite Facility (https://www.asf.alaska.edu/) which collaborates with EARTHDATA (https://earthdata.nasa.gov/). LCPA was also computed in ArcGIS 10.6, using the same DEM to compare the process and the generated results between the two software systems. LCPs were generated using the Cost Path tool and the Path distance tool provided by ArcGIS 10.6 and the Spatial Analyst toolbox. The former tool was used to generate the cost friction raster and ultimately the LCP between two plotted points whereas the latter tool basically uses the same algorithms taking also into account horizontal and vertical factors (https://www.esri.com). Additionally, in the latter case the Tobler's hiking function imported as a .txt table was employed in order to examine how the hiking speed in relation to the slope fluctuation (Tobler 1993), would affect the yielded LCP.

4. Results

4.1 Maps and overviews

QGIS 3.4 was used in order to generate 2D maps exhibiting the recorded points from fieldwork. The basemap's resolution of a single pixel ranges from 15 to 30 cm provided by Google Maps which results in sharp images. QGIS provides all necessary tools to plot and edit all features on shapefile layers, which can then be easily exported as .jpg on .png images of high resolution (Figure 4).

In Figure 5, the Mycenaean Highway M4, with all its possible branches which connect Mycenae to Tiryns, is displayed over the Corine land cover map. This image is produced by activating a plug-in in QGIS which allows the user to choose basemaps from a wide range of FOSS platforms, the Corine land cover being one of them. Furthermore, it demonstrates that in current times the ancient roads traverse mainly through agricultural land. As this paper focuses on the effectiveness of interchangeability use between different FOSS platforms, the analysis of how ancient roads were tracked and recorded is discussed in a different publication (Brysbaert et al. 2020)

4.2 Least Cost Path Analysis.

Least cost paths (LCPs) were generated between Mycenae and Tiryns, directly and via the sanctuary of the Argive Heraion. Figure 6 shows the differences in the generated LCPs between the usage of the integrated QGIS LCP tool and the GRASS r- tools. This is due to the usage of the Dijkstras' algorithm alone in the first case (QGIS 3.4 forum) contrary to the combina-

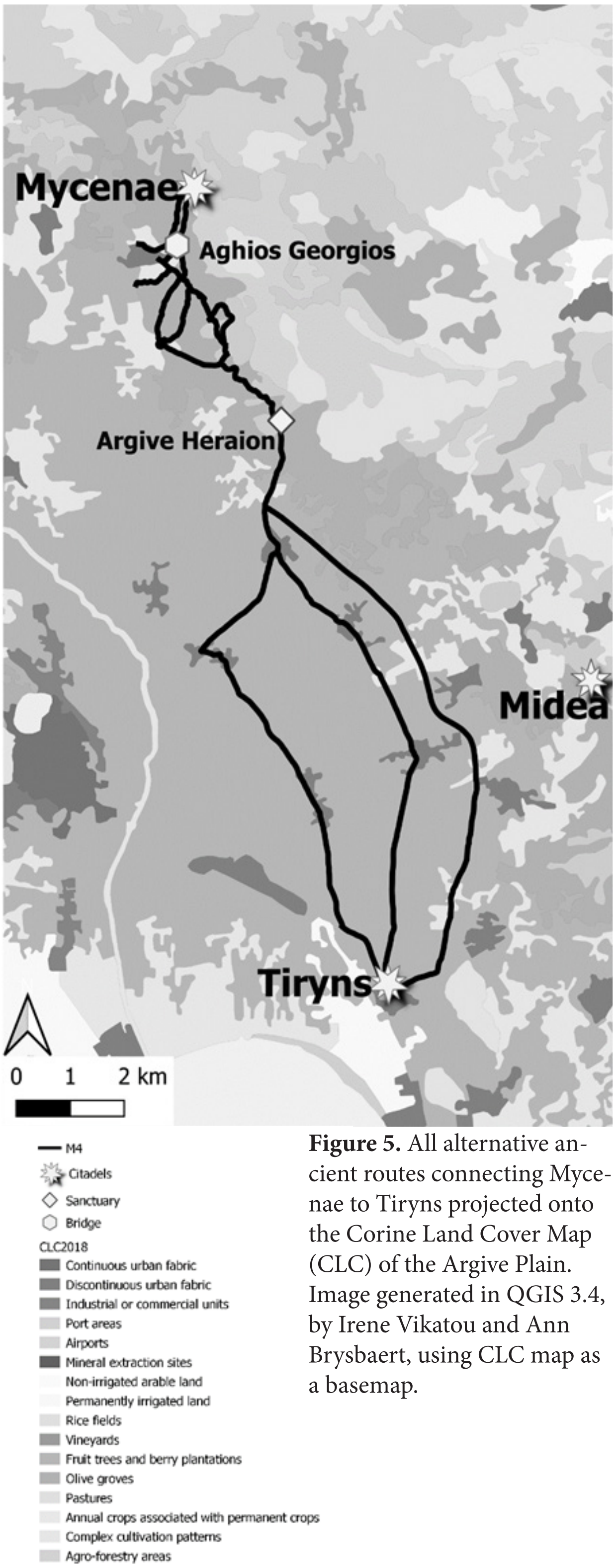

Figure 5. All alternative ancient routes connecting Mycenae to Tiryns projected onto the Corine Land Cover Map (CLC) of the Argive Plain. Image generated in QGIS 3.4, by Irene Vikatou and Ann Brysbaert, using CLC map as a basemap.

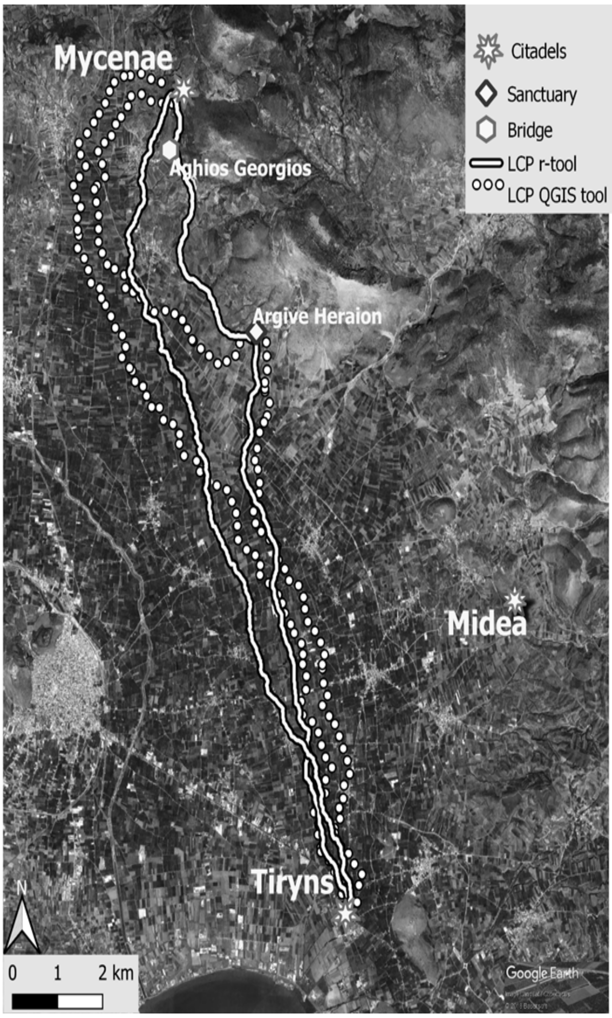

Figure 6. LCP trajectories generated using the LCP tool (dotted line) and the r- tools (solid lines). Images created by Irene Vikatou and Ann Brysbaert in QGIS 3.4 using Google Maps as a basemap.

tion of the formulas employed by the r.walk tool. The generated LCPs using ArcGIS are shown in Figure 7. The differences between the QGIS LCPs and the ArcGIS ones, are attributed to each platform's different algorithms and possibly the differences in resolution of the basemap. Since the main aim of this paper was to examine and compare GIS generated corridors to ground-truthed ones, we found the trajectories produced in QGIS using the integrated GRASS tools to be the most likely ones to have been used. This is owed to the fact that the GRASS tools formulas take more factors into account than what Dijkstra's algorithm does alone which is used in the QGIS LCP-tool. Regarding the ArcGIS generated trajectories, we consider them the least likely to have been used since they do not appear to be following the natural contours of the landscape. Lastly, while providing a table comparing least-cost values, such as time (T) needed to get from point A to B, would be interesting to examine, the time cost comparison is beyond the scope of this paper.

5. Discussion

5.1 Applying FOSS in a Greek Landscape

The majority of archaeological studies focusing on the Greek region have been using ArcGIS as their main GIS software for LCPA in an attempt to analyse and potentially reconstruct ancient city- and landscapes (e.g.: Newhard et al. 2014). Galaty et al.'s early study (2014) used modern routes as the basis for the LCPA in the Argolid and Messenia and these were based on slope only. More detailed work followed soon for which complex algorithms were integrated and adapted and in which the LBA settlements in Greece formed the basis for spatial analysis and LCPA, employing ArcGIS and its tools (esp. Efkleidou 2019; see also Bevan 2002; Bevan 2010; Bevan and Conolly 2002–2004; Fernandes et al. 2018; Sarris et al. 2008; Tartaron et al. 2006). Until now, we have not come across any studies in Greek LBA landscapes using exclusively FOSS. For this paper with a methodological emphasis QGIS/GRASS was used in order to generate maps and compute LCPA. In contrast, ArcGIS was used only to demonstrate similarities and differences compared to QGIS in the workflow and the yielded results. This led to the following points:

a. QGIS and other FOSS are gaining popularity due to their user-friendly interface and easy data accessibility. These are now also routinely taught in university context.

b. QGIS, being independent of a computer's OS, establishes it as a useful tool for independent researchers/students who want to recreate and test methodologies and test generated results.

c. LCPA is more transparent when computed with GRASS since the algorithms and the tools are found and explained on the program webpage (https://grass.osgeo.org/). Additionally, GRASS generated routes were more realistic because they took the contours of the landscape into account, contrary to the ArcGIS-generated

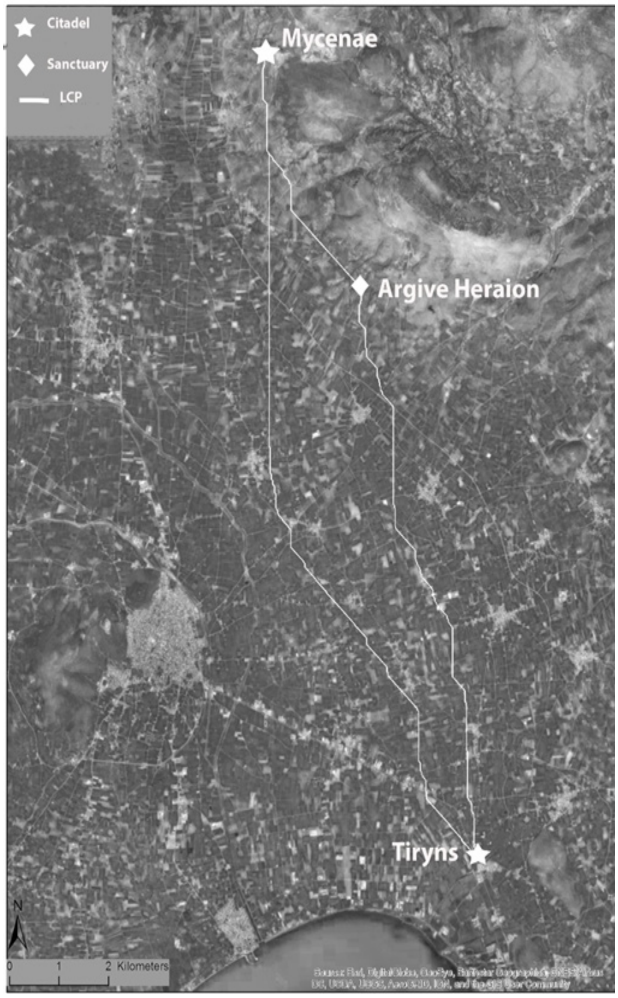

Figure 7. LCPs in ArcGIS 10 using ESRI maps as a basemap. Image generated by Irene Vikatou and Ann Brysbaert.

routes. More specifically, as the yielded results indicate, LCPs generated in GRASS appear to be following the contours of the natural landscape, even some of the lowest ones. This stands in contrast to the trajectories produced with ArcGIS, which appear as fairly straight lines. Similar observations, as to the straightness of lines, were made by Verhagen and Jeneson (2012) who used the Tobler's hiking algorithm to predict Roman routes in the Dutch province of Limburg. According to Herzog (2014) this is expected unless there are very steep slopes in the terrain, something which does not characterise the Argive plain. Therefore, we believe that the Aitken 1977/Langmuir 1984 formula, implemented by GRASS, is more appropriate in this case, since it takes into account slopes between 5 and 12 degrees for moderate human walking downhill (https://grass.osgeo.org/grass76/manuals/r.walk.html). Furthermore, comparing the real routes (Figure 2) to the GRASS-generated LCPs (Figure 6), shows a high degree of resemblance to the surveyed routes. This does not apply to the straight lines connecting Mycenae to the Argive Heraion in Figure 7. Lastly, it should be noted that we never explored a route from Mycenae straight to Tiryns since such a direct connection, bypassing the Argive Heraion, is not described in any literature source, nor are there enough archaeological remains, to our knowledge, to suggest the existence of such a route. Moreover, for large and heavy-duty cargoes pulled by beasts of burden, a straight route would also mean steep descents, something the oxen would have grave difficulty with. All this however, does not mean that a straight route between both places never existed. Consequently, the direct LCP connecting Mycenae to Tiryns remains to be ground-truthed.

d. Additionally, there is a large amount of support through the exchange of questions and comments uploaded in the forum groups.

Using FOSS in our study helped keeping the financial costs of the research to the minimum of owning a smartphone device and a laptop in addition to the costs of travelling. The remarkable advances in software developing makes scientific research conveniently applicable, and, most importantly, easy to be accurately reproduced. Hence its credibility can be easily tested, once the steps are well determined and specified. Designing maps in the latest version of QGIS 3.4 (as implemented in 2019 when this paper was written) is easy, quite intuitive, and the generated shapefiles can be used interchangeably between Google Maps and Google Earth Pro to generate 2D and 3D images.

An image of an overview of all potential ancient routes connecting Mycenae to Tiryns was generated using also ArcGIS (Figure 8) for the purpose of comparison to the equivalent one produced in QGIS (Figure 2). The ArcGIS satellite image, provided by ESRI and used as a basemap, is of low 96 dpi resolution (https://www.esri.com), and lacks in sharpness compared to the QGIS equivalent one. On the contrary, QGIS provides satellite images by Google Maps and Bing Maps, among many others, as the project's basemap with the resolution that these platforms offer. Additional to the cost factor and its related OA advantages, this constitutes an important added benefit of QGIS because it allows the researcher to accurately plot the surveyed area and consequently deliver to the reader a sharp and detailed 2D image.

5.2 Spatial analysis, LCPA, and the human factor

ArcGIS is a product of ESRI and the most widely used software in archaeology to compute spatial analysis and LCPA since ESRI, held a 43% market share of the world's GIS packages (https://www.esri.com/esri-news/releases/15-1qtr/independent-report-highlights-esri-as-leader-in-global-gis-market, date accessed on 13/01/2021), according to the 2015 ARC report with a forecast until 2018. Reports from late 2022 demonstrate that this trend has not only remained unchanged but it is even expected to grow another 10.8% until 2026 (https://gisfeed.com/how-esri-dominates-the-gis-market/, date accessed on 23/02/2023. However, QGIS has been offering the option of free spatial analysis since its previous LTR versions, by using the integrated tools of r.slope.aspect, r.walk and r.drain provided by GRASS GIS. (https://grass.osgeo.org). The LTR QGIS version, 3.4, offers a plug-in that runs the analysis and generates the paths. The only requirements are a DEM file in order to create the slope raster, for the cost value, and the shapefiles with a starting and end points accordingly. The process requires a few minutes and is much faster and simpler compared to using the r tools. However, the results are not identical. This is owed to the usage of different algorithms and hence it is important that the researcher defines what kind and how precise he wishes the result to be. Slawisch and Wilkinson (2018) recommend using FOSS for LCPA since they provide transparent formulas, compared to proprietary software, reassuring the reproducibility of the results. Additionally, Conolly and Lake (2006: 252-256) advise archaeologists, in particular, to be cautious when applying LCPA in order to reconstruct ancient routes for which most of the sections, if not the entire route, are missing. Lastly, it should be reminded that the applicability of the LCPA formulas is still at an evolving stage along with the FOSS usage. The lack of specific guidelines from the developers of both QGIS and ArcGIS is a factor that currently does not allow

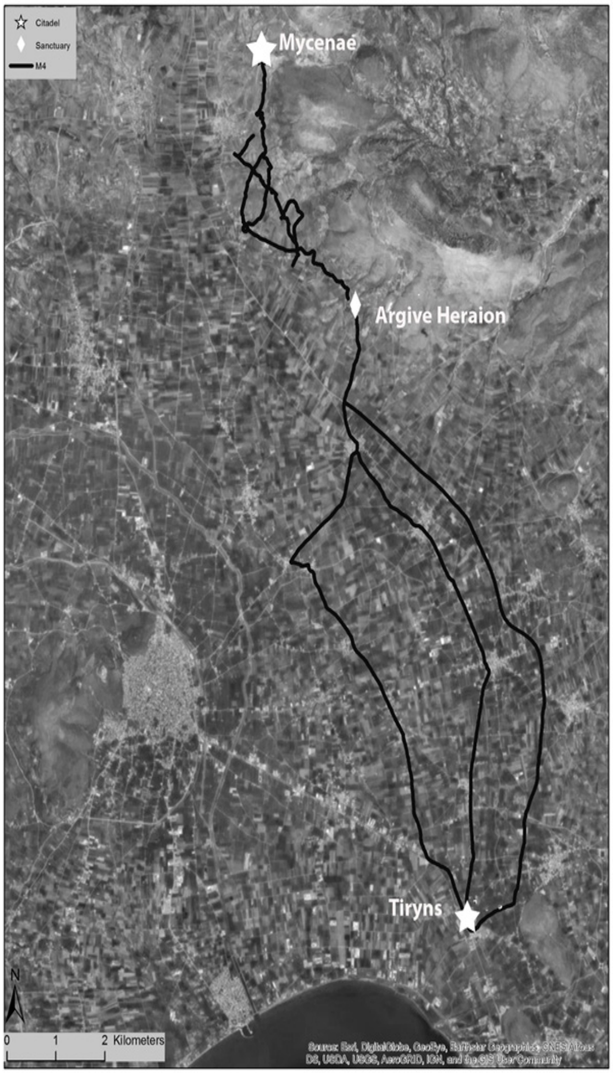

Figure 8. Overview of M4 generated in ArcGIS. Image by Irene Vikatou and Ann Brysbaert.

us to safely conclude which GIS platform is better at reconstructing past environments. However, this will change as more studies rely on using FOSS, and when applied with caution and always in correlation with fieldwork, they yield more holistic results.

6. Conclusions

This paper, therefore, demonstrates that FOSS can produce results equal to those of proprietary software. However, it should be emphasised that fieldwork is still the best way to achieve a better understanding of the past and to reconstruct its environment, and therefore GIS analyses constitute a complementary tool to this procedure.

As our paper has shown, GIS offers plenty of benefits in reconstructing and understanding better how ancient connections between past locations were constituted. FOSS aids scholars in archaeology to study in an affordable and easily approachable way the features they would like to reproduce and test the results of. While initially more time consuming, the QGIS results are very comparable to ArcGIS results and are more transparent in terms of the workflow. Between both means, the cost factor is not comparable and clearly favours QGIS and FOSS overall, but the initial time consumption to become familiar with the programmes also needs to be counted for. As the resolution obtained by QGIS equals the ArcGIS images, data produced in QGIS can be made available through OA and could, in the future, be usefully employed for heritage walks on people's mobile phone apps. Resulting thus from the data's OA, these data can be totally reproducible and testable by anyone who has a smartphone and a laptop and who wants to try.

Spatial analysis and LCPA are still at a developing stage but have already offered an insightful approach in recreating past locale interactions. The availability of high resolution DEMs could help in yielding even more accurate results, but it appears that correctly employed algorithms play the most important role. In the last case, the weight falls mainly upon the researcher, who needs to properly evaluate the movement costs between two or more locations, and upon the GIS developers who should, in the near future, provide the research community the appropriate guidelines. Most importantly, it seems rather unrealistic that accurate LCPA is solely computed on a GIS platform, using a few mathematical formulas and requiring some mouse-clicks, a conclusion also reached by Newhard et al. (2014) and Efkleidou (2019). Walking the actual landscape provides the researcher with a clear understanding of the logistics through a real terrain and, therefore, spatial analysis should be complementary to fieldwork observations. Lastly, the emotional human factor should not be ignored. However, it will take time before this is integrated in an algorithm and it remains to be seen if this will be truly representative of the real thing.

Acknowledgements

We like to thank the following colleagues for their help in various aspects of this research: Walter Laan for teaching us QGIS and Hanna Stöger (†) for her input in the first fieldwalking campaign in 2017, she is sorely missed. Dr. Spyridon Vicatos is thanked warmly for his generous help in providing useful insight with hardware and software specifications. Victor Klinkenberg initiated us to QGIS and Riia Timonen discussed ArcGIS issues with Irene. We also warmly thank Dr. Efthymia Priki for allowing us to present this work in her ERC session at Krakow CAA 2019 since it was the ERC funding that prompted the use of FOSS in this project to start with.

This research is part of the ERC Consolidator SETinSTONE project directed by Prof. Ann Brysbaert and funded by the European Research Council under the European Union's Horizon 2020 Programme / ERC grant agreement n° 646667.

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URL Links:

Alaska Satellite Facility in collaboration with NASA and Earthdata: https://www.asf.alaska.edu/

ArcGIS: https://www.arcgis.com/index.html

Copernicus: https://www.copernicus.eu/en

Corine Land Cover: https://land.copernicus.eu/pan-european/corine-land-cover

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