HAROKOPIO UNIVERSITY

SCHOOL OF ENVIRONMENT, GEOGRAPHY AND APPLIED ECONOMICS

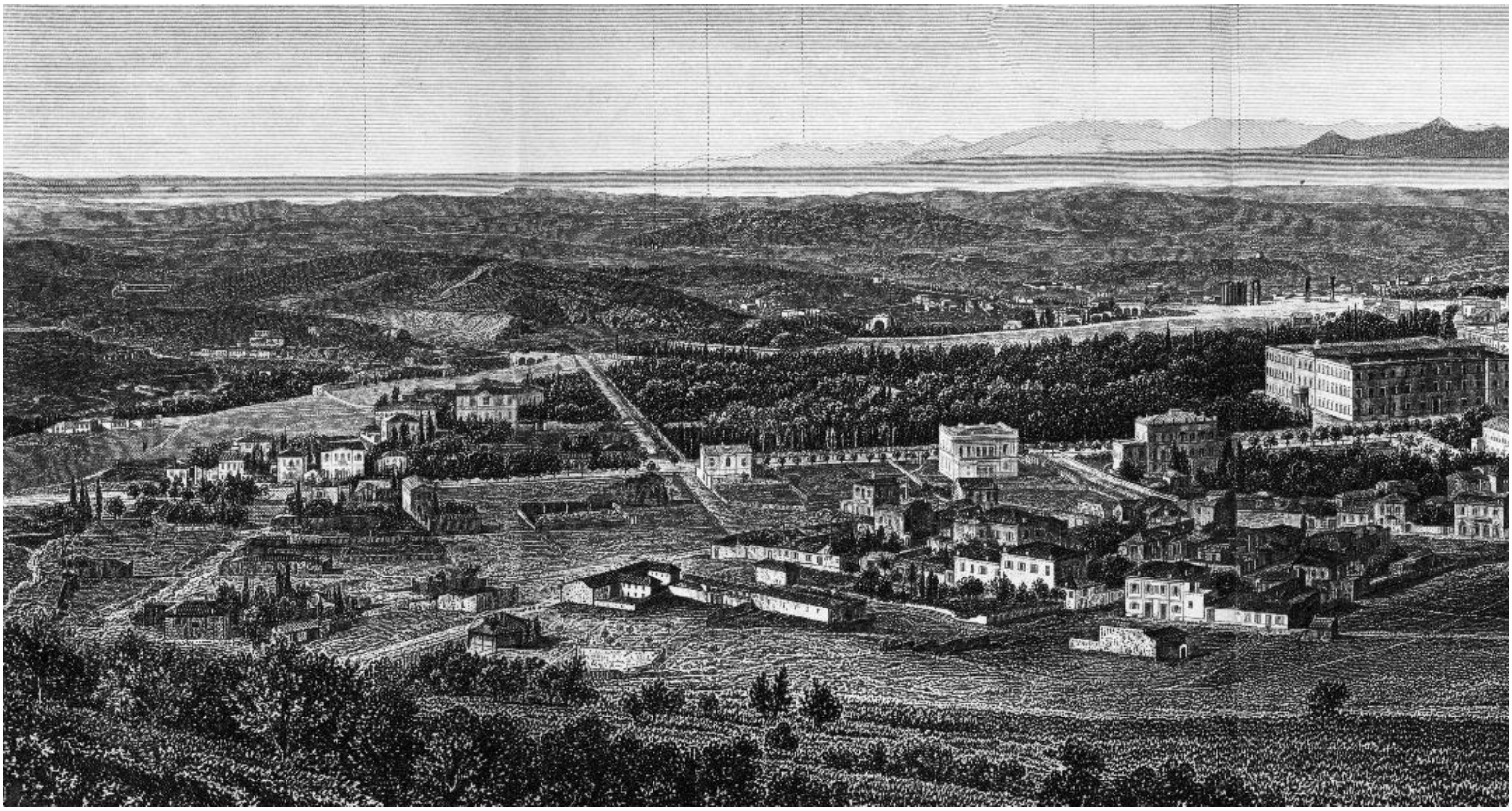
DEPARTMENT OF GEOGRAPHY

Postgraduate Programme: "Applied Geography and Spatial Planning"

Course: Geoinformatics

Utilization of old visual representations for the creation of historical geospatial data

Koilakou Maria



Athens, 2020

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Acknowledgements

I would like to express my sincere gratitude to my supervising professor Chalkias Christos, for the opportunity he has given me to deal with such an exciting subject in the context of my master. His consistent support, as well as his valuable and constructive suggestions, have been decisive in the elaboration of my master thesis. Besides my supervisor, i would also like to thank the rest of my thesis examining committee: Prof. Maloutas Thomas and Prof. Parcharidis Issaak.

I am also particularly grateful for the assistance given by the PhD Candidate at the Department of Geography Papadias Evangelos, for his valuable contribution during the execution of the methodological processing of the photograph.

I wish to express my deepest gratitude to Sylvia Ioannou Foundation for its overall support and the provision of useful for this thesis material. My special thanks extend to the staff of National Library of Greece for providing me all the necessary bibliography and additional data needed, as well as to the staff of National Historical Museum and Benaki Museum for helping me choose appropriate for my thesis photographic evidence.

I am also grateful for the support and assistance given by my friends and colleagues. They kept me going on, and this thesis would not have been the same without their input. Finally, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis.

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Abstract

The wealth of information visual materials can carry renders them as a powerful tool for many research fields. Even though aerial photography and satellite imagery are the primary sources of information nowadays, terrain oblique photographs can also be used to detect and measure changes in the manmade and natural environment. Recent advancements in information technologies supported the development of robust GIS methods that allow oblique photographs to be processed and analyzed to produce historical geospatial data. The use of georeferenced historical photographs combined with other historical information from illustrations, maps and documents, can play a decisive role in the study of landscape and its evolution.

This study aims to present a methodology for the processing of an oblique photograph and a historical map of Athens from the late 19th century, to export historical land cover information. In the second instance, the land covers to be extracted from the above sources will be compared with the Urban Atlas 2012 land covers, to identify changes in the landscape. For the processing of the photograph, the WSL Monoplotting toolbox is utilized. The basic methodology followed consists of the estimation of the shooting point, the identification of at least five control points between the orthophoto and the photograph, and lastly the identification and vectorization of geographical entities. Concerning the historical map, the digitization of the past land covers, their reclassification and their final comparison with the Urban Atlas 2012 land cover was accomplished by the software ArcGIS Pro.

The results show that both the proposed methodologies are very promising for recording historical land covers. Regarding the processing of the photograph, despite the small errors of each monoplotting scenario, the georeferencing of the photograph and the digitization of the land cover entities require further verification in terms of accuracy, mainly due to not corresponding input data. Additionally, the use of Curtius historical map made it possible to visualize the landscape of Athens before its full urbanization, followed by an in-depth quantitative analysis of the land cover changes between 1881and 2012.

By having historical photographs of the broader area from different time periods, coupled with modern methods of aerial photography, such as Unmanned Aerial Vehicles/UAVs, an integrated survey of the area can be accomplished. The georeferencing that is enabled through the proposed processes can contribute to the recognition and reconstitution of land features that have disappeared or are vague nowadays.

Keywords: Land cover change, Photogrammetry, Historical photographs, Historical maps, Athens, WSL Monoplotting Toolbox

Περίληψη

Ο πλούτος των πληροφοριών που μπορεί να εμπεριέχονται σε ιστορικά εικονογραφικά τεκμήρια τα καθιστά ένα ισχυρό εργαλείο, χρήσιμο σε ποικίλους ερευνητικούς τομείς. Παρά το γεγονός ότι στις μέρες μας οι αεροφωτογραφίες και οι δορυφορικές εικόνες αποτελούν τις κυριότερες πηγές γεωγραφικών πληροφοριών, οι κοινές φωτογραφίες μπορούν επίσης να αξιοποιηθούν για τον εντοπισμό και τη μέτρηση αλλαγών στο ανθρωπογενές και φυσικό περιβάλλον. Η τεχνολογική πρόοδος των τελευταίων δεκαετιών έχει συμβάλει καθοριστικά στην ανάπτυξη μεθόδων Γεωγραφικών Πληροφοριακών Συστημάτων (ΓΠΣ) που επιτρέπουν την επεξεργασία και ανάλυση επίγειων φωτογραφιών με σκοπό την εξαγωγή πληροφοριών για τη δημιουργία ιστορικών γεωχωρικών δεδομένων. Η χρήση γεωαναφερόμενων ιστορικών φωτογραφιών σε συνδυασμό με άλλες ιστορικές πληροφορίες από εικονογραφήσεις, σκίτσα, χάρτες και έγγραφα, μπορούν να διαδραματίσουν καθοριστικό ρόλο στη μελέτη της εξέλιξης του τοπίου.

Η παρούσα διπλωματική εργασία έχει ως στόχο να παρουσιάσει μια μεθοδολογία για την επεξεργασία μιας ιστορικής φωτογραφίας και ενός ιστορικού χάρτη που απεικονίζουν την Αθήνα στα τέλη του 19^{ου} αιώνα, για την εξαγωγή πληροφοριών κάλυψης γης. Σε δεύτερο στάδιο, οι καλύψεις γης που θα εξαχθούν από τις παραπάνω πηγές, θα συγκριθούν με τις σύγχρονες καλύψεις γης Urban Atlas 2012, για τον εντοπισμό των μεταβολών του τοπίου. Για την επεξεργασία της φωτογραφίας, χρησιμοποιήθηκε το λογισμικό WSL Monoplotting Toolbox, μέσω του οποίου εκτιμάται το σημείο λήψης, προσδιορίζονται τα σημεία εδαφικού ελέγχου καθώς και προσδιορίζονται και ψηφιοποιούνται οι επιθυμητές γεωγραφικές οντότητες. Όσον αφορά στον ιστορικό χάρτη, η ψηφιοποίηση των ιστορικών καλύψεων γης, η επαναταξινόμηση τους καθώς και η τελική τους σύγκριση με τις σύγχρονες καλύψεις γης του Urban Atlas 2012, πραγματοποιήθηκαν με τη χρήση του λογισμικού ArcGIS Pro.

Τα αποτελέσματα καταδεικνύουν πως και οι δύο προτεινόμενες μεθοδολογίες είναι πολύ ελπιδοφόρες για τη καταγραφή των ιστορικών καλύψεων γης. Όσον αφορά την επεξεργασία της φωτογραφίας, παρά τα μικρά σφάλματα κάθε σεναρίου, η γεωαναφορά της καθώς και οι εξαγόμενες οντότητες απαιτούν περαιτέρω έλεγχο όσον αφορά στην ακρίβειά τους, λόγω της μη χρονικής αντιστοίχισης των δεδομένων εισόδου. Επιπρόσθετα, η χρήση του ιστορικού χάρτη του Curtius κατέστησε δυνατή την απεικόνιση του τοπίου της Αθήνας πριν από την πλήρη αστικοποίησή του, ακολουθούμενη από ποσοτική ανάλυση των αλλαγών της κάλυψης της γης μεταξύ 1881 και 2012.

Μέσω της χρήσης ιστορικών φωτογραφιών διαφορετικών χρονικών περιόδων, σε συνδυασμό με σύγχρονες μεθόδους αεροφωτογραφίας, όπως Συστήματα μη Επανδρωμένων Αεροσκαφών (ΣμηΕΑ), μπορεί να επιτευχθεί μια ολοκληρωμένη και διαχρονική γεωγραφική μελέτη ενός χώρου. Η αξιοποίηση των φωτογραφιών αλλά και των χαρτών μπορεί να συμβάλει καθοριστικά στην αναγνώριση και την ανασύσταση χαρακτηριστικών μιας περιοχής που έχουν εξαφανιστεί ή δεν είναι εμφανή στις μέρες μας.

Λέξεις κλειδιά: Μεταβολή καλύψεων γης, Φωτογραμμετρία, Ιστορικές φωτογραφίες, Ιστορικοί χάρτες, Αθήνα, WSL Monoplotting Tool

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List of Abbreviations

Abbreviation	Term
CP	Control point
CSV	Comma-separated values
CTR	Carta Tecnica Regionale
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital terrain model
EEA	European Economic Area
ETRS89	European Terrestrial Reference System 1989
EU	European Union
EUA	European Urban Atlas
FUA	Functional Urban Area
GGRS87	Greek Geodetic Reference System 1987
GIS	Geographical information systems
KML	Keyhole Markup Language
LUA	Large Urban Area
LUZ	Larger Urban Zone
MMU	Minimum Mapping Unit
RMSE	Root-Mean-Square Error

UAV	Unmanned Aerial Vehicle
VHR	Very High Resolution
WGS84	World Geodetic System

1. Introduction

The ability to document and quantify ecosystem and landscape change over time contributes to our understanding of ecological processes, historical ecology, environmental conservation and environmental restoration (Higgs, Bartley & Fisher, 2014). Investigating, monitoring and visualizing the landscape composition and heterogeneity over time is a powerful tool for all modern societies, as those changes are the resulting outcome of a series of dynamic processes, both environmental and anthropogenic.

The end of 19^{th} century and the beginning of the 20^{th} was a time when due to rapid population growth, urbanization and technological advancements, significant changes took place in many parts of the world concerning the landscape (Stockdale, Bozzini, Macdonald & Higgs, 2015). The built environment was developed at the expense of open and green spaces, old buildings were entirely demolished and replaced, many natural features disappear as rapid topographic changes related to agricultural production, resource extraction and urban expansion occurred, new roads and infrastructure are constructed; all leading to dramatic changed in urban and non-urban landscapes to meet their cultural and functional requirements (Papayannis & Howard, 2012; Sevara, Verhoeven, Doneus & Draganits, 2018).

Much of the existing research on landscape change focuses on the use of aerial photography and in recent years on satellite imagery, which, although they are ideal means of research at broad areas, their use is limited to the recent past. However, oblique terrestrial photographs also have great value to add on the study of landscape change often showing key differences from satellite or aerial imagery, giving the researchers a human eye-level perspective (Altaweel, 2018). For as long as history records, societies forged its knowledge of past times and unknown places by capturing, transporting and displaying visual evidence (Mitchell, 2012). While maps used to be one fundamental key source for gaining historical spatial information, the representations of the landscape and its changes was shaped by the arrival and the dissemination of photography (Holdsworth, 2003; Mitchell, 2012).

Photographs have always played a significant role in geographical studies. Ever since its invention in the 1830s, photography became a surrogate for travelling at a time when travel was the premier avenue to the knowledge of the world. The new medium offered a means of observing, describing, studying, ordering, classifying, and, thereby, knowing the world. "*That immediate and direct access to the past served as an aide-mémoire, a device of memory, a form of time travel*" (Schwartz, 2000). With the increasing use of photographic cameras in the coming decades, photographs assumed to be ideally suited to answer that eminently geographical question, '*what is this place like*?', as can convey a great deal of information than words (Rose,2008). Photographs are seen as exact copies of the depicted scenes, exempted from artist's interpretations and by extension, suited as better evidence of past landscapes (Jager, 2012). The vast number of photos available in private archives, museum and university libraries, renders photography as an accessible and valid instrument for the recognition of long-term landscape dynamics.

In general, there is an undeniable wealth of geographical information in all kinds of visual representations such as sketches, engravings, photographs and maps. Images of past landscapes can be a precious resource for the study of the processes and effects of change in the environment, as all three aspects of geographic phenomena are encompassed: space, time, and theme. If the location on the photograph can be identified, then the photograph itself is a form of geographical information. Images and texts, stock in trade for most historians, often contain a wealth of spatial information, though frequently it will be descriptive, requiring some interpretation before locations can be precisely defined (Plewe, 2002).

By using Geographical Information Systems (GIS), it is possible to correlate historical spatial information to its corresponding geographic location to record, analyze and visualize the relationships between different types of data that were hard to compare otherwise (Siebert, 2000). The challenges associated with georeferencing oblique terrestrial photographs limited until recently their analysis for qualitative description of landscape changes (Stockdale et al., 2015). The improvement of computing power, the wide availability of GIS and the production of high-resolution Digital Elevation Models (DEMs), made more approachable the utilization of historical oblique photographs for photogrammetric purposes (Monoplotting) (Bozzini, Conedera & Krebs 2012; Triglav-Čekada, Bric & Zorn, 2014).

The present Master thesis aims in the utilization of old visual representations for the creation of historical geospatial data for the Athens area. In more detail, a historical photograph and a topographic map of the same period are used for the reconstruction of their depicted land covers. In the second instance, the historical land covers that occur from the above visual representations will be associated with recent land cover data, to draw conclusions on the changes in the landscape of Athens.

The content of this thesis is structured in eight Chapters besides the introduction, where the general topic of the thesis is presented. Chapter 2 aims to provide general information about photography and how photographs and other visual material are used as evidence. Chapter 3, includes a brief description of Monophotogrammetry, and Chapter 4 describes the WSL Monoplotting Toolbox software and review studies based on it. The following chapter 5 consists of a description of the study area and an overview of the datasets. The Chapter 6 analyzes the applied methodology, followed by Chapter 7, where the results and the analysis is taking place. In Chapter 8 are discussed the overall findings, limitations and suggestions. The conclusions of the thesis are drawn in Chapter 9, and lastly, the bibliography used is cited, followed by an Appendix of additional to the study figures.

2. Historical photographs and other primary visual material as evidence

In 1839, geographical imagination acquired a powerful ally. The discovery of two similar processes for fixing an image directly from nature in England and France caused excitement and curiosity that spread throughout the Western world (Schwartz & Ryan, 2003). Immediately after its development, the documenting value of photography to capture landscape features and dynamics became perceptible (Bozzini, Conedera & Krebs, 2013). Historically speaking, in a relatively short time after its discovery, photography came to function as a communicator to coordinate, control, and transmit all manner of information in all societies (McLaughlin, 1989).

Photography shares an attribute of "*visual language*", which differs from "*natural language*" as there is no single signification system, but a heterogeneous complex of codes upon looking at photographic evidence (Burgin, 1982, p.143). That "*visual language*", in compound with the ability of photographs to expand the range of observable space through time, made the world visually and semantically more accessible to everyone, regardless of social class and language (Schwartz & Ryan, 2003).

The rapid commercialization of photography was followed by the release of an affordable, smaller and easy to use Kodak camera in 1889. The maturation of photography and the widespread availability of photographic cameras to both professionals and amateurs led to a high volume of existing photographic evidence. For decades after being available for research, historians paid little heed to photographs and recognized their unique documentary potential rather slowly, as being not just adjunct to written evidence, but original sources themselves (Rundell, 1978; McLaughlin, 1989).

Oblique terrestrial and aerial photographs have historically been used for visualization and interpretation purposes, rather than for metric applications. However, until recently, oblique terrestrial photographs were generally outside of the focus of scientists. Terrestrial historical photographs present the unique advantage of reproducing landscape under a human's everyday perspective of the oblique view (Grenzdörffer, Guretzki & Friedlander, 2008; Bozzini et al., 2013). Until a few years ago, the notion of making reliable measurements and maps using a single oblique photograph seemed impossible (Warner, 1993). Recent advancements in information technologies have enabled the development of robust methods that allow oblique photographs to be georeferenced, processed and analyzed so that photographs could be regarded as a new data source for photogrammetry and GIS.

Photographs and more specifically historical terrestrial photographs, should not only be construed as objects "*to look at*", as the information they carry may be hidden. In-depth reading, deciphering and interpreting is required to reveal it, in combination with other forms of evidence, in order for the extracted information to be accurate. (Schwartz & Ryan, 2003). Because of the difficulties in obtaining quantitative geographical data from single oblique photographs (unknown camera parameters, georeferencing etc.), they remained unexploited by being an adjunct to the research or as a decorative element in the publication. The reconstructions of landscape history were based on the descriptive analysis of historical maps, written evidence or aerial photographs. Even until recently, scholars who have recognized the evidential weight of photographs, interpret and use them rather qualitatively (McLaughlin, 1989; Bozzini et al., 2012).

The significance of photography in the construction of notions of space, place, time landscape and identity may be found in different scales, such as in photographs of individual persons, their surrounding landscape even the whole earth from space. However, each photograph requires thorough analysis, as the notions mentioned above are neither distinct nor fixed (Schwartz & Ryan, 2003).

2.1 History of landscape photography in Greece

Historically, landscape representations appeared in European art around 1420, when in paintings with an indoor scene, the gaze began to spread through the window towards the countryside. Thus, although "*topiography*" was established as an autonomous theme in the mid-16th century art, there are Greek writings from the 17th century in which landscape is characterized by the word "*Parergon*"[1], which undoubtedly indicates its diminished importance. From the Grand Tour years, when European travellers visited classical and biblical places, to the modern age of technology, Greek landscape has sparked various visualizations, narratives as well

[1] "*Πάρεργον*" in Greek

as being the base of poetic and literary works. It was used as fiction for utopian space in mythological revivals and as a realistic film scene. In short, the Greek landscape was a field of study and an inspiration for art, poetry and film (Papaioannou, 2014). Although depictions from travellers were initially limited, they began to grow in the 18th and 19th century, the "G*olden age*" of tourism, with Greece attracting educated Europeans due to its classical past. The theme gradually seems to be expanding in both the illustrations and the texts, with three main axes: the ancient monument, the persons and the costume, as well as the landscape (natural and structured space). Until the development of photography (1839) and its dissemination in the following years, illustrations and records were the main tools for the dispersion of information, contributing to the acquisition of knowledge about distant and unknown places (Kouria, 2016). During the first decades of the dissemination of photography as a method of imprinting a snapshot unchanged in time, the literary, photographic and extensively the visual recordings of the time, were primarily motivated by the desire of European travellers to approach the roots of classical culture.

Athens, as the capital of the newly established Greek State, began to develop a peculiar relationship with photography, from the early years of its appearance. Although it attracted the pioneers of the new "*art*", photographers intended to create "*real images*" of classical monuments, in response to the vision of the ideal Greek landscape that had prevailed in Europe. As a result, the foreign, as well as the first Greek photographers[2], followed the already established and formulated stereotype, the visualization of the ancient monument. Every foreign photographer arriving in Athens rushed to photograph each of the monuments of the Acropolis, including the Propylaea, the Parthenon, the Erechtheum as well as other monuments in the city such as the tower of winds, Lysicrates monument and the temple of Olympian Zeus. At the same time, Athens was rapidly transformed by the reconstruction of public buildings and roads, but it continued to be depicted as a surrounding of the classical monuments and not as an independent landscape (Antoniadis & Papaioannou, 2013).

The trend of topographic photography developed in 1850, with a growth lever being the imprinting of "*exotic*" places, the effort to gain knowledge about the world and tourist development, were important stepping-stones for its mass commercialization

[2] Their visualizations were shaped by the view of Europeans, with the depiction of ruins, costumes, portraits and historical subjects being the main theme, with the absence of depiction of the natural or anthropogenic landscape.

of photography during the same decade[3]. However, the natural landscape remained in the shadows in the 19th century, as the imprints of foreign excursionists remained the central theme on demand in the market for classical Greece (Papaioannou, 2014).

The "*photographic portrait*" of Athens was actually created for the first time in the last two decades of the 19th century. In this, a decisive role was played by the new urban and architectural changes in the character of Athens, as well as the new preferences of the increasing number of visitors, who seemed interested in the depiction of the daily life of Greece. Moreover, there was also a significant increase of local photographers, due to the simplification of the photographic process with the dissemination of the smaller and easy-to-use Kodak portable camera in 1889. Choosing unusual shooting angles and focusing on parts of the city's surroundings beyond the monuments, local photographers created photographic shots with particular aesthetic and pictorial interest (Kardamitsi-Adami, Constantinou & Lugosi, 2003).

With the combination of all those mentioned above, the imprints were increased and gradually highlighted beyond the aesthetic, the documenting and archival character of this new medium. However, unlike the evolution and study of paintings about the landscape in Greece, the photographs of the Greek landscape, despite its widespread dissemination, were not utilized for research.

The depictions of Athens were enriched around 1900 with stereoscopic photographs released in America and Europe, as a kind of visual ethnological and geographical "*Encyclopedia*". Stereoscopic photographs consist of two images of the same object, taken at the same time from two different angles, which, if observed through a stereoscope, give the illusion of three-dimensional space. At the beginning of the 20th century, the photographic depictions of Athens were disseminated in their printed form, through the illustration of books, although the representations of ancient monuments still prevailed. For the first time in 1920, a printed photo album dedicated exclusively to the modern city was released. This album was the *Athènes Moderne* by Edmond Boissonnas, son of the well-known photographer Fred Boissonnas. The publication was part of the series *L'Image de la Grèce*, published

[3] Key features of the topographic photography are the complete tonal performance, the exquisite detail, the technical excellence, and the printed titles at the bottom of the image. Often the name of the creator was not listed as well as the lack of originality was something common (Newhall, Beaumont 1988, as cited in in Papaioannou, 2014).

after the conclusion of a contract in March 1919 in Paris between the Greek Government and Fred Boissonnas for the photographic projection of Greece (Kardamitsi-Adami et al., 2003). The shift from ancient monuments to the landscape has been the result of the restriction of geographical expansionism, the consolidation of folklore research, the search for a new aesthetic and ideological basis, combined with the effects of industrialization and urbanization (Papaioannou, 2014, p. 191).

With regard to the utility of historical information that photographs may bear, the objectivity of photographic illustrations can only be limited through selective imprinting, as the photographic lens narrows the margins of bypass or transformation of a landscape through imagination. This ability of the lens, to accurately note the distances, proportions, contrasts of light and shadow, as well as to maintain the details and shades, makes the photographs much more faithful and accurate representations than any other pictorial representation. Landscape photography as a method of keeping a snapshot unchanged in time should be treated not only as a work of art with only aesthetic characteristics but also as an image that preserves the historical memory expressions of the natural and cultural landscape[4] (Papaioannou, 2014).

2.2 Basic photographic components

The identification of entities on the surface of the earth using photographs (terrestrial, aerial and satellite) requires the study of a series of photointerpretative characteristics. These characteristics could be considered as visual vocabulary elements, as they help the identification of objects and in the overall "*reading*" of photographs (Zinkham, 2006).

The visual vocabulary of photographs includes the following elements (**Figure 2.1**):

- **Tone/colour:** Tone is the relative brightness of grey level on a black and white image and more specifically is the measure of the intensity of the reflected or emitted radiation of the objects of the terrain. Objects with smaller reflectance appear relatively dark, while higher reflected objects appear bright. On colour photographs, hue, brightness, saturation and tone, are used to distinguish objects. Tone variations are also significant, as it allows distinguishing elements with

[4] For further details on the evolution of photography in Greece from 1839-1900, see Athens 1839-1900: Photographic testimonies (3rd ed.). (2004). Benaki Museum.

different shape, texture and pattern. It should be noted that the tone of an object is not always the same in all photographs but is subject to significant changes such as the type of recording medium, the location of the object, meteorological and topographic conditions

- **Size:** The size of objects in an image must be considered in the context of the image scale or resolution. The size of a target element should be cooperatively taken into account with other objects in a scene. The most used parameters are length, width, perimeter, area, and sometimes volume. For example, in distinguishing zones of land cover/use, an identified area with several large buildings such as factories or warehouses would suggest a commercial property, whereas small buildings would indicate residential use.
- **Shape:** Shape refers to the general form, structure or outline of an individual object. Generally, regular and straight-edge shapes (squares, rectangles, circles) are signs of man-made or man-modified objects (buildings, roads, and cultivated fields). Conversely, more irregular shapes with no distinct geometrical pattern, indicate natural features (rivers, forest boundaries, etc.). The shape is an important factor for identification, as it establishes the class of objects to which an unknown object may belong.
- **Texture:** Texture refers to the arrangement and the frequency of tonal changes in an image. An aggregate unit of features produces texture, which may be too small to be distinguished individually on the image. Generally, the texture is the result of the combination of tone, size, shape and shadow and is always dependent on scale or resolution. Same reflected objects may have a difference in texture, which helps in their identification. Rough surfaces would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have minimal tonal variation. The texture as smoothness or roughness of an area can often constitute a valuable clue for the identification of an entity.
- **Pattern:** Pattern is the spatial arrangement of objects. Patterns can be either man-made or natural. That regular or irregular arrangement of objects with a repetition of forms, tones and textures can be a diagnostic element of features on the landscape. Patterns are more visible in aerial photographs, where larger areas are depicted, as from the ground where it is more difficult to detect them.

- **Shadow:** Shadows reveal information about the shape, size, and construction of features, and in some cases can yield an immediate identification. Interpreters using vertical photographs are more benefited by shadow, as the outline/shape of the shadow affords the impression of the profile view of the object. Also knowing the time when the photograph was taken, one can estimate the solar elevation, which helps in the estimation of an object's height.
- **Site:** Site refers to topographic or geographic location. It is also an essential element in image interpretation when objects are not clearly identified using the previous elements. The appearance and occurrence of many features vary in different parts of the world.
- **Association:** Association is not related to a specific object. The photointerpreter associates the objects or their location to other recognizable objects or features in proximity to the target of interest. It refers to the interpretation we give based on our knowledge and experience in the photointerpretative process. For example, a small smooth vegetation site in an urban area indicates a park and not agricultural land. (Colwell, 1978; RSSC,1998; Petersen, Sack & Gabler, 2010; Shankar, 2017)

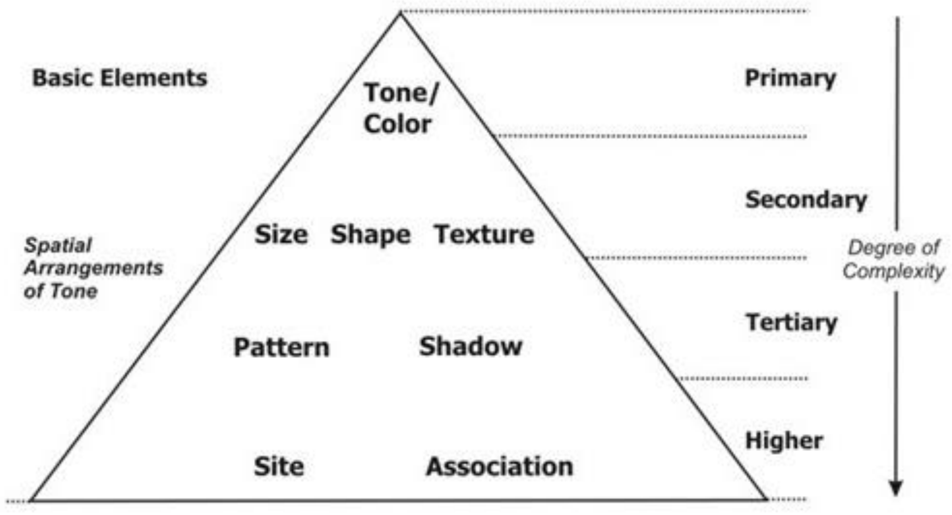

Figure 2.1. The primary ordering of image analysis elements in visual photo interpretation (Estes et al., 1983).

To summarize the above, the information contained in a photograph is perceived through the processing of the depth of field, shapes, planes and boundaries revealed by contrasting reflection and absorption of light, and by the nuances of grayscale or colour change of different element. The viewer or the interpreter of the photographic image will engage their mind unconsciously comparing the image’s elements with past similar visual experiences in an attempt to derive meaning from the information in the image (Achterberg, 2007).

While the camera lens views the world objectively, the photographer regularly judges, intentional or not, deciding how and what to photograph in a scene. The aforementioned in compound with the words that accompany the photographs may also play a vital role in the way we "*read*" them. Even though photographs often distort, mislead, it cannot be omitted that they carry useful information (Meskin & Cohen, 2008). Although photographs are carrying evidential weight, there is a type of information that they fail to provide: information about the spatial location of the objects. To conclude, the amount of data that photographs carry does not refer to the impartiality, realism and the accuracy of the photographs, for the discovery of which the interpreter is responsible, to lend support in historical research.

2.3 Advantages, disadvantages and limitations of photography as evidence

Historical photographs contain a significant amount and variety of information that may be used effectively in many research fields, as it encompasses all three aspects of geographic phenomena: theme, space and time (Plewe, 2002; Achterberg, 2007).

2.3.1 Advantages of photography as evidence

Photography, as a primary visual source of information and due to its high popularity as a recording medium, offers a wide range of advantages (Strausz, 2001). As mentioned before, soon after its development in the first half of the 19th century, photography became very popular as an effective method of documenting landscape features and dynamics (Bozzini et al., 2013). The rapid commercialization of photography led to a high volume of photographs produced by the mass spread of affordable photographic cameras to the public (McLaughlin, 1989). As a result, many photographic collections of historical photographs in public or private archives exist nowadays, representing an enormous resource for the study of landscape evolution (Achterberg, 2007; Gabellieri & Watkins, 2019). Besides, due to the numerous collections, photographs are available in a higher density than existing surveying data, representing a vast resource for the study of past landscapes.

More thoroughly, one of the main advantages of using oblique terrestrial historical photographs as evidence is the fact that they depict views of the anthropogenic and natural environment, prior to the first aerial photographs. This allows the extension of the analysis back to the late 19th century, providing detailed evidence which is invisible from the aeroplane (Gabellieri & Watkins, 2019). In addition, oblique terrestrial photography presents a unique landscape view under human's everyday perspective and perception (Bozzini et al., 2013). Additionally, a hidden advantage that can occur is that by enhancing the negatives in an analogue or digital manner, information that was hidden in the original photograph can be discovered (Achterberg, 2007). To conclude concerning the advantages, it is more effective to capture, transmit, and preserve information through photographs than it is to write a roughly equivalent description of the same event and its context (Achterberg, 2007).

2.3.2 Disadvantages and limitations of photography as evidence

The disadvantages apropos of the use of terrestrial photographs as evidence could better be considered as limitations, as they are not essential elements for preventing their use. Photographs, as any other form of historical sources, needs to be interpreted to be used (Gabellieri & Watkins, 2019).

Based on the above, the first limitation could be considered the choice of a suitable photograph for the requirements of the project. The requirements include the high quality of the photograph, the entire study area to be apparent, the date of the photo being known and all the desired elements being clearly visible (buildings, geographical characteristics, etc.). The detection of the above elements is critical and may be proven a challenging and time-consuming task. The oblique angle of the terrestrial photograph complicates the location of the shooting point and the identification of suitable ground control points (CPs), and in combination with the unknown camera parameters as well as the lack of techniques to estimate them, makes their georeferencing a painstaking task (Achterberg, 2007; Gabellieri & Watkins, 2019).

On account of the difficulties mentioned above and limitations in obtaining quantitative geographical data from single oblique terrestrial photographs, photography as evidence have been until recently unexploited and limited to quantitative analysis (Stockdale et al., 2015; Gabellieri & Watkins, 2019).

2.4 Examples of other primary visual materials as evidence

As primary sources are considered all the materials that may contain direct evidence, first-hand testimony, or an eyewitness account of a topic or event, and they are most often produced around the time of the events they depict. They may also in a more prominent or hidden way reflect their creator observations or beliefs about the event, providing a powerful window to the time period studied. Secondary sources, in contrast, give an interpretation of the past based on primary sources.

Except for photographs, other visual sources include:

- **Original art:** Paintings, drawings, watercolors, graphic art, prints, sculpture, and architectural drawings and plans
- **Moving Images**: films, documentaries, animations, cartoons
- **Prints**: graphic art, etchings, engravings, travel narratives, lithographs, woodcuts, mezzotints, posters, trade cards, artists' prints, computer-generated graphics, and book illustrations. (Illinois University Library (n.d.); NYU Libraries, 2020b).

An interesting example of the utilization of the above visual sources of evidence constitutes the four research projects funded by the Sylvia Ioannou Foundation. The programs are created in collaboration with academic and research institutions and are based on rare documents of its Collection[5].

In more detail:

- The **"Ottoman manuscript chart of the Mediterranean"** research program concerns the creation of an online application based on a unique handwritten Ottoman map were an anonymous cartographer (17th-18th century) recorded 842 place names, denoting coastal towns, islands, islets, reefs, bays, capes and river estuaries of the Mediterranean basin. It is a hand-drawn Ottoman map, measuring 256x112 cm, on 15 sheets of paper joined together. The map is drawn

[5] All of the research programmes listed below are available through the Sylvia Ioannou foundation's website at https://sylviaioannoufoundation.org/en/academic-programmes/research-programmes/

with ink and watercolor, and - according to the watermark - dates back to the last quarter of the 17th century. The place names are written in Ottoman script, and there are affixed labels on selected spots written in Italian. Certain places of importance highlighted in gold, such as the Nile and Istanbul. Mount Etna is depicted as erupting. Thanks to the remarkable drawing accuracy of the anonymous cartographer, information on geophysical changes along coastlines and the height of sea level are preserved.

The web map application guides the user through the exploration of the authentic place names and their corresponding modern ones that were placed on the interactive map. A search can be carried out through the 'Search for a toponym’ field. Typing in either Greek or Latin characters) the user can select one of the suggested results, and the application will locate the specific point in the map. Clicking on it shows the place's international name, its modern local name and the transcription of the original.

The scientific research and documentation were conducted by Agamemnon Tselikas, philologist-paleographer, Head of the Historical and Paleographic Archive of the National Bank of Greece Education Foundation, who undertook the transcription of their place names and their correspondence with the modern ones. The interactive map was created by PhD candidate Evangelos Papadias, Department of Geography, Harokopio University.

- The online application entitled “Kitchener's Survey of Cyprus 1878-1883 - The First Complete Trigonometrical Survey of Cyprus” is based on the results of the Research Programme “**Construction of a Cartographic Database and online application of the geographic information of the Kitchener’s Map of Cyprus (1885 edition)**”, created by the Department of Geography at Harokopio University in 2016, under the scientific supervision of Professor Christos Chalkias and funded by the Sylvia Ioannou Foundation. The Kitchener's map of Cyprus is considered a milestone for the cartography of Cyprus and includes multiple detailed information of geographical, historical and cultural interest about the island that until recently has neither investigated nor research thoroughly.

The research programme constitutes of four phases: the georeferencing of the map sheets, the creation of the spatial database, the compilation of the place name database and index and lastly the design and implementation of the digital map and the web application. In more detail, cartographic information on Land covers, place names, settlements, distances and many more was identified, digitized and organized in thematic layers. The interactive features of the map application include:

1. Navigation on Kitchener’s map (zoom in/out, change the scale)
2. Display all or selected layers of information (coastline, roads, settlements, land-cover classification etc.) by clicking on the symbol of each layer
3. Capability to display Kitchener's original map as a backdrop
4. Presentation of the features of each map entity (e.g. a settlement in a dialogue box that provides the details recorded in the database for that settlement)
5. Search for geographical entities by typing in a keyword and be navigates to the entities location on the map
6. Overlay any new thematic information layer onto Kitchener’s original map to compare them
7. View general or specific information about the production and content of Kitchener’s map

Through the implementation of this research project, a dual objective was fulfilled: to record and organize all the details of Kitchener’s map, and to promote the free dissemination and utilization of this information through the web application.

- The “**Zefyros**” research programme for Cyprus (15th-18th century) addresses the indexing of information on Cyprus in an innovative scientific way through travel literature. The programme was designed and developed in 2016-2017, under the scientific supervision of Julia Chatzipanagioti-Sangmeister, Professor of Modern Greek Literature at the University of Cyprus. Twenty-five researchers in seven countries (Cyprus, Greece, Italy, The Netherlands, Portugal, Sweden and the Czech Republic) collaborated in gathering and classifying information on the natural and built space, the culture and history of Cyprus. They indexed 125 books on travel literature found in the Sylvia Ioannou Foundation Collection written in 11 languages (English, French, German, Greek, Spanish, Italian, Latvian, Dutch, Portuguese, Swedish and Czech).

Zefyros is also linked to the INSPIRAL online portal, created to cover other areas of the Eastern Mediterranean (including Cyprus) so that one can easily access information through the original texts. This online portal on travelling and historical geography hosts rare 15th-18th century documents and is gradually building its international character by hosting content from public and private collections.

- Lastly, an interactive application utilizing rare historical maps of 16th - 19th century Cyprus was created based on the results of the "**"Representations of the Coastal Zone of Cyprus through Historical Map Segments and Other Illustrations"** research programme, created by the Department of Geography at Harokopio University (2018-2019), under the scientific supervision of Professor Christos Chalkias and funded by the Sylvia Ioannou Foundation. Based on the undeniable fact that historical documentation (books, documents, maps, drawings) contains important geographical information concerning both the natural and manmade environments of the places to which it refers, a web application was created.

  The open-access web application offers to the users the opportunity to journey to the historical past of Cyprus through documented pictorial material and to investigate and contrast it with the current reality. When selecting a representation, all identified entities are displayed. Through the selection of one of them, the user is redirected to a new page with the entity's location presented on the Kitchener's map, together with all the illustrations that also depict it. The users also have the option to search through the corresponding field geographical characteristics such as place names, churches, as well as to add a series of filters to limit his search. In addition, any user of the application may contribute to further enrich the documentation by providing new material or by participating in the interpretation of the existing content.

3. Monophotogrammetry

3.1 Definitions

In this day and age, recent advancements in information technologies, improvements in the creation and precision of DEM, as well as the implementation of user-friendly GIS, brought out new perspectives for a broader range of photogrammetric uses of single terrestrial oblique photographs (Bozzini et al., 2013). Due to the above, photogrammetric techniques and software appear to be an emerging solution, as today's user-oriented software is easier to handle by non-experts, lowering the counterpart costs (Karras, Patias, & Petsa, 1996). Photogrammetry is commonly defined as stereophotogrammetry, which is the technique for collecting and extracting 3D data from a stereo-pair (two overlapping aerial photographs) with well-known intrinsic and extrinsic camera parameters (Wolf and Dewitt, 2000; Mikhail et al., 2001 as it refers to Bozzini et al., 2012). Makarovic in 1973 coined the term "Monoplotting" to describe a method for achieving a 3D reconstruction from a single oblique and unrectified photograph taken from the ground (Gabellieri & Watkins, 2019, p.95). More specifically, monoplotting or monophotogrammetry[6] describes a photogrammetric system where single oblique and unrectified photographs (or aerial nadir images) are related to the real world, represented through DEMs (**Figure 3.1**).

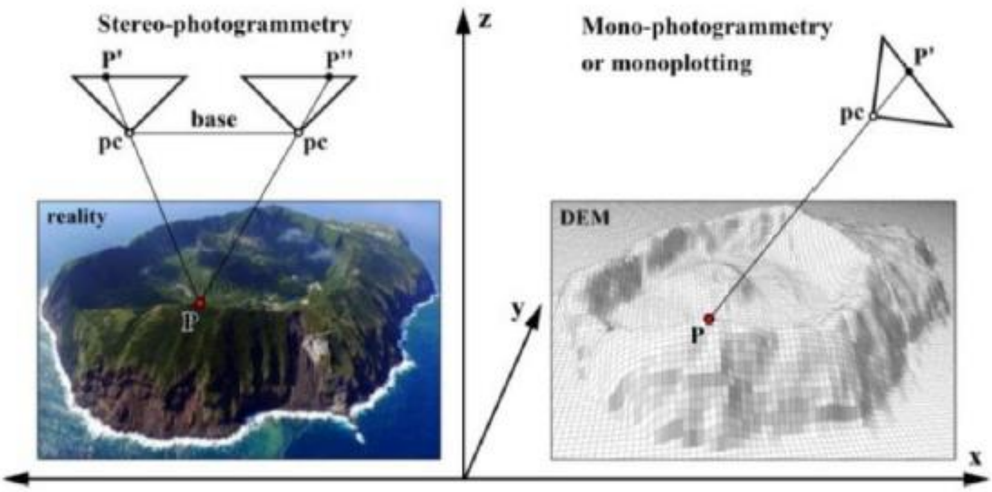

Figure 3.1: Principles of stereo and monophotogrammetry applied to the Japanese volcanic island of Aogashima (Bozzini et al., 2012, p.7). **Legend**: pc = projection centre, P = object point, P' = representation of P in the first photo, P" = representation of P in the second photo, base = distance between the projection centres of the stereo pair.

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[6] Monophotogrammetry belongs in the province of terrestrial photogrammetry, and more specifically in the region of short-range photogrammetry (Gruner, 1955).

In reference to monophotogrammetry, the camera, the photograph and the DEM are related to each other, so that a line from the camera center, passing through a selected photograph point, will intersect the land surface represented by the DEM in the corresponding real point (**Figure 3.2**). The basic and important difference between stereophotogrammetry and monophotogrammetry is that, while the first enables the calculation of the position of any point within the camera's field of view, in the second only points located on the land surface (DEM-surface) can be precisely located (Bozzini et al., 2012).

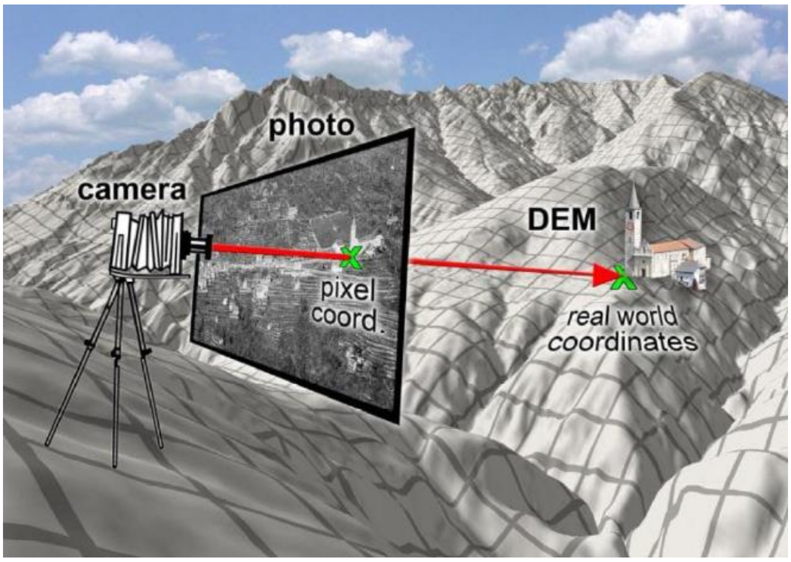

Figure 3.2: Implementation of a monoplotting system (Bozzini et al., 2012, p.8).

The exploitation of monophotogrammetry can be extremely beneficial for the reconstruction of historical characteristics of the landscape, which are not evident today, due to the existence of many extensive collections of single oblique photographs (Kull, 2005; Hendric & Copenheaver, 2009). As mentioned, besides the advantages of historical photographs, their accurate georeferencing remains a difficult task, preventing reliable quantitative geographical information to be obtained from such photographs.

3.2 Monoplotting Principle and camera parameters

The principles of photogrammetry, and more specifically, monophotogrammetry, applied to the study of historical photographs, can bring many benefits to the research of past landscapes (Bozzini et al., 2012).

The monoplotting principle is described by collinearity equations, which assume that the camera station, a point in the photograph in two dimensions (2D) and the corresponding location of the imaged object in the real world (3D), all lie on a straight line. This relationship is visually depicted in **Figure 3.3** and described by the below collinearity **equations 3.1 & 3.2**.

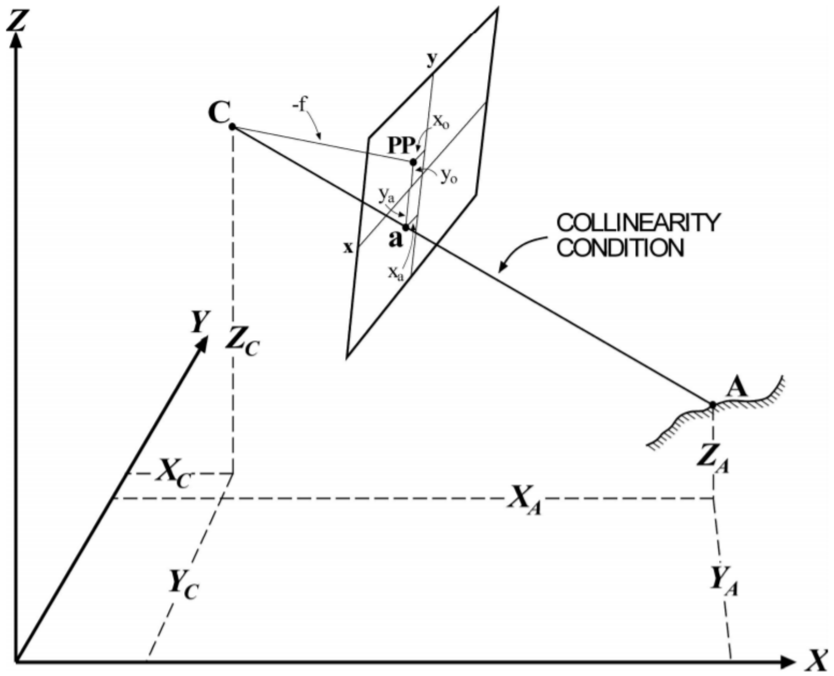

Figure 3.3: The Collinearity Condition (C, a and A all lie on a straight line) (Strausz, 2001, p.14).

$$x_a = x_0 - f\left[\frac{m_{11}\ (X_A - X_C) + m_{12}(Y_A - Y_C) + m_{13}(Z_A - Z_C)}{m_{31}\ (X_A - X_C) + m_{32}(Y_A - Y_C) + m_{33}(Z_A - Z_C)}\right] \quad [3.1]$$

$$y_a = y_0 - f\left[\frac{m_{21}\ (X_A - X_C) + m_{22}(Y_A - Y_C) + m_{23}(Z_A - Z_C)}{m_{31}\ (X_A - X_C) + m_{32}(Y_A - Y_C) + m_{33}(Z_A - Z_C)}\right] \quad [3.2]$$

Equation 3.1 & 3.2: Collinearity equations

In these equations:

- $\mathbf{x_a}, \mathbf{y_a}$ are image coordinates of an object A
- $\mathbf{X_A}, \mathbf{Y_A}, \mathbf{Z_A}$ are the object's coordinates in object space

- $\mathbf{X, Y, Z}$ are the object space coordinates of the camera position
- $\mathbf{m_{11}} - \mathbf{m_{31}}$ are the coefficients of the orthogonal transformation between the image plane orientation and object space orientation, and are functions of the rotation angles $\boldsymbol{\omega}, \boldsymbol{\varphi}$
- $\boldsymbol{\kappa}, (\mathbf{x_0}, \mathbf{y_0}), \mathbf{f}$ is the interior orientation parameters of the mage, the image coordinates of the photographs principal point and the camera focal length, respectively [7, 8]

In photogrammetry in general, the orientation of an image is fundamental and consists of the interior and exterior orientation, each of them having several parameters. The interior orientation elements are the focal length of the camera, which is the perpendicular distance from the film plane to the focal node of the lens, and the Principal point (PP), which is the location on the image where that perpendicular line intersects the image plane. If an image is going to be used for photogrammetric measurements, knowledge of these parameters is essential. In a non-metric camera, defined as any camera not explicitly designed for photogrammetry, the interior parameters are not necessarily known with any precision.

The exterior orientation is defined by six parameters, the three spatial coordinates of the camera station and three angular measurements that define the spatial orientation of the image plane. In the United States, it is conventional to use the terms ω, φ and κ to indicate the rotation around respectively and in order, the x, y, and z axes of an orthogonal coordinate system parallel to space coordinate system in use to transform a plane parallel to the x, y axes of the space coordinate system into a plane parallel to the image plane (Figure 3.4). These rotations are considered positive in a right-handed sense relative to their respective axes. These six parameters of exterior orientation need to be known to recreate a historic photograph (Strausz, 2001, p. 39).

[7] "In the conventional situation where the elements of interior orientation are known the collinearity equations can be used to solve for the six unknown elements of exterior orientation by developing two equations for each of at least three control points of known location" (Strausz, 2001, p. 15).
[8] For more information about the deriviation of the Collinearity Equations, see Apendix A in Strausz Jr, D. A. (2001). An application of photogrammetric techniques to the measurement of historic photographs.

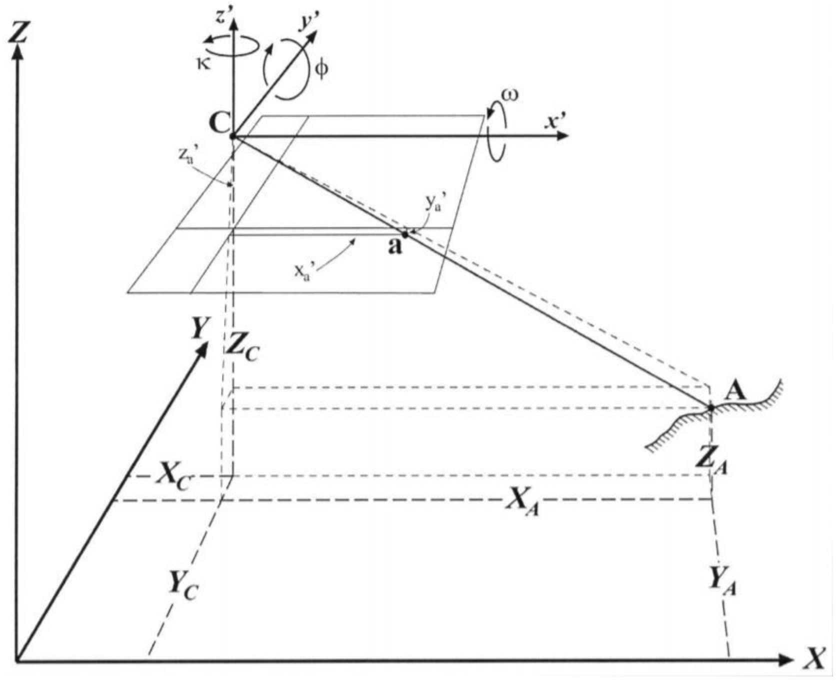

Figure 3.4: Orthogonal image coordinate system (Strausz, 2001, p. 39)

3.3 Software and techniques

The implementation of the monoplotting principle in a valuable tool has been constrained by the lack of adequate data (accurate DEM and appropriate photographs) or the inadequacy of the available computing power. Due to the above, the pioneering work of Makarovic (1973, 1982)[9], has long remained isolated (Conedera, Bozzini, Ryter, Bertschinger & Krebs, 2018).

The improvements in digital photography in the last 20 years, such as the availability of high-resolution digital cameras, the recent trend of digitalization and preservation of historical pictures in high-resolution and the advancements in computing science in general, have opened new possibilities for developing innovative and user-friendly monoplotting tools for both expert and non-expert users (Bozzini et al., 2012).

Following the work of Makarovic, several attempts have been made to develop software and tools for monoplotting oblique photographs. These include the OP-XFORM project (Doytsher and Hall, 1995), the JUKE method (Aschenwald, Leichter, Tasser & Tappeiner, 2001), Georeferencing oblique terrestrial photography (Corripio, 2004), the 3D Monoplotter (Mitishita, Machado, Habib, &

[9] Makarovic B. (1973). Digital monoplotters. The ITC Journal. 4:583-600 and Makarovic B. (1982). Data base updating by digital monoplotting. The ITC Journal. 4:384-390

Gonçalves, 2004), and the DiMoTeP (Fluehler, Niederoest & Akca, 2005) (Bozzini et al., 2012). However, the widespread use of these products has remained limited due to the subject-specific nature, the lack of operational flexibility and user-friendliness (Conedera et al., 2018). More recently, in 2011, the WSL Monoplotting Tool was developed by the Bellinzona Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) group, closing the gap in the availability of monophotogrammetry software by being intuitive, easy to use and shareware (Bozzini et al., 2012; Gabellieri & Watkins, 2019).

3.4 Application fields

Besides historical land cover change detection, which is the application of this thesis, there are more fields which can benefit from by the use of single oblique photographs through the implementation of monophotogrammetric software, such as:

- **archaeology and history** in mapping and recovering disappeared or no longer recognizable landscape elements such as roads, trails and routes, channels for water and material transport, agricultural terraces and old buildings
- **landscape evolution** for the reconstruction of forest boundaries and structure, glacier's dynamics and the detection of land-use changes (i.e. urbanization)
- **geographic reconstruction of past natural events** such as floods, fires, landslides, avalanches, the impact of seismic events
- **monitoring of current processes,** including the surface of glacier meltwater and snowmelt, wind erosion, sea-level changes (Bozzini, Conedera & Krebs, 2011; Steiner, 2011).

4. WSL Monoplotting Toolbox [10]

As mentioned above, Monoplotting techniques have a vast mapping potential for data acquisition utilizing archive historical imagery, for the monitoring of natural disasters and current processes as well as monitoring or studying the development of different geomorphic processes through time.

4.1 Characteristics and Structure of the WSL Monoplotting Tool

The georeferencing of oblique terrestrial images developed by Bozzini, Conedera, & Krebs (2012) and the implementation in the WSL Monoplotting Tool, follow the monoplotting procedure. The primary aim of this tool is to offer an intuitive platform for georeferencing recent and historical terrestrial oblique photographs to a large number of non-expert potential users. As described before, through WSL Monoplotting Toolbox is possible to georeference a historical or present-day oblique terrestrial photograph by relating each photographic pixel to its real-world latitude, longitude, and elevation, to extract spatially referenced vector data.

Based on the above, WSL Monoplotting toolbox has the following main features and characteristics:

- A user-friendly, intuitive, and self-explanatory interface enabling the simultaneous visualization of one or more photographs of the target landscape as well as related orthophotos, maps, or other georeferenced representation of the terrain surface
- A computer-assisted, semiautomatic, and interactive calibration process for the camera, including the reconstruction of all elements in the monoplotting system (e.g., snapshot location)
- An immediate estimate of the error for each CP used for the calibration of the oblique photograph
- A simple editor for defining and measuring features of particular interest (e.g., polygons, lines, points, and heights) on the photographs
- The ability to handle native ERSI-shapefiles

[10] The software is free to download from the Swiss Federal Institute for Forest, Snow and Landscape Research WSL website: https://www.wsl.ch/en/services-and-products/software-websites-and-apps/monoplotting-tool.html

- Export-import routines allowing data exchange (e.g., Comma-separated values (CSV) or shapefiles) between and from conventional geographic information systems (GIS) (Conedera et al., 2018, p.5)

The WSL Monoplotting Tool consists of three main sections (**Figure 4.1**). First, there is the tab-section where the import and export of data take place. More specifically in the

- **Photo tab**, the photograph as well as the CPs are inserted
- **Camera tab**, the camera in which the calibration is accomplished is added
- **Point**, **Polygon** and **Polyline** tabs, the respective data are imported and exported
- **Maps/Dems** are inserted the corresponding Image raster (Photograph) and Value raster (DEM)

The second section represents the photograph, and lastly, the third section contains the topographic map or the orthophoto.

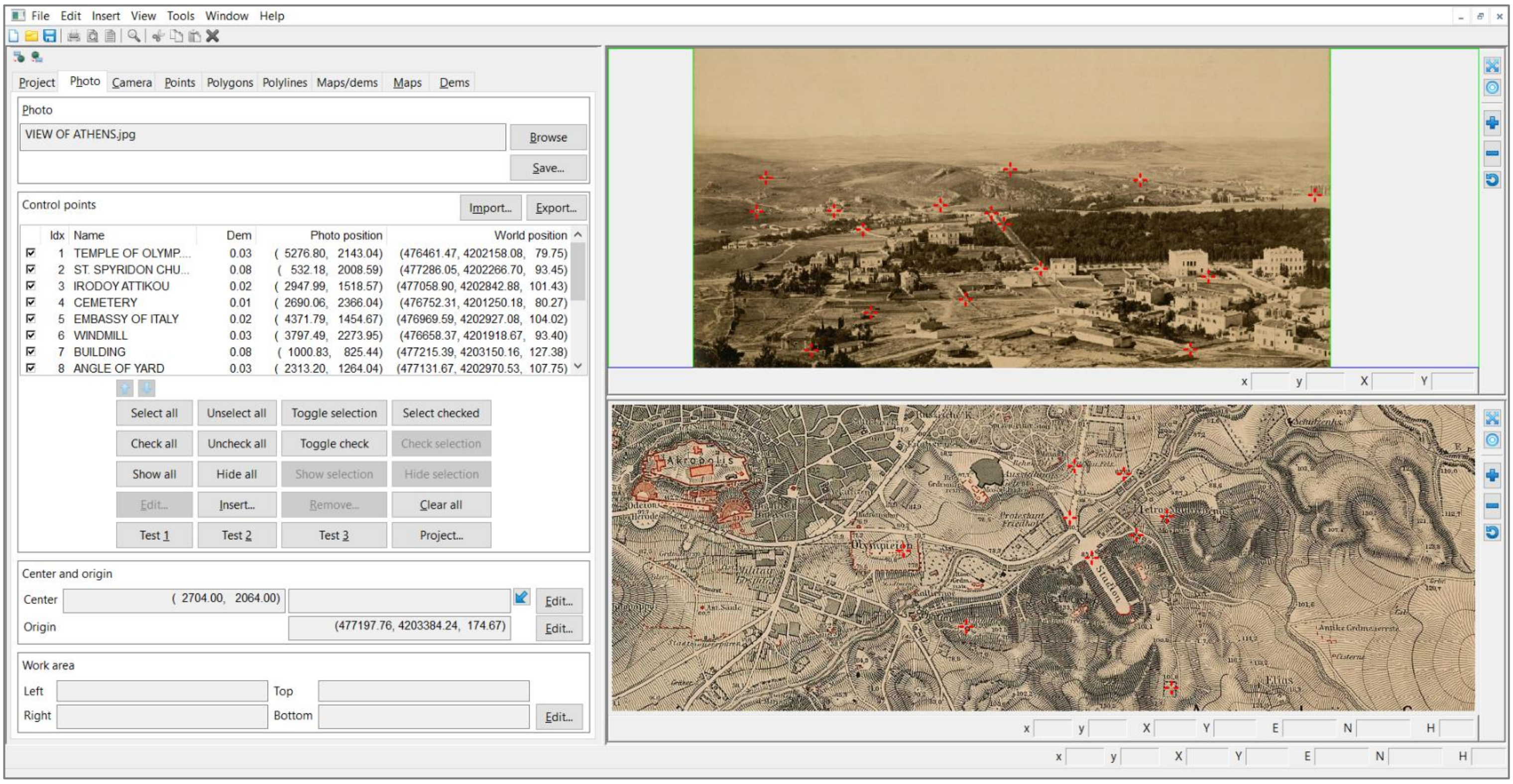

Figure 4.1: Snapshot of the environment of the WSL Monoplotting Tool

4.2 System Implementation

4.2.1 Requirements (Input data) and essential components

The WSL Monoplotting Tool requires the following input data:

- A **digital image** derived from modern digital cameras or scanned old pictures (oblique historical or modern photograph, postcard or other iconographic evidence). The system accepts photos of any type of camera and lens, even small-format and non-metric cameras. Camera and lens characteristics may determine the final accuracy of the monoplotting.
- A **Digital Elevation Model (DEM)**, represented by a regularly spaced grid (e.g. raster in GeoTIFF format), either as a bare ground surface without any objects (DEM) or the earth's surface including objects such as plants and buildings (Digital Surface Model/ DSM).
- A **georeferenced orthophoto or a map** with as high resolution and accuracy as possible, in which CP common with the photograph can be identified.
- **Control points (CPs)** which have to be clearly visible and precisely identifiable on both the photograph (pixel coordinates) and the real world (in the orthophoto or the map as world coordinates latitude, longitude, and altitude). CPs typically consists of unambiguous features that are distinguishable at pixel level on the photo and is advisable to include permanent, visible, natural or anthropogenic elements such as road intersections, rocky outcrops, buildings. There should be at least four recognizable CPs evenly distributed across the photograph, within which the desired area is included.
- The **Camera** (i.e. the mathematical model of the camera used to take the photograph used) including the extrinsic and intrinsic camera parameters which most of the times are not known (Bozzini et al., 2012; Wiesmann et al., 2012).

4.2.2 Camera Calibration and identification of control points (CPs)

The first step during the utilization of the monoplotting toolbox is the camera calibration, or more specifically, the precise estimation, calculation and simulation of the extrinsic and intrinsic camera parameters (**Table 4.1**). The software enables the camera calibration through the determination of a minimum of five CPs, and once the camera is calibrated, world coordinates are assigned to every image pixel.

In addition, each pixel of the orthophoto or topographic map is assigned image coordinates, based on the same principle (Steiner, 2011).

In detail, camera calibration is addressed through an iterative approach, generating a sequence of improving approximations of the camera parameters that minimize the error of the camera model applied to the input data. The iterative approach consists of the application of collinearity equations, including the estimation of unknown camera parameters by the mean of the least square method after linearization of the collinearity equations (Strausz, 2001; Bozzini et al., 2012).

Ox, Oy, Oz	Real-world coordinates of the projection centre (perspective centre or pinhole), i.e. the point inside the lens where all light rays intersect
Rx, Ry, Rz	Euler rotation angle describing the camera orientation around the correspondent axis
Cx, Cy:	Pixel coordinates of the image center (principal point) that is the point where the optical axis (the line perpendicular to the image plane passing through the projection center) intersects the imaging surface
D	multiple of the focal distance (focal distance = D * factor). Speaking about focal distance is not correct because the pictures are scanned and are not in the original format.
Rf	+1 or -1, according to the correct solution of the calibrating equation.

Table 4.1: Extrinsic and intrinsic camera parameters (Bozzini et al., 2012; WSL Monoplotting Tool, 2014)

Explicitly, the following procedure is iteratively calculated for every single CP. “The image centre is defined based on the image size, whereas the focal length will be estimated through CPs. The camera gets calibrated by firstly defining an initial value for the camera position in the orthophoto. Based on the intersection of the initial camera position and the measured image point p, the light ray r’ is defined (Figure 4.2). Further, the intersection of the light ray r’ and the DEM calculates the real point P’. Whereas, the junction of the light ray r’ and the plane Π’ calculates the real point

P_{Π}'. Thereby, the plane Π goes through the real point P and is perpendicular to the light ray r. In addition, the light ray r is defined based on the intersection of the measured real point P and the initial value of the camera position. The intersection of the light ray r and the image plane Π calculates the image point p'" (Steiner, 2011, p. 19).

Based on a perfect camera calibration, the points p and p' (measured and calculated image point), as well as the points P and P' (measured and calculated real points), should be the same. This means the blue and red circles should be superimposed. However, there are several influences in the monoplotting quality, as shown in the next section, which makes the perfect camera calibration difficult (**Figure 4.3**).

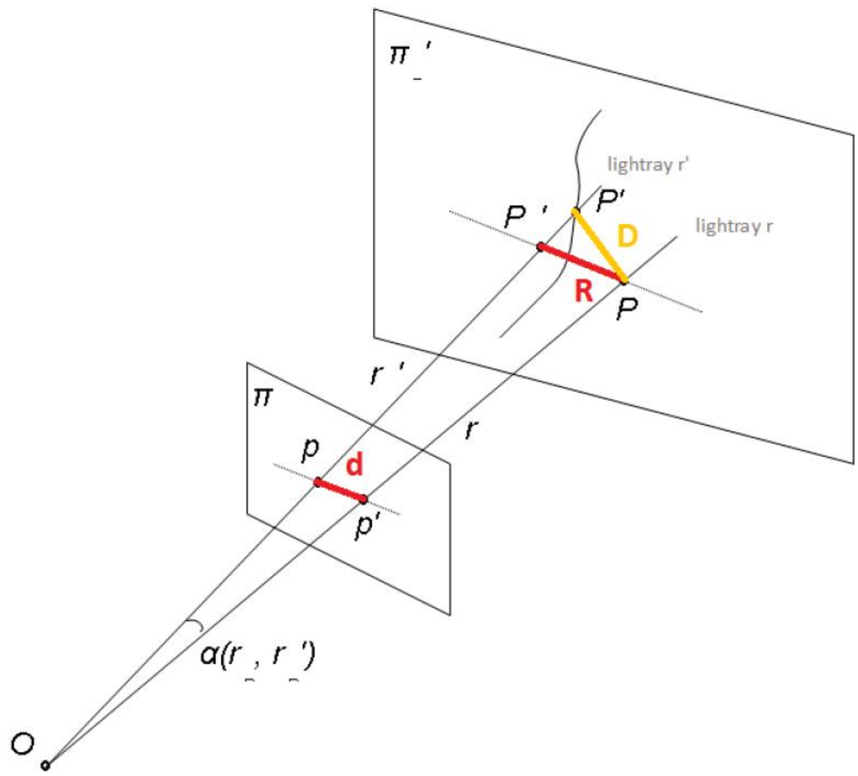

Figure 4.2: Camera calibration principle (Steiner, 2011, p. 19)

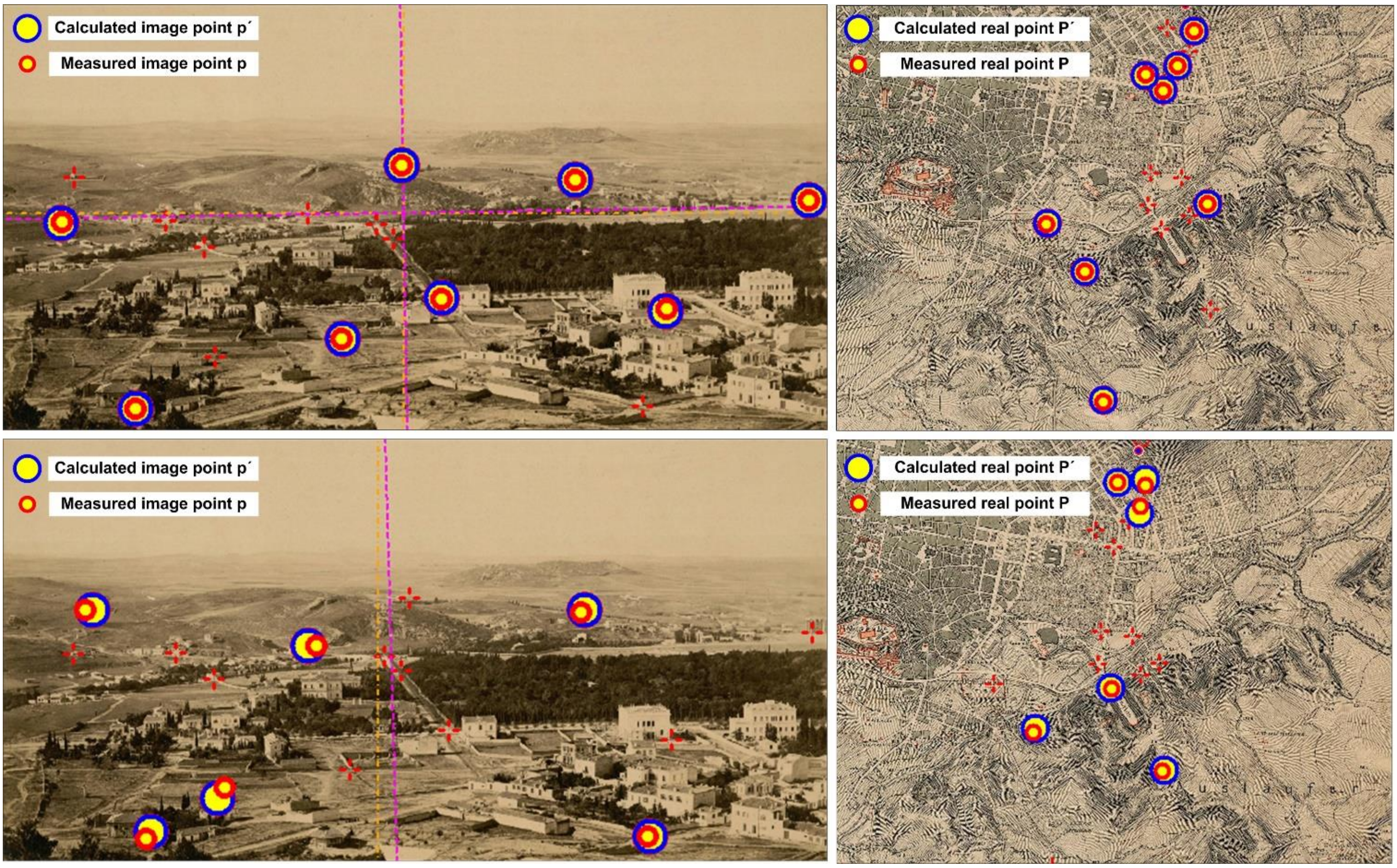

Figure 4.3: Agreement (Up) and disagreement (Down) of the measured and calculated image and real points based on the camera calibration.

When the camera calibration is successfully achieved, the tool generates a model of all the extrinsic and intrinsic camera parameters (see **Table 4.1**), thereby simulating the conditions under which the photograph was taken (Bozzini et al., 2012). Once the photograph and the orthophoto or map are bidirectionally linked, it is possible to digitize directly in the oblique photograph whereby the digitized point, polyline or polygon is stored in real-world coordinates. The above methodology is summarized in **Figure 4.4.**

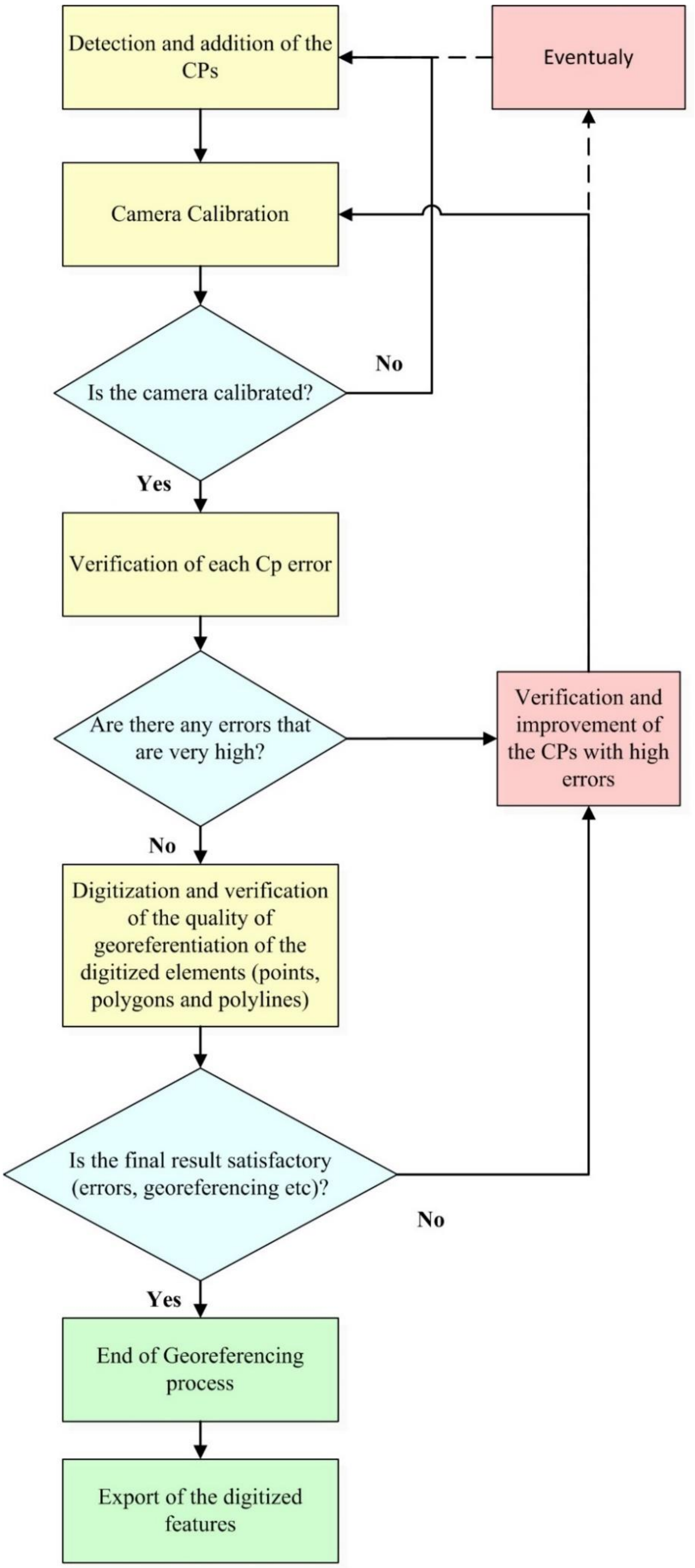

Figure 4.4: Methodological approach (Modified from WSL Monoplotting Tool (2014)).

4.2.3 Influences in Monoplotting quality and error types

Since camera calibration is based on the estimation of CP, the georeferencing (or monoplotting) quality is highly dependent on the accuracy of the defined CP. While it is important to define as many as possible well distributed over the whole image CPs, each of them is dependent on the following factors:

- quality and resolution of the photograph (e.g. lens distortion, film unflatness, etc.)
- accuracy of the topographic map or orthophoto
- accuracy of the DEM
- topographic congruence of the DEM with the orthophoto or topographic map
- on the angle of perspective incidence of the camera light ray with the DEM With a decreasing angle, increases the distance error in the object space, based on the setting of the CPs (Steiner, 2011; Gabellieri & Watkins, 2019)

To minimize these influences, it is advisable to keep the following requirements:

- high spatial resolution of the DEM, with as little distortions as possible, especially in steep areas and morphology similar to the image. To avoid bugs and have a decent processing time, crop the DEM to the area visible in the picture.
- high resolution of the image and orthophoto or map
- high georeferencing accuracy of the orthophoto or map
- completely visible region of interest
- well distinguishable, accurate and stable on the meantime CPs, detectable in both image and orthophoto or map. This includes avoiding:
  - CPs in hidden areas, as the world coordinate for the hidden object, is calculated based on the intersection with the interrupted DEM point, instead of the point
  - CPs that have maintained substantially unaltered morphology, so that the current DEM is similar to the image's height
  - CPs on tops of hills/ridges/terrain breaks where there is a high risk to cause displacement due to long distances
  - uniform distribution of CPs around the region of interest, as well as the whole image (Steiner, 2011; Bozzini et al., 2012; Triglav-Čekada et al., 2014, Stockdale, Bozzini et al., 2015).

The sources of uncertainty mentioned above, adversely and accumulatively affect the precise estimation of CPs, which directly affect camera calibration, forming the resulting errors shown in **Table 4.2**

Error	Unit	Index	Description
Pixel	px	d	The distance between the CP in pixels as defined in the picture and the corresponding point calculated by the camera in the real world
Angle	o	α(rp,rp')	The angle between the line connecting the camera to the CP I the picture and the line connecting the camera with the calculated real coordinates of the correspondent point in the DEM. The best-case corresponds to an angle = 0. **Errors below 0.1 may be considered as very good**
Radius	m	R	The distance from P to PΠ'
World (2D)	m	D	The distance from P to P', 2D projection of the error.
World (3D)	m	D2d	The projection to a horizontal plane, real error distance in 3D

Table 4.2: Types of errors (Steiner, 2011; WSL Monoplotting Tool, 2014)

4.2 Applications

The WSL Monoplotting Toolbox has been used for the assessment of landscape changes (Gabellieri & Watkins, 2019) and the evolution of vegetation cover changes (Stockdale, Bozzini et al., 2015; Bozzini et al., 2012), the reconstruction of historical and real-time natural hazard events (Conedera et al., 2018), glacier morphology (Steiner, 2011; Wiesmann et al.,2012) and for the retrieval and recording of cultural heritage place names (Bozzini et al., 2013). Below some of the aforementioned examples of the usage of the WSL Monoplotting Toolbox are presented thoroughly.

Apropos landscape changes in general, Gabellieri & Watkins (2019) studied how vectorized topographical photographs help in the measurement of land-use changes in the mountainous landscape of Liguria and Trentino in the late nineteenth and twentieth century, by carrying out 3 case studies. The historical photographs were georeferenced using the Regional Technical Map (Carta Tecnica Regionale (CTR) of 2009 and the digital terrain model (DTM) of 2007), both produced by the Liguria Region. For each image, at least nine CPs were identified on the CTR. In the case study of Santo Stefano d'Aveto in north-east Liguria, the digitized polygons from the photograph were compared with the information collected from the Carta Generale degli Stati Sardi di Terraferma of 1852 and the 2015 Land Use Map of Regione Liguria. From the digitization of land uses in the above sources, revealed that due to the rural depopulation and land abandonment, only 27% of the area remains under the same land use (**Figure 4.5**). Regarding the terraced landscapes in the Cinque Terre National Park., after the vectorization of the Carta degli Stati di S. M. Sarda in Terraferma, 1827, a historical postcard (1912) and a current aerial photograph (2016), emerged that in the selected area totalling 75 ha, the area of terraces has decreased from 40 ha in 1833 to 9 ha in 1911 and only 3.4 ha in 2016 (**Figure 4.6**). Subsequently, the case study of the Primiero valley focuses on the flood and the landslide which damaged the town of Mezzano (Trento) in November 1966. The mudslide and the flood vector that occurred from the two photographs that were used were then overlapped with the current vector layer of the Province of Trento. From the composition of the above, it is evident the part of the town covered by the mudslide and the level reached by the River Cismon in the lower valley. The mud flood covered an area of 18 ha, from the Stona stream down the slope to the very centre of the town. Also, the part of the valley which was flooded in 1966 is now built up, mostly with storage buildings (**Figure 4.7**). All the above case studies make apparent the Monoplotting Tool's potential for analyzing historical photographs for measuring small-scale land-use changes.

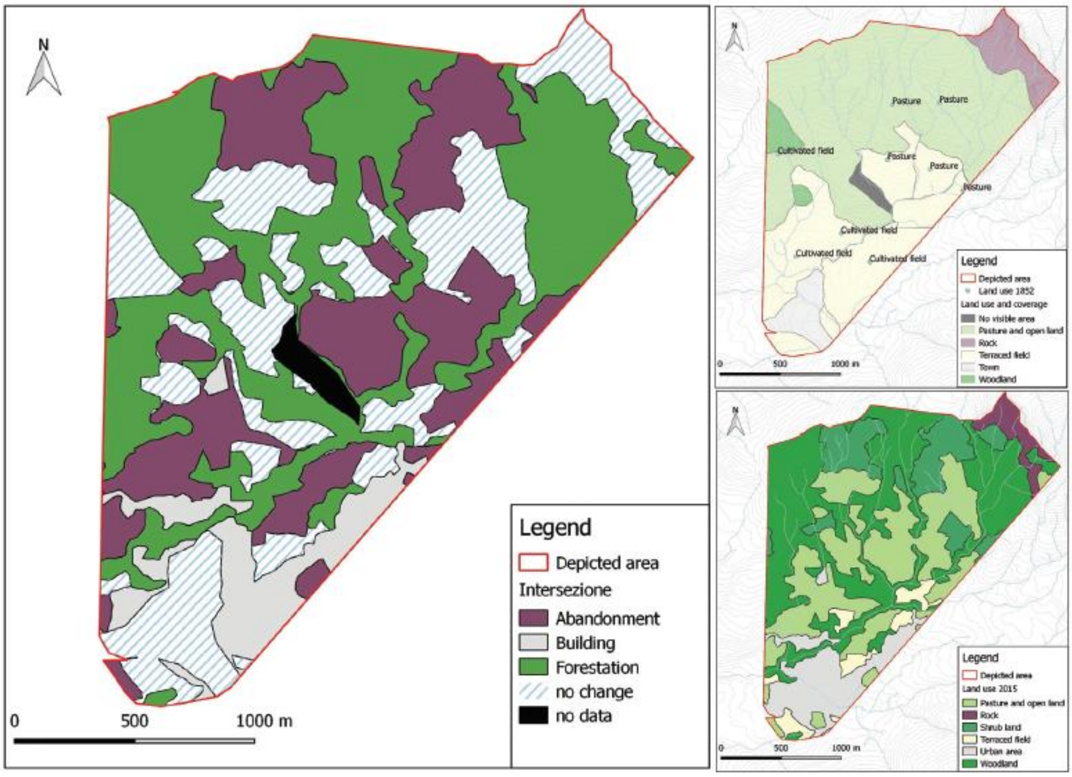

Figure 4.5: Changes in land use and coverage around Santo Stefano d'Aveto from 1889-2015: comparison of the 1889 map and the current Land Use Map of Liguria Region (2015) (Gabellieri & Watkins, 2019, p.8)

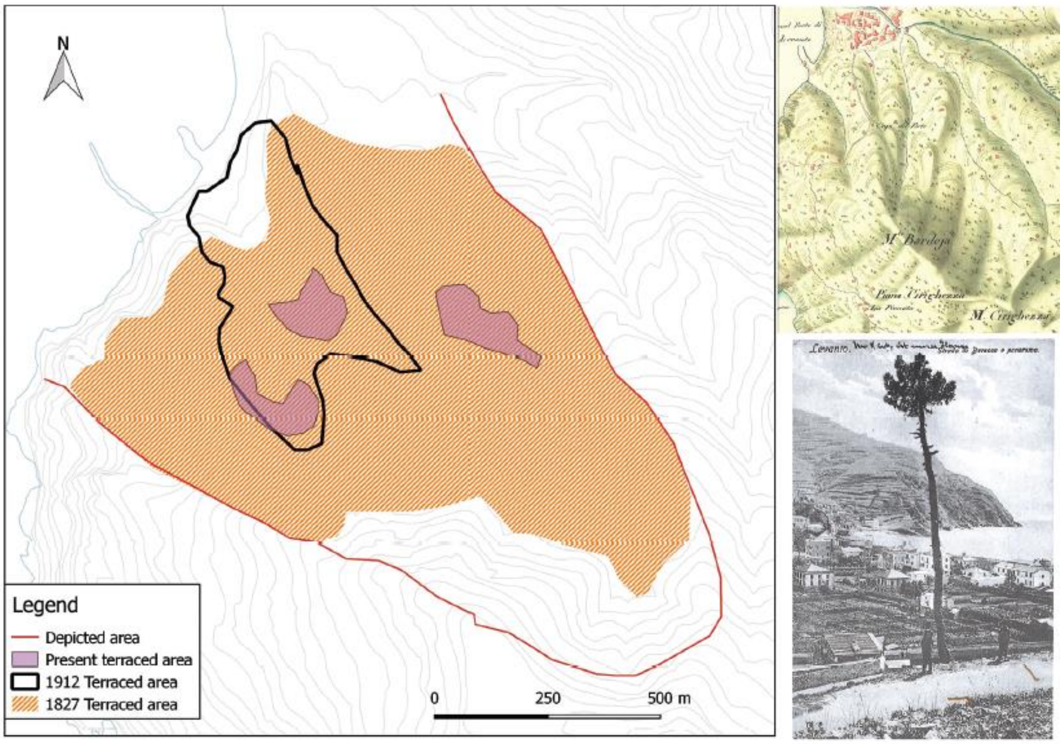

Figure 4.6: Terraced areas in the northern side of Mesco Promontory (Levanto). The map is the result of the vectorisation of historical cartography (Carta degli Stati di S. M. Sarda in Terraferma, 1827), the historical postcard (1912) and current aerial photographs (2016) (Gabellieri & Watkins, 2019, p.10).

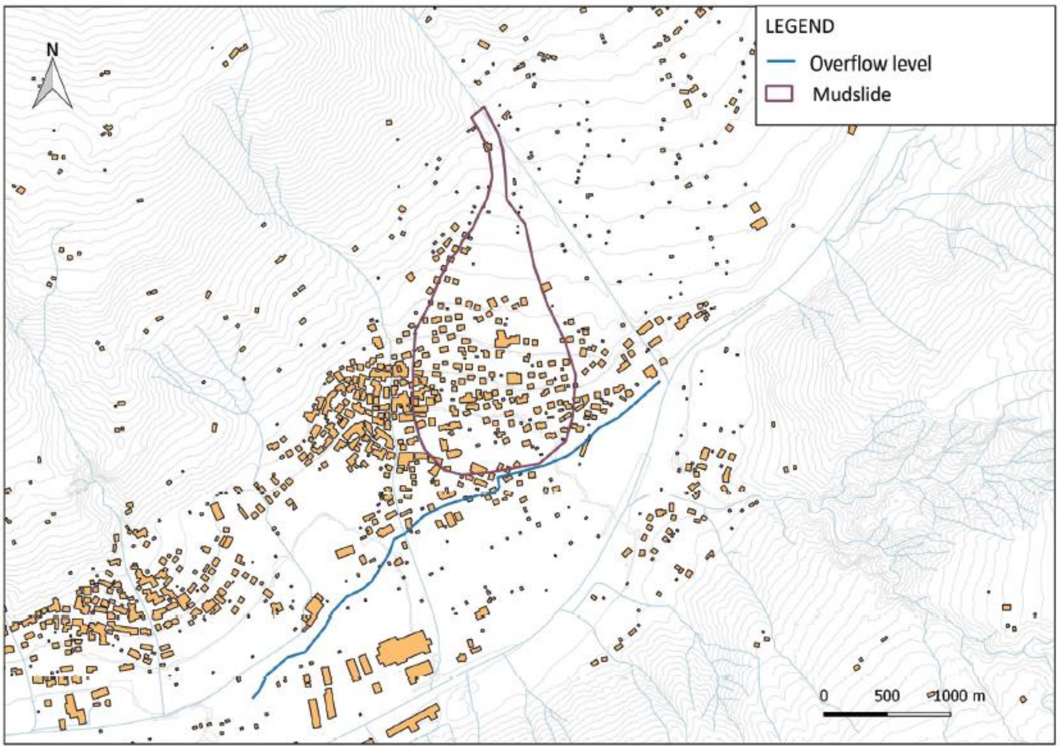

Figure 4.7: Map of the mudslide and flood extension, which affected the town of Mezzano (TN) in 1966. The map is the result of the vectorisation of photographs (Plate IV) using the WSL Monoplotting Tool.

Conedera et al., (2018) in their study, presented the basic components and the application of the WSL Monoplotting tool on selected case studies of natural historical (2) and current (2) damaging events or protection infrastructures (1) in Switzerland. Indicatively, two of the above mentioned examples will are analysed, one natural, historical event and one verifying the efficiency of protection infrastructures. Due to heavy precipitation during the autumn of 1927, several flood events of varying severity took place in southern Switzerland and northern Italy. The worst occurred in Ticino (Switzerland) on Sunday afternoon on September 25, 1927, as a consequence of a long-lasting and robust waterspout above the mountain village of Olivone. This flood is still considered the most damaging natural event of the last century in the region. It destroyed part of the village of Campo Blenio and flooded the plain of Olivone over an area of at least 199,366 m^2 (ArcGIS computation of the perimeter as digitalized with the monoplotting tool), affecting two sawmills and several private buildings. While no fatalities were recorded, the area affected by the flood may be a measure of comparison for protective measures under similar circumstances in the future (**Figure 4.8**).

As mentioned in their study, documenting protection infrastructures during particular events or climatic situations may also be very helpful when assessing their functional capability and reliability in preventing natural events. Snow bridge reliability against avalanche detachment is highly dependent on correct dimensioning of supporting structures. A prerequisite for snow bridge efficiency is that the snow never rises above the supporting area of the structure. When such requirements are not satisfied for a significant part of the snow bridge, avalanches can detach from the exceeding snow cover, damaging the snow bridges located downhill, and threatening the infrastructures in the danger zone. The reliability of the snow bridge can be best assessed under real circumstances during exceptional snow cover conditions. This was the case in Adelboden (Canton Berne, Switzerland) during the heavy snowfalls combined with heavy snow blowing winds that repeatedly occurred in the winter season of 2017/2018, causing partial blanketing of the snow bridges in the upper part of the study area. On January 24 of 2018, 2 days after the end of a massive snowfall event, a helicopter recognition mission was organized, and the snow bridge area was photographed in order to document the blanketed parts. Through the georeferencing process of the photographs, the bridges were digitalized and exported to a GIS file, making it possible to identify the blanketed snow bridge parts, which may fail in their protective function (**Figure 4.9**).

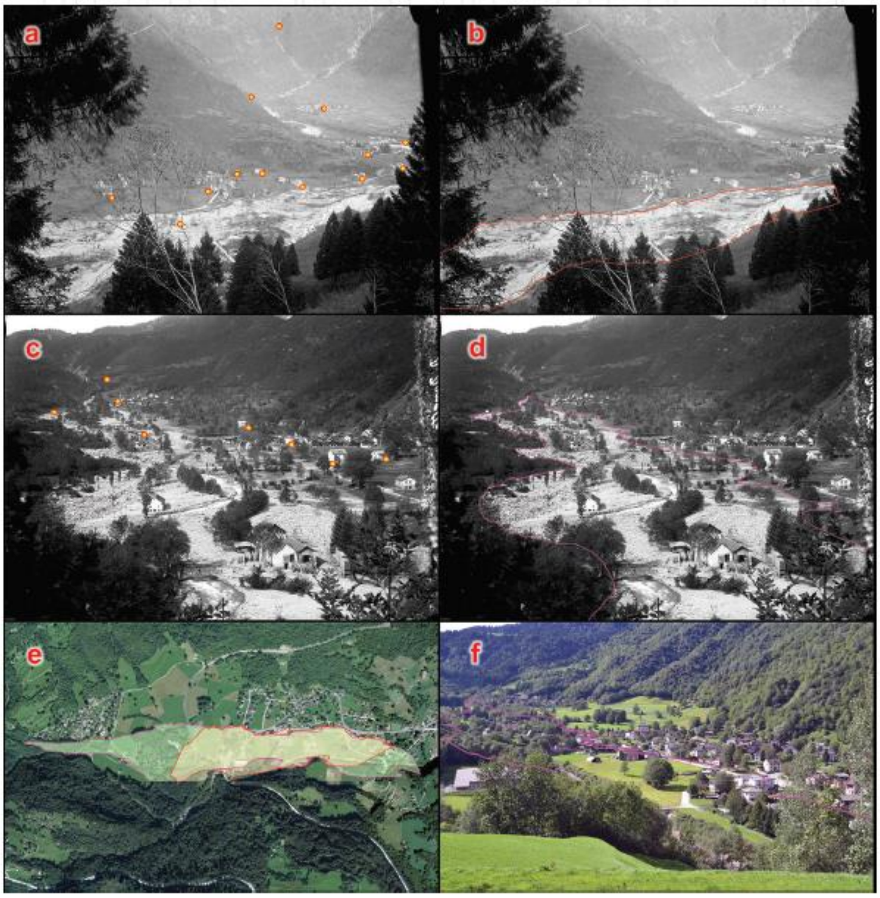

Figure 4.8: Flood of the Sommascona plain (Olivone, 1927). (a+b) original oblique images with CPs. (c+d) Digitalization of the flood contours on the original oblique image. (e) Projection of the digitalized flood contours on the current orthophoto. (f) Projection of the digitalized flood contours on the current oblique terrestrial image (Conedera et al., 2018, p.9)

Figure 4.9: Snow bridges. (a) Original oblique image of the snow bridge constructions with CPs. (b) Digitalization of the snow bridges. (c) Projection of the digitalized bridges on the current orthophoto highlighting in blue the parts covered by snow (Conedera et al., 2018, p.13).

Wiesmann et al. (2012) reconstructed the historical glacier states of Rhonegletscher based on oblique terrestrial photographs. More thoroughly, for the study different available sources of information on documented frontal positions of Rhonegletscher were collected, such as historical photographs, field measurement reports, special maps from field campaign, and official Swiss national maps. The maps and field reports were georeferenced; the glacier boundary was digitized manually and stored in the same spatial database as the states derived from the historic photographs. For some years, the frontal position is available from different sources, which allows a direct comparison of the results to assess the reliability of the various methods. For the time period from 1879 until 2010 (131 years), the reanalyzed length changes are compared to the published values in the Glaciological reports (1881-2011). Following the merge of all available sources of information on frontal positions, one consistent, georeferenced database was created, allowing the interpretation of the length fluctuation over more than 400 years and the visualization of the states over time (**Figure 4.10**). The results showed that the cumulative length change of 1539m deviates by 273m from the values. The evolution of differences between the two cumulative length changes can be roughly divided into two periods with different trends: 1879 until 1910 and 1910 until 2010. Most of the deviation accumulates in the first period.

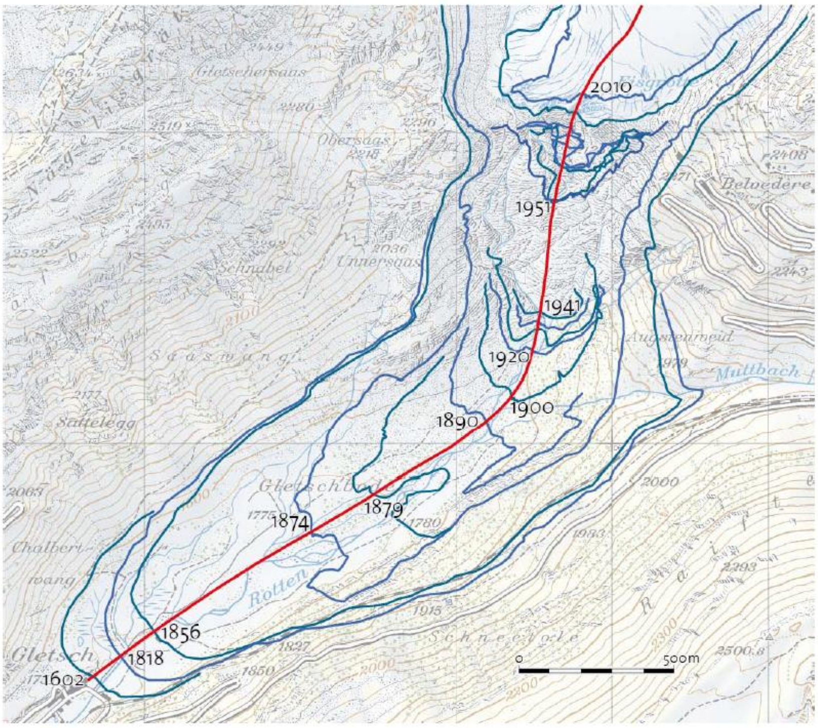

Figure 4.10: Selected historic glacier states of Rhonegletscher between 1602 and 2010 and central profile (red) used for reanalysis of length change (Wiesmann et al. 2012, p. 10)

Bozzini, Conedera & Krebs, (2013) carried out a study concerning the retrieval and recording of the place name cultural heritage through monoplotting. As highlighted in their study traditional place names (toponyms) reflect the immaterial cultural heritage of past land uses, particular characteristics of the territory, landscape related events or inhabitants, as well as relevant cultural and religious background. This legacy is particularly significant in European countries, where the cultural landscape has a rather long history. Most often, traditional place names and their precise localization is non-written and familiar only to old local native persons who experienced the former rural civilization. Due to the above, the aim of this study is the localization of these place names through the synchronization of terrestrial oblique landscape pictures with DEMs and then their exploitation in order to obtain the place name localization from local responders (**Figures 4.11, 4.12, 4.13**). The results showed that monoplotting-assisted set up of historical picture for georeferencing place names are very promising since the responders do not have to face the difficulty of orienting the maps or orthophotographs and usually enjoy the possibility of studying the historical landscape.

Figure 4.11: On a 1:25.000 map, the localization of place names is far from being self-intelligible for ordinary people who are not familiar in reading and orienting maps and may fail in giving precise information. (© Swisstopo)

Figure 4.12: Localization of place names on recent orthophotos may reach a good precision, but many of the sites are hardly recognizable because of the new colonization by forests. (© Swisstopo)

Figure 4.13: Precise localization of place names on a historical terrestrial picture. Most sites are perfectly recognizable in their original shape before the abandonment of traditional land use. (© Swisstopo)

5. Description of the study area and the available datasets

5.1 Study Area

As early as 1834, when Athens has officially declared the capital of the Greek state, the centre of Athens has transformed its social and economic structures, causing significant changes in the urban landscape. Immediately, a significant trend of urbanization was created, resulting in the dawn of the 20th century in the spatial expansion of Athens, while its population is four times larger than in 1860 (Bournova & Dimitropoulou, 2015). Since the end of the 19th century, Athens has changed radically both in terms of its architectural form, as well as with regard to its organization and the way of lifestyle. The city expanded even more, open spaces were occupied by buildings and new roads and infrastructure were created, all leading to a radical change in the face of the city.

In order to measure the land cover changes in Athens utilizing a photograph and a historical map, the study area should be clearly visible in both of the above sources. In this way, after the combined qualitative observation of the photograph and the historical map (See **Appendix Figure A.1**), the study area map was created (**Figure 5.1**). In more detail, the study area is located entirely within the Municipality of Athens, in the Southeast part of it, and encompass Lykavittos, Kolonaki, Ilisia, Zappeio, Odeio, Pagkrati, Neos Kosmos, Stadio, A Nekrotafeio, Gouva, Profitis Ilias and a part of Dourgouti districts. Moreover, the Zappeio, the Greek Parliament as well as a section of the Kolonaki and Pagkrati districts, constitute the eastern part of the historical centre of Athens.

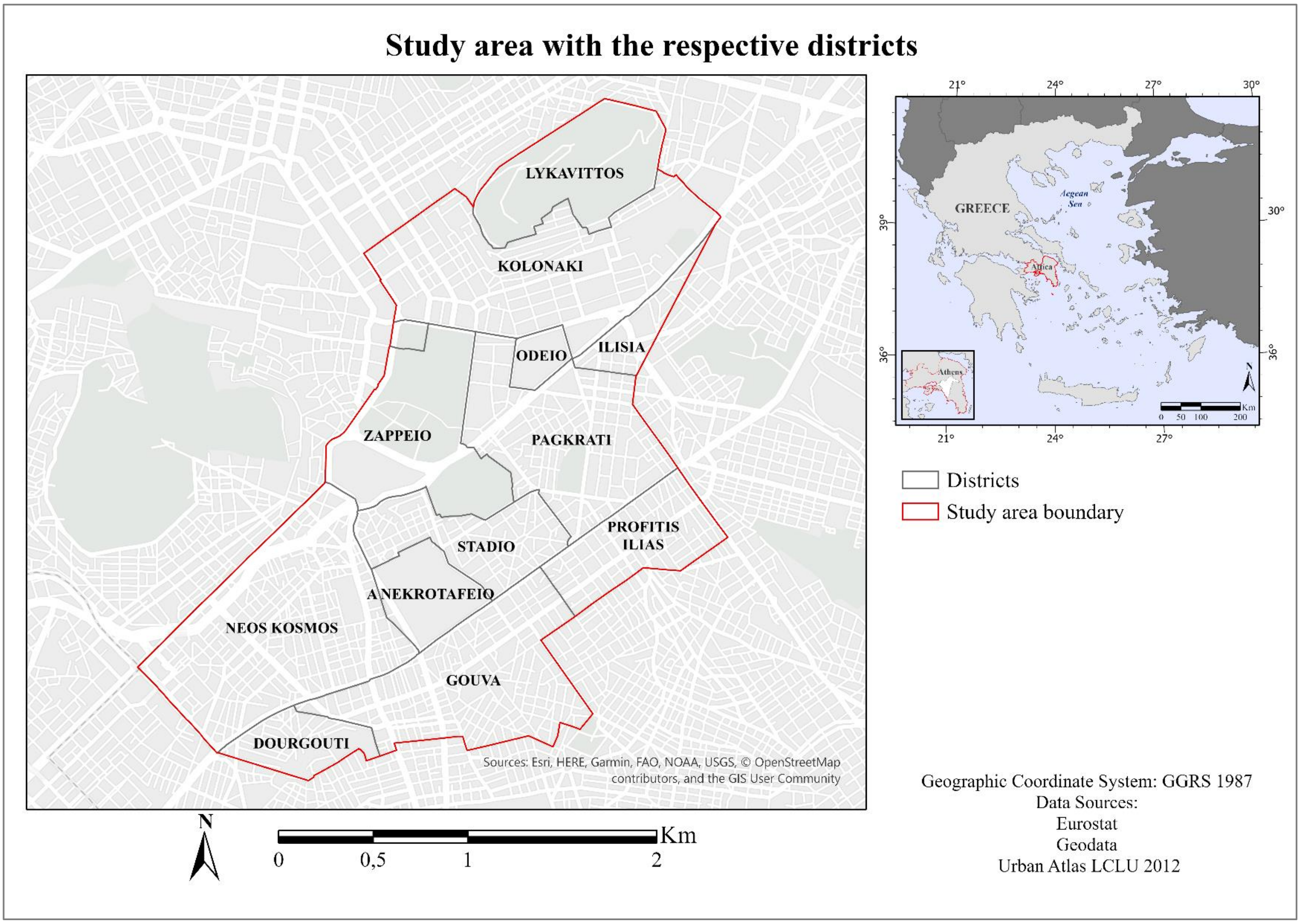

Figure 5.1: Study area

5.2 Datasets

Necessary in all phases of data collection is the knowledge of how each dataset is influenced by different factors that may increase the errors during processing since these errors are cumulatively inherited in the finished product.

5.2.1 Terrestrial photograph

The most important data for the utilization of WSL Monoplotting Toolbox, are terrestrial photographs. For this reason, the photographs used have to achieve the below requirements:

- There should **full coverage of the area of interest** in question presented on the photograph. While archival imagery from old books and magazines is a valuable source of information, sometimes the original photographs are cropped and contain only parts of them, for the better composition of image content.

- **High spatial resolution and contrast**. The photograph's content should represent relevant enough to the purpose of studying details. The spatial resolution depends on the image scale. It should not be neglected that oblique images have a very varied scale and therefore the pixel area on the ground may have of different size and form from one to the other side of the image[11].
- The **date of capture** (year) and ideally the **season** must be known. If it is desirable to study a landscape over time using photographs, the same season of capture will make a comparison between the years easier
- Identification of at least **five** easily recognizable **CPs**. The CPs should be clearly visible and evenly distributed, surrounding the area of interest. Since these points receive ground values from the existing DEM, these points should not be building peaks or their shadows, but features that are close to the ground, such as building edges, road junctions, stable physical characteristics such as cape edges and river confluence. Due to the weak scale in some parts of the photograph, the respective identification may not be ideal, therefore worse accuracy of image orientation can be expected.
- their **capture angle** has to be **nearly orthogonal** to the scene (Steiner, 2011; Triglav-Čekada et al., 2014).

To that end, and given that in this thesis, the photograph is the main subject on which the landscape evolution of Athens will be based, the first step is looking at repositories for the ideal photograph that match the project requirements and the desired historical quality. Maintaining all the above requirements, the search for photographs was quite extensive. It took place both in digital repositories of museums and organizations as well as in books, magazines and analogue archives in the libraries of institutions. The selected photograph for the purposes of this thesis is from the Digitized heritage collections of the libraries of the University of Strasbourg, and more specifically belongs in the "*Photographs of classical archaeology*" collection[12].

[11] The varying scale of the image influences also on the accuracy of the image orientation with the DEM (Steiner, 2011, p.21)
[12] The original photograph can be retrieved from the Digitized heritage collection of the libraries of the University of Strasbourg at: https://docnum.unistra.fr/digital/collection/coll4/id/212

As captured by the photographer Sébah Pascal between 1870 and 1874, with the original title being “Panoramic view of Athens taken from Lycabettus” (**Figure 5.2**), the photograph shows in the foreground the Kolonaki district, on the southwest flank of the Lycabettus hill, under construction. In the background of the photograph the Zappeio (on the right) and Pangrati (on the left) districts, as well as the Panathenaic Stadium on the middle-left part, the excavation of which started between 1869- 1870 (with the repair work for the track been carried out in 1874) are distinguished.

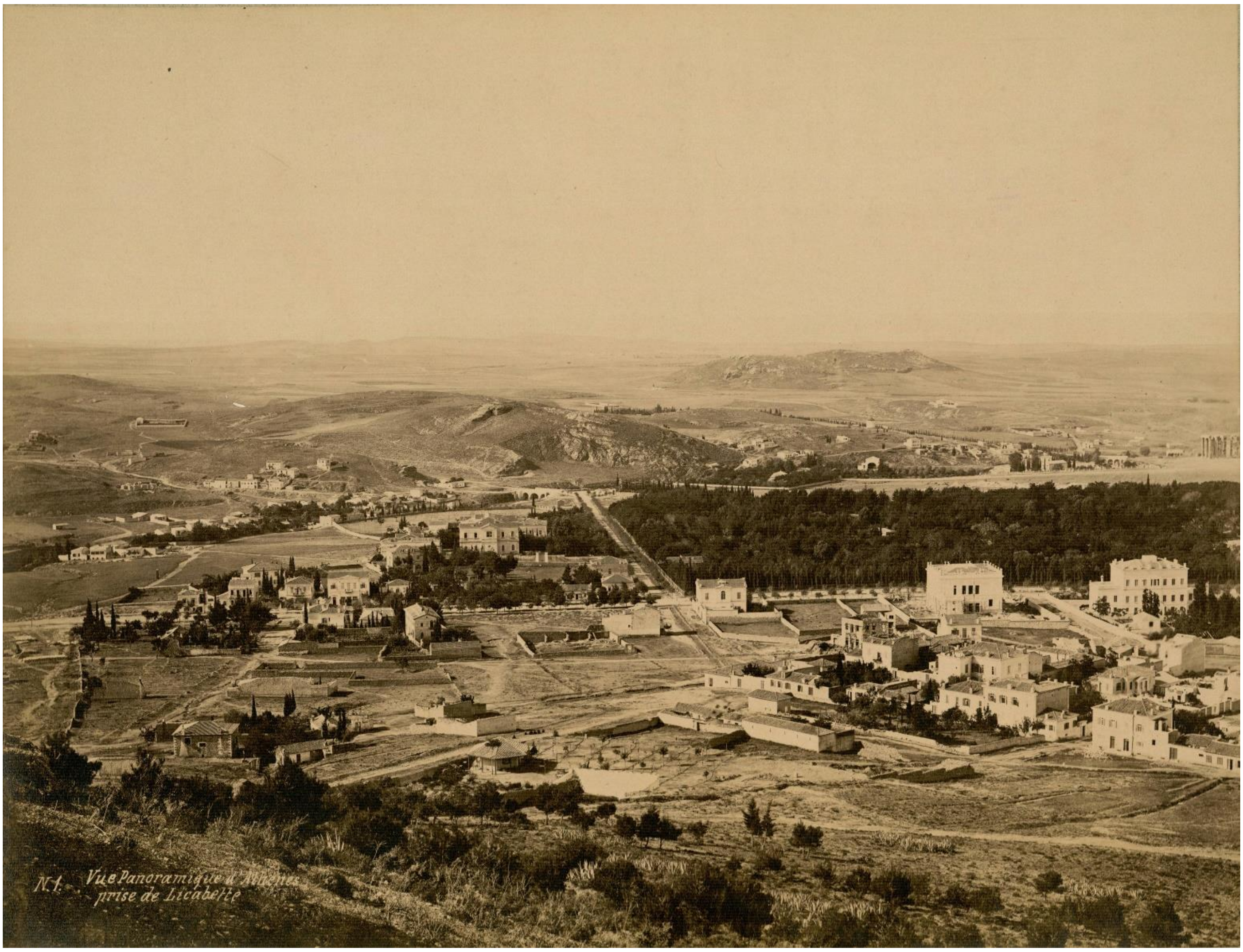

Figure 5.2: Panoramic view of Athens taken from Lycabettus (Sébah Pascal, Between 1870 and 1874)

Concerning the physical description of the evidence, the photograph is mounted on cardboard: albumen paper, from negative on collodion glass, with size 6.1 x 34.1 cm, the title "N.1. Panoramic view of Athens taken from Lycabettus” is written on the negative, and appears in white lettering at the bottom left of the positive proof (NUMiSTRAL, 2009).

5.2.2 Topographic Map

Historical maps often contain a wealth of information retained by no other written source, extending the examination of humans' environmental impact back before the advent of photography and satellite imagery. As in this case, maps can confirm the position of places and settlements as well as physical features that have been modified or even erased by human development (Rumsey & Williams, 2002). A researcher's first issue is the existence of appropriate maps where the study area will be clearly visible, containing useful information and the date of the map not being far from the time period studied (Siebert, 2000). In addition, the analysis of the map should be high in order to achieve an accurate georeferencing, upon which further processes are going to take place.

Athens, as the capital of the Greek state, has been mapped many times over the centuries, in greater or lesser detail. In this case, maps depicting the centre of Athens were searched near the time of the photograph, i.e. close to 1870-1874. For this purpose, the Ernst Curtius & Johann A. Kaupert detailed topographic maps of Attica, "*Karten von Attika*, 1881" were considered appropriate[13].

The production of the below maps of Attica was accomplished thanks to the German historian, surveyor, archaeologist and philhellene Ernst Curtius. In charge of mapping Attica, which took two decades to complete (1875-1894), was a team of scientists from the Topographic Service of the Prussian army led by Johann A. Kaupert. The final form of the project included 24 sheets (dimensions 54×58 cm) with a scale of 1:25,000, 4 sheets on a scale of 1:12.500, 11 smaller sheets (28×29 cm) with a scale of 1:100,000, a large sheet (81×103 cm) with a map of the whole of Attica on a scale of 1:100,000 and lastly, a massive 280-page volume with explanatory texts and an index (**Table 5.1, Figure 5.3**). In their printing, these maps have mainly three to four colours. Black is used for geographical borders, buildings, roads, current names, altitudes etc. Sepia is attributed to the terrain and blue to the sea, lakes and the flow of torrents. Lastly, red is used to identify ancient ruins or traces, historical toponyms etc.

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[13] The Maps of Attica can be retrieved from the digital collection of Heidelberg's university through the following link: https://doi.org/10.11588/diglit.776#0001

1:12500	1:25000				1:100000
I. Athen und Umgebung	V. Kephisia	X. Perati	XVI. Laurion	XXI. Salamis	Übersichtskarte von Attika & Übersichtskarte von Attika (gesamt)
Ia. Alt-Athen mit seinen nachweislichen Denkmälern, Platzen und Verkehrstrassen	VI. Pyrgos	XI. Porto-Raphti	XVII. Olympos	XXIV. Phyle	Laurion
II./IIa. Die Halbinsel Peiraieus	VII. Spata	XII. Pentelikon	XVIII. Drakonera	XXIV. Phyle	Spata
III. Athen – Peiraieus	VIII. Vari	XIII. Markópulo	XIX. Marathon	XXV. Megalo Vuno	Marathon
IV. Athen – Hymettos	IX. Raphina	XIV./XV. Cap Sunion	XX. Tatoi	XXVI. Eleusis	Kalamos

Table 5.1: Overview of the maps contained in "Karten von Attika", in their respective scales (Curtius & Kaupert, 1903)

Through the study of the above topographic maps, it is apparent that they can be a vital source of historical geographic information. The information they bear on the natural and man-made environment, as well as archaeological and folklore information in the form of ruins and toponyms, respectively, can form the basis of the evolution of the landscape study.

As mentioned previously, the map of Athens and its suburban from 1881 (*I. Athen und Umgebung*) from "*Karten von Attika"* was used for this thesis, which is a high but not known topographic accuracy map, including geophysical elements (some of which no longer exist) settlements, streets, place names and archaeological information **(see Appendix Figure A.2**). The map is chosen as the reference world map instead of an orthophoto, as the changes in the landscape are so pronounced that they would not allow the accurate identification of CPs.

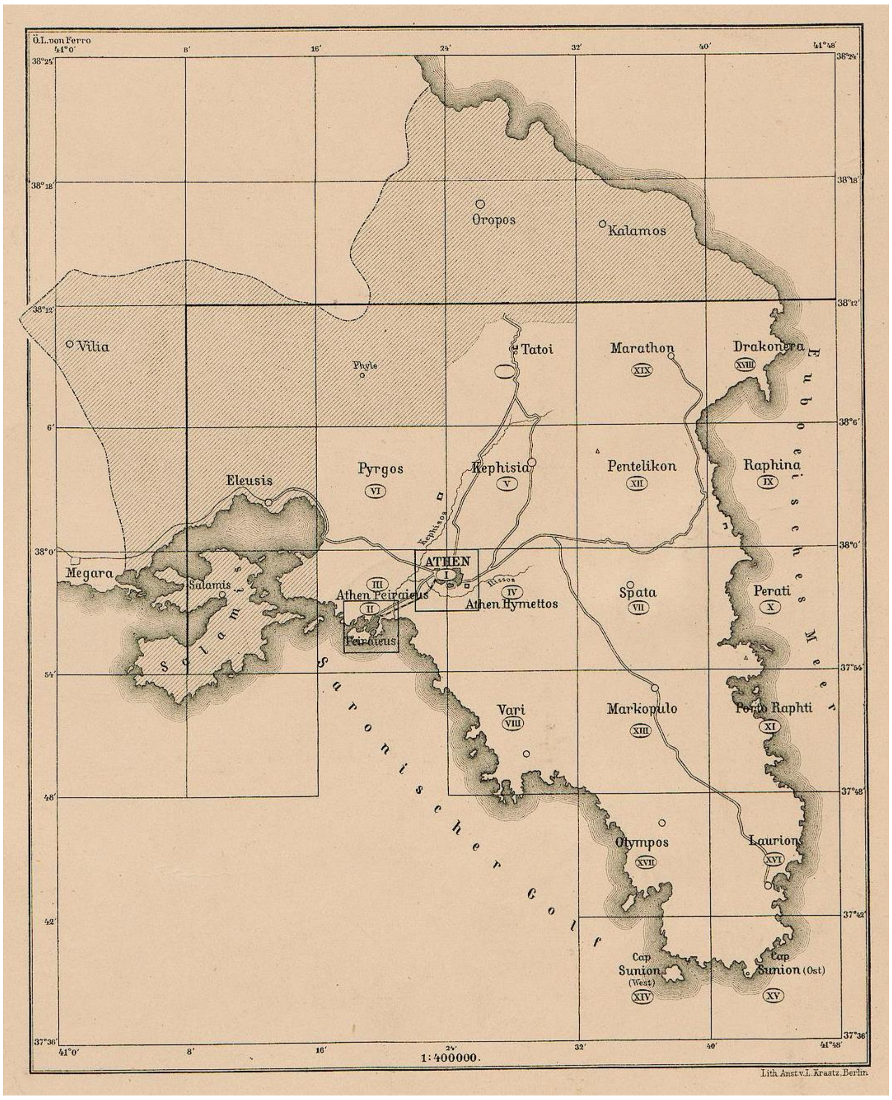

Figure 5.3: Map of all the included sheets (Curtius & Kaupert, 1903)

5.2.3 Digital Elevation Model/DEM

As mentioned previously, it would have been ideal to have a DEM at the same time period as the topographic map used, in order to exclude topographic differences between the two of them. However, as a relevant DEM was not available, the DEM of the Hellenic Cadaster, covering all of Greece, was chosen to be used. The DEM was created using automated photogrammetric methods from aerial Photographs of an approximate scale 1:25000 in the period 2007-2009 with a spatial resolution of 5 meters. Each DEM tile is a separate image file with dimensions of 4.6 Km x 3.6 Km on the ground, following the distribution of Map Sheets of a 1:5000 scale at GGRS87 projection system.

5.2.4 Urban Atlas Dataset[14]

The European Urban Atlas (EUA), which is part of the Copernicus Land Monitoring Service, provides reliable, inter-comparable, high-resolution land use/cover maps in 1:10000 scale. Those land cover maps cover more than 300 Large[15] Urban Areas (LUA) and their surroundings for the 2006 reference year in European Union (EU) member states and over 800 Functional[16] Urban Area (FUA) and their surroundings in EEA39 (European Economic Area) countries for the 2012 (EEA, 2017).

The Urban Atlas (UA) 2012 Dataset, which will be used in this thesis, is constructed based on the combination of (statistical) image classification and visual interpretation of Very High Resolution (VHR) satellite imagery. Multispectral SPOT 5 & 6 and Formosat-2 pan-sharpened imagery with a 2 to 2.5m spatial resolution is used as input data, with a temporal extent from 2011 to 2013. The built-up classes are combined with density information on the level of sealed soil derived from the High-Resolution Layer imperviousness to provide more detail in the density of the urban fabric. Finally, the UA product is complemented and enriched with functional information (road network, services, utilities, etc.) using ancillary data sources such as local city maps or online map services. (European Union, 2016). **Table 2** shows the main Corine Classes of UA, with their respective characteristics as to the Minimum Mapping Unit (MMU) and the accuracy.

	CORINE Classes	Levels provided	MMU	Thematic Accuracy	Positional Pixel Accuracy
Urban	1. Artificial surfaces	I - IV	0.25 ha	>= 85%	<+/- 5 m
Rural	2. Agricultural areas 3. Natural and semi-natural areas 4. Wetlands 5. Water	I-II	1 ha	>= 80%	<+/- 5 m

Table 5.2: Product Accuracies (European Union, 2016)

[14] The Urban Atlas Service is available at https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012?tab=mapview

[15] Areas with more than 100.000 inhabitants as defined by the Urban Audit. The Urban Audit, recently renamed as 'City Statistics' (http://ec.europa.eu/eurostat/web/cities/overview), is a Eurostat program through which a range of statistical information and indicators are published on a regular basis for cities in the EU, Norway, Switzerland and Turkey.

[16] Areas with more than 50.000 inhabitants.

As Bossard, Feranec & Otahel (2000) explained in the CORINE land cover technical guide, when the MMU is defined, one should consider that final land cover of an area is the combination of surfaces which to a certain degree are homogeneous/heterogeneous, whatever the scale is. In addition irrespective of their processing, satellite data do not provide a representation of the actual land cover situation, nor can land cover be mapped in all of its complexity (Poulicos & Chrysoulakis, 2011).

Urban areas boundaries in UA are specified as in Urban Audit, with cities defined by considering the Larger Urban Zone (LUZ). The LUZ represents the functional urban, not just the city core and often covers an area significantly larger than what is usually considered a metropolitan area (Prastacos, Lagarias & Chrysoulakis, 2017).

In the case of Athens, the urban Atlas boundaries cover more than just the core of the city, but the administrative boundaries of the Attica region, an area by far exceeding what is referred to as Athens Metropolitan Area (**Figure 5.4).**

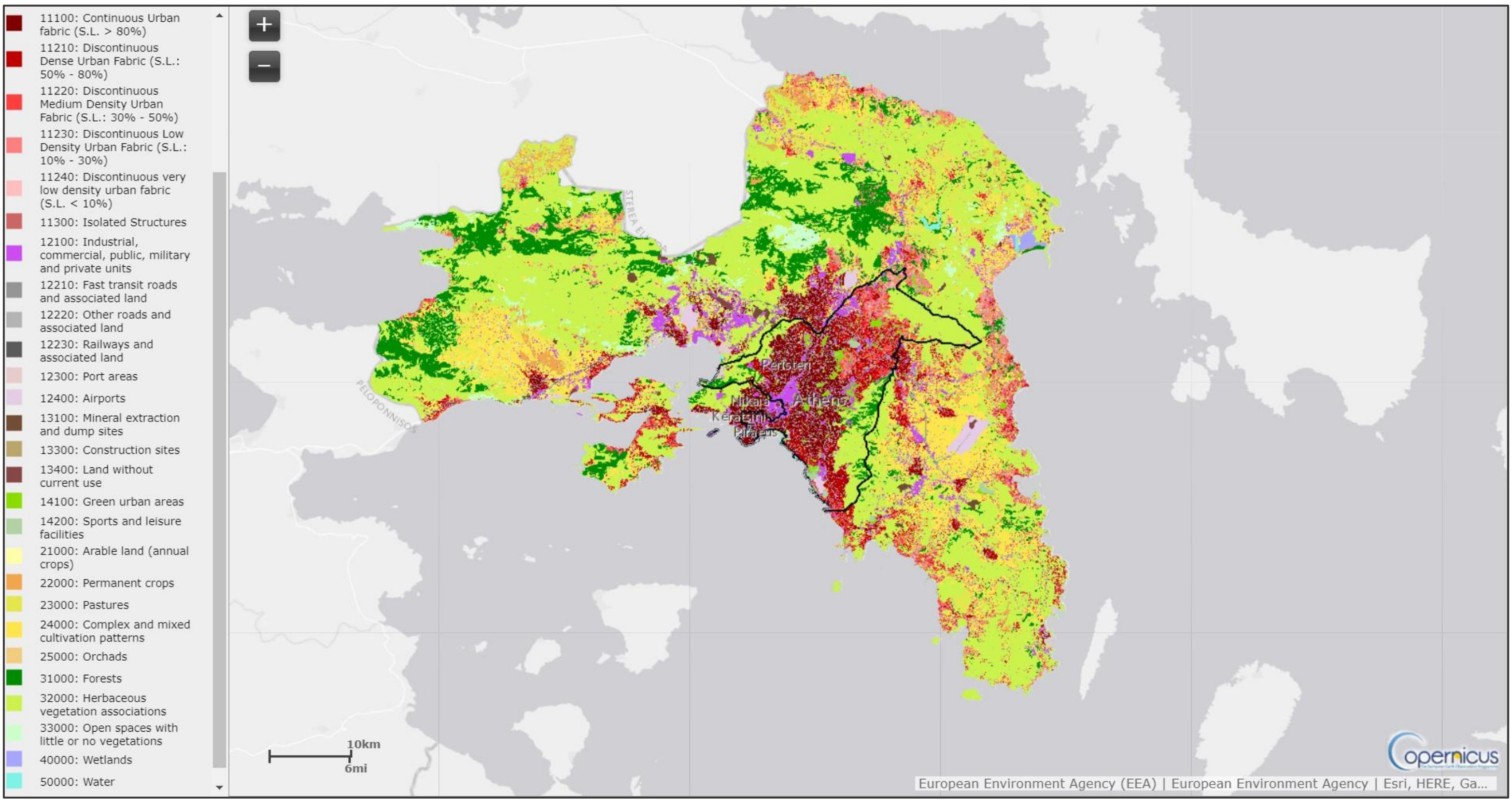

Figure 5.4: Urban Atlas of Attica region (Copernicus, 2020)

5.2.5 Additional Data

For the precise identification of entities, so as to use them as CPs later, an engraving was used, derived from a series of photos published by Baedeker in several editions of the "*Guides to Greece*" (Baedeker, 1883) (see **Appendix Figure A.3**). As seen in **Figure 5.5,** the below part of the engraving is a faithful copy of the photograph of Sébah Pascal, the information is rendered with grayscale, and inscriptions of the most important monuments and physical elements of Athens and its suburban are included in its perimeter as well. In addition, Google Maps and a modern photograph of the area were used (**Figure 5.6**).

A series of vector layers were also used for the production of the final maps. More specifically, the polygon layer of the world countries by Eurostat, as well as the polygon layer of the Boundaries of Districts of the Municipality of Athens by Geodata was used (Eurostat, 2018, Geodata, 2019).

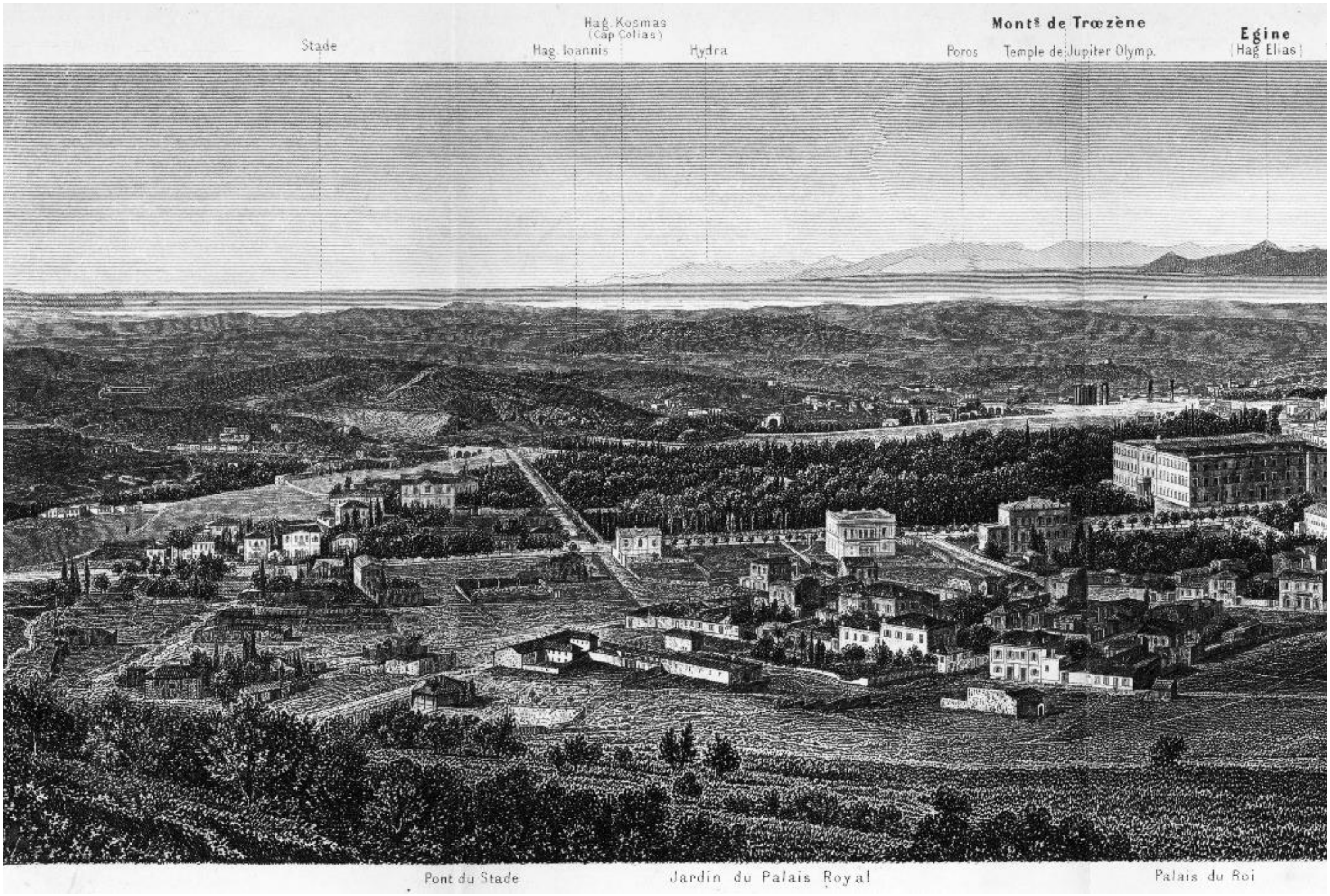

Figure 5.5: Part of the original engraving of the Panoramic view of Athens (Baedeker, 1883)

Figure 5.6: Modern photographic view

6. Methodology

6.1 Investigating the photograph's content

The use of representation in historical GIS often involves painstaking procedures in order to reconstruct the location of settlements and monuments, administrative boundaries and geographical features as they existed in the past (O'Neill, (n.d)).

Knowing the visual vocabulary for reading photographs (see section 2.2) through which information is communicated, helps professionals or amateur users of archives explore and interpret photographs. That exploration and interpretation could be better attributed as photointerpretation, consisting of a series of phases in which the content of the photograph is investigated to draw correct conclusions about it (**Figure 6.1**).

Figure 6.1: Photointerpretation phases

More explicitly:

- The “**Processing**” phase includes all those techniques designed to improve the image medium, to facilitate the next steps as well as an evaluation of the photograph.

In this case, it is not necessary to follow any image enhancement processing since the high clarity of the photograph enables the detection and identification of a significant number of physical and anthropogenic entities. Whether Photography is going to be used as a primary or secondary source of information, an essential step in the research process is its evaluation. During the evaluation of a photograph, it is crucial to detect the phenomena of deceptiveness. That is because while the camera lens views the world impartially, the photographer constantly judges, deciding what and how to photograph communicating the desired message[17] (Library of the Congress, (n.d.)).

For that case, there are some essential evaluation criteria for all visual sources:

- Author/Authority: Who created the original photograph? What is his or her affiliation? What is his or her relationship to the information contained in the source? What particular way of seeing does it offer? Whose representation is it?
- Audience and Purpose: Who is the intended audience? Why was the item created? What issues are raised by reproducing such photographs in geographical studies?
- Accuracy and Completeness: Is the evidence reliable? Are the important points covered? How does the source compare to other similar sources? What then happened to the photo? How did it end up in the archive? Does that matter?
- Footnotes and Documentation: Are the author's sources clearly identified with complete citations to allow you to find the original source yourself

[17] For further investigation of the use of the photographs as Illustrations in Human Geography see Rose, G. (2008). Using photographs as illustrations in human geography. Journal of Geography in Higher Education, 32(1), 151-160.

- Perspective and Bias: How do the author's bias and perspective inform the arguments and evidence presented? (Zinkham, 2006; Rose, 2008; NYU Libraries, 2020a[18]).

In addition to the above basic criteria, there are some more specific when utilizing photographs:

- Where was the image first displayed or published?
- Do the angles, lighting, or cropping suggest a particular bias? (NYU Libraries, 2020a[19])

Although in this case, the photograph used does not fall under phenomena of deceptiveness, in the use of photographs for sociological research and human geography, deceptiveness is very often identified, since those photographs are carrying particular visions of social relations (Photography as representation, evocation, material culture).

- In the “**Detection**” the location of useful information is established, while in the "**Recognition**" phase, the characteristics of the object (size, shape) are observed, and according to them, an object is identified as known or unknown.
- During "**Interpretation and Identification**" the object identified is classified under the name of a particular group, using the aforementioned features as well as additional knowledge through other sources of information. To gain knowledge about an entity of a photograph, it is crucial to use as many as possible diverse and accurate sources of information such as maps, etchings, written recordings and other photographs during the same or near time period of the photograph used.
- In the “**Classification**” phase, the entities are grouped into categories according to a range of qualitative and/or quantitative characteristics.
- Lastly, through the “**Knowledge**” phase, the observations and results of the previous steps are drawn, leading to conclusions. Following this step, which is the last in the interpretative phase, the conclusions drawn can be safely used for

[18] The following questions were adapted from The Information-Literate Historian by Jenny L. Presnell (New York: Oxford University Press, 2007)

[19] Adapted from *A Pocket Guide to Writing in History*, 6th ed. by Mary Lynn Rampolla (New York: Bedford/St. Martin's, 2009).

further processing of the image medium (Zinkham, 2006; Perakis, Moysiadis & Faraslis, 2015, p.44).

Following the above photointerpretative steps and through the use of additional material such as the Curtius Map of Athens (Section 5.2.2) and the Baedekers engraving (Section 5.2.4), it was possible to accurately identify existing and time-lost entities as well as the identification of the relevant position from where the photograph was taken.

6.2 Preprocessing of data, georeferencing and digitization of topographic map

6.2.1 Preprocessing of data

The pre-processing mainly concerns the additional data. More specifically, the DEM tile used was clipped at the border of Curtius Map to limit its extent, as well as the gaps contained, were filled using the Fill function in ArcGIS PRO.

The world countries by Eurostat used in the embedded map of Greece were clipped to Greece and its neighbouring countries and then transformed from the World Geodetic System (WGS84) to Greek Geodetic Reference System 1987 (GGRS87).

Lastly, the polygon layer of the Boundaries of Districts of the Municipality of Athens was clipped in the study area that contains Lykavittos, Kolonaki, Ilisia, Zappeio, Odeio, Pagkrati, Neos Kosmos, Stadio, A Nekrotafeio, Gouva, Profitis Ilias and a part of Dourgouti district.

6.2.2 Georeferencing and digitization of topographic map

Maps and more specifically large-scale topographic maps constitute powerful sources of urban history (Rumsey & Williams, 2002). Maps often hold information retained by no other written source, such as place-names, boundaries, and physical features that have been modified or erased by modern development. Also, a historical map is of great assistance when “reading” photographs, as it can be viewed as a data structure that preserves three-dimensional geometrical and topological entities. By adding large scale historical map to a GIS, its utility is increased, as the historical entities can be used together with modern ones in order to designate the evolving appearance of landscape features (Rumsey & Williams, 2002; Hu,2010).

The use of historical maps in the analysis of the spatial information in a GIS requires that the maps are georeferenced. **Geo-referencing** is the process by which map (or photograph) coordinates are converted into real-world coordinates on a projection system. This allows distances and areas to be calculated and data from different sources to be integrated (Gregory, 2003).

While georeferencing can be considered relatively easy using modern maps, where coordinate grids are shown, and projection information is readily available, it can be a difficult task when using historical maps. In historical maps, often a coordinate grid is not provided, or it displays errors. This issue can be resolved by using a selection of CPs, i.e. points on the source map and their corresponding actual location, either by assigning geographical coordinates to each point or by linking each point to its modern, on an accurate digital map[20]. Once the CPs are in place, a mathematical algorithm is applied, to warp the original map to fit the chosen map projection as nearly as possible (Gregory, 2003).

Before using a historical map, one must consider that as a digital representation of a paper map has very rarely equal quality to the original map, and inevitably, that causes errors or inaccuracy. Apart from that, it is important to distinguish and minimize the locational errors during georeferencing and digitizing, since these errors are cumulatively inherited in the finished product.

In more detail for this thesis, for the georeferencing of Curtius Topographic map of Athens and its surroundings, the insertion of points with known coordinate system was selected. In more detail, the fixed points between the historical map and the modern map were initially identified. Of these, the ten being more accurately identified were selected, and through the option to create maps offered by Google Maps ("My maps" option), those spots were added in a new layer. After completing the addition of the 10 points, which are in their majority churches (9 churches and 1 in the Zappeio Mansion), they were exported as a Keyhole Markup Language (KML) file.

[20] Appropriate features can be unchanged by the passage of time points, such as churches, lighthouses, settlements and crossroads.

Then, the KML was imported to ArcGIS 10.2, where from the set of columns, only the name of the points were kept, followed by the conversion of the coordinate system from WGS84 to GGRS87. In a new project in ArcGIS, the georeferenced map of Athens and the CPs are imported. For the georeferencing of the map, it is also necessary to activate the Georeference Toolbar, as well as the Snapping Tolerance option. Afterwards, through the "Add Control Point" option, the CPs are connected sequentially with the corresponding ones on the map. Finally, through the "Rectify" option on the Geoprocessing tab and with the selection of "Spline" technique, the map is interpolated using a two-dimensional minimum curvature, resulting in a smooth surface that passes precisely through the input CPs (**Figure 6.2**).

The final Root-Mean-Square Error (RMSE) of the georeferencing was 9.8 meters. If during the above georeferencing all the depicted churches of the Curtius map were chosen as CPs s, then it is estimated that the final RMSE would have been considerably smaller. Despite this georeferencing error, it should be noted that the map might contain inherent errors in both the imaging of the entities and in their exact location.

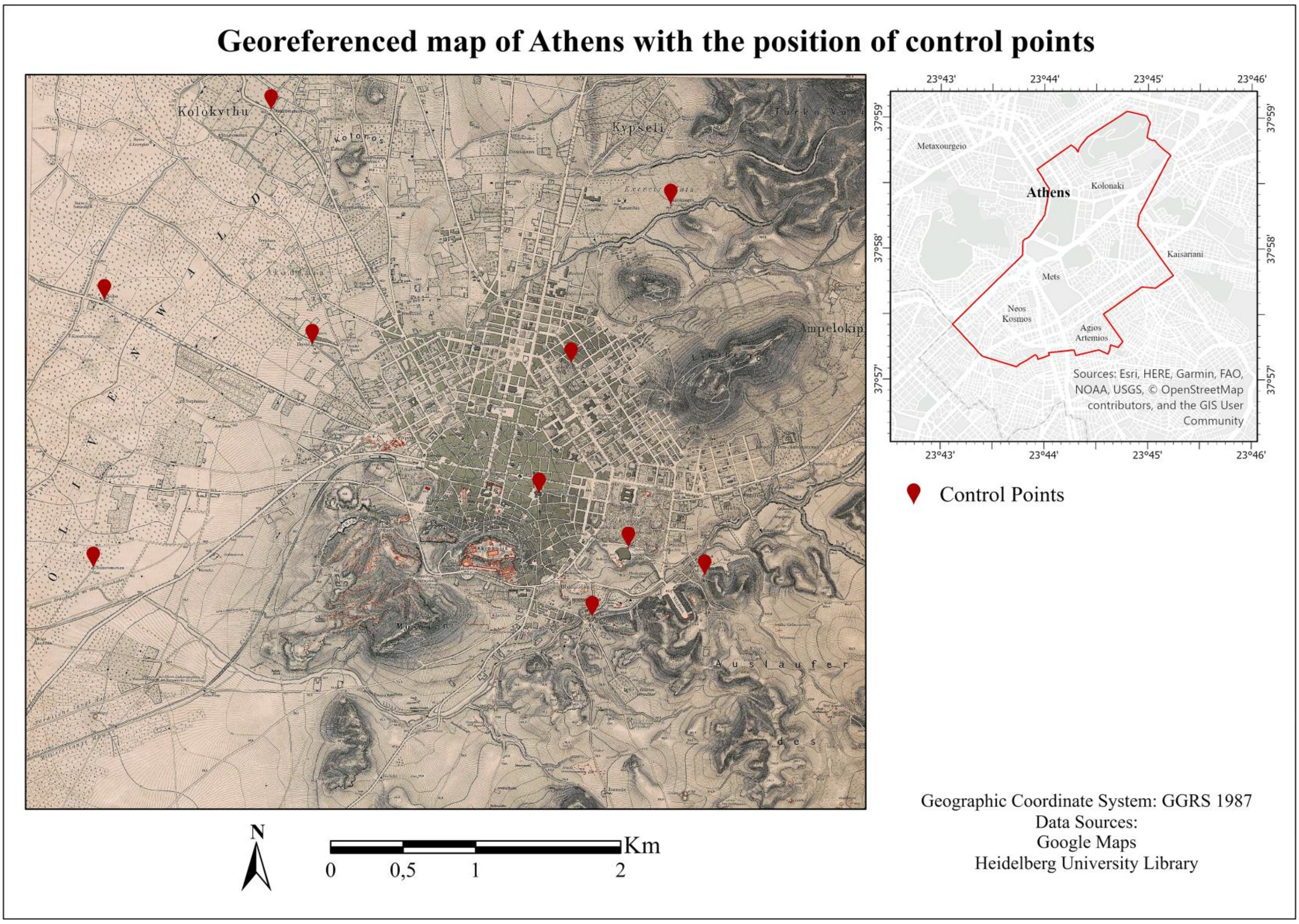

Figure 6.2: Georeferenced map of Athens with the positions of CPs

While it could be considered sufficient to just georeference the historical map and only visual overlay the results to it, it was deemed to be appropriate to further digitize the desired parts of it, to use them as reference data, and to compare them with existing land covers. This includes that for the study area, all entities contained in the map would be digitized at the respective categories of land cover. Digitization of entities as points, lines and polygons is a far more time-consuming process than georeferencing but increases their processing and analysis capabilities in a GIS (Rumsey& Williams, 2002).

In more detail, for the comparison of historical land covers with the Urban Atlas 2012, both must have similar thematic categories. To this end, the map was digitized based on the following categories[21]:

- **Built Environment [1],** in which are included artificial surfaces for residential use and house ruins
- **Green Urban Areas [2],** in which except public green areas for predominantly recreational use such as gardens, parks, and cemeteries, were also added the house gardens
- **Industrial, commercial, public, military, archaeological, sport and private units [3]**
- **Roads and associated land [4]**
- **Open spaces with little or no vegetation [5]**
- **Water [6],** including rivers as well as seasonal streams leading to them

After the creation of a new polygonal Shapefile, the entities were digitized separately, and for each of them in a new column, the corresponded category code from the above classification was included.

6.3 Monoplotting Processing[22]

As mentioned previously, there are many influences on the monoplotting quality that cause errors in the final products (Section 4.2.3). Apart from these, it is essential that the orthophoto or topographic map used, have the same time period as the DEM, as corresponding data decrease errors and increase the overall accuracy. This is not happening in the present study, as the DEM is produced from 2007-2009 orthophotos. Therefore there are significant differences in the topography of the area. To reach the overall goal of reconstructing the historical land cover of Athens using a single terrestrial historical photograph, the first step is the georeferencing of that photograph. As mentioned above, this will be done using the WSL Monoplotting Toolbox (Chapter 4) with the additional required data (Section 4.2.1).

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[21] These categories, as well as the colours used for the maps, were based on the Urban Atlas counterparts (Section 5.2.4) with some modifications due to the scale of the map.

[22] The following data processing is based on the short methodological tutorial: WSL Monoplotting Tool (2014). Landscape study with Historical Photographs through Monoplotting: Short Tutorial. 27-28 June 2014, Corzoneso, Switzerland

First, it is necessary to create a new project file (.gis) in the environment of the WSL Monoplotting Toolbox, where the terrestrial photograph, the map and the DEM are going to be imported in the respective tabs (**Figure 6.3 & 6.4**). It is recommended to use a .jpg photograph format and a .tiff format map, to provide the system with zoom pyramids (if existing) enabling a quick image handling.

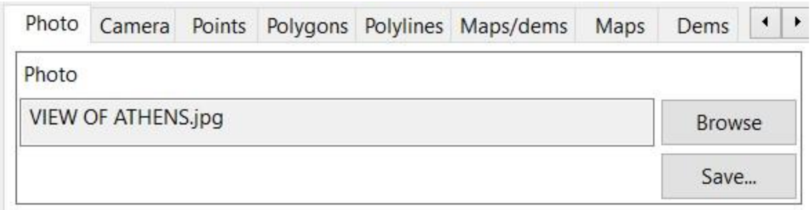

Figure 6.3: Imported photograph on the respected tab

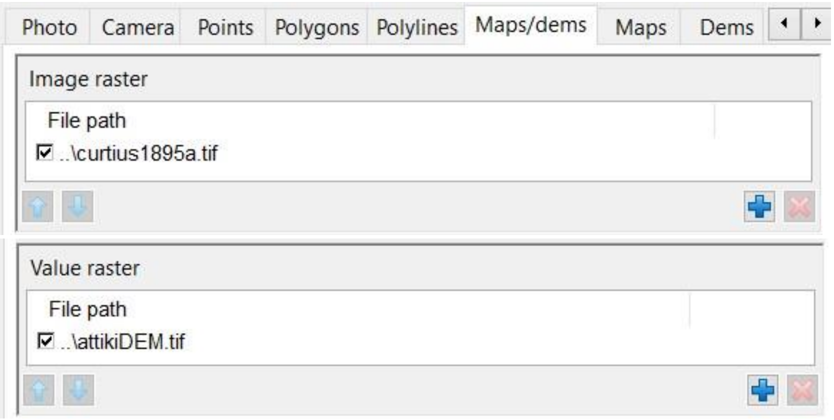

Figure 6.4: Imported map on the upper section (Image raster) and DEM on the lower section (Value Raster) on the respected tab

In the lower part of the Photo tab, in Center and Origin section, the centre of the photograph is calculated automatically by clicking or manually through the edit function if the centre is known in pixel.

For the reconstruction of the original camera position at the time of photo shooting by clicking edit on the Origin option, the coordinates can be inserted manually if known, or by clicking on the shooting point directly on the map/orthophoto. At this point, the location of the shooting point can be approximated in order to have the right shooting direction and can be identified with better precision later (**Figure 6.5**).

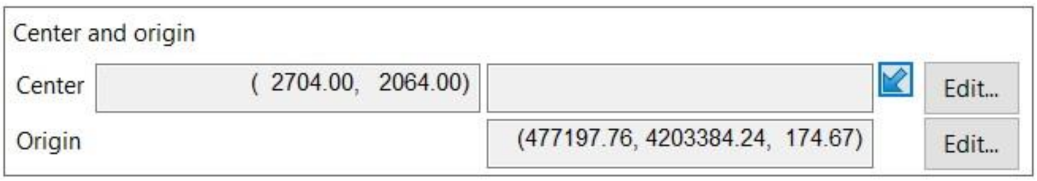

Figure 6.5: Center and origin section of the Photo tab

After applying the origin coordinates, the supposed camera position will be indicated by a red circle on the map/orthophoto  . At this point it should be noted that, in the interface of the WSL Monoplotting Toolbox, two coordinate systems are mentioned: the image in pixels and the world coordinate system in meters (**Figure 6.6**). The image coordinate system has its origin in the top-left point of the image used. The image dimensions are defined in pixels, and thus the relative location of the image in real-world space (Greek Grid/GGRS87) is unknown. In this thesis, the world coordinate system is defined as the Projected coordinate system for Greece (Greek Grid/GGRS87). The goal of georeferencing is to establish a connection between the coordinate system of the image and the real-world space. The addition of CPs accomplishes the relation between the two.

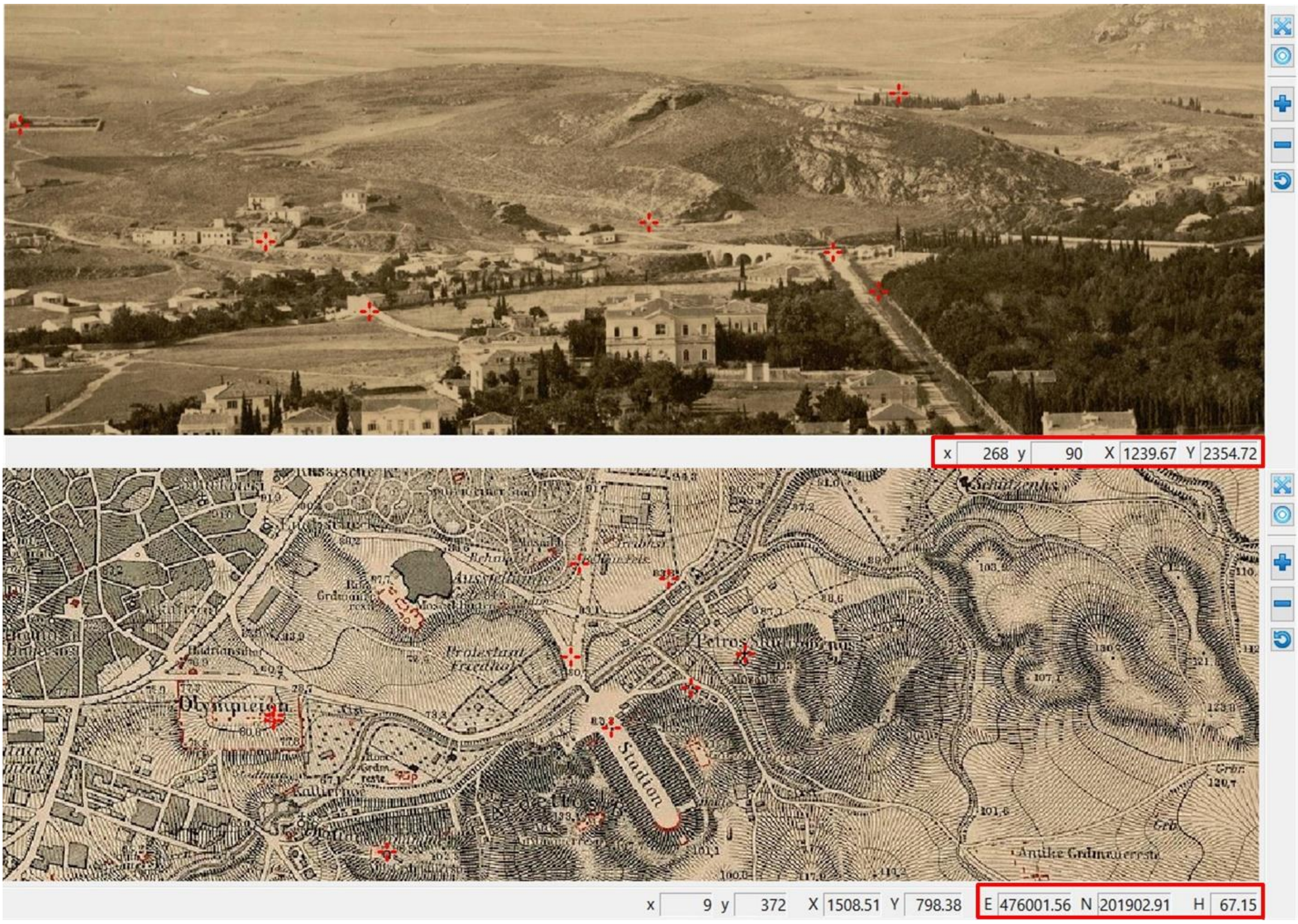

Figure 6.6: Image and World Coordinate System

Consequently, by inserting the first four CPs in the Control point section of the photo tab, the georeferencing progress is initialized, which helps in the definition of CPs. The CPs should be at least five, clearly visible and not hidden behind objects and well scattered in the image, specifically around the features to be digitized later. Furthermore, CPs should be located if possible on a regular surface to avoid gullies and small hilltops that are not represented in the DEM. Generally, there are not always many GCPs available within specific regions. Therefore, the results are not controlled, and the errors are generalized to the photographs extend. In this case, when locating the CPs, some of them showed really high errors during the calibration process.

For this reason, the selection of the final five CPs was made after many attempts to find the smallest possible error. By clicking Insert, the point editor is activated, and the definition of the CP in both the photograph and the map is possible. The software also allows deleting, modifying or disabling CPs if necessary. When the desired CPs are inserted, the camera calibration can be accomplished.

In the Camera tab, where the calibration is going to take place, it is first necessary to add a Camera definition. By activating the Camera, it is now possible to edit it (**Figures 6.7 & 6.8**).

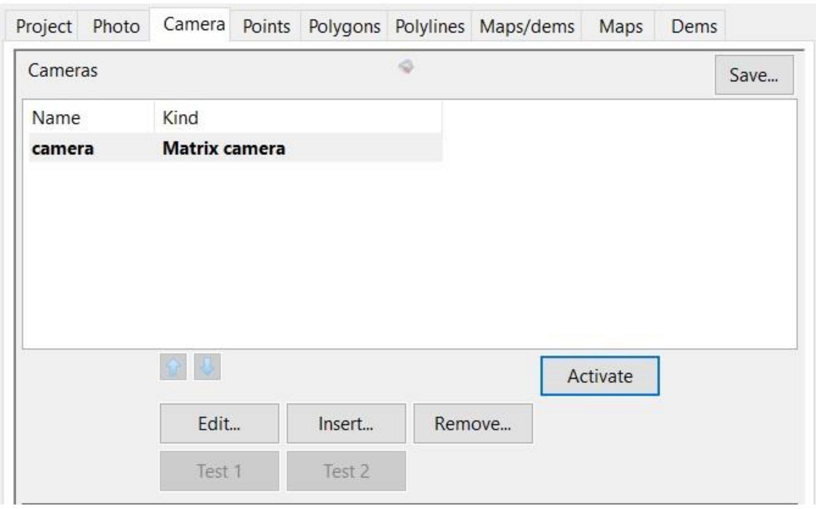

Figure 6.7: Activation of the camera

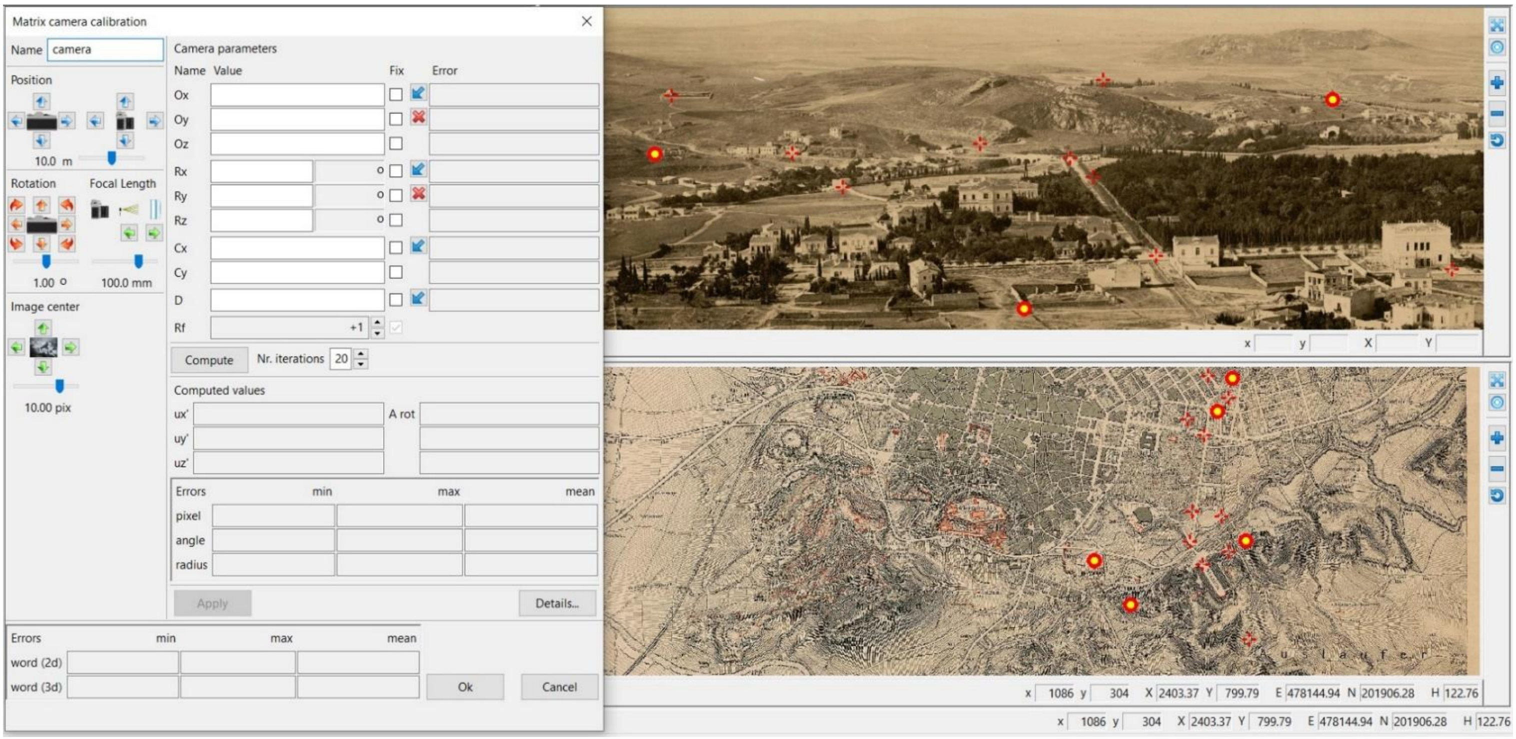

Figure 6.8: Camera calibration before editing

By clicking in the C_x/C_y and D option, the center of the photograph and the focal length are automatically imported. Then directly check the know parameters in the Checkbox, so the defined values are not calculated during the calibrating procedure. The camera calibration is done under a certain number of iterations (Default=20) until it reaches the minimal error in pixels, angle and radius. Launching the Compute routine the camera calibration is enabled, and the results are visualized.

The red dot on the map shows the calculated location of the shooting camera, while the blue dot indicates the camera direction. If the resulting direction is entirely wrong (180° or opposite), the "Rf" parameter can be redefined, which does not require the relaunching of the calibrating routine.

Once the camera is calibrated, the synchronized cursor is activated, showing the projection of the mouse movement of the photograph, on the map and vice versa. The CPs are visualized as blue and red circles: in the best cases, the red circle is placed in the yellow filling of the blue circle which means a perfect correspondence of the centres of both circles. Shifts in the position of the paired circles mean an imprecision of the CPs (**See Section 4.2.2 Figure 4.3**). To further improve the

calibration, the routine can be relaunched (Compute) without defining the Focal distance (D) and the camera position (Ox, Oy, Oz) (**Figure 6.9**).
In more detail, as mentioned in the software user manual, the parameters and the error types included in the camera calibration process are the following:

- **Parameters for the camera calibration:**
  - **Ox, Oy, Oz:** coordinates of the camera position.
  - **Rx, Ry, Rz:** Euler angles, not important for the calibration.
  - **Cx, Cy:** Image centre (pixel coordinates).
  - **D:** as a multiple of the focal distance (focal distance = D * factor). Speaking about focal distance is not correct because the pictures are scanned and are not in the original format.
  - **Rf:** +1 or -1, according to the correct solution of the calibrating equation.

- **Error types:**[23]
  - **Pixel**: the distance between the CP in pixels as defined in the picture and the corresponding point calculated by the camera in the real world.
  - **Angle:** the angle between the line connecting the camera to the CP in the picture and the line connecting the camera with the calculated real coordinates of the correspondent point in the DEM. The best-case corresponds to an angle = 0. **Errors below 0.1 may be considered as very good**.
  - **Radius:** the distance between the real point and the intersection point of the ray calculated by a plane perpendicular to the ray of the real point. This value is based on the distance of the point.
  - **World (2d):** 2D projection of the error.
  - **World (3d):** real error distance in 3D.

[23] Those errors arise from the camera calibration and not from the DEM accuracy or the map georeferencing.

At this point, it should be noted that for this thesis, four georeferencing scenarios were carried out with raging CPs and errors, as shown in **Table 6.1**[24].

	Control Points	Max Pixel Error	Max Angle Error	Max Radius Error	Max World (2d) Error	Max World (3d) Error
Scenario 1	5	1.345	0.009	0.153	1.977	1.977
Scenario 2	6	6.038	0.043	0.501	4.175	4.279
Scenario 3	9	10.829	0.074	1.871	13.668	13.689
Scenario 4	10	20.675	0.141	2.334	17.011	17.011

Table 6.1: 4 Monoplotting scenarios

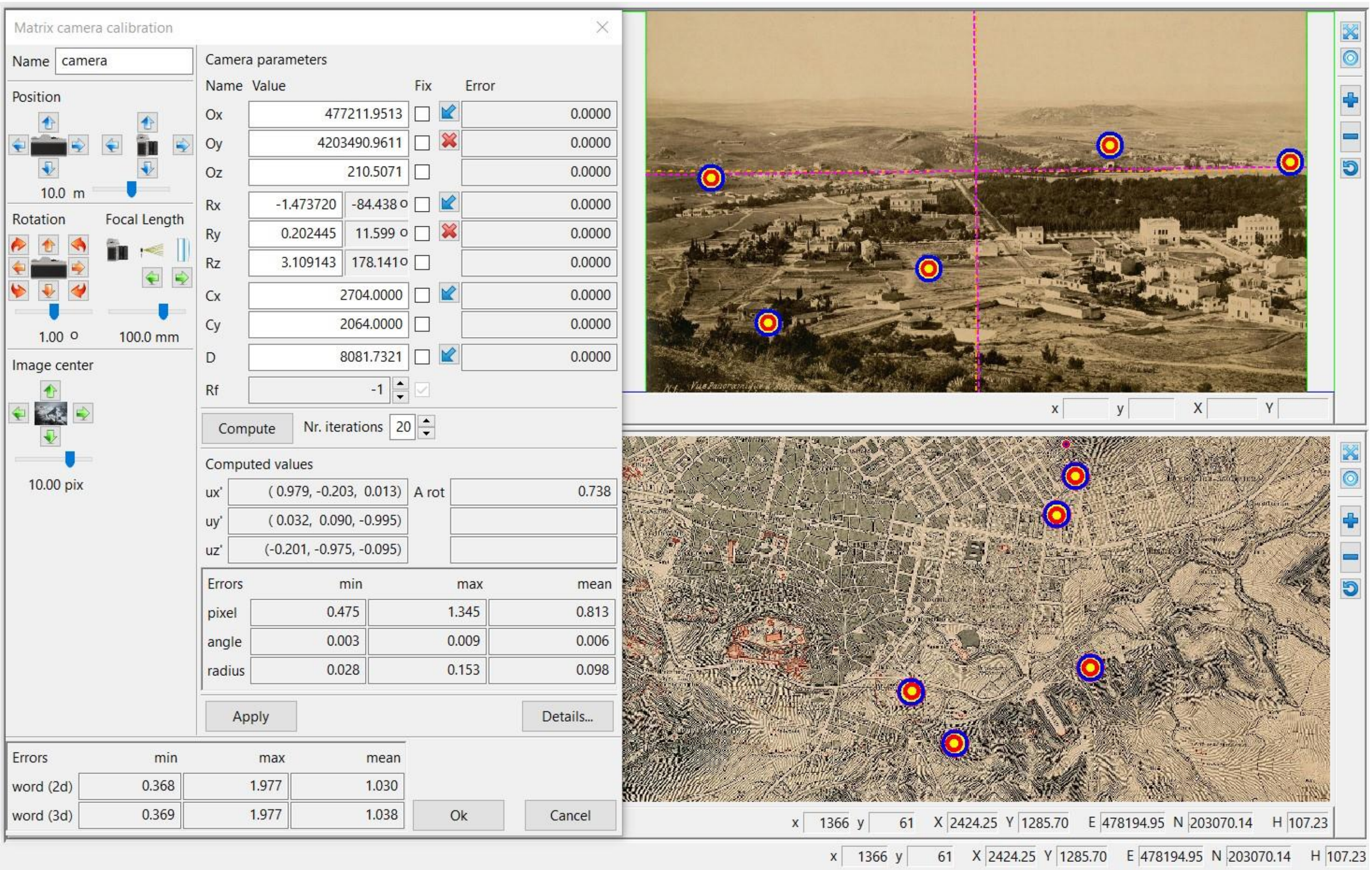

Figure 6.9: Final Camera calibration (Scenario 1)

[24] For more details about the Scenarios see Appendix Figures A.4, A.5 & A.6.

Once the camera calibration is achieved, the photograph is georeferenced, and one can export and save the CPs in a Comma Separated Value format (.csv) for further use. Ultimately, it follows the digitization of the desired features as Points, Polygons or Polylines, under the correspondent tab. The software allows the bidirectional digitization of entities, i.e. both from the photo and the map. Digitization from the photograph leads to the export of the desired entities that may not be visible elsewhere. Respectively, digitization on the map and the projection of the entities in the photograph can provide useful information for further identification of features. In addition, it is possible to label the elements and additional process points and whole or parts of the polygons and polylines.

The export of digitized entities can be carried out as ArcGIS World/Pixel file (.txt, .csv) or as ArcGIS World/Pixel Shapefile (.shp)[25]. In this case, the features were exported as ArcGIS World Shapefiles, to use them directly in ArcGIS for further processing. The final export of the results will be based on the creation of comparable maps per point, polygon and polyline digitized entities, where the corresponding errors will be assessed.

A key element before mapping and exporting the land covers of the photograph is the error inspection for all four scenarios in specific known points. In more detail, six points were selected on Curtius map, as shown in **Figure 6.10**, three of which correspond to point and three to polyline entities. This was followed by the digitization of respectively point and polyline entities related to these points, in order to verify the accuracy of the four georeference scenarios of the photograph, before proceeding to the export of the final land covers.

[25] Likewise, vector data can be imported and superimposed on the terrestrial photographs.

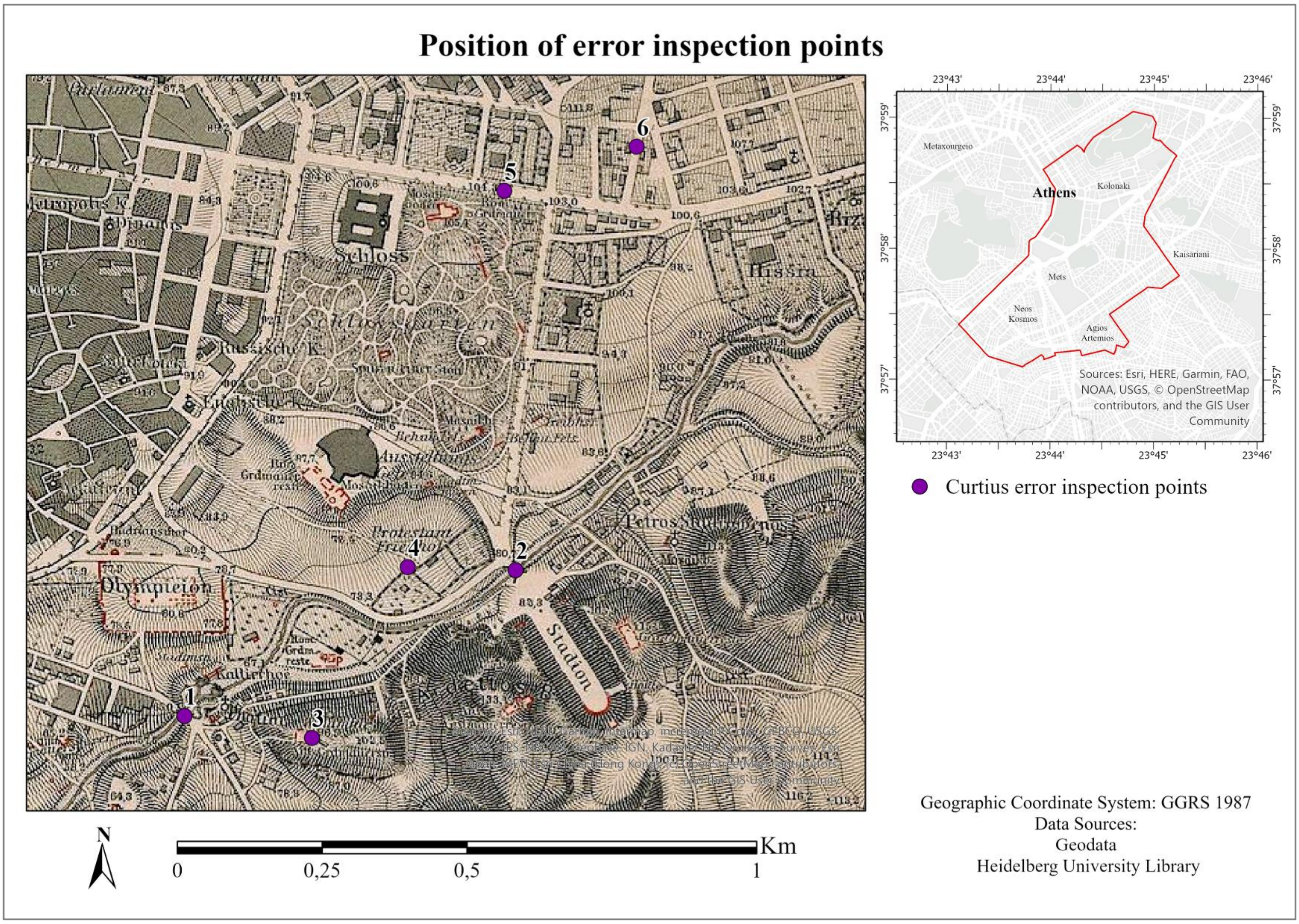

Figure 6.10: Error inspection points

6.4 Urban Atlas 2012 processing

For all the data to be compatible, it is initially necessary to convert the projected coordinate system of the Urban Atlas dataset from European Terrestrial Reference System 1989 (ETRS89) to GGRS87, and then clip it in the study area. Then, for the comparison of the historical land covers with the existing ones, it is necessary to reclassify the Urban Atlas dataset into broader classes, as mentioned in section 6.2.

More specifically, for the creation of:

- **Built environment** category, all the urban fabric subcategories were incorporated (Continuous Urban fabric (S.L. > 80%), Discontinuous Dense Urban Fabric (S.L.: 50% - 80%), Discontinuous Medium Density Urban Fabric (S.L.: 30% - 50%), Discontinuous Low Density Urban Fabric (S.L.: 10% - 30%)

- **Green urban areas, Open spaces with little or no vegetation** and **Water** categories were used unchanged
- **Industrial, commercial, public, military, archaeological, sport and private units** category, in which the ***Industrial, commercial, public, military, private and transport*** units
 and ***Sports and leisure facilities*** were included
- **Roads and associated land** category, in which was used unchanged the ***Other roads and associated land***

For the reclassification of the dataset, in the existing shapefile, a new column was created. Then each of the existing entities was matched with the corresponding one's bellow, as it happened in the Curtius map:

- **Built Environment [1]**
- **Green Urban Areas [2]**
- **Industrial, commercial, public, military, archaeological, sport and private units [3]**
- **Roads and associated land [4]**
- **Open spaces with little or no vegetation [5]**
- **Water [6]**

6.5 Land cover changes

As the Urban Atlas and Curtius land cover layers have been categorized based on the codes mentioned above corresponding to land covers, the identification of changes between the two followed. The changes were detected in the ArcGIS Pro software, where using the “Intersect” tool, the geometric intersection of the two input polygonal layers is computed. Through this tool, features or portions of features that overlap in all layers and/or feature classes are written to the output feature class (ArcGIS Pro, (n.d.)). In this way, a new polygonal layer is produced with the information of both input shapefiles being preserved in the attribute table. The small topological differences, being either normal or due to the scale, the georeferencing or illustrational errors, resulted in rather few sliver polygons. After the recognition of these, were included accordingly in the existing entities.

Through the selection of entities based on their attributes, it is easy to identify the areas that differentiated over time as well as those that have remained undifferentiated. Common land cover codes in the respective columns of Curtius and UA land cover codes indicate entities that remained unchanged over time, while correspondingly differentiated codes between the two columns represent entities that altered their land cover in the intervening time.

More specifically, land covers that remained unchanged over time were selected following the expression shown in **Figure 6.11**.

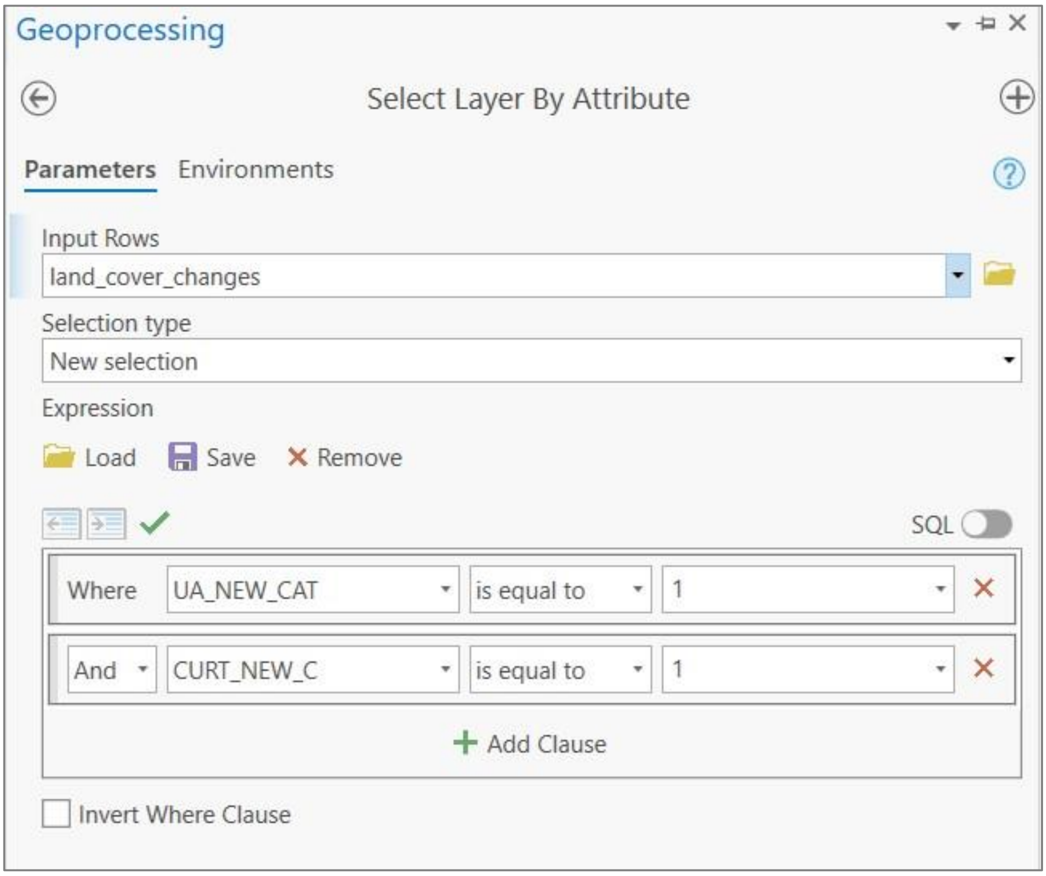

Figure 6.11: Selection of undifferentiated land covers

After selecting all entities with common land covers over time (UA Land cover=1 and Curtius land cover=1, etc.), they were exported as a new shapefile for further processing and visualization. The same approach was also followed, and for the land covers that have been differentiated (**Figure 6.12**).

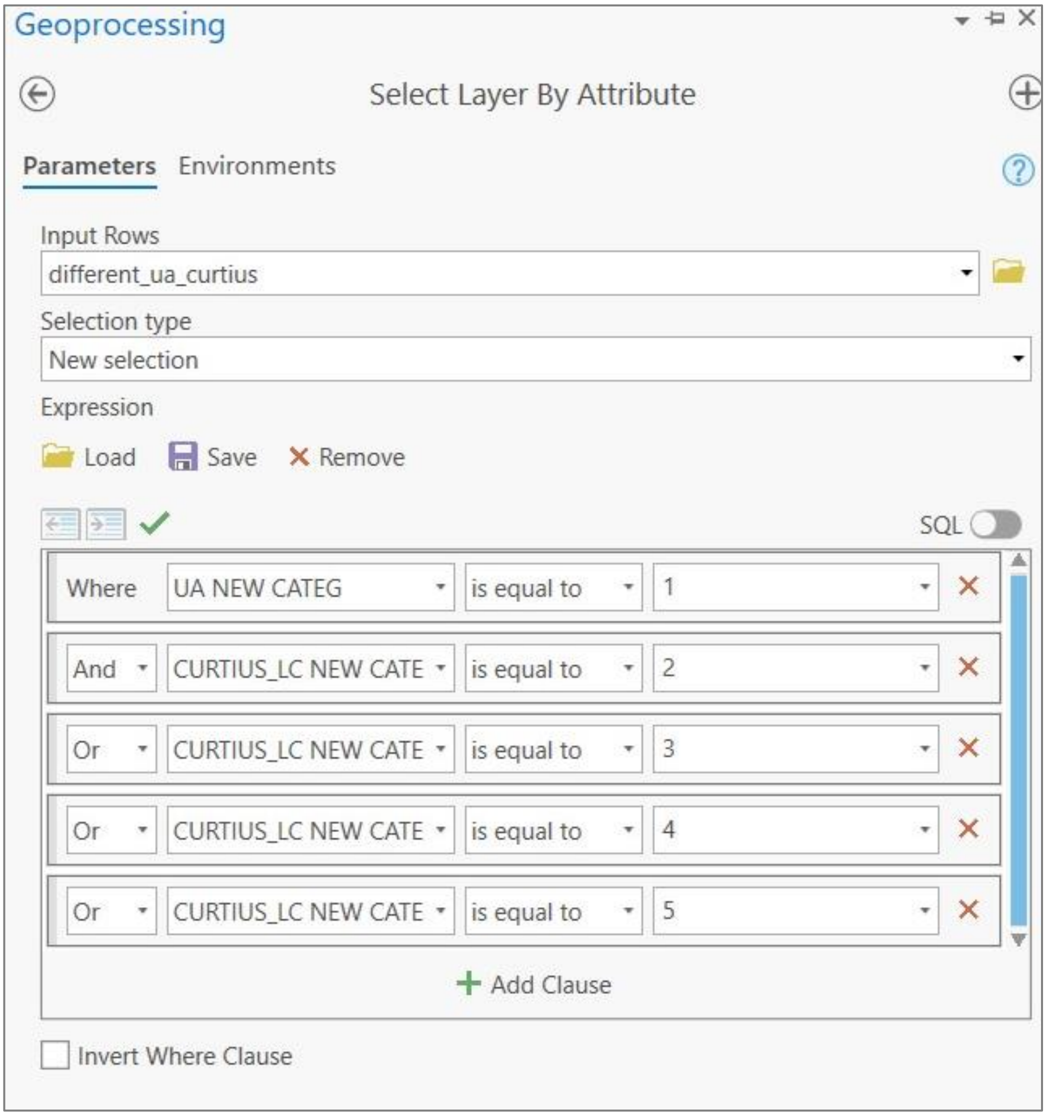

Figure 6.12: Selection of differentiated land covers

The result of the above procedures is the production of two separate shapefiles for land covers that remained stable and for those changed, for which the calculation of areas for quantitative comparison and the visualization took place

7. Results and Analysis

7.1 Monoplotting results

As mentioned respectively in section 6.3 of the monoplotting methodology, the inspection of errors in specific points of the georeferenced photograph is essential. For this reason, the following **Table 7.1** was created, where the errors corresponding to the points in **Figure 6.10** are presented for each scenario.

Error Inspection Points	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
[1] Temple of Olympian Zeus Bridge	183 m	181 m	177 m	191 m
[2] Panathenaic Stadium Bridge	60 m	54 m	59 m	68 m
[3]Windmill	13 m	0 m	15 m	0 m
[4] Zappeio walls	53 m	50 m	56 m	55 m
[5] Vas. Sofias Street	32 m	20 m	0 m	27 m
[6] Neofytoy Douka Street	9 m	9 m	8 m	10 m

Table 7.1: Error inspection points for each scenario

As can be seen from **Table 7.1** in combination with **Figures 7.1 & 7.2**; the measured errors do not follow the per-scenario variance of errors that occurred when georeferencing the photograph (**Table 6.1**). Based on **Table 6.1,** it would be expected that scenario one would show the smaller errors while moving to scenario four the errors would increase. This is mainly owed to the long time that has passed between the DEM and photograph, as many topographical variations have emerged. It may also be due to the inherent errors of the DEM/map, as well as to a lesser extent to errors in the manual digitization of entities such as shifts or incorrect digitization.

Looking at **Figures 7.1 & 7.2** concerning the points and lines digitized from the photograph, their deviation from their actual position is more clearly understood. In the case of point entities, as verified by the measurements of **Table 7.1**, the windmill (Point 3 on **Figure 6.10**) and the points of Temple of Olympian Zeus Bridge and Panathenaic Stadium Bridge (Points 1 & 2 on **Figure 6.10**) show approximate error deviations between the four scenarios

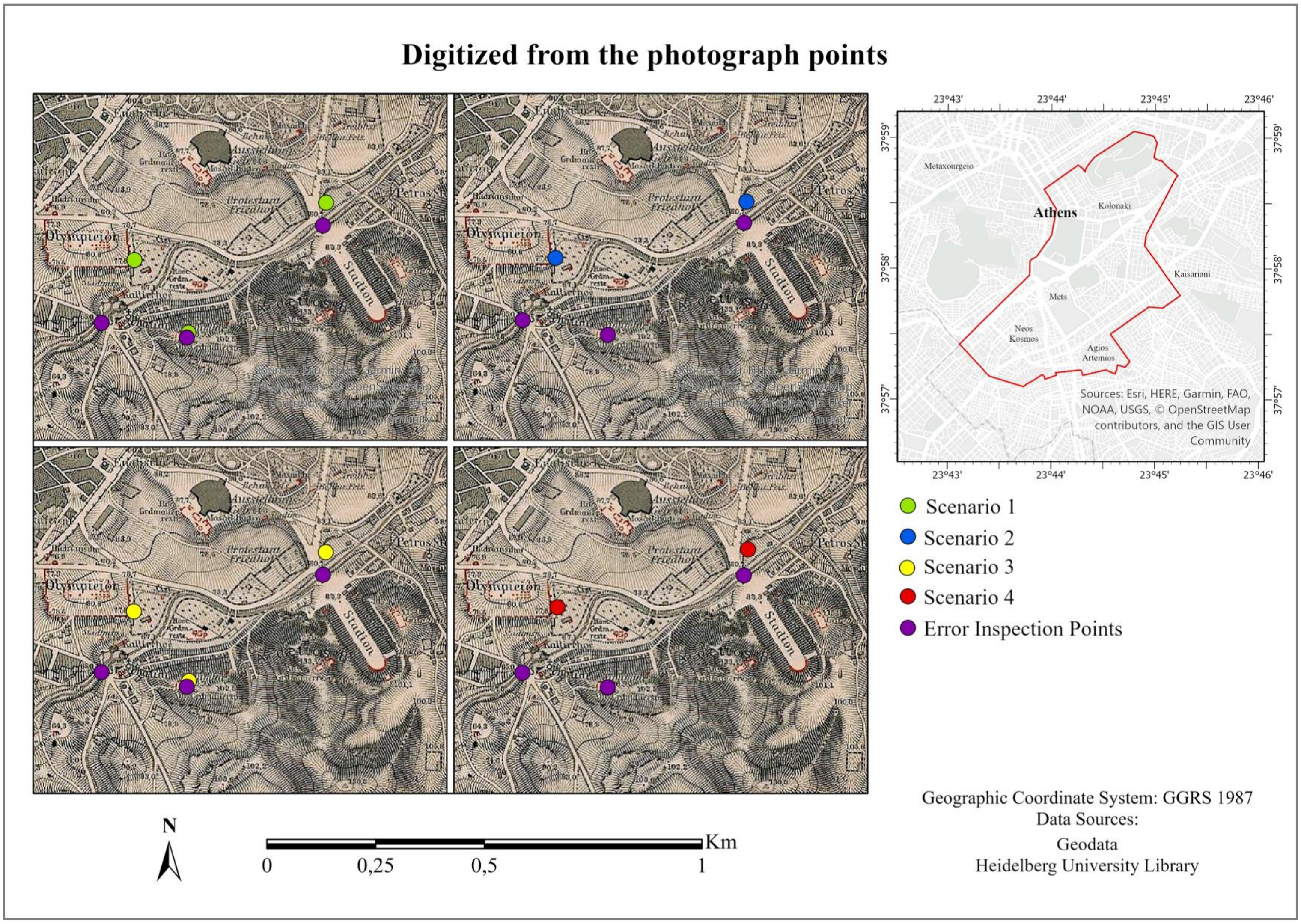

Figure 7.1: Digitized from the photograph points

Similarly, observing **Figure 7.2,** it is apparent that for most entities that fall in a straight line from the shooting point, the errors involve the simple movement of the object. This might mainly be due to the inherent inaccuracies of the DEM/map, as well as to the errors during the digitization of the map. For linear entities that show beyond displacement and deformation, the topographical changes in the surrounding area are responsible.

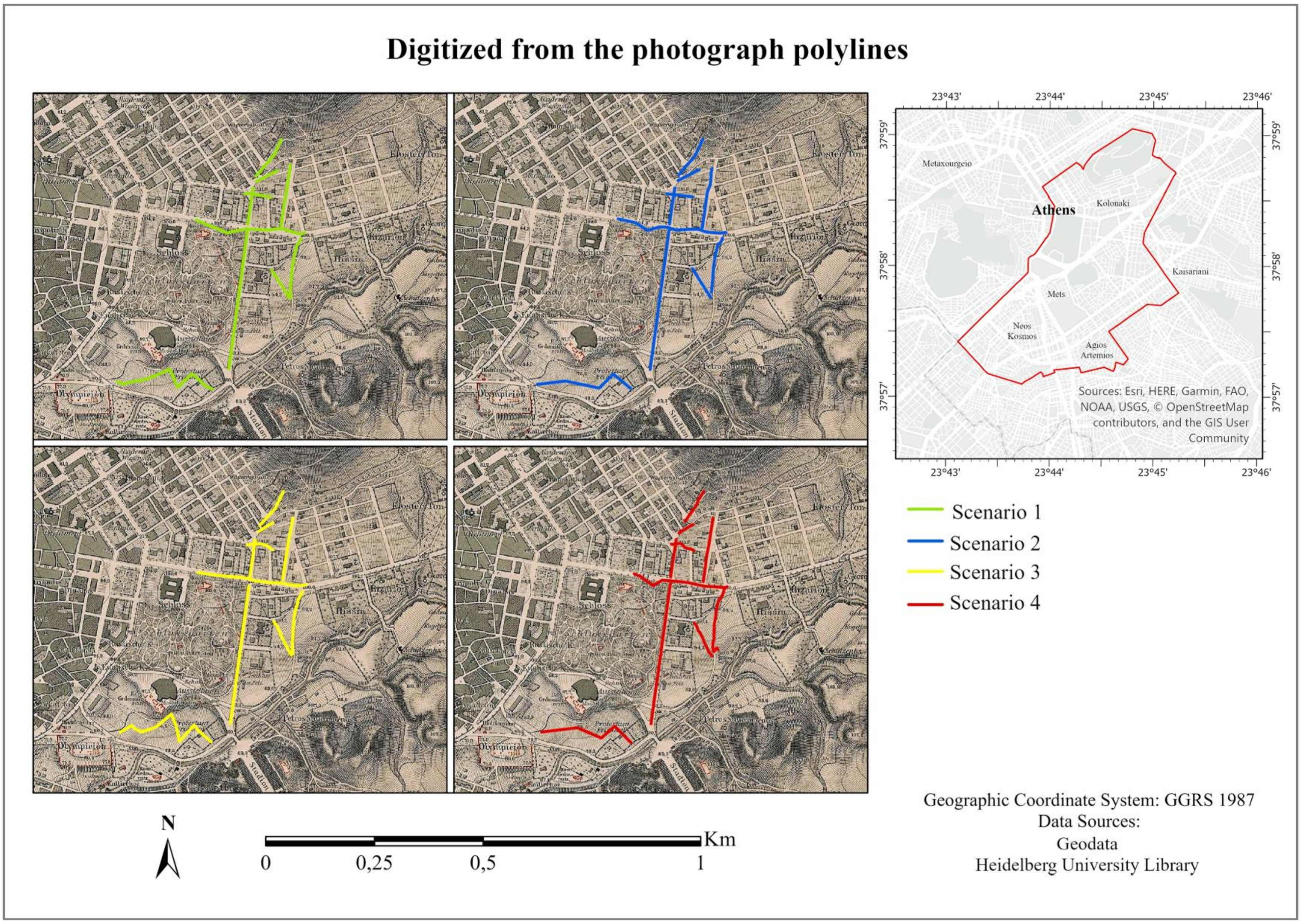

Figure 7.2: Digitized from the photograph polylines

In addition to the above, the digitization of polygonal entities was also attempted, showing inaccuracies and deviations that are even more significant from the actual positions of the objects. These inaccuracies were mainly found in the digitization of the parts of polygons that were not in the foreground, resulting in the final polygons showing severe deformations.

As it is evident, neither scenario can be used to extract land covers from the photograph accurately. Nevertheless, the digitization of entities can help despite their error deviations, in the qualitative recognition and certification of individual characteristics and land covers from historical maps of the time, as in our case the extraction of land covers from Curtius map.

7.2 Curtius and Urban Atlas 2012 Land cover change

As analyzed in the corresponding section of the methodology (Section 6.4), in order to be able to achieve an over time comparison of land coverages, the data must be categorized into common categories. For this reason, the land covers of **Figure 7.3** were classified into the previously mentioned broader categories as presented in **Figure 7.4**.

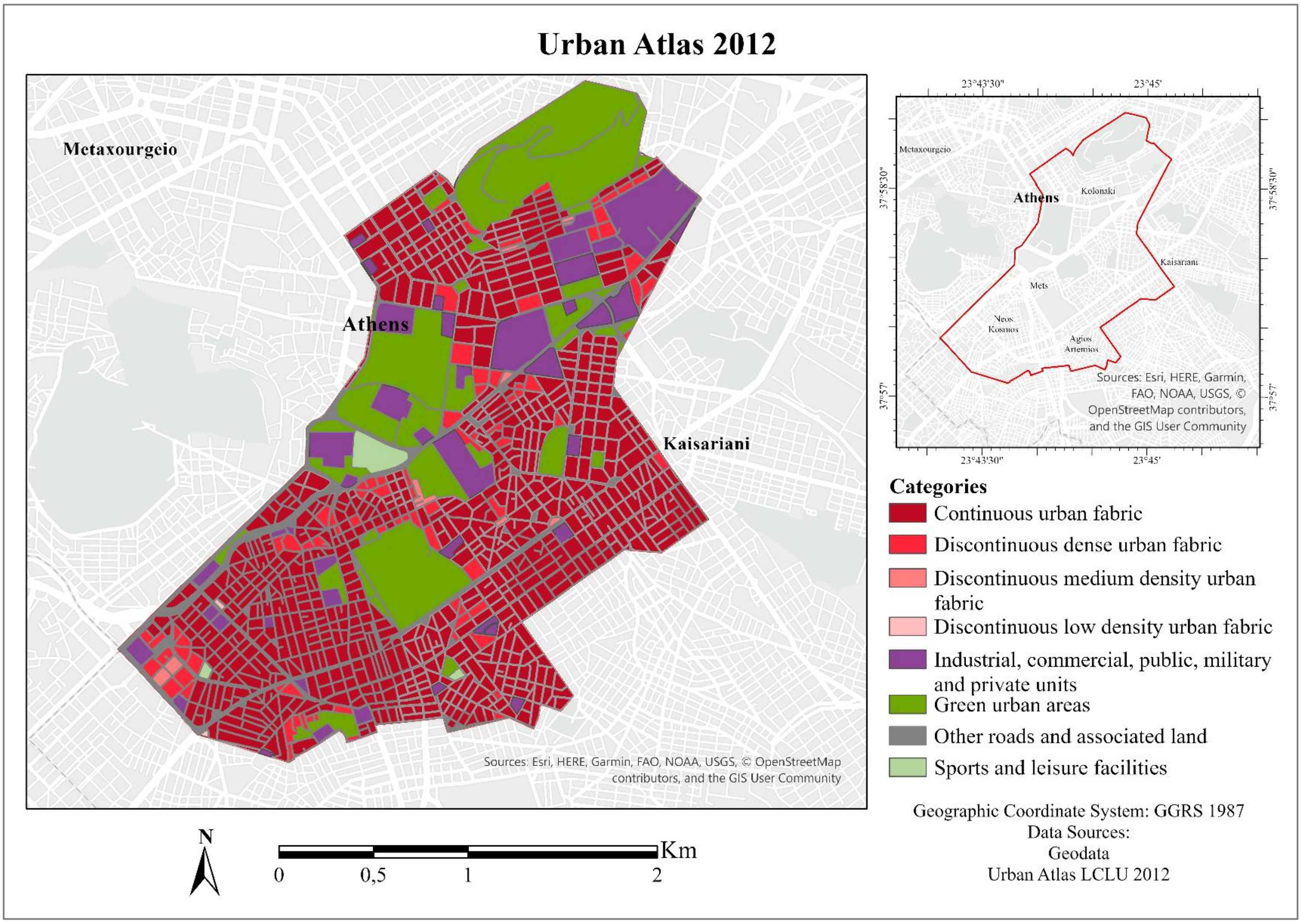

Figure 7.3: Urban Atlas 2012 Categories

Observing **Figure 7.4** in combination with the quantitative data of the land covers of **Diagram 7.1**, it is understood that after the reclassification of the land covers, 50% of the study area is covered by "Built environment" (287.23 ha), followed by "Green urban areas", covering 20% of the study area (117.57 ha). Furthermore, due to the addition of the "Sport and private units" in the wider "industrial, commercial public, military, archaeological, sport and private units" category, the latter showed a small increase of 5 hectares.

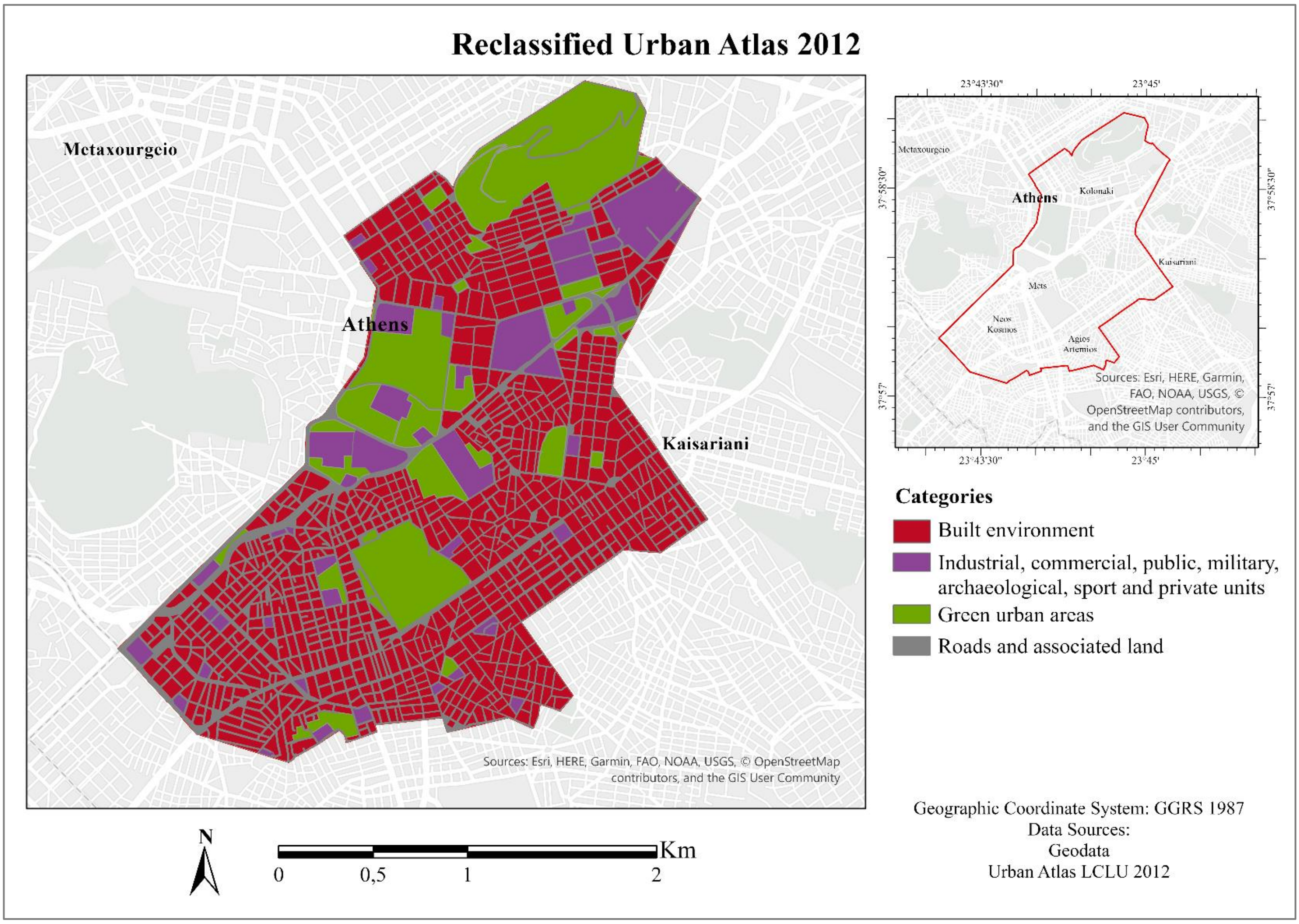

Figure 7.4: Reclassifies Urban Atlas 2012

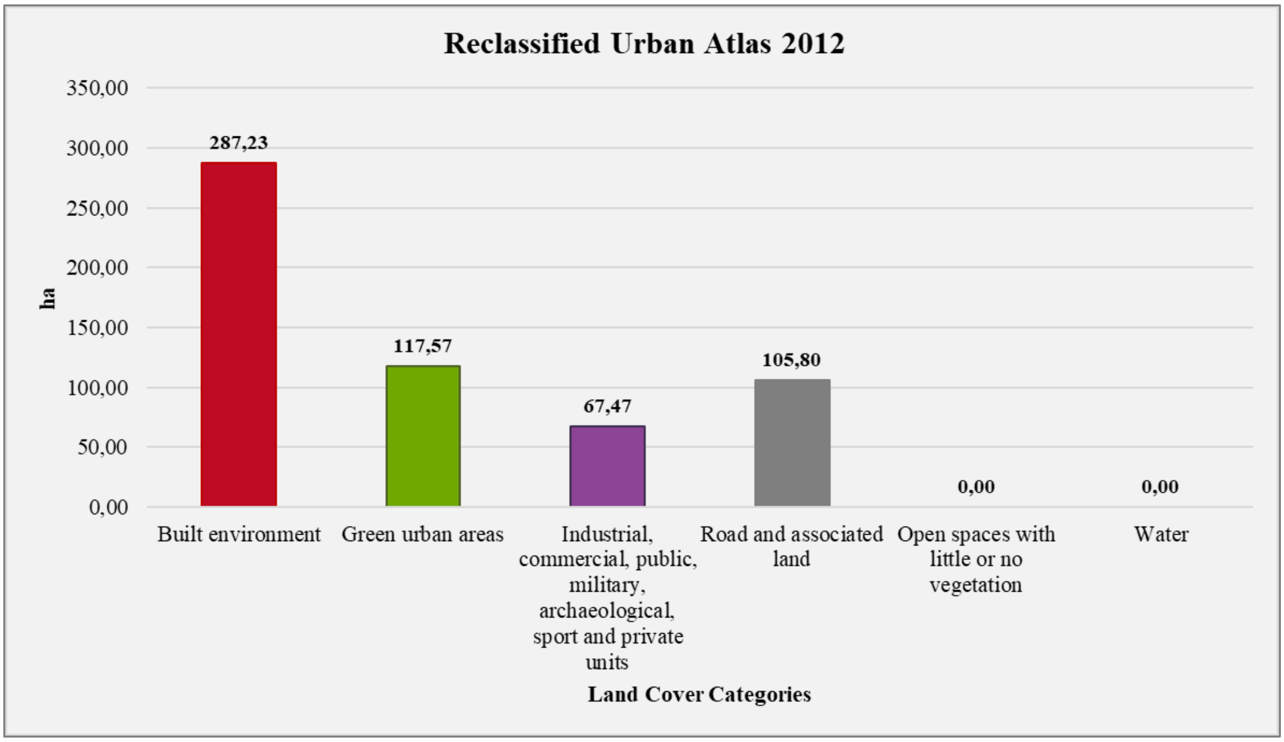

Diagram 7.1: Reclassified Urban Atlas 2012 areas by category

Regarding **Figure 7.5**, concerning the land covers of the Curtius map, the difference in geometry and symmetry of the entities in relation to the UA land cover map is immediately perceived. This is mainly due to the unregulated construction, which was a common occurrence for Athens at that time, and it was accurately reflected in the map below. At a technical level this is due to the scale of digitization of the Curtius land covers (1:4000 or in some cases 1:2500) where the buildings were digitized individually, in contrast to the detail of the urban atlas. From **Figure 7.5** it is easy to observe that in relation to the map of the UA land covers (**Figure 7.4**), two additional land covers are included: "Open spaces with little or no vegetation" and "Water". As expected, the residential development of Athens occupied the "Open spaces with little or no vegetation", as well as the development of the road network mainly occupied the area of the Ilissos River. In combination with **Diagram 7.2**, it is evident that the most extensive area within the study area, i.e. 80%, consists of "Open spaces with little or no vegetation" (462.54 ha) followed by "Green urban areas" (41.65 ha), covering 7.2% of the total study area.

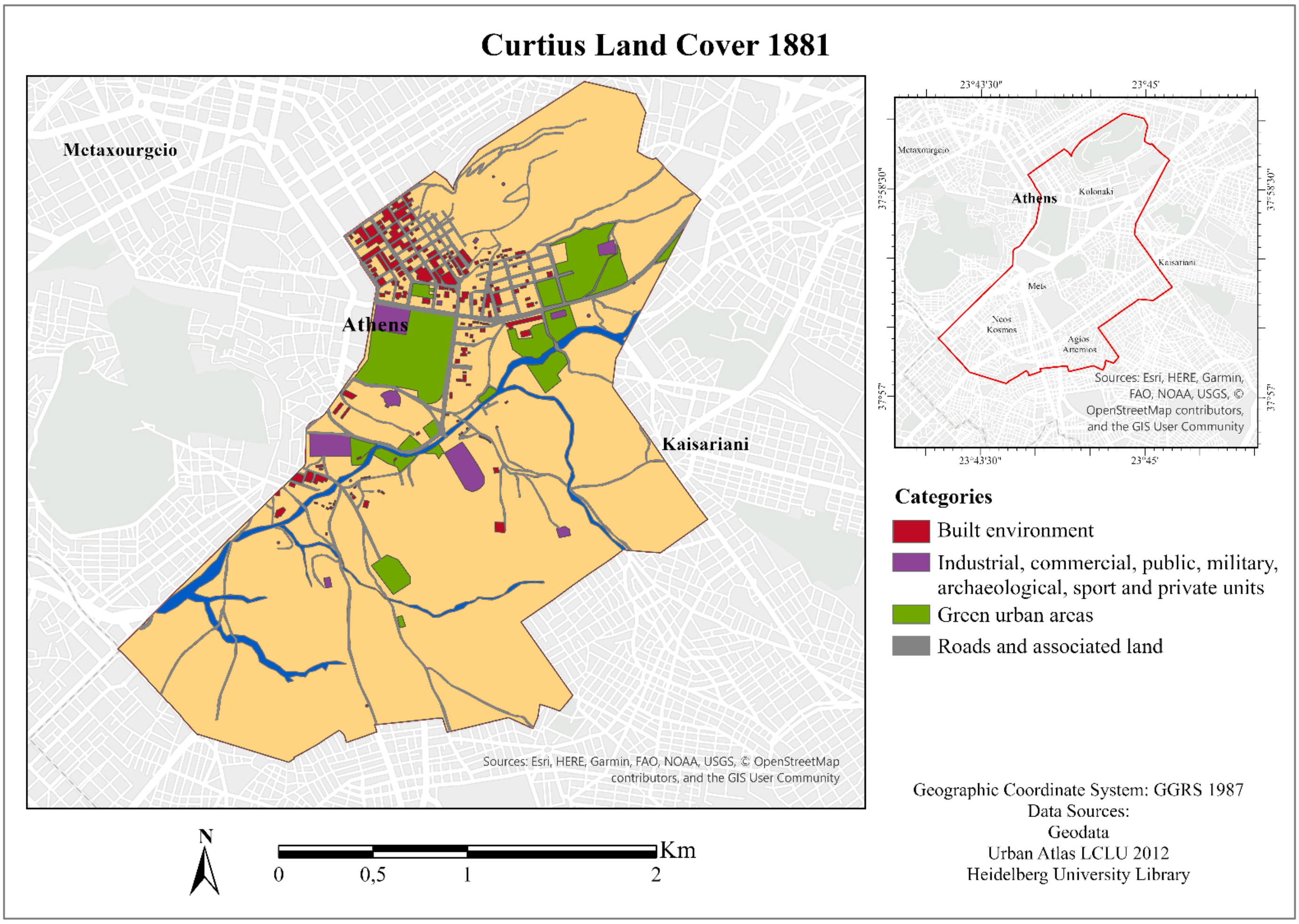

Figure 7.5: Curtius Land Cover Categories

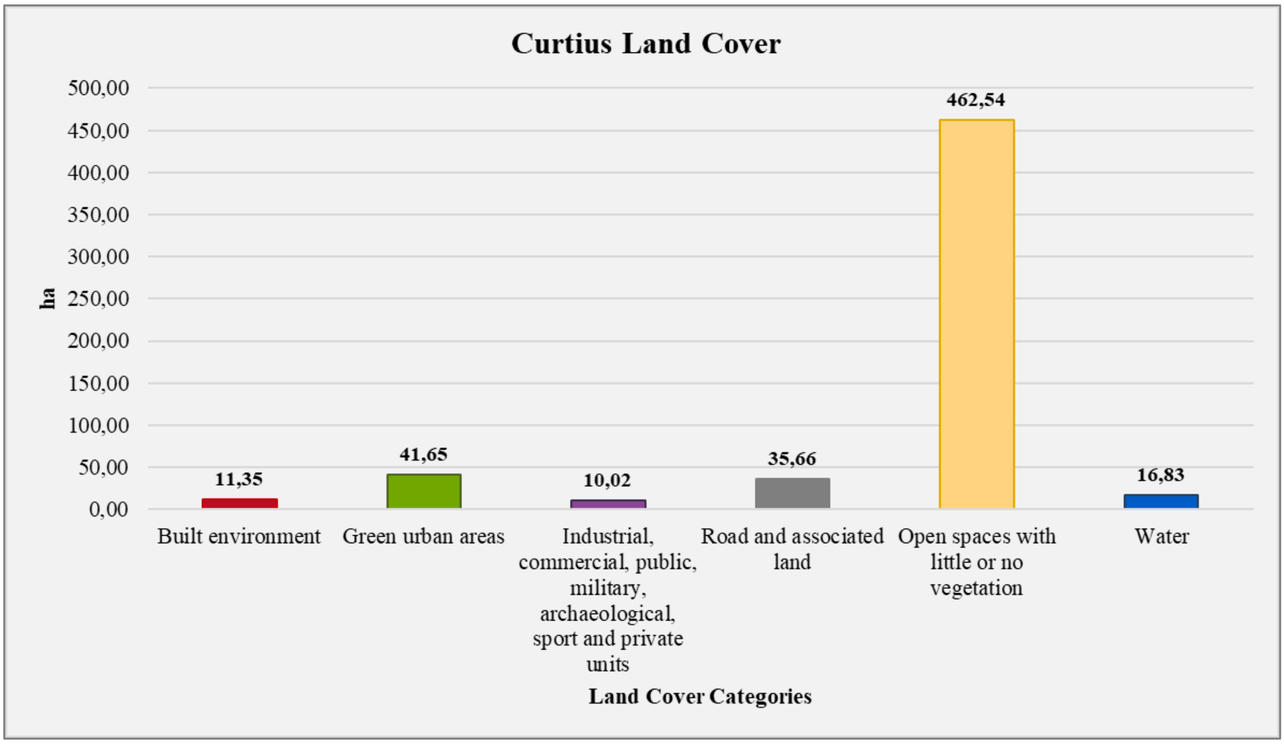

Diagram 7.2: Curtius Land Cover areas by category

Following the implementation of the Intersect tool and the production of two separate layers of the areas that differentiated or remain undifferentiated over time, as mentioned in the methodology (Section 6.5), **Figure 7.6** was created. As is immediately perceived, between Curtius land cover map of 1881 and UA land cover map of 2012, 96.9% of land covers differentiated, while only the remaining 3.1% of the study area remained unchanged over time.

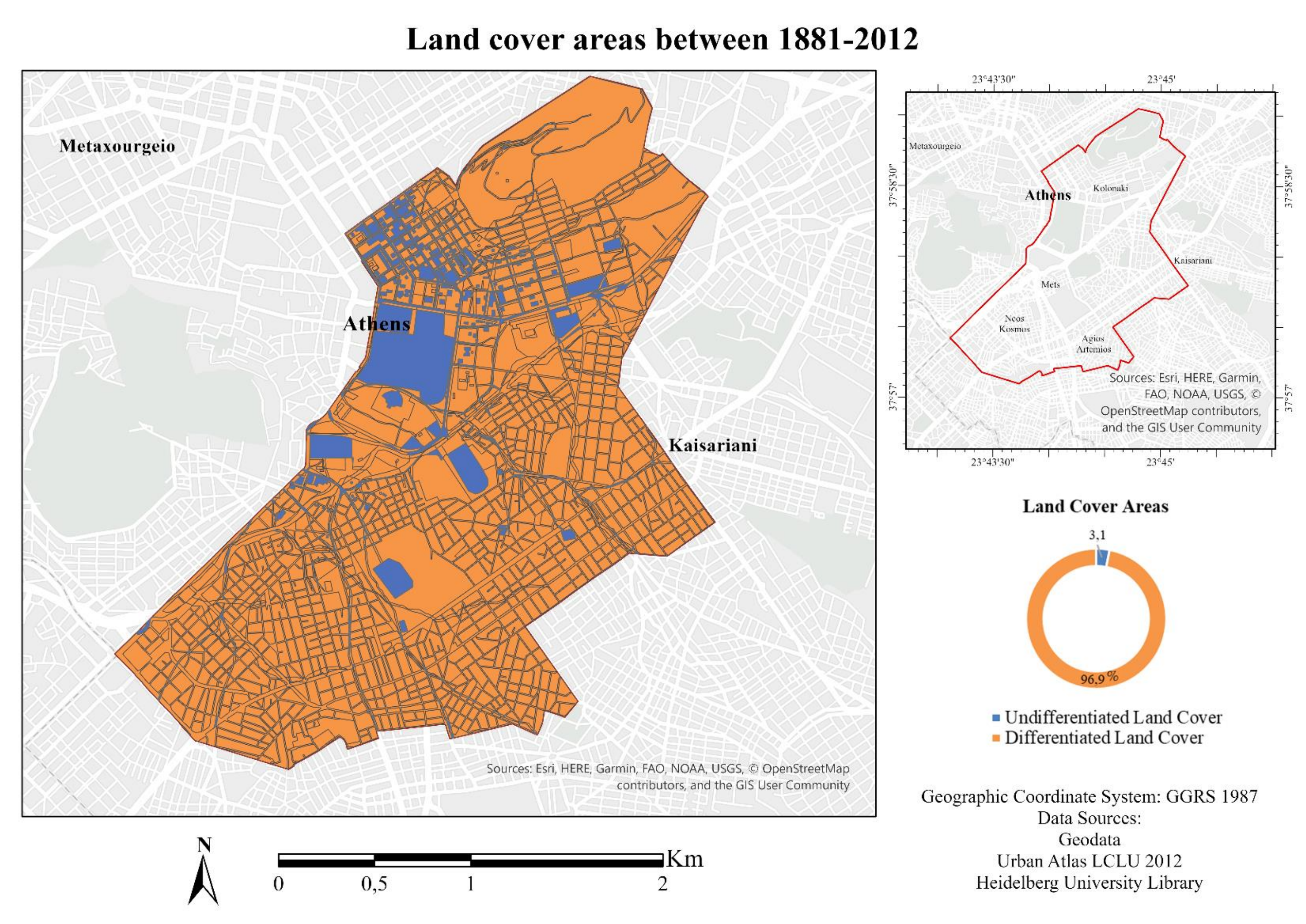

Figure 7.6: Land cover areas change between Curtius land cover map of 1881 and UA land cover map of 2012

In order to better understand the changes that have taken place between the two land cover maps, it was considered necessary to analyze quantitatively further both the areas that have changed and those that have remained stable over time. More specifically, concerning undifferentiated land covers, looking at **Figure 7.7** and **Diagram 7.3** it is evident that of the total 17 hectares remaining unchanged, 14 hectares relate to “Urban green areas”, i.e. 83% of the total study area. By 2 hectares follows of the “Industrial, commercial, public, military, archaeological, sport and private units” category (13%).

Ostensive, the urban green areas constitute of the National Garden of Athens, the First Cemetery of Athens and today's parks of Rizari and Evangelismos. Similarly, the undifferentiated “Industrial, commercial, public, military, archaeological, sport and private units” category consists of the Temple of Olympian Zeus, the Panathenaic Stadium as well as the Hellenic Parliament.

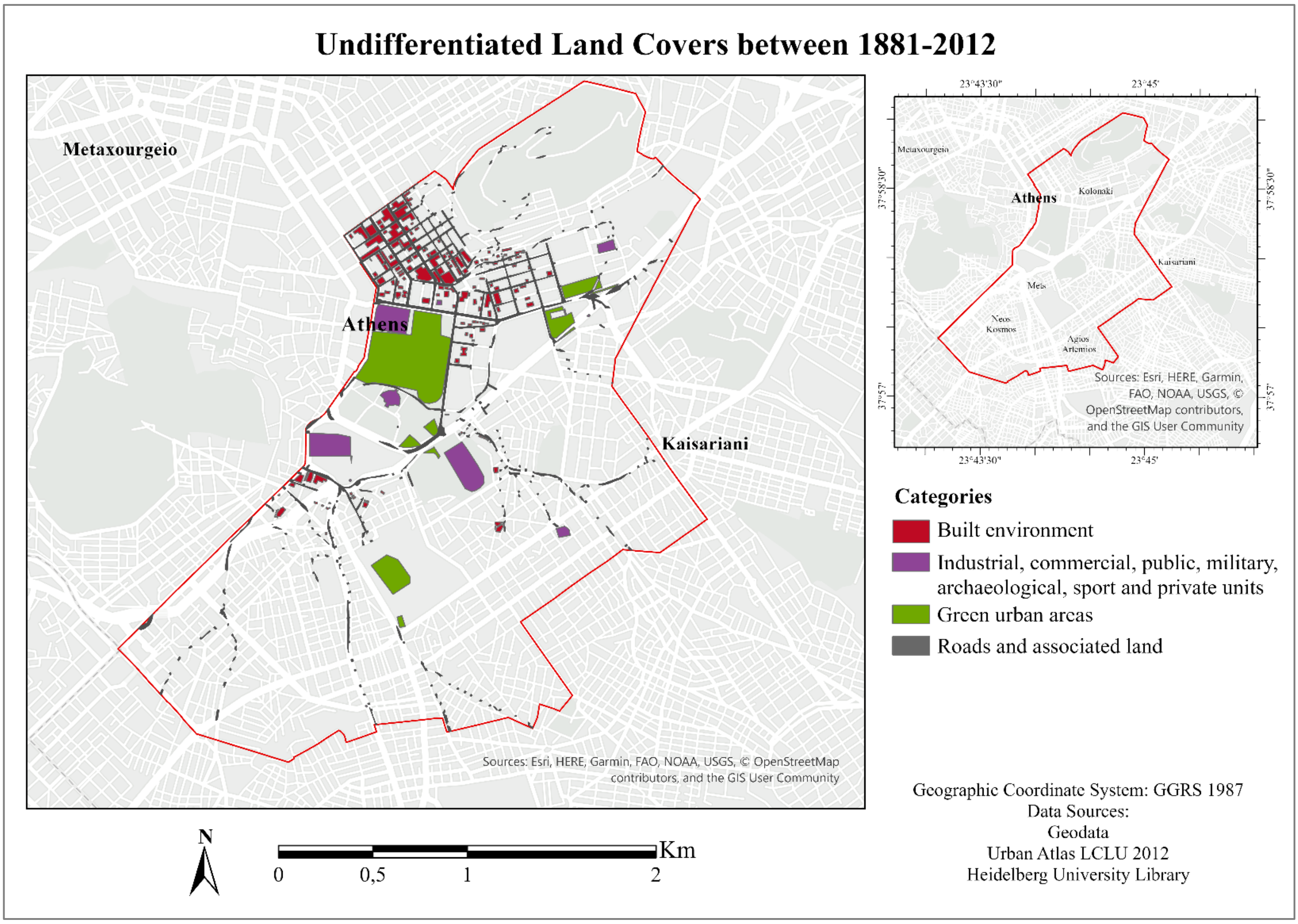

Figure 7.7: Undifferentiated land cover areas Curtius land cover map of 1881 and UA land cover map of 2012

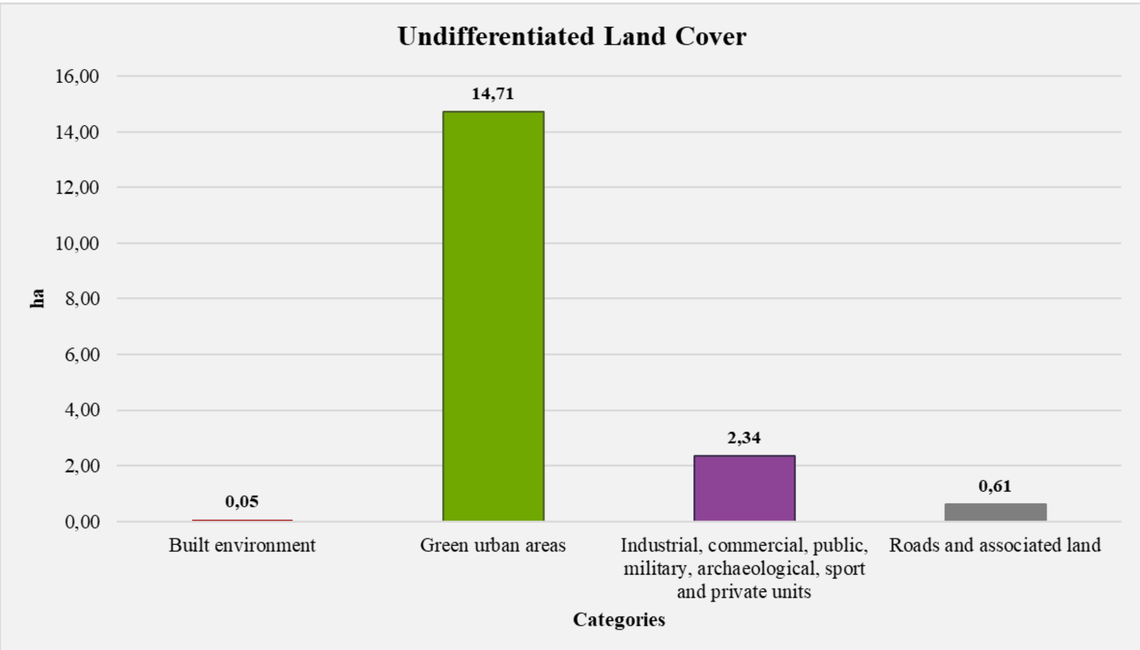

Diagram 7.3: Undifferentiated land cover areas between Curtius land cover map of 1881 and UA land cover map of 2012

In the case of the land covers that differentiated over time, **Figure 7.4** shows the coverage to which the change has occurred. In more detail, it is observed that of all changes that took place, more than 55% (311.76 ha) refers to a transition from other existing land covers to "Built Environment", change that was expected due to the residential development of Athens during the 20th century. The changes in "Built environment" follows an increase by 96.50 hectares in "Green urban areas", mainly due to the reforestation of Lycabettus, as well as by a 93.84 hectare increase of the "Roads and associated land" category.

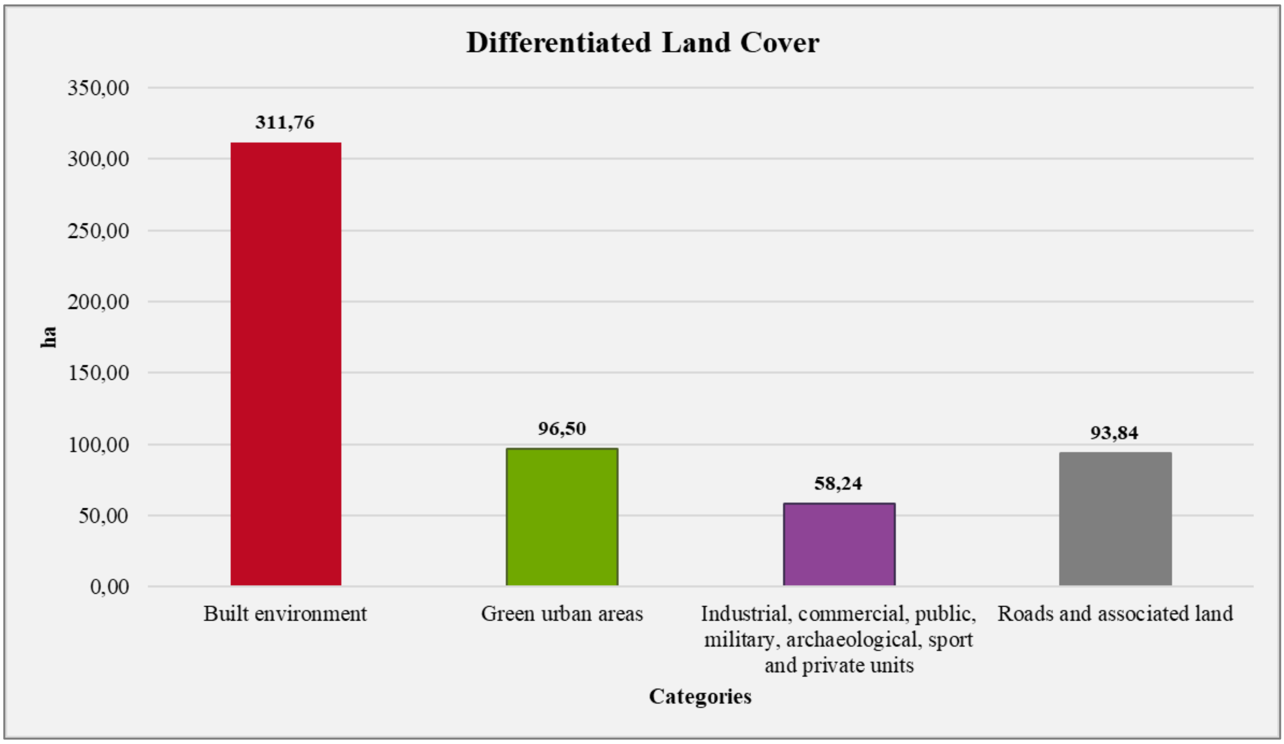

Diagram 7.4: Differentiated land cover areas between Curtius land cover map of 1881 and UA land cover map of 2012

Apart from the simple diagrammatic presentation of land cover changes, it was considered necessary to present a more analytical table, in which the details about the land cover changes are introduced. In this way, **Table 7.2** shows the land covers that have been differentiated and to which they have changed to, followed by the corresponding quantitative data.

In more detail, as expected from the above maps, the most significant change occurred to "Open spaces with little or no vegetation" as they decreased by 496.22 hectares. Of these, 284.86 hectares relate specifically to transition to "Built environment". The "Water" category has been much less changed (reduction of

16.83 hectares). However, as with “Open spaces with little or no vegetation”, it has completely disappeared as a land cover category within the study area.

As mentioned above relatively equal changes were also accepted by the categories “Green urban areas” and “Roads and associated land” as large parts of the areas of “Empty spaces with little or no vegetation” have been incorporated into them.

From Curtius 1881 land cover ⟶	**To UA 2012 land cover**	**Hectares**	
Built environment	Green urban areas	**0.45**	
Built environment	Industrial, commercial, public, military, archaeological, sport and private units	**0.91**	**2.37**
Built environment	Roads and associated land	**1.01**	
Green urban areas	Built environment	**6.03**	
Green urban areas	Industrial, commercial, public, military, archaeological, sport and private units	**11.55**	**20.53**
Green urban areas	Roads and associated land	**2.95**	
Industrial, commercial, public, military, archaeological, sport and private units	Built environment	**0.15**	
Industrial, commercial, public, military, archaeological, sport and private units	Green urban areas	**0.50**	**0.81**
Industrial, commercial, public, military, archaeological, sport and private units	Roads and associated land	**0.16**	
Roads and associated land	Built environment	**14.67**	
Roads and associated land	Green urban areas	**4.46**	**23.61**
Roads and associated land	Industrial, commercial, public, military, archaeological, sport and private units	**4,48**	
Open spaces with little or no vegetation	Built environment	**284.86**	
Open spaces with little or no vegetation	Green urban areas	**89.12**	**496.23**

Open spaces with little or no vegetation	Industrial, commercial, public, military, archaeological, sport and private units	**38.21**	
Open spaces with little or no vegetation	Roads and associated land	**84.04**	
Water	Built environment	**6.06**	
Water	Green urban areas	**1.97**	**16.83**
Water	Industrial, commercial, public, military, archaeological, sport and private units	**3.10**	
Water	Roads and associated land	**5.70**	

Table 7.2: Detailed presentation of land cover changes between Curtius land cover map of 1881 and UA land cover map of 2012

8. Discussion

The main research question of this thesis is to what extent could different types of historical visual representations lead to the production of accurate historical geospatial data. More specifically, the utilization of a historical photograph and a map of the same period was tested, to extract from them data on past land covers. In a second instance, their comparison them with modern ones was attempted, to identify changes in the landscape of Athens.

In terms of the historical photograph, the WSL Monoplotting Toolbox was used, in which images with initially unknown camera parameters can be georeferenced based on their automatic estimation (Section 4.2). Although the literature review (Section 4.3) indicated significant results in the accuracy of digitized entities from historical images, the not congruent data (DEM and Historical photograph) and their possible intrinsic data errors, did not allow the accurate georeferencing of land cover entities. Although the pattern of the objects was maintained to a certain extent, sufficiently to be qualitatively recognized, the deviations in their representation did not allow their final use for the precise extraction of land covers. The effect of changes on the topography is so significant that despite the 15 meters difference in accuracy between scenario one and four, no corresponding size differences are found.

The overall methodology has shown that for successful georeferencing of the photograph it is not enough to select the CPs with the smallest errors, as the effect of topographical changes and errors of the DEM can lead to in insufficient results. The use of reference data if existing is also essential, as without them, it cannot be detected whether an entity has been correctly spatial located or not. Ideally, in cases of landscape change detection, the extracted of the software vector data would enable researchers to detect, visualize and determine more efficiently and with high accuracy spatial changes.

The methodology followed for the production of historical land cover from Curtius map, and its further comparison with modern ones indicated significant results. The historical land covers were produced as accurately as the georeferencing of the map (9.8 meters) resulting in the production of slightly few sliver polygons after the intersection of them with the UA Land Covers of 2012. The digitization of the historical land covers indicated that most of the study area consisted of “Open spaces with little or no vegetation", as ascertained and by the photograph used. After intersecting the two layers of land coverage, it emerged that only 3% of the study area (0.177 hectares) remained undifferentiated while more than 50% of the total change (284.86 hectares) is related to conversion from "Open spaces with little or no vegetation" to "Built environment".

While in this case, the results of the WSL Monoplotting Toolbox require further verification of their accuracy due to not corresponding input data, meaningful conclusions can be drawn about its overall use and utility. The software allows the comparison between different types of visual material from various time periods (photographs, maps, sketches, postcards) bypassing their differences in terms of perspective and shooting point (Bozzini et al., 2012). As to the technical characteristics, WSL Monoplotting Toolbox is user friendly; the calibration process is computer-assisted, semiautomatic, and interactive as well as it shows all important information concerning the setting of CPs, camera calibration parameters and produced errors. It is possible to change the camera parameters manually if known, as well as it includes export and import routines allowing data exchange and visualization. All in all, WSL Monoplotting Toolbox has a great potential use on many research fields such as geomorphology, glaciology, archaeology and in the overall geographic reconstruction of past or nowadays events.

When WSL Monoplotting Toolbox or any other monophotogrammetric software is used, it is essential to remember that photographs are not maps, for the simple reason that while a map has (or are supposed to have) uniform scale, a photograph does not (Warner, 1993). The reliability and accuracy of the georeferencing process on the final products are limited by several factors, such as:

- the quality of the photograph
- the inherent errors of the input data. For example, topographical errors due to changes in the terrain morphology that took place between the time the image was shot and the DEM measurement, inaccuracies of the DEM, higher than acceptable RMS Error of the georeferenced historical map/orthophotograph used, camera lens distortions etc.

- the number and placement of the control points on the image, for example in places that are at low angles of incidence or close to terrain breaks. This can result in sizeable horizontal displacement
- the final camera calibration parameters

Some limitations can be identified that are not however attributed to the software itself. Although the user is not required to be a professional to use this software, knowledge of the limitations that weigh on it is necessary, as this directly affects the results. There is also a considerably high investment of time required for the photointerpretation of the photograph, the identification of suitable control points and the finalization of the desired camera parameters. In addition, when more than one raster was inserted and used as “Image Raster” on the respective tab, a severe system delay was detected that could be caused by the size of the used file. Concerning the land cover change based on the Curtius historical map, the existing quality of the digital file was a critical limitation, for the identification of past land covers. Despite the specific scale of digitization, cases were found where it was challenging to separate mainly vegetation-related land covers.

The growing interest in using historical photography and other forms of data, combined with the recent advancements in computing power, allows researchers having suitable photographic material to reconstruct events dating back more than a century with very satisfactory precision. The value of being able to reconstruct historical lost in time entities and spatially quantify entities visible in oblique terrestrial photographs, should not only be restricted in the pre-aerial photography and satellite imagery era. The high availability of historical photographic material, the ability to obtain a modern land-based photograph both in terms of cost and availability, in combination with the wealth of existing software, constitute photographs as valuable tools for the geographical and historical research (Stockdale et al., 2015).

9. Conclusion

This thesis aims to the utilization of old visual representations for the creation of historical geospatial data for the area of Athens. In more detail, the utilization of a historical photograph and a topographic map of the same period was attempted to reconstruct their depicted land covers. In second instance, the association of their historical land covers with modern ones was attempted, to conclude on the changes of the Athens landscape.

Regarding the processing of the photograph, despite the small errors of each monoplotting scenario, the georeferencing of the photograph and the digitization of the land cover entities require further verification of their accuracy due to not corresponding input data. Additionally, the use of Curtius historical map made it possible to visualize the landscape of Athens before its full urbanization followed, by an in-depth quantitative analysis of the land cover changes between 1881and 2012.

The use of GIS paired with other forms of historical visual evidence that have been long ignored, such as oblique terrestrial photographs, postcards and historical maps, can enrich their research by designating their spatial and attribute aspect. Through the documentation, visualization and interpretation of data, a more integrated spatial understanding of many aspects of history are provided.

Although in this master thesis the utilization of a historical oblique photograph for the production of its land covers was not entirely successful, the future use of monoplotting techniques paired with the exploitation of other forms of historical spatial information can bring significant benefits for reconstructing past environments.

Historical ground-level imagery is a crucial element in the reconstruction of the past. This, along with combinations of modern or historical maps, remote sensing data from satellites or UAVs and ground-based images, construct a valuable tool for documenting the pace of change experienced due to climatic change and other anthropogenic factors.

Bibliography

Achterberg, R. A. (2007). *Photographs as primary sources for historical research and teaching in education: The Albert W. Achterberg Photographic Collection* [Doctoral dissertation, The University of Texas at Austin]. Available at: https://repositories.lib.utexas.edu/bitstream/handle/2152/3538/%EE%80%80achterberg%EE%80%81r40536.pdf?sequence=2

Altaweel, M. (2018). *Using Ground-level Imagery to Map Landscape Change.* Available at: https://www.gislounge.com/using-ground-level-imagery-to-map-landscape-change/

Antoniadis, K. D. & Papaioannou, I. (2013). *Greek photography and photography in Greece: An anthology of texts.* Athens: Nefeli Publications. [In Greek].

ArcGIS Pro (n.d.). *How Intersect works.* Available at: https://pro.arcgis.com/en/pro-app/tool-reference/analysis/how-intersect-analysis-works.htm

Aschenwald, J., Leichter, K., Tasser, E. & Tappeiner, U. (2001). *Spatio-temporal landscape analysis in mountainous terrain by means of small-format photography: a methodological approach.* IEEE Transactions on Geoscience and Remote Sensing, 39(4), 885-893. https://doi.org/10.1109/36.917917

Baedeker, K. (1883). *Griechenland: handbuch für Reisende: 'Panorama d'Athènes'.* Leipzig: Baedeker

Bossard, M., Feranec, J. & Otahel, J. (2000). *CORINE land cover technical guide* – Addendum 2000. Technical report No 40. European Environment Agency. Available at: https://www.eea.europa.eu/publications/tech40add

Bournova, E. & Dimitropouloy, M. (2015). The capital's social and professional stratification, 1860-1940. Available at: https://www.athenssocialatlas.gr/en/article/social-stratification-1860-1940/

Burgin, V. (1982). *Looking at photographs.* In Burgin, V. (1982). *Thinking photography* (pp. 142-153). London: The Macmillan Press LTD.

Bozzini, C., Conedera, M. & Krebs, P. (2011, September). A *new tool for obtaining cartographic georeferenced data from single oblique photos.* In XXIIIrd International CIPA [Symposium]. Prague, Czech Republic. Retrieved from:

Available at: https://pdfs.semanticscholar.org/7ba4/d718498d2b3f72fbf308afa81d11bfddd03b.pdf

Bozzini, C., Conedera, M. & Krebs, P. (2012) *A new monoplotting tool to extract georeferenced vector data and orthorectified raster data from oblique non-metric photographs*. International Journal of Heritage in the Digital Era, 1(3), 500-518. https://doi.org/10.1260/2047-4970.1.3.499

Bozzini, C., Conedera, M. & Krebs, P. (2013). *A new tool for facilitating the retrieval and recording of the place name cultural heritage*. ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5/W2, 115-118. Available at: https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-5-W2/115/2013/isprsarchives-XL-5-W2-115-2013.pdf

Colwell, R. N. (1978). *Fundamentals of Photographic Interpretation*. In Skylab EREP investigations summary NASA SP-399. Johnson Space Center. 399, 377-380. Available at: http://adsabs.harvard.edu/full/1978NASSP.399..377C

Conedera, M., Bozzini, C., Ryter, U., Bertschinger, T. & Krebs, P. (2018). *Using the Monoplotting Technique for Documenting and Analyzing Natural Hazard Events*. In *Natural Hazards-Risk Assessment and Vulnerability Reduction*. IntechOpen. Available at: https://www.intechopen.com/books/natural-hazards-risk-assessment-and-vulnerability-reduction/using-the-monoplotting-technique-for-documenting-and-analyzing-natural-hazard-events

Copernicus (2020). *Land Monitoring Service: Urban Atlas, 2012*. Available at: https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012?tab=mapview

Corripio, J.G. (2004). *Snow surface albedo estimation using terrestrial photography*. *International Journal of Remote Sensing*, 25(24), 5705-5729. https://doi.org/10.1080/01431160410001709002

Doytsher, Y. & Hall, J.K. (1995). *FORTRAN programs for coordinate resection using an oblique photograph and high-resolution DTM*. Computers & Geosciences, 21(7), 895-905. https://doi.org/10.1016/0098-3004(95)00023-2

Curtius, E. & Kaupert, J. A. (1878). *Atlas von Athen*. Berlin: Reimer. https://doi.org/10.11588/diglit.765#0037

Curtius, E. & Kaupert, J. A., (1903). *Karten von Attika.* Berlin: Reimer. https://doi.org/10.11588/diglit.776#0001

Estes, J. E., Hajic, E. J., Tinney, L. R., Carver, L. G., Cosentino, M. J., Mertz, F. C. & Stow, D. A. (1983). *Fundamentals of image analysis: Analysis of visible and thermal infrared data.* Manual of Remote Sensing, 1, 987-1124.

European Environmental Agency (EEA) (2017). *Copernicus Land Monitoring Service - Urban Atlas.* Available at: https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-urban-atlas

European Union (EU) (2016). *Mapping Guide v4.7: For a European Urban Atlas.* Available at: https://land.copernicus.eu/user-corner/technical-library/urban-atlas-2012-mapping-guide-new

Eurostat (2018). *Administrative or Statistical unit: Countries 2016.* Available at: https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries

Fluehler, M., Niederoest, J. & Akca, D. (2005 June 1-3). *Development of an educational software system for the digital monoplotting*, In ISPRS, Working group VI/1 - VI/2 (Tools and Techniques for E-Learning), Germany, Potsdam.

Gabellieri, N. & Watkins, C. (2019). *Measuring long-term landscape change using historical photographs and the WSL Monoplotting Tool.* Landscape History, 40(1), 93-109. https://doi.org/10.1080/01433768.2019.1600946

Geodata, (2019). *Boundaries of Districts of the Municipality of Athens.* Retrieved from: https://geodata.gov.gr/en/dataset/op1a-euvo1k1wv

Gregory, I. N., Arts, & Humanities Data Service (England). History Data Service. (2003). *A place in history: A guide to using GIS in historical research* (p. 80). Oxford: Oxbow.

Grenzdörffer, G. J., Guretzki, M. & Friedlander, I. (2008). *Photogrammetric image acquisition and image analysis of oblique imagery*. The Photogrammetric Record, 23(124), 372-386. Available at: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1477-

9730.2008.00499.x?casa_token=EOr9bw2BsqUAAAAA:_lxxNO0n4GLvc7fbJ2uDcQJR-6N8m2Wog9HKOI-J6ByFgRsIuvCjsaIB_0zhSY6BFPtlW329n9p1MMM

Gruner, H. (1955). *New Aspects of Mono-Photogrammetry. Photogrammetric Engineering*, *21*, 39.

Harley, J. B. & Woodward, D. (Eds.). (1987). *Cartography in prehistoric, ancient, and medieval Europe and the Mediterranean.* Chicago: University of Chicago Press.

Hendrick, L. E. & Copenheaver, C. A. (2009). *Using repeat landscape photography to assess vegetation changes in rural communities of the Southern Appalachian Mountains in Virginia, USA. Mountain Research and Development*, *29*(1), 21-29. https://doi.org/10.1659/mrd.1028

Higgs, E., Bartley, G. & Fisher, A. (2009). *The Mountain Legacy Project* (2nd ed., p. 80). University of Victoria Press.

Holdsworth, D. W. (2003). *Historical geography: new ways of imaging and seeing the past.* Progress in Human Geography, 27(4), 486-493

Hu, B. (2010). *Application of geographic information systems (GIS) in the history of cartography. World Academy of Science, Engineering and Technology*, 42, 185-189. Available at: https://pdfs.semanticscholar.org/25be/6a21765f14a9fc584a5baabc040c0a129c58.pdf

Illinois University Library (n.d.). *Types of Sources and Where to Find Them: Primary Sources.* History, Philosophy, and Newspaper Library Available at: https://www.library.illinois.edu/hpnl/tutorials/primary-sources/

Jager, J. (2012). *Picturing Nations: Landscape photography and national identity in Britain and Germany in the Mid-Nineteenth Century in Picturing Place: photography and imaginative geographies.* London: I.B Tauris & Co Ltd

Kardamitsi-Adami, M., Constantinou, F. & Lugosi, L. (2003). *Athens Then and Now.* (2nd ed). Athens: Olkos. [In Greek]

Karras, G. E., Patias, P. & Petsa, E. (1996). *Digital monoplotting and photo-unwrapping of developable surfaces in architectural photogrammetry. International*

Archives of Photogrammetry and Remote Sensing, 31, 290-294. Available at: http://hdl.handle.net/11400/4969

Kouria, A. (2016). *Greece in European Travellers' Imagery (15th-19th centuries): Identities, alterities, metamorphoses.* Athens: Panagioti kai Efis Micheli Foundation. [In Greek]

Kull, C. A. (2005). *Historical landscape repeat photography as a tool for land-use change research. Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, 59(4), 253-268. https://doi.org/10.1080/00291950500375443

Library of the Congress (n.d.). *Does the Camera Ever Lie?* Available at: https://www.loc.gov/collections/civil-war-glass-negatives/articles-and-essays/does-the-camera-ever-lie/

McLaughlin, R. (1989). T*he evaluation of historical photographs: Considerations for Visual Resource Curators and Librarians in Museums and Archives. Art Documentation: Journal of the Art Libraries Society of North America*, 8(2), 55-60. Available at: www.jstor.org/stable/27948038

Meskin, A. & Cohen, J. (2008). *Photographs as evidence in Photography and philosophy*: Essays on the pencil of nature, 70-90.

Mitchell, W. J. (2012). *Picturing Place in the Post-Photographic Era: photography and imaginative geographie*s. In Picturing Place London: I.B Tauris & Co Ltd

Mitishita, E.A., Machado, A.L., Habib, A.F., & Gonçalves, G., (2004, July 12-23). *3D monocular restitution applied to small format digital airphoto and laser scanner data.* Proceedings of Commission III, XXth ISPRS Congress (International Society for Photogrammetry and Remote Sensing), Istanbul (Turkey). Available at: https://www.isprs.org/proceedings/xxxv/congress/comm3/papers/243.pdf

NUMiSTRAL (2009). Digital heritage library of the Alsatian site: *Vue panoramique d'Athènes prise de Licabette. University of Strasbourg and University of Haute-Alsace.* Available at: https://docnum.unistra.fr/digital/collection/coll4/id/212

NYU Libraries (2020a). *New York University Libraries: Primary Sources: Visual Materials.* Available at: https://guides.nyu.edu/c.php?g=276619&p=1848088

NYU Libraries (2020b). *New York University Libraries: Primary Sources: Definitions.* Available at: https://guides.nyu.edu/c.php?g=276619&p=1845101

O'Neill, K. (n.d). *Digital History: Historical GIS*. Harvard University. Available at: https://scholar.harvard.edu/koneill/historical-gis

Papaioannou, I. (2014). *The photograph of the Greek Landscape: Between myth and ideology.* Athens: Agra [In Greek]

Papayannis, T. & Howard, P. (2012). *General reflections on landscapes. In Reclaiming the Greek landscape.* Med-INA: Athens, Greece. Available at: http://www.med-ina.org/LinkClick.aspx?fileticket=IRPlLizdoVA%3D&tabid=67&mid=436

Perakis, K., Moysiadis, A. & Faraslis, I. (2015). *Remote Sensing in 13 sections.* Athens: Association of Greek Academic Libraries. Available at: http://hdl.handle.net/11419/1840 [In Greek]

Petersen, J., Sack, D. & Gabler, R. E. (2010). *Fundamentals of physical geography.* Cengage Learning.

Plewe, B. (2002). *The nature of uncertainty in historical geographic information. Transactions in GIS*, 6(4), 431-456. https://doi.org/10.1111/1467-9671.00121

Poulicos, P. & Chrysoulakis, N. (2011). U*rban Atlas, land-use modelling and spatial metric techniques*. https://doi.org/10.4000/cybergeo.28051

Prastacos, P., Lagarias, A. & Chrysoulakis, N. (2017). *Using the Urban Atlas dataset for estimating spatial metrics: Methodology and application in urban areas of Greece. Cybergeo: European Journal of Geography.* https://doi.org/10.4000/cybergeo.28051

Remote Sensing Core Curriculum/ RSCC (1998). *Introduction to Photo Interpretation and Photogrammetry*: V1, Module 2: Elements, Aids, Techniques, Methods, and Procedures of Airphoto Interpretation. University of Minnesota. Available at: https://rscc.umn.edu/

Rose, G. (2008). *Using photographs as illustrations in human geography. Journal of Geography in Higher Education*, 32(1), 151-160. https://doi.org/10.1080/03098260601082230

Rumsey, D. & Williams, M. (2002). *Historical maps in GIS. Past Time, Past Place: GIS for History*. Available at: https://www.davidrumsey.com/gis/ch01.pdf

Rundell, W. (1978*). Photographs as Historical Evidence: Early Texas Oil*. The American Archivist, 41(4), 373-398. Available at: www.jstor.org/stable/40292812

Schwartz, J. M. (2000). *Records of Simple Truth and Precision: Photography, archives, and the illusion of control*. Archivaria, 50, 1-40.

Schwartz, J. & Ryan, J. R. (2003). *Introduction: Photography and the Geographic Imagination in Picturing Place: photography and imaginative geographies*. London: I.B Tauris & Co Ltd

Sevara, C., Verhoeven, G., Doneus, M. & Draganits, E. (2018). *Surfaces from the visual past: Recovering high-resolution terrain data from historic aerial imagery for multitemporal landscape analysis*. Journal of archaeological method and theory, 25(2), 611-642.

Shankar, D. R. (2017). *Remote Sensing of Soils*. Springer.

Siebert, L. (2000). *Using GIS to document, visualize, and interpret Tokyo's spatial history*. *Social Science History*, 24(3), 537-574. https://doi.org/10.1017/S0145553200010294

Steiner, L. (2011). *Reconstruction of glacier states from geo-referenced, historical postcards*. [Doctoral dissertation, Institut fur Kartografie und Geoinformation, Eidgenossische Technische Hochschule, Zurich]. Available at: https://www.researchgate.net/publication/280918409_Reconstruction_of_Glacier_States_from_Geo-Referenced_Historical_Postcards

Stockdale, C. A., Bozzini, C., Macdonald, S. E. & Higgs, E. (2015). *Extracting ecological information from oblique angle terrestrial landscape photographs: Performance evaluation of the WSL Monoplotting Tool. Applied Geography*, 63, 315-325. https://doi.org/10.1016/j.apgeog.2015.07.012

Strausz Jr, D. A. (2001). *An application of photogrammetric techniques to the measurement of historic photographs*.

Sylvia Ioannou Charitable Foundation (2020). Research programmes. Available at: https://sylviaioannoufoundation.org/en/academic-programmes/research-programmes/

Triglav-Čekada, M., Bric, V. & Zorn, M. (2014). *How to decide which oblique image has the highest mapping potential for monoplotting method: A case studies on river erosion and floods. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences*, 2(5). https://doi.org/10.5194/isprsannals-II-5-379-2014

Warner, W. S. (1993). C*onsiderations when measuring from a single photograph: Positional uncertainty of digital monoplotting*, *Norwegian Journal of Geography*, 47(1), 39-50. https://doi.org/10.1080/00291959308552305

Wiesmann, S., Steiner, L., Pozzi, M., Bozzini, C., Bauder, A. & Hurni, L. (2012, September 16-18). *Reconstructing historic glacier states based on terrestrial oblique photographs*. In *AutoCarto International Symposium on Automated Cartography, Columbus, Ohio, USA.* Available at: https://cartogis.org/docs/proceedings/2012/Wiesmann_etal_AutoCarto2012.pdf

WSL Monoplotting Tool (2014). *Landscape study with Historical Photographs through Monoplotting: Short Tutorial.* 27-28 June 2014, Corzoneso, Switzerland

Zinkham, H. (2006). *Reading and Researching Photographs In Photographs: Archival Care and Management* (59-77). Chicago: The Society of American Archivists. Available at: https://www.loc.gov/rr/print/resource/Reading_Researching_Photographs.pdf

Appendix A

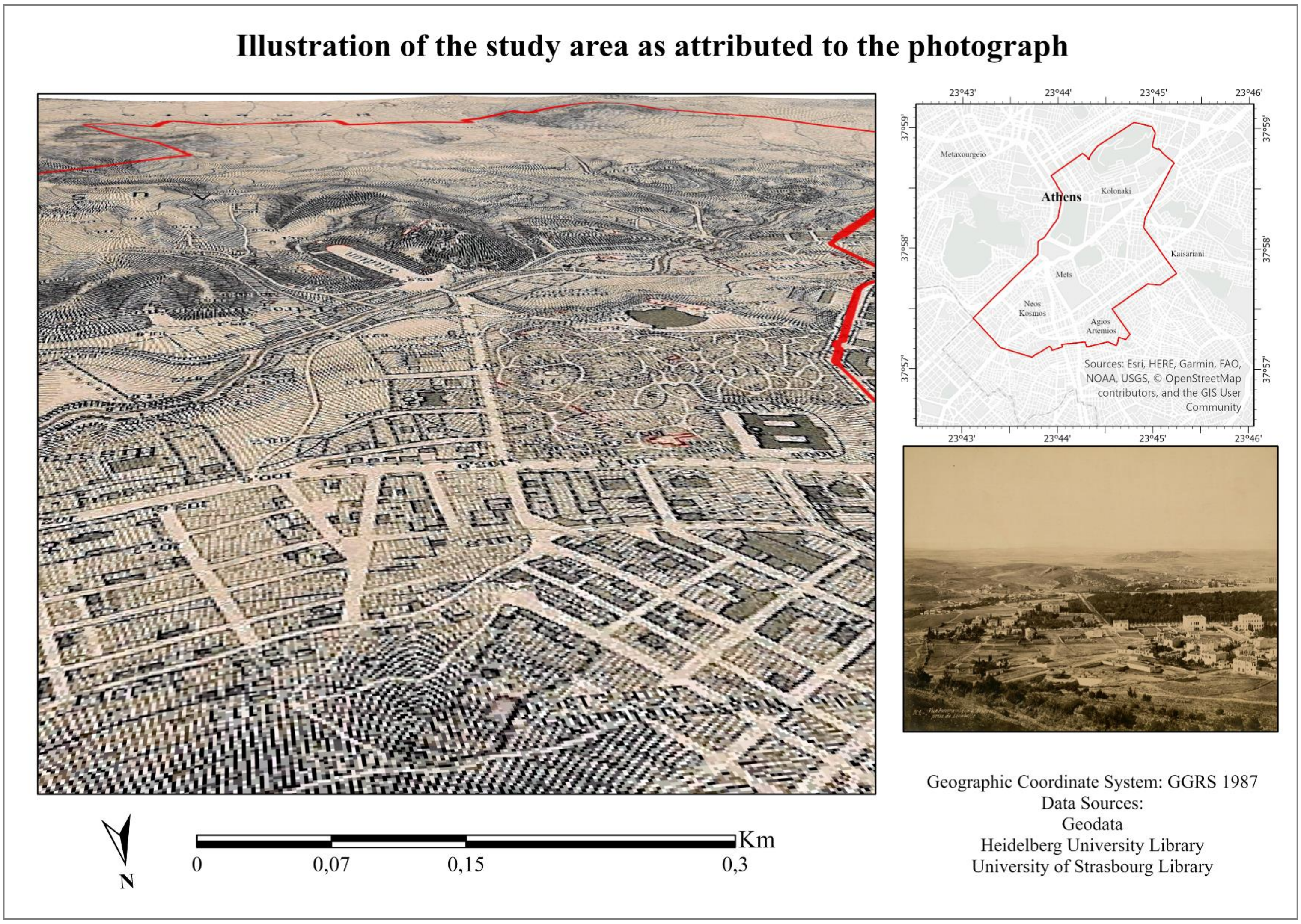

Figure A.1: Illustration of the study area on Curtius map as attributed to the photograph

Figure A.2: Athens and its suburban (I. Athen und Umgebung) from" Karten von Attika, 1881" (Curtius & Kaupert, 1903)

Figure A.3: Panoramic view of Athens (Baedeker, 1883)

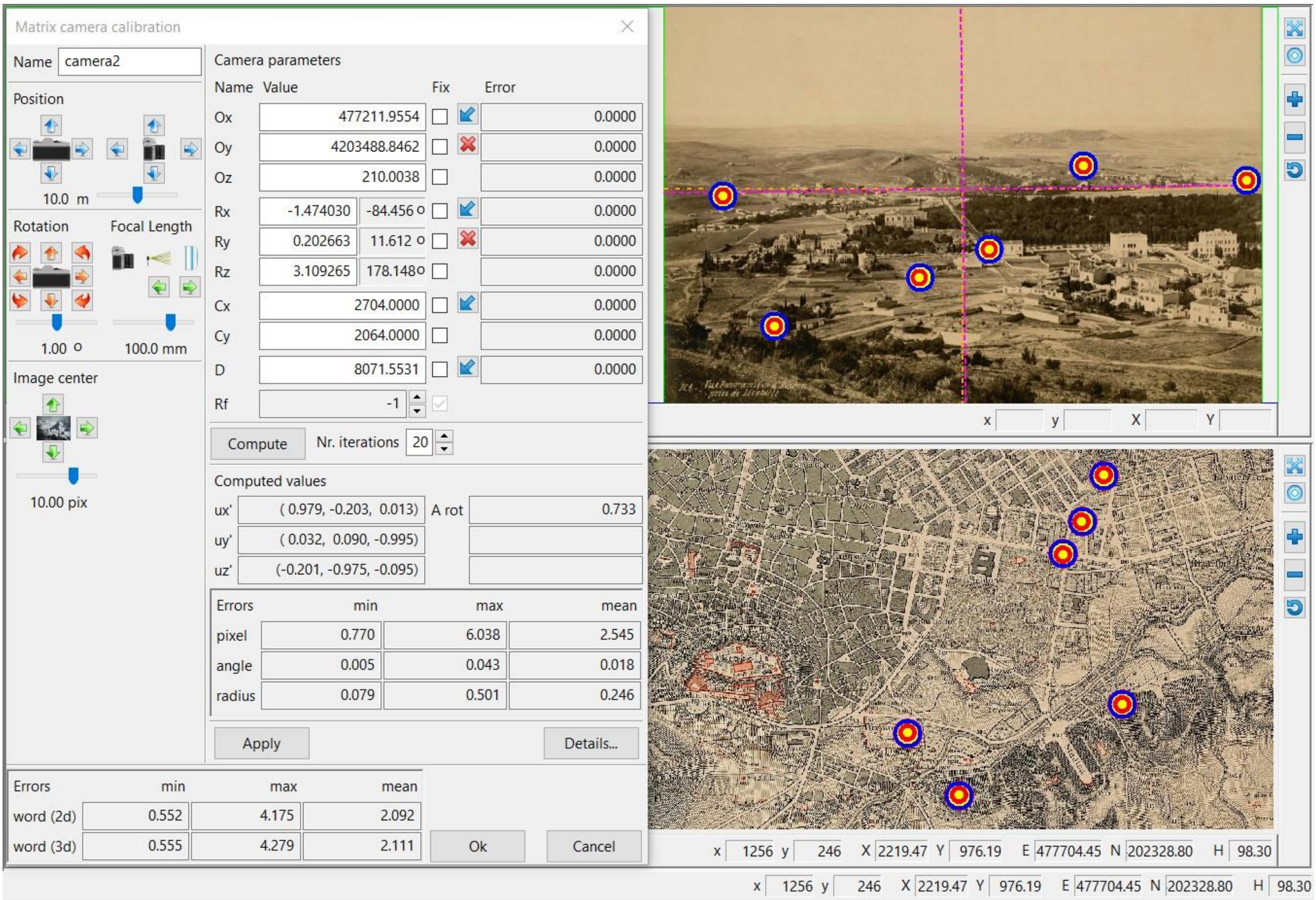

Figure A.4: Camera parameters and errors during camera calibration, shown in the WSL Monoplotting Toolbox for Scenario 2

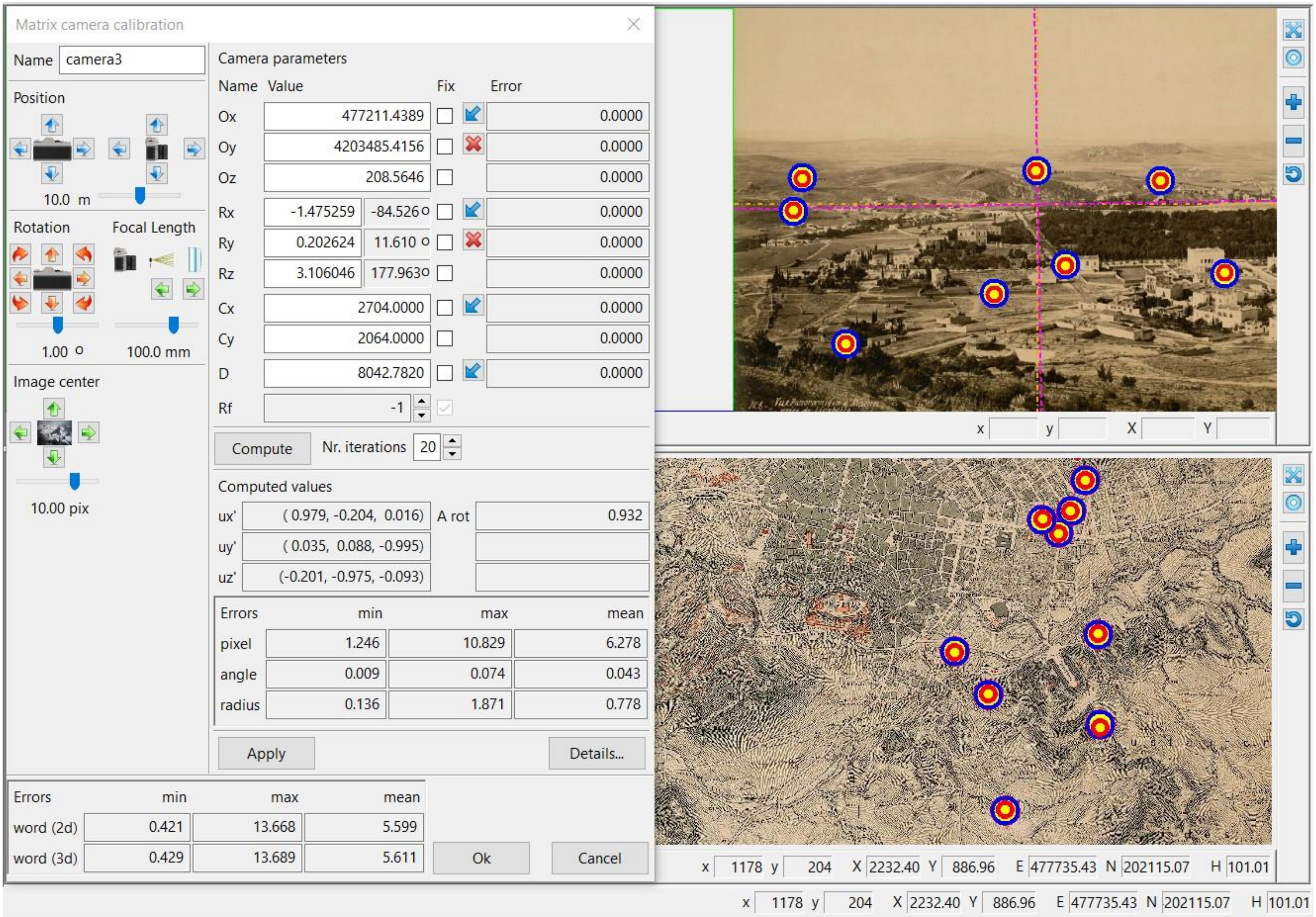

Figure A.5: Camera parameters and errors during camera calibration, shown in the WSL Monoplotting Toolbox for Scenario 3

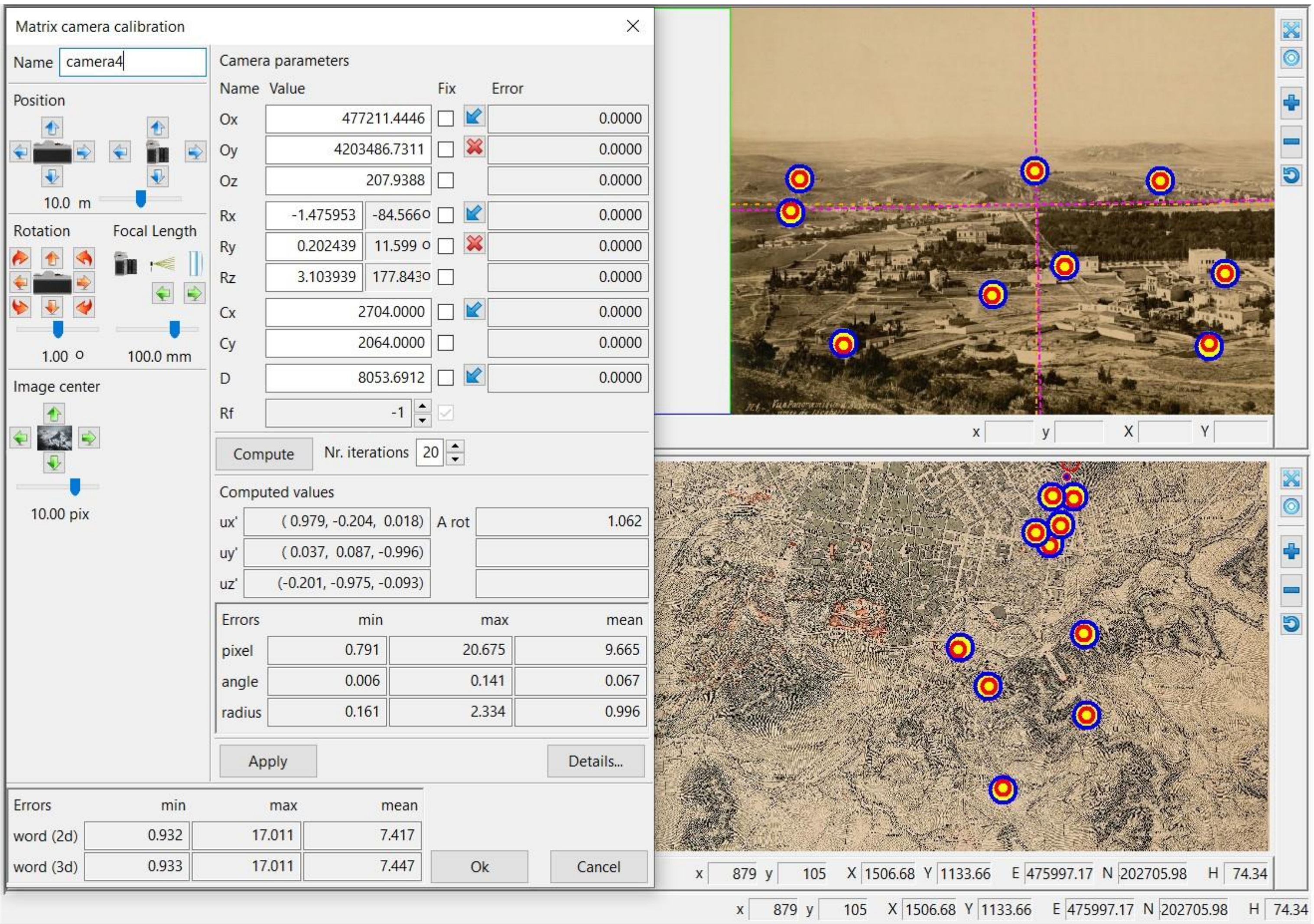

Figure A.6: Camera parameters and errors during camera calibration, shown in the WSL Monoplotting Toolbox for Scenario 4