NATIONAL TECHNICAL UNIVERSITY OF ATHENS
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GEOMETRIC DOCUMENTATION OF CLIMBING ROUTES

3D maps of sport climbing fields

The case study of Villanueva de Valdegobia

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ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ

ΣΧΟΛΗ ΑΓΡΟΝΟΜΩΝ & ΤΟΠΟΓΡΑΦΩΝ ΜΗΧΑΝΙΚΩΝ

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ΕΡΓΑΣΤΗΡΙΟ ΦΩΤΟΓΡΑΜΜΕΤΡΙΑΣ

ΓΕΩΜΕΤΡΙΚΗ ΤΕΚΜΗΡΙΩΣΗ ΑΝΑΡΡΙΧΗΤΙΚΩΝ ΔΙΑΔΡΟΜΩΝ

3D χάρτες πεδίων αθλητικής αναρρίχησης

Μελέτη της περίπτωσης του πεδίου Villanueva de Valdegobia

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Διπλωματική Εργασία

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ABSTRACT

The present Diploma Thesis, whose subject of study is the geometric documentation and presentation of sport climbing fields, focuses on the development of climbing maps (Topos) and climbing guides, proposing the creation of three-dimensional climbing maps (3D topos) as well as a climbing guide application containing them.

Sector 2 (Campa) of the field Villanueva de Valdegobia, a limestone-type rock of 50x25m, is selected as case study. The 3D model of the rock is generated by using the Structure from Motion (SfM) method, converted into a three-dimensional climbing map (3D topo) using 3D models' editing software, and published on a storage platform (3D Warehouse). In addition, part of the archaeological site of Necropolis de San Martin, located at the base of the rock, is documented geometrically.

At the same time, a digital climbing guide application is created through a drag-n-drop Android application development platform. To navigate the three-dimensional map, the HTML tool is used, where 3D viewer embed code, provided by the 3D Warehouse, is inserted.

Finally, the use of simple and low-cost tools of photogrammetry and programming is being studied, so that the above procedures can be carried out by the climbers themselves.

ΠΕΡΙΛΗΨΗ

Η παρούσα ΔΕ, της οποίας αντικείμενο μελέτης είναι η γεωμετρική τεκμηρίωση και παρουσίαση των πεδίων αθλητικής αναρρίχησης, εστιάζει στην εξέλιξη των αναρριχητικών χαρτών (topos) και οδηγών αναρρίχησης, προτείνοντας τη δημιουργία τρισδιάστατων αναρριχητικών χαρτών (3D topos) καθώς και εφαρμογής οδηγού που τα περιέχει.

Ο τομέας 2 (Campa) του πεδίου Villanueva de Valdegobia, ασβεστολιθικού τύπου βράχος διαστάσεων 50x25μ, επιλέγεται ως αντικείμενο μελέτης. Το τρισδιάστατο μοντέλο του βράχου δημιουργείται με τη χρήση της μεθόδου Δομή από κίνηση (SfM), μετατρέπεται σε τρισδιάστατο αναρριχητικό χάρτη (3D topo) με τη χρήση λογισμικού επεξεργασίας τρισδιάστατων μοντέλων και δημοσιεύεται σε πλατφόρμα αποθήκης (3D warehouse). Επιπλέον, τεκμηριώνεται γεωμετρικά και μέρος του αρχαιολογικού χώρου Necropolis de San Martin, που βρίσκεται στη βάση του βράχου.

Παράλληλα, δημιουργείται εφαρμογή ψηφιακού οδηγού αναρρίχησης μέσω drag-n-drop πλατφόρμας ανάπτυξης Android εφαρμογών. Για την πλοήγηση στον τρισδιάστατο χάρτη, χρησιμοποιείται το εργαλείο "HTML", όπου εισάγεται κώδικας ενσωμάτωσης 3D viewer, που παρέχεται από την αποθήκη 3D.

Τέλος, μελετάται η χρήση απλών και χαμηλού κόστους εργαλείων της φωτογραμμετρίας και του προγραμματισμού, ώστε οι παραπάνω διαδικασίες να μπορούν να πραγματοποιηθούν από τους ίδιους τους αναρριχητές.

PREFACE

The most important source of information in sport climbing is the climbing maps or *topos*. By the term "topo" the graphical representation of a rock face with the climbing routes depicted on it is meant, usually with their name and grade as well, or only the route reference numbers and a companion legend (number-name-grade-length-creator). Originally started being created for the mountain routes, the rough concept of the topo surely predates their formal documentation or mass distribution and it could have been as simple as a handmade map of a ridgeline drawn on a napkin in a mountain café in the Alps. During their evolution, several figurative products (sketch, croqui, drawing, photograph) were used as base.

The attempt to collect as much information as possible, grouped per field or region, brings the generation of the climbing guides. By the term climbing guide the informative database that contains, apart from the topos and the routes' description, further information about the rock type, climate, historical elements, ethics etc. is meant. Originally started being published as books, the imprinted form of climbing guide still remains popular. However, nowadays there are several climbing forums, websites and android applications providing plenty of information about the climbing fields around the world.

The present study is focusing on the 3rd dimension of the climbing maps, considering its importance for this kind of activity, as it provides useful information about the slopes and the surface topography of the rocks. For the case study of the climbing field of Villanueva de Valdegovia, a 3D topo is created, taking advantage of the potential of photogrammetry. Following the technological evolution, a climbing guide android application enriched with a 3D topo is developed. Moreover, the use of simple and low-cost tools is studied and proposed, so that the above procedures can be carried out by the climbers themselves.

STRUCTURE

The present study is divided in 3 parts; Introduction, Case Study and Conclusions.

More specific:

In Part I, firstly an introduction to mountaineering and climbing is given, as well as a brief description of the climbing guides' and maps' (topos) evolution, for the better approach of the study object. Then, to clarify the needs, aims, methods and concerns over the subject, the most inspiring part of the bibliography is summarized.

In Part II, firstly the climbing field of Villanueva de Valdegobia is described. The whole procedure from the field work up to the 3D topo follows, including the study of basic concerns. Finally, the climbing guide application procedure is presented, to visualize the final products.

In Part II the conclusions of this study are described, as well as some proposals for future projects.

PART I

INTRODUCTION

A.Climbing maps and guides

A.1 Mountaineering

Mountaineering, by the etymological approach of the term, is indissolubly connected with the history of human's roaming the earth. The mountains, majestic, inaccessible and dangerous, firstly awe human, who deifies or demonizes but does not approach them. Sooner or later, though, both the curiosity as livelihood reasons (hunting, lumbering, farming, cultivation) lead him to the foothills. Afterwards, for mercantile and military reasons, he traverses and ascends the mountains, the natural boundaries and bulwarks between the tribes, utilizing them both as passages to facilitate the trade transactions and as places of strategical importance. Moreover, he is stepped in curiosity of exploring his surroundings, need for explanation of phenomena that accompany them or worship whatever he cannot understand, so he starts mountaineering for scientific, philosophical and religious reasons. Until the Middle Ages, there are several assumptions, evidences or recordings of sporadic mountain ascents, including the (primitive) gear use. Since 16th century the mobility towards the mountains is raised mainly due to scientific and artistic reasons.

Nevertheless, the history of mountaineering begins only in 1786, with the first ascent to Mont Blanc with main, if not exclusive, motivation the "conquest" of the peak; ever since, the relationship between human and mountain starts to acquire clearly recreational character (obviously influenced by the Renaissance and the French Revolution) and to become systematic, which both are characteristics of the modern mountaineering that separate it from the rest human activity on the mountain.

For almost 100 years, mountaineering groups, helped by the development that the Industrial Revolution brings, are dedicated themselves to the pursuit of the alpine peaks' "conquest", culminating in the "Golden Age", that begins in 1854 and is culminated in 1865 with the ascent of the last summit, the Matterhorn.

From this point up to the outbreak of the 1st WW, the mountaineering activity includes mainly the resumption of the first climbs in the Alps and few peak "conquests" around the world. In this first period of Modern Mountaineering, besides love for the mountain and recreation, motives such as ambition, vanity, glory, economic benefits etc., are appeared.

By the end of the War, the second phase of Contemporary Mountaineering starts, which is characterized such by the search for new routes to the peaks and new ascent techniques, as by its wide now spread beyond the geographical boundaries and altitudinal limits of the Alps, and is coming to a head after the end of the 2nd WW. The first ascent of Mt Everest in 1965 is a milestone in Mountaineering; having reached even to the highest peak of the world, the contemporary mountaineer is looking towards the more intense search of more difficult routes, and it is the fact of the ascent itself that does lead the evolution of mountaineering to what it is nowadays.

Mountaineering is the art of the safely wandering across the mountains and ascending their summits, regardless of altitude, terrain, or route, combining physical fitness and spiritual clarity with the excellent knowledge of the application of its basic techniques, which are the mountain trekking, the mountaineering ski and the climbing.

A.2 Climbing

Although there are indications of applying climbing techniques, even for reasons completely independent to mountaineering (a typical example is the rock climbing at Meterora by cenobites already from the 10° century) the climbing activity gets started just in the beginnings of the past century through and for the mountaineering.

On the way to the summit, the mountaineer is faced with large-scale, steep rock volumes, which he must either bypass and continue walking, or follow using his hands. And, initially bypasses them, since his goal is the ascent to the summit and the path towards it still unexplored. However, as long as the ascents are getting increased and the number of the "unconquered" peaks is getting decreased, he cannot but succumb to the charm that the rocks have exerted to him from the beginning. So, he turns to the exploration for new, shorter and more challenging paths towards the peak, that are passing through the rocks (routes), and that's how he starts climbing.

Climbing follows the evolution of mountaineering as an integral part of it and offers to the mountaineer more and more challenges and excitement; it is not only the "conquest" of the peak, but the difficulty of the route that gives value and meaning to the ascent. Initially he starts climbing alone and without safety equipment (belay). Although, such is the degree of dangerousness that almost from the begging necessitates the development of safety equipment and techniques. At the same time, the development of strong bonds of trust seems equally necessary, and this is the fact that defines climbing as an art based above all on comradeship.

Although, the rocks do not meet only at the high mountains, so climbing, apart from its evolution as a basic mountaineering technique, meets a parallel evolution as a particular sport. Since about 1880, intense climbing activity is recorded in 3 places that are considered to be the birthplaces of rock Climbing; Elloe Sandstone Mountains in Germany, Lake District in England and Dolomites in Italy.

Moreover, since 1950 climbing is also considered as an independent sport, with various categories (indicative to the range of its fields of application), some of which have nothing to do with the mountains or the rocks. In 1988, sport climbing is firstly recognized as an official sport, which will be hosted for the first time in the Olympic Games of 2020. Below, the basic categories of climbing are briefly shown. (Table 1)

Table 1 Climbing Categories

Terrain	Equipment	Height
Rock	Solo	Boulder
Ice	Sport	Single pitch
Mixed	Traditional	Multi pitch
Artificial		Big wall

A.3 Guides

In 1574 the "De Alpibus Commentarius" is published by professor Josias Simpler and it is the first book that refers whatever is ever written until then about the mountains, the paths, the difficulties and the dangers. But, by the rising of mountaineering, the need for more specific information becomes obvious; the mountaineers take notes, make croquis, and narrate their adventures, with the intention to prove their ascent, but mostly to share their experience and provide information for future attempts. The dissemination of the route information relies basically on oral transmission, that progressively starts to be recorded and posted in articles, since the first ascent to a summit or the first climb of a route is considered significant fact. The croquis (primitive *topos*) and the personal notes are so important that they are either carefully studied or even manually copied by those who are interested to attempt a repetition or search for new routes. In 1857 the Alpine Club of London is the first mountaineering club to be established, it signals the systematic chronicle of the ascents and the routes, and gradually it becomes an info center. In 1863 the first annual mountaineering journal, the Alpine Journal, is published, covering all aspects of mountains and mountaineering, including the "conquests" and the tragedies.

The progress of the climbing achievements becomes rapid and leads to the creation of a wide database of spare croquis and notes, that have to be gathered and then grouped per region, so the first climbing guidebooks are printed; they are books, that apart from the sketches and the routes' description, provide further information about the rock type, climate, historical elements, ethics etc.

Although, the creation of an accurate guide is a time-consuming operation and it cannot follow the impressive volume of the new routes, even new fields. The technological evolution gives the solution to keep the database updated; Nowadays, apart from the traditional climbing guide, there are several climbing forums, websites and mobile phone applications providing plenty of information about the climbing fields around the world. This information could be divided in two categories, descriptive and visual, as shown briefly below (Table 2).

Table 2 Information Categories

Descriptive		Visual	
Area	**Routes**	**Horizontal**	**Vertical**
Coordinates Access Distance Parking Approach Altitude Orientation Weather Prohibitions Surrounding area	Grade of difficulty Needed equipment Height Quantity of routes Climbing style Rock type Holds type Historical elements	Maps Topos	Pictures Topos Panoramic views Videos

I. Descriptive Information

There is information about a particular area and the existing routes, which are both useful for the proper selection of the climbing field.

a. Area

The very first information for a climbing field is its location. So, there is a description of the road access to the field, the distance from the nearest big city and the average needed driving time (*access*). By approaching the area, there is provided information about either authorized parking area if it exists or other suggested places, in order to respect the local community (*parking*). From the parking area, there is usually a path that should be followed until the climbing field. So, there is information about the distance, the grade of difficulty and dangerousness of the path (*approach*). Moreover, there is information about the altitude, orientation, weather and the climbing prohibition seasons due to nature or culture respect reasons, which all are useful for the selection of the best season for climbing in each climbing field. Finally, there is additional information about the surrounding area, such archeological site, other sport facilities, camping sites.

b. Routes

A great criterion about the selection of a climbing field is the existing information about the available routes. The grade of difficulty of the routes, the needed gear and the pitches´ height, are the most important information for safe climbing.

Further information, such as the quantity of the existing routes, the climbing style (sport, traditional, multipitch, single pitch), the rock and holds type, enforce the advantage of choosing a place depending on desire criteria. Finally, there are historical information about the date and the creator of each route, the first ascent and legendary routes.

II. **Visual Information**

There is information about the landscape and the rocks that could generally be divided in two categories respectively: Horizontal and Vertical.

a. Horizontal

Imprinted and digitized maps are widely used by climbers, for their road and path access, as described before. Additionally, as rock climbing field is a part of a mountain, and contains many routes, it is usually divided according to mountain's topography in sectors. It is also common for one field to be consisted of different blocks of rocks, which could be thought as different sectors as well. To prevent misunderstandings there are sketches for the description of the way that these sectors are placed in a field. (Image 1).

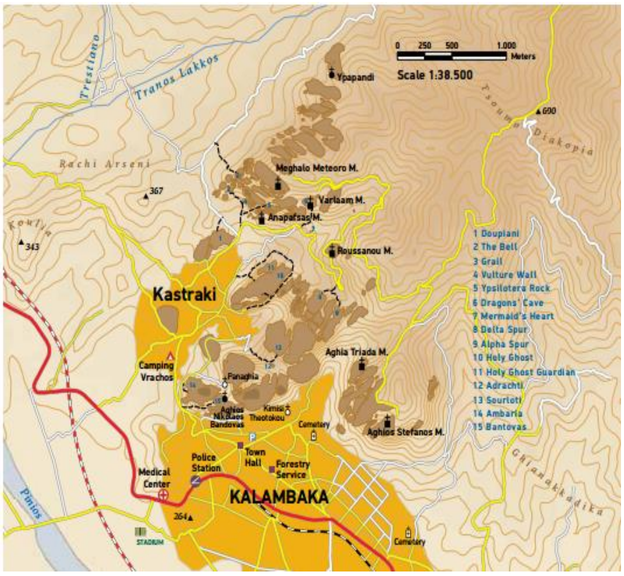


Image 1 Horizontal topo of Meteora

b. Vertical

As rock is the main object of the climbers, pictures of them could not be missing. Of course, the topos, as described before and will be analyzed in the next chapter, have a great importance in this category. Lots of sketches show the order that the routes are placed on the rock and define meanwhile the general direction of each route (Image 2).

Image 2 Horizontal topo of Torcall de Antequera

Moreover, in multipitch routes these topos provide figurative information about the gear and the different techniques that should be used according to the mountain surface. (Image 3)

Panoramic views, either including the design of the routes (topos as well) or not, provide a general option of the rocks. (Image 4)

Moreover, there are several videos that present a climbing ascent, and provide visual information as well, as at the following link for example.

(Laurene Sibue and Xavier Gaboriaud climb over 30 stories on the "Monolithe de Sardières" in Savoie, France.)

https://www.youtube.com/watch?v=VUQjhidxg8I

In *APPENDIX A*, there are more examples of different kind of topos.

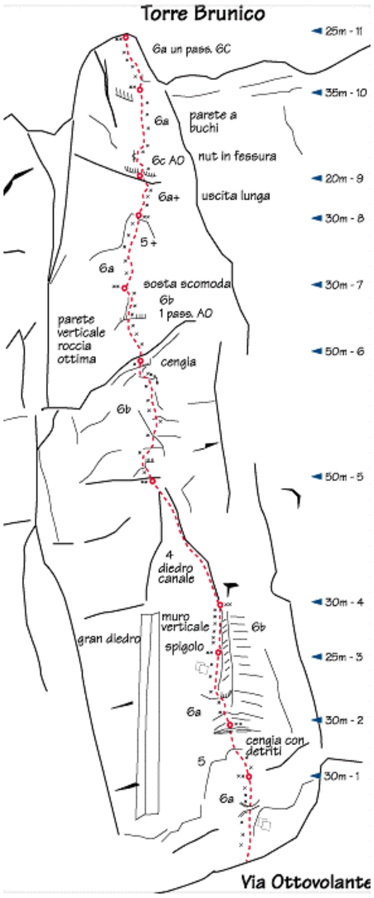


Image 3 Vertical topo of Ottovolante multipitch route

Image 4 Panoramic topo of Half Dome

A.4 Topos

The term "topo" means the graphical representation (sketch, croqui, drawing, photograph) of a mountain or a rock face with the path or the climbing route, respectively, depicted on it. The rough concept of the topo surely predates the formal documentation or mass distribution and it could have been as simple as a handmade map of a ridgeline drawn on a napkin in a mountain café in the Alps.

As rock climbing first started on the mountains, where the access to the start point of the route could be tricky and time-consuming by its own, the firsts topos are drawings of the mountains that are being used to lead the climbers to the bottom of the rock face easier, without losing their way and time which all have great importance in climbing, especially high mountains and that era with the poor equipment and means of communication.

Gradually, and in addition to them, similar topos are created, focused on the rock face, representing its general outlining and the followed route, preventing the climbers from following unknown routes, that can be impossible or extremely dangerous to be climbed. With the rise of the climbing activity and the increase of the climbing routes, the need for the mapping of the climbing areas is intense. In 1970 George Meyers creates a route mapping system, introducing the inclusion of lines and symbols (at the already widely used topos) to represent specific rock features (roofs, cracks, corners) that demand different climbing techniques. The main aim is offering useful information that can be easily translated to the realities of a climb and transcend the language barriers, and it is so successful and useful that, enriched with more symbols and information, these topos nowadays remain on of the most important information tool. In multipitch routes the handmade or digitally designed topos, provide plenty of information, such as the number, the length, and the grade of the pitches, belay sites, cruxes, special rock formations and techniques, gear requirements etc. Apart from the detailed topo of one route, there are topos of the climbing fields; they are croquis, sketches, drawings, photos or panoramic photos of the whole field, where the routes are depicted on, usually with their name and grade as well, or only the route reference numbers and an companion legend (number-name-grade-length-creator). The field topos are the basic object of the climbing guides.

B. SotA

B.1 Mountain and Alpine Routes

B.1.1 Creating the Virtual Eiger North Face (1)

This study demonstrates the alpinistic potential of the face digital model of an alpine slope. The selected object was the Eiger (3970m) North Face, a worldwide famous and historical climbing rockface with an average steepness of 60°. While oblique or traverse projections are considered as superior to the nadir projections for slopes steeper than 45°, instead of a conventional DTM a Steep Slope Model (SSM) was created from an oblique pair of colored air photos taken at an angle of 58°.5 of vertical and 8 GCPs transformed from the Swiss National Coordinates into the Model 2000 System. The whole process from the air photos digitization to the generation of the first products (3.7m grid resolution DTM and 0.25m resolution digital orthophoto) was accomplished using the CARL ZEISS PHODIS hardware and software. Finally, an anaglyph representation, a virtual model (using Virtual-GIS TM), a Combined Image-Line map and a route profiles diagram were produced.

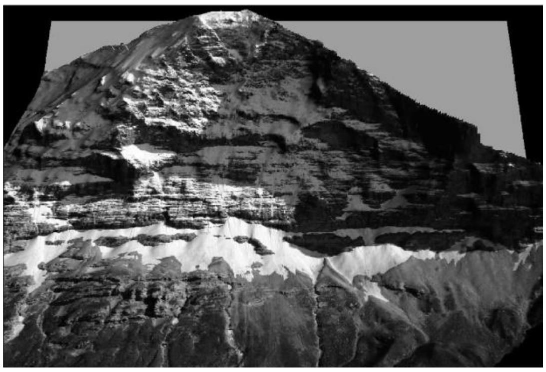


Image B.1.1 CIL map representation and Virtual Eiger North Face

B.1.2 Visualization and Animation of Mt Everest (2)

In this study, modern photogrammetric techniques for 3D model building and specific modelling and visualization problems associated with very steep terrain, such as Mount Everest, is demonstrated. The project was focused on a 25x25km^2 area around the summit of Mount Everest. 9 sheets of the original photogrammetric plot 1:10.000 were selected, digitalized with a 40m contour interval, and converted into a raster DTM of 10m grid size and 1m natural texture pixel size, from which the 3d textured model was derived as well. In addition, 40 aerial B/W images (in 5 strips at 60-80% forward overlap and 35% sidelap) of the area and 3 color images of the summit, were scanned with a resolution of 21 and 12,5 micron pixel size respectively, to produce a B/W orthomosaic with 1m footprint for the area and 50cm for the summit. Finally, the National Geographic 1:50.000 topo map was scanned and, including the printed ascent routes, was overlaid to the raster DTM.

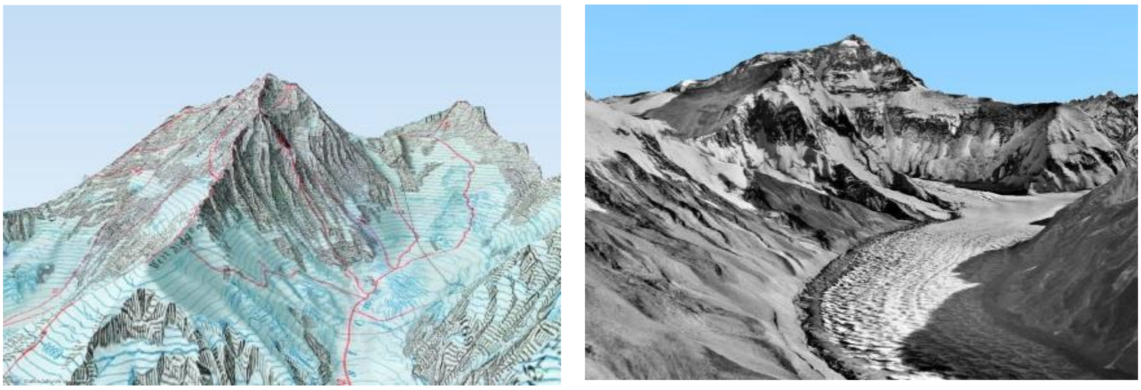


Image B.1.2 DTM topo map and Orthomosaic of Mt Everest

B.1.3. Rockfalls in High Alpine Rock Walls(3)

In this study, a technique based on lidar measurements was used for first the time in high mountain environment for the quantification of the rock falls due to permafrost effect on high alpine rock walls.

A surface of 67000m^2 of the East Face of Tour Ronde (3792m), a popular mountaineering and alpine climbing destination at Mont Blanc, was laser scanned in July 2005, July 2006, and October 2006. 22 partially overlapping scans were performed from two positions at 100m distance (which gives a 30mm laser beam diameter and results a 3-5cm accuracy), using an Optech ILRIS 3D terrestrial laser scanner, with a field of view of 40°x40° and 2000 points/sec sampling rate. The individually aligned point clouds, were merged into a single local reference system, and derived a single point cloud of the entire scene and a High Resolution Triangulated Irregular Network model (HRTINM).

The point clouds of the 3 data sets were aligned and compared to identify the rock fall areas. For each area, the volumes between a reference plan and the surface of each date compared to calculate the volume of the rock fall, which reached 536m2 in the scanned region and matches an erosion rate of 8.4mm/year.

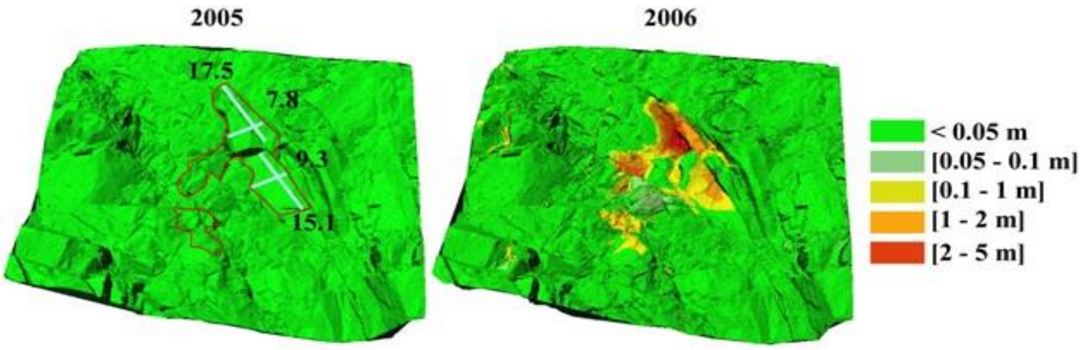


Image B.1.3 Rockfalls Volume Comparison

B.2 Bouldering

B.2.1High-resolution mapping and Visualization of a climbing wall(4)

In this study the possibility of applying close-range photogrammetry to create a high-resolution map and its 3D visualization of a climbing rock, to provide further type of information to the climbers, is examined.

The research object was a part of a 4m high and 100m long limestone steep (close to vertical) traverse in Krakow, whose surface is very rough and irregular. The dimensions of the selected part of the object were 4x6m and the maximal differences of depth did not exceed 60 cm. 4 photographs, overlapping by 40-55%, were taken with a Nikon D80 amateur digital camera, which previously had been calibrated with Topcon's ImageMaster software, in one facing strip at a distance of 5.5m from the object.

9 GCPs and the approximate coordinates of camera positions were measured with Leica GPS 1200 receiver and AX1203 GG Leica antenna in the Polish National Coordinate System "2000". Some problems occurred because of the LPS software demand for approximate parallelism between object x, y-plane and image plane, and also due to the overhanging terrain. They were solved by setting a reference plane and a local coordinate system and applying spatial 3D transformation to the measured values. The data was preprocessed (images calibration and CGP coordinates transformation to the Local Coordinate System) and input to Leica Photogrammetry Suite 8.7 for performing the photogrammetric process (orientations and triangulation) to generate the quasi-DEM (0.01m final pixel size) and quasi-orthophotos (0.005m pixel size with some insignificant for the realistic visualization purposes distortions) and 1.8mm terrain pixel size. The stereo model of this boulder can be observed in anaglyph with the use of red-blue or red- green glasses and a textured virtual 3d model can be studied in the exported VRML format.

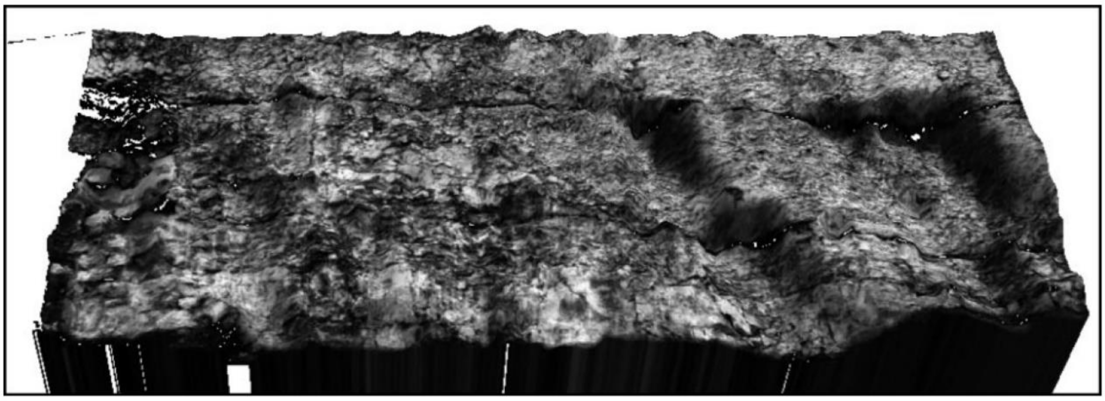


Fig. 9. Virtual model of the climbing wall seen in 3D.

Image B.2.1 Virtual Model of the climbing wall seen in 3D.

B.2.2 Benefits of 3D topos[5]

This study is about a 3D topo prototype and its usefulness to the climbers. As 3D topo, is defined a 3D model of a climbing rock with conventional topo features added on it, and the usefulness is derived as a conclusion of an online questionnaire. The authors selected a boulder in Koivusaari (Helsinki, Finland), the dimensions of which are not mentioned. Two cameras, Canon Mark 2 and Canon G9, were used to shoot overlapping photos circling around boulder. The cameras' position was on standing level, 4m high with the use of ladders, surrounding climbable trees and the top of the boulder. In the next step, 133 photos were input into VisualSFM software in order to create the dense point cloud, but the algorithm did not recognize the top and the sides of the boulder as a uniform mass and two separate dense point clouds were created. The dense point clouds were imported to Meshlab software, manually aligned and merged into one dense point cloud. After performing Poison surface reconstruction, filters to simplify and clean the model from and artefacts, and applying texturing from photographs, the final 3D model of the boulder was imported to Autodesk Mudbox software, in order to be converted in a 3D topo by adding climbing information (route lines, start hold, beta holds and excluded areas). Finally, the 3D topo was imported to Unity 3D engine to get better in the operation and compressed to 35MB download size.

As the objective of the study is the climbers' opinion about the 3D topo, a 6-pages online questionnaire was created and distributed via Finish and international discussion forums, as well as several climbing-related groups on social media. The participants were asked to download the 3D topo and answer the questions that were divided in six categories: Information sharing, planning, on-site use, climbing sequence, general, demographic. Apart from the general and demographic questions, the participants had to compare the 3d topo to the 27Crags web topo. This survey points out that the climbers' opinion fluctuation is not related to their grade or climbing experience and confirms the existing onsight – flash conflict. The conclusion after processing the results of the 52 participants' survey is that 3D topos are considered superior to the existing normal web topos, and highly useful especially in sharing, planning and on-site use.

Image B.2.2 Interactive topo for bouldering

B.2.3 Replicating Outdoor Climbing[(6)]

A prototype fabrication method, through a combination of photogrammetry and digital fabrication techniques, to replicate the crux of a rock-climbing route on an indoor climbing wall is proposed in this study.

The cruxes of two climbing routes (TATAN, Rumney crag, New Hampshire & Pilgrimage, Southern Utah) with differing geological features (schist & sandstone, respectively) but same difficulty grade (7a+, FR) and inclination (vertical face), were selected for the validation of the proposing method. To detect the exact key hold and footsteps of the crux, a video of the climber's ascent was captured, and its individual frames were being studied. For each crux, region of 1-2m approximately, 200-500 sufficiently overlapping photos of the rock were captured by a regular digital camera from multiple viewpoints while rappelling the route. Several additional photos of the rock face with a calibration marker for the scaling of the 3d product, as well as of the free hanging rope for the definition of the crag gravity direction, were also taken. Once the 3D model of the crux area was created by the procedure of the whole data set (photos and video frames) in Agisoft Photoscan software, the recognition of the regions where the body extremities were in contact with the rock face have been achieved. The 3D position of these contact points gave the approximate location of the center of key rock features, and then their boundaries where defined.

The high-resolution geometry of the contact regions that the created reconstruction provides, gave the prototype for the fabrication of the climbing holds. Once the 3D replicas have been fabricated (3D printing and foam cutting with a CNC router), the holds were mounted on the indoor climbing wall, in such positions as simulating the outdoor route. Finally, the videos of the outdoor and indoor ascents were compared, focusing on the body poses, to verify the accuracy of replicating the features and configuration of the rock route.

https://www.youtube.com/watch?time_continue=2&v=dQ8lKfc3ypA

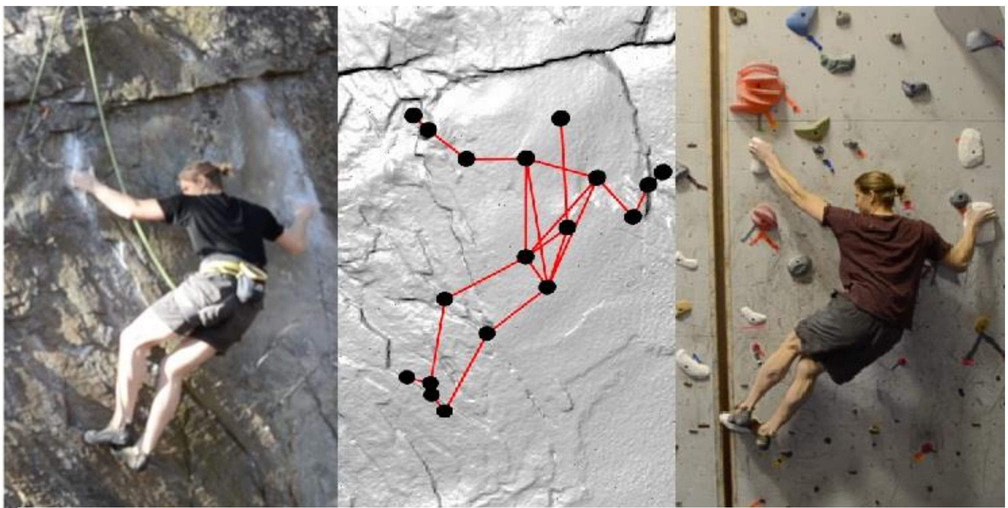


Image B.2.3. Replicating the crux of an outdoor climbing route.

B.2.4 Climbing heritage preservation[(8)]

This study is a collaborative project between ACCORD (Archaeology Community Coproduction of Research Date) members and local climbers, that develops counter-archaeologies focused on the prominence of climbing heritage and examines the impact of the 3D modelling and recording on the climbing community.

Dumbarton Rock, Scotland, was selected to be geometrically documented, because, beyond of its politically and tactically importance position and its recognition as a protected archaeological site due to the existence of historical monuments, it is also highly significance part of climbing heritage due to the volcanic geology, the unique character of the surrounding, the technical complexity and difficulty, and the climbing culture that has been raised since 1960s. Furthermore, the traditional rock-climbing route "Rhapsody", is considered as one of the hardest traditional routes in the world and the first of its grade (E11, UK) to be ascended (Dave MacLeod, 2004). In addition to the archaeology and sport heritage, the graffities that are painted on the rocks, as far as they are considered as modern art, give in that place a cultural heritage dimension.

As far as the collaboration was a main aim of the project and all the participants were fully engaged with the data acquisition and process, consumer-level equipment, open or free software and relatively easy to use photogrammetric techniques (SfM) were selected for the 3D documentation of Eagle and Sea Boulders, "Pongo" route on Home Rules boulder. Exceptionally, seizing the opportunity of capturing the "Requiem" and "Rhapsody", mythical routes, and the Dumpy cliff-face, a terrestrial laser scanning was undertaken with Leica C10. Moreover, the some graffities were recorded using Reflectance Transformation Imaging (RTI). Finally, the products met a great acceptance and enthusiasm of the climbers

.

Image B.2.4 Climbing Heritage, Dumbarton rock in 3D

B.2.5 Exploring Rock Climbing in mixed reality Environment[(7)]

The development of a prototype of a Virtual Reality Climbing System, projecting on an indoor climbing wall a virtual environment that enforces the sense of climbing a high mountain terrain, using an artificial wall and HTC Vice equipment.

Once the 3D model of an indoor climbing surface of 3x4m² (including an overhanging panel and 3 volumes) had been created using Kinect v1 and Skanect software, it was imported in a Unity Scene. A height map of Matterhorn was applied to a terrain, and the 3D model was placed at the top of the mountain to create the feeling of the height.

Four easily recognizable both in the 3D model and in the artificial wall calibration points were established in the indoor wall and registered in the Unity scene at the respective positions in order to obtain their coordinates in the Unity space, with which the 3d model was rotated and transported. In this way the calibration of the virtual and physical environment was achieved, and the virtual holds were matching the physical ones. Using the Microsoft Room Alive Toolkit and the corresponding Unit Plugin, as far as an HMD equipped with a Leap Motion Controller, each climber, while climbing the artificial wall, was able to immerse in the Virtual environment. Features of the iconic environment, such as the texture of the climbing face, were projected on the artificial wall in order to include the audience as well.

https://www.youtube.com/watch?v=FuAaH8mACFg

Image B.2.5 Mixed Reality Environment

B.3 Big Wall

B.3.1 Yosemite Extreme panoramic imaging project

A database of 10000 high resolution images, 20 separate gigapixel panoramas, a 1-meter DTM and 2 single vertical orthographic views of Yosemite Valley, were the products of a partnership project between Yosemite National Park Services and xRez Studios, supported by 70 volunteer photographers and funded or sponsored by several organizations and companies.

Yosemite Valley is a 12 km long, 1.6km wide and 1km deep glacial valley in the Western Sierra Nevada mountains, Central California. 20 image sets of 500 overlapping photos each, were captured simultaneously by 20 separate photographic teams from key/vantage overlapping locations, using Gigapan devices, which are small robotic mounts that allows the camera to focus on one small area at a time and then stiches all the frames together into a result, with Canon G9 cameras. Each image set derived a gigapixel panorama in PTGui, and all 20 panoramas were projected on UC Berkeley's (National Center for Laser Airborne Mapping) DEM and derived 2 single vertical orthographic views in Maya. Moreover, as DEM data did not provide vertical relief data, the representation of the valley walls came as product of a point cloud data, acquired during a hang-gliding flight with 3 time-lapse cameras and proceeded on Photosynth.

Apart from being an impressive photographic project, the imagery has already been used to cover the needs for surface details of other projects and researches on earth sciences. (e.g. 2017)

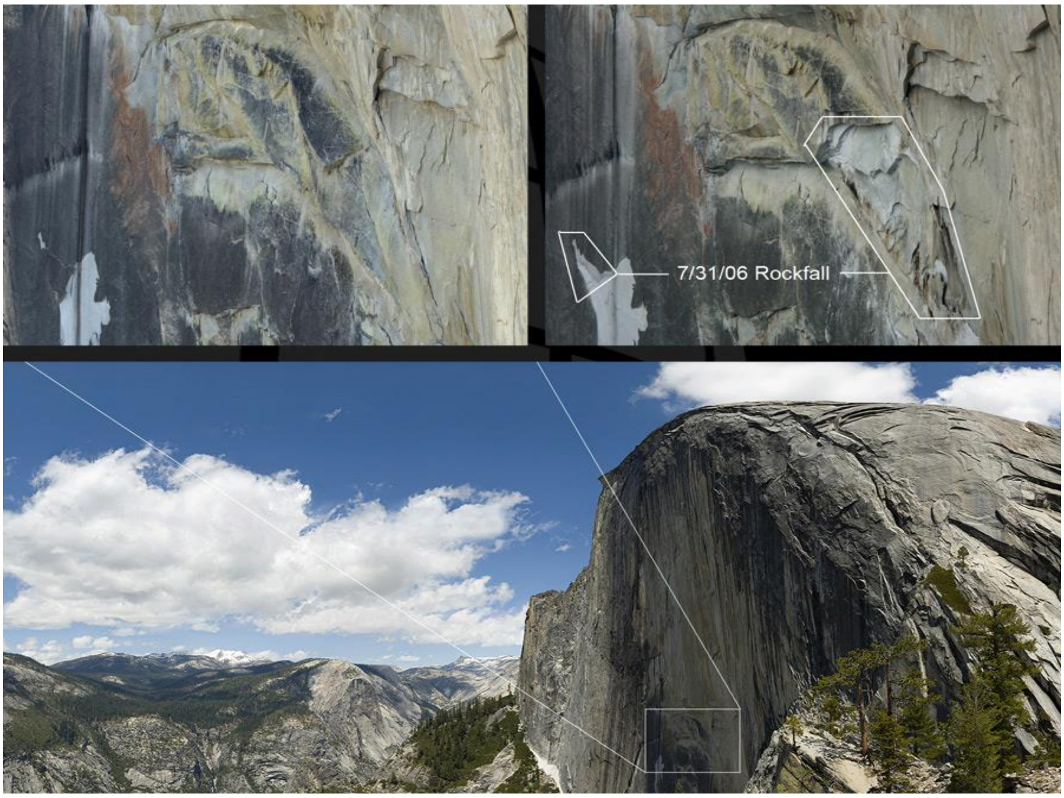


Image B.3.1 Yosemite panoramic imaging project

B.3.2 El Capitan Southeast Face Geologic map[9]

The results of this research, which is focused on the determination of the chronology and geometry of the emplacement of the South East Face of El Capitan, are visually represented as a detailed geological map on a 3D model of the physical structure of this 1km tall vertical rock face.

The mapping was based on terrestrial LiDAR data, high-resolution gigapixel photographs (captured from the ground at 1.2-1.5 km away from the face, with Nikon D5000 SLR, 300mm lens, giving a 2.2-2.7 cm/pixel resolution), individual close-up photographs of the rock texture (taken by the climbers, who contributed to the project, while ascending), and Tom Evan's photographs (taken from El Capitan Bridge with 1cm/pixel theoretical resolution).

8 specific climbing routes were selected to be ascended for the collection of representative samples of the all rock units of the base, face, and summit of El Capitan. Small samples were carefully chipped off for geochemical analysis, without impacting the climbing routes and avoiding areas of significant evidence of mingling and mixing.

Image B.3.2 Geological Map of El Capitan

B.3.3 Rock face Stability analysis and 3d geological mapping[10]

This research is focused on the recognition of the most probable future rockfall sources, based on TLS observation in Yosemite

The study of the point clouds, derived from the 2 TL scan series, conducted in 2010 and 2012, lead/led to the calculation of the past rockfall volumes and the development of a methodology to carry out kinematic tests on TLS point clouds.

The 3d mapping over wide areas of sheeting joints and exfoliation sets, was validated by field observations and high-resolution digital photos.

B.3.4 High resolution 3D imaging and visualization of rock falls[(11)]

A precise and accurate approach in quantifying rockfall source areas in high cliffs, using integrated far-range high resolution imaging techniques, is achieved in this work.

Glacier Point, eastern Yosemite Valley, where the most destructive rockfall in Yosemite National Park history took place in October 2008, was selected to be studied.

ALS data (collected by National Center of Airborne Laser Mapping in collaboration with National Park Service in September of 2006, consisted of 9.1 million data points, deriving a high resolution DEM) were merged with TLS data (of an 8 million points cloud, collected with an Optech ILRIS-3D^{ER} in October 2007) in a single point cloud, which derived an interpolated surface in VRMesh, textured from a gigapixel panoramic photograph in Maya 3D. By repeating the (TLS and photography) data collection in May 2008 and the process described above, a post-rockfall high-resolution textured surface was created.

Furthermore, pre and post-rock fall TLS-based surface models (created with InnovMetric PolyWorksTM, using kriging, TIN and IDP interpolation methods) were compared (Applied Imagery Quick Terrain Modeler TM).

The volumetric, structural and stability analyses indicate that a vertically oriented, near planar sheeting joint of 2750m2 surface and 2.1m uniform mean thickness, followed the shear (sliding) failure mode, creating a cumulative rock-fall volume of 5663 +/-36m2.

B.3.5 Quantifying 40 years of rock fall activity in Yosemite with SfM and TLS analyses [(12)]

The creation of a new rockfall documentation database, based on the comparison between results of the comparison between SfM and TLS products with the existing database, based mostly on human observation, are the main disciplines of this paper.

37 photographs, captured from a Yosemite's Search and Rescue team helicopter in 1976, were used to generate a high resolution DTM of El Capitan and Middle Brother areas. Repeated TLS data since 2010 was used for the comparison with this DTM, in order to quantify the last 40 years rockfall activity. The results were compared with the existing database, based mostly on human observation, resulting a great difference between them, such on the number as on the volume of the rockfalls.

Finally, it is proposed the use of more historical photos to extend the data base.

B.3.6 Dawn wall interactive visualization

Dawn Wall on El Capitan, Yosemite, a 1000m height climbing route of 32 pitches (all of them harder than 5.13 and two graded 5.14d (9a)), is considered to be the most difficult big wall in the world, and Tommy Caldwell and Kevin Jorgeson were the first to ascent it, after 19 days of climbing, on 14 of January 2015.

To provide the readers a webGL interactive visualization of the historic first free climbing ascent of Dawn Wall, the New York Times enriched the event coverage article with a 3D model of the rock and the climbing route, with the contribution of the University of Lausanne and xRez Studio.

The first attempt to upload the whole 1.6 Gb file of the 36 million points' cloud of the Lidar scan dataset created by M. Jaboyedoff, B. Matasci, and A. Guerin, researchers from the University of Lausanne, was rejected for being too time-consuming for the user-reader (more than one hour to be loaded).

The researchers provided the NYT team with a high-resolution polygon model of the same dataset, which could easier be converted in smaller enough file, but it was as well rejected as not such detailed.

The xRez Studio's extremely high-resolution photograph could have been a pretty detailed visual approach to the climbers' attempt, but it was lacking the advantages of the 3D features.

Finally, the polygon model and the photograph were merged, and the product was uploaded beside the main article, giving the reader the opportunity to get navigated through the rock while reading the text.

https://www.nytimes.com/interactive/2015/01/09/sports/the-dawn-wall-el-capitan.html

Image B.3.6 Dawn Wall interactive 3D

B.4 Digital Guides

B.4.1 Vertical life

The Vertical Life application is one of the most well designed and easy to navigate climbing guidebook, created in cooperation with local developers and climbing guide authors, for both outdoor crags and indoor gyms mostly in Europe. As for the rock-climbing fields, numbering more than 36000 sport climbing and bouldering routes, it provides complete location information, maps, topos, route lists and information. Moreover, it provides a series of features such as list of the user's climbed routes, contact with other users and invitation of challenging one route, real-time ascents, photographs and comments from the users. The topos are full color photographs with the lines of the routes and the grade drawn on them to be easily recognizable, as shown below.

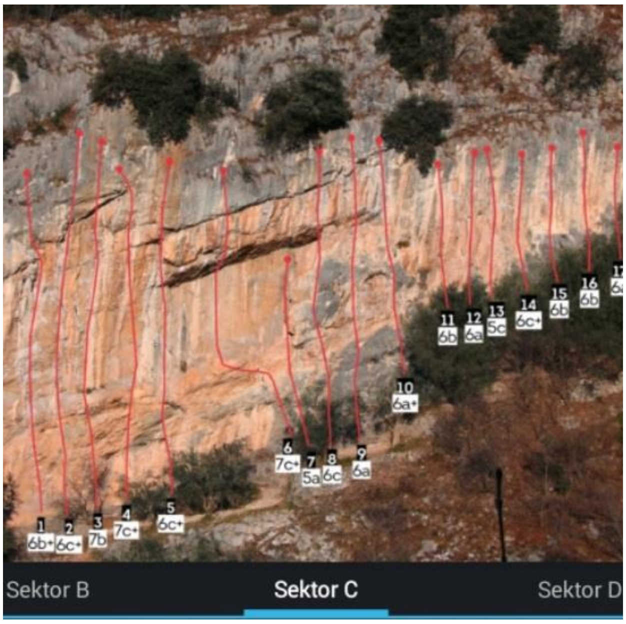


Image B.4.1 Vertical life app

B.4.2. Climbing away

The Climbing Away application is a digital guidebook of more than 5000 rock climbing and boulder areas all over the world, but mostly focused on Europe. It provides a map with all the climbing sites, textual search function with intelligent search patterns, connection with the phone GPS for better navigation, detailed information, a climbing grades converter and a dictionary with climbing terms in 5 languages. The digital guidebooks contain topos made by high definition photos where the routes are tracked with different colors depending the grade.

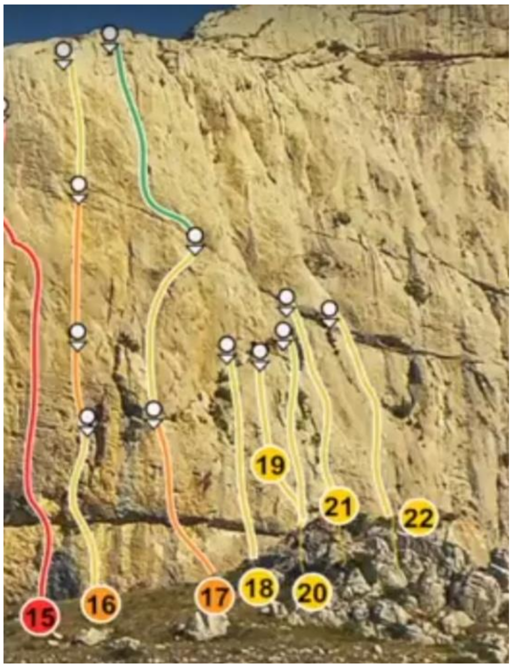


Image B.4.2 Climbing away app

B.4.3 Kalymnos

Kalymnos, numbering more than 2600 routes and the new route development in progress, is one of Europe's most popular climbing destinations. With more than 7000 visitors annually, the need of the route re-equipment and maintenance is obvious.

This application is an effort to combine the climber's need for information with the funding of the route maintenance. It is a guidebook that provides the lines of the routes, individually checked by the equippers, on super high-quality bright color photos. In these topos, same grade routes are shown with the same color. In further features are included the high-quality approach maps, crag's grade spread, grade filter, personal tick list.

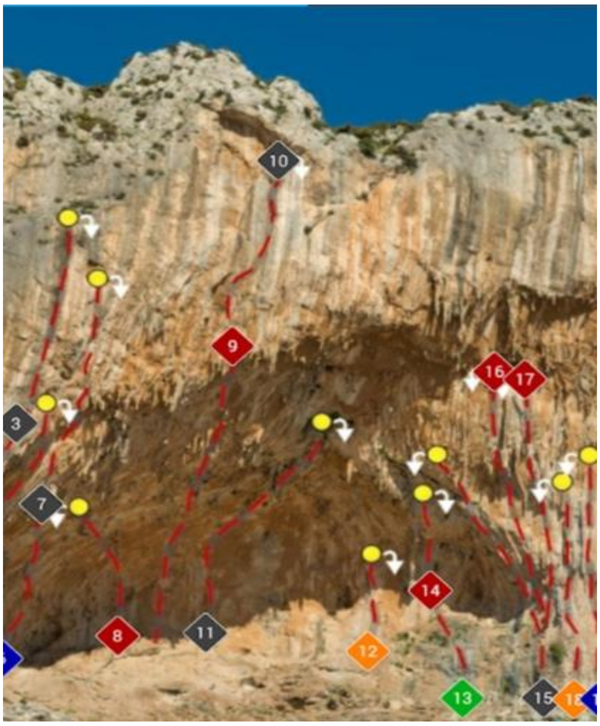


Image B.4.3 Kalymnos app

B.4.4 27 crags

The 27 Crags Climbing Topo application is a digital climbing guide of 88191 climbing routes and 134612 boulder problems in 104 countries. As most of this kind of applications, offers plenty of maps, information, photos, offline mode, to-do list, GPS features and latest access permission info. Additionally, it provides to its users the opportunity either to add a route line on an existing topo or to create easily their own topo in a few steps. The user must search first if the crag has already a topo. If so, the route's details and information must be given and then the route's line can be drawn on the existing topo (high quality photo) with just a few clicks. If not, the user must search in the map for the field of interest, define its borders, fill in the necessary details and further information of the crag, upload a photo and then continue with the line.

Image B.4.4 27 Crags app

B.5. Other Apps

B.5.1 ARTopos – AR Terrain Map Visualization (13)

In this study, a prototype smartphone application called ARTopos, that combines paper topographic maps with digital terrain model, is proposed to ease a hiking route planning between the team members, either they are at the same place or not.

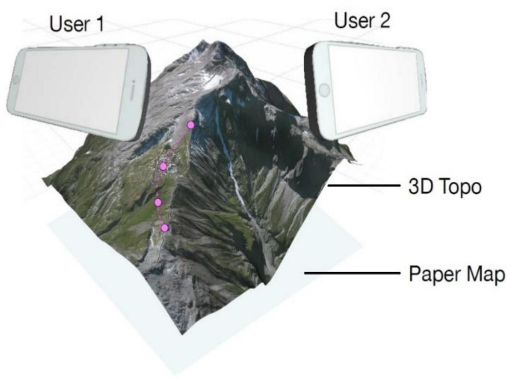


Image B.5.1 AR Topos app

The 3D terrain model, which is referenced on WGS84, is aligned with the paper topographic map and projected on each smartphone, offering in the same time the opportunity of the virtual navigation with the physical movement over the paper. Once the crucial points of the route are defined, the respective profile is created, and the route is rendered as a 3d mesh.

B.5.2 3D exploration of the San Lucano Valley, Dolomite (14)

In this study, the prominence of the geomorphosites is proposed, as an extra feature in the Openalp 3D project, for educational and touristic reasons.

Openalp 3D is a free to download pc application that combines a 3D navigation software with an informative database, focused on the natural, historical, and cultural importance of UNESCO World Heritage Site, Dolomites. The virtual 3d scenario provides the users the opportunity to get navigated through the 2300km2 territory with 5x5m cell resolution and select between a large gamut of maps or sites of interest and itineraries, which are represented as lines, points, and polygons, georeferenced, and accompanied by the relating significant information (including accommodation and tourism facilities). The option of creating custom itineraries or special maps that can be used on mobile phones and GPS units, is also provided. Focusing on the importance of the geoheritage, 49 geomorphosites of San Lucano Valley were implemented in the Openalp 3D system, aiming to contribute to the public understanding of science.

B.6 Games

B.6.1 Everest VR


Image B.6.1 Everest VR game environment

The Everest VR™ is a virtual reality game, developed by Sóflar Studios and RVX, published by Sóflar Studios and released on August 2016. The goal of the game is reaching the summit of Everest, beginning with the preparation of the expedition at the Base-camp and passing through famous parts of the path like Khumbu Icefalls, Lhotse face, Camp 4 and Hilary Step. Even though the player does not actually use mountaineering and climbing techniques, even if some of them are described in the tutorial, the panoramic view of the landscape combining with the from human size to 1500x zoom scale selection, is impressive. RVX, the Everest movie visual effect company, created a more than 300000 high definition image database, with which Soflar Studios, using photogrammetric techniques, has generated a 3d point cloud and built the 3d mesh and textures of Everest and surrounding areas.

B.6.2 The climb


Image B.6.2 TheClimb game environment

The Climb™ is a first-person virtual reality video game, developed and published by Crytek, released on Oculus Home April 2016. The goal of the game is the ascent to the top of the rock or ice climbing routes. While ascending, the grips are getting gradually more complex and the stamina falls. The virtual environment had to be impressively detailed, as the player is close to the rock surface, climbing equipment, vegetation, insect life, and so on. As for the grip graphic quality, Crytek used photogrammetry methods on wide range of real rock surfaces, duplicate them into the virtual space and combine them to create larger, more impressive, and still convincing rock masses.

PART II

Case Study

1. Villanueva de Valdegobia

1.1 General description

The Iberian Peninsula has a largely mountainous terrain, consisted by rocks of almost every geological period and containing almost any type of rock. The numerous climbing fields, surrounded by spectacular natural landscapes, including countless climbing routes, make this place a great attraction for climbers from all over the world.

Basque Country, *Euskal Herria*, at the north of the peninsula, offers generously climbing routes for every desire: Ice or mixed climbing routes for the winter and high traditional multi-pitch routes at the Pyrenees, plenty of sport climbing fields and lots of crags for bouldering problems spread over the inland. Around Gasteiz, the capital of Euskadi, and within the maximum 50km distance, there are more than 20 climbing fields. One of them, Valdegobía, was selected for this study, because its features met the following criteria (Table 3).

Table 3 Field Selection Criteria

Existing 3d model	No
Path Access	2 minutes comfortable walking with the local permission
Safety	Total
Road access	Less than one hour
Grade of difficulty	5c-9a
Variety	13 subsectors – 200 routes

1.2 Field description

Valdegobia or San Martin is a famous sport climbing field in a small valley close to Villanueva de Valdegobia, the capital village of the municipality of Gaubea in Áraba´s province. It is roughly located at *42° 51' 35'' N, 3° 6' 25'' W*, on 650m altitude. Its 13 sectors are spread around the two meadows of the valley (Chorreras and Campa) according to *Guía de escalada en Villanueva de Valdegobia*[(15)]. (Image 1.1). The distance from Gasteiz is 40km to the west (40min driving) and there are several parking sites at the village. The free camping is prohibited in the area, and an organized camping base at Angosto is recommended. The access varies depending on the sector, but it is an approximately 1.5 km easy uphill walk, following the road from the center of the village at the elevation of the information desk to the north. This main path, where driving is prohibited, leads straight to the Campa meadow, while the path which is met on the right side after the first 5-7 minutes, leads to Chorreras.

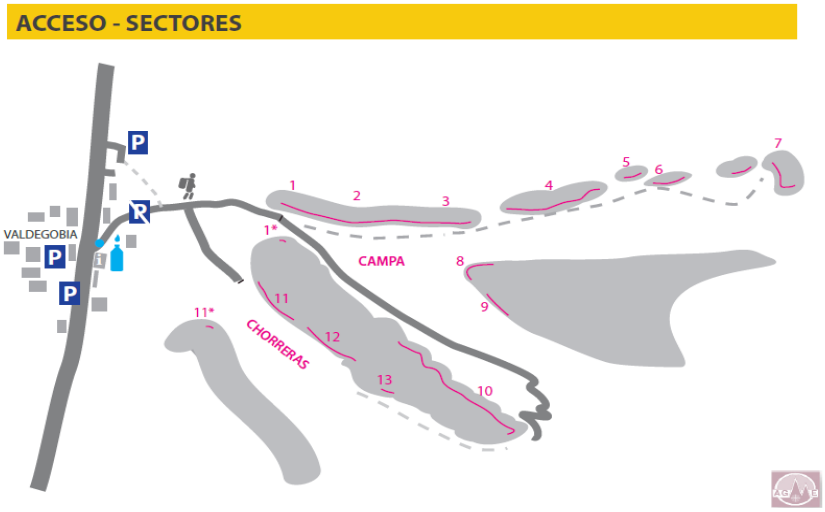


Image1.1 Field approach and sectors Sketch

The rock type is limestone approximately 40m high, 80m maximum, and there are more than 200 single pitch sport climbing routes, spread in all over the crags. The rock is steep vertical or overhanging, while the type of holds is holes and crimps. The orientation, depending on the sector and the route, varies (W – WS – S – SW – E) and the best season for climbing is summer. The grade of difficulty rages from 5c to 9a in French Grading System. With Table 4, a brief comparison between different Grading Systems is shown, so that a general view of the difficulty level of the chosen field is provided.

The first routes started to be bolted around 1990, and since 2000 Valdegobia is one of the most important climbing fields of the region. Psikoretapia (9a) is considered to be the most mythical route of the Field; Patxi Usobiaga was the first to ascent it in 2004, and Iban Larri'on was the first to repeat it in 2009.

Table 4 Grading Systems Comparison

Metric scale	UIAA	French (Fr.)	US-American (YDS)
5.66	6-	5b/c	5.8
6	6	5c/6a	5.9
6.33	6+	6a/6a+	5.10a
6.66	7-	6a+/b	5.10b/c
7	7	6b/b+	5.10d
7.33	7+	6b+/6c	5.11a/b
7.66	8-	6c+	5.11c
8	8	7a	5.11c/d
8.33	8+	7a+/7b	5.12a/b
8.66	9-	7b/7b+	5.12b/c
9	9	7c/7c+	5.12d
9.33	9+	7c+/8a	5.13a
9.66	10-	8a/ 8a+	5.13b/c
10	10	8b	5.13d
10.33	10+	8b+/8c	5.14a/b
10.66	11-	8c/8c+	5.14b/c
11	11	9a	5.14d
11.33	11+	9a+	5.15a
11.66	12-	9b	5.15b

The most famous guidebook, *Guia de escalada en Villanueva de Valdegobía*[(15)], is created by the Mountain Federation of Araba (Arabako Mendizale Federazioa, AMF) and the High Mountain School of Araba (Arabako GoiMendi Eskola, AGME), contains all the croquis/topos, designed by Garbiñe Uriarte, and it is complete and free of access and copy. Information about the field can be found in other commercial guidebooks of the region, as well as in several climbing websites, blogs, and mobile phone applications. More visual information is provided by a few pictures, mostly of Campa sector) and some videos which present climbing ascents.

https://www.youtube.com/watch?v=E6-La1pz1SU

(Adam Ondra is trying on site the route *Psicoterapia*, FR 9a.)

For the rest days, the visit to Salt mine of Anhana (10km) and the Natural park of Valderejo (14km) is proposed. Alternatively, the circular path from the Campa to the peak of El Raso (1047mt) is an interesting proposal.

1.3 Sector 2 or Campa

The main path, after 1km of easy uphill walk, reaches to a splendid narrow valley, San Martin de Valparaiso, orientated in direction N-S, and traversed by a small/little stream. The valley is surrounded by impressive loamy limestone crests, where the 10 of the 13 Sectors of the field are placed (according to *Guía de escalada en Villanueva de Valdegobia*).

At the entrance, the west edge of the valley is formed by a 20-25 meters high rock wall, where the first 3 Sectors (San Martin, Camba, Techo or 1, 2, 3 respectively) rise up. In addition, this area consists an archeological site as well, which, since 1996, is included in the Register of Qualified Cultural Property, due to the carved on the rock remains of a settlement complex (village-necropolis-possible temple) of Early Middle Age.

The Sector 2 (Campa, also known as Valparaiso/Valdegobia B) was selected for this study. In this sector, the limestone rock, facing to the North, reaches maximum 25 meters height. Across its 50m length, there are 29 routes (Image 1.2), grading from 6a to 8b, but most of the routes are at 7c (Image 1.3). Almost the entire sector is negatively slant, with parts of it reaching an angle of 60° with the horizontal.

2 CAMPA

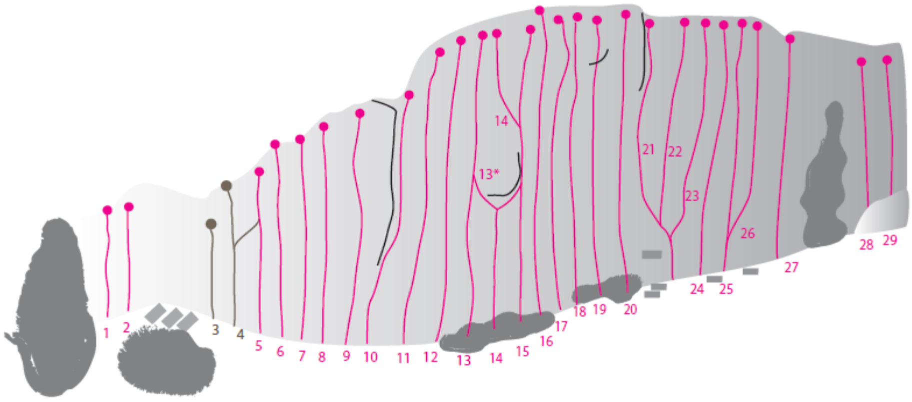


Image 1.2 2D topo of sector 2

2 CAMPA

1_	5+	Penumbra
2_	6a+ /b	La reina de Valparaíso
3_	6a	ELIMINADA
4_	6a+	DESVIADA
5_	6b+	Elo
6_	6b+	Yoli
7_	7b	Caballo loco
8_	7b+ /7c	Aupa el Rubio
9_	7c+/8a	Risitas
10_	8a+/b	Maktub
11_	7c+	Gandhi
12_	8a+/b	Aluminosis
13_	8b+	Olatz
13*_		La tía Olatz
14_	7c+	La tia Mildred

15_		
16_		
17_	8a/+	Kroma Presas
18_	7c	El club del Marisco
19_	7b	Nostraladamus
20_	7a	Metamorfosis
21_	7c	No me la cortes
22_	7c+/8a	Osito for ever
23_	7c	Pier no doyuna
24_	7c	Oker Dabiltza
25_	7c	Pati Glamour
26_	7c+/8a	La noche del mamífero
27_	7c	Tres de marzo
28_	7a+	El vaquilla
29_	7b	El Larguirucho

Image 1.3 Route Legend

1.4 The Necropolis of San Martin De Valparaiso

The remains of an Early Middle Age (possibly IX-X century) complex (village – necropolis – church), probably belonging to the settlement of people from the first migrations towards the Meseta (high plain of Central Spain) up to the Cantabrian mountains after the Muslim invasion, is located at the entrance of the valley of San Martin de Valparaiso (0º 34' 51'', 42º 51' 33'', 630m altitude). This valley is a privileged place for the enjoyment of its environment/surrounding, being prone to its deterioration. It is a relatively enclosed area but endowed with the necessary resources for the subsistence (water, hunting, cultivable terrain). It is hidden form the principal road, an ideal location for an unstable political and social moment. The archeological site is sheltered in the base of the west rock wall and 2 differentiated zones, the necropolis and the settlement zone, can be clearly identified, while there are only evidences for the exact position of the supposed temple.

Settlement zone

The settlement is located at the southern part of the rock face and it is attested to by the presence of a series of more than 50 carved holes on the rock, that possibly were served to support the houses' roofs. These weep holes have semicircular and quadrangular form, they are met in a 4meters distance from the actual ground level and they form one more or less regular line without interruption, even if it is assumed that this long section was divided in different compartments. The regularity of the roof was facilitating the rainwater flowing, impending the formation of pockets at the roof. A confirmed important erosion of the primitive ground level, produced by water washout because of the irregular regime of the streams, permits to presume the loss of possible archeological remains, which could have been buried in the subsoil.

Necropolis

The necropolis, consisted of 30 in total dug on the cliff graves, is divided in 2 sectors, separated by a small corner of the rock, that abandons the N orientation of the settlement to take a N-W direction. All the graves have extremely round (oval) or rectangular shape, some of them present the feet zone narrower, while some other present an elevated rabbet as a pillow.

Sector 1

Sector I, the closest to the settlement site, is situated at the South of the corner. 19 graves, with diverse orientation, ranging between 75º E and 175º S, appear distributed among different groups, constitute an heterogeneous Sector. In general, they present good condition, conserving in many cases the fitting of the covers. In some cases, the exterior part of the tombs has been made in such way that they might resemble sarcophagus on their own.

Sector 2

Sector II is the worst conserved zone of the entire site, due to natural erosion and destruction caused by human activity. 11 graves, all of them following the direction of the cliff profile with an almost stable orientation ranging between 140º SE and 120º SE, are located 30m after the Sector I. They are all crowded together, one over the other as if there wasn't sufficient space, and present different state of conservation. Furthermore, there is a series of narrow gutters, the antiquity and utility of which is difficult to appreciate. In addition, at 3m height above the graves No 27 and No 28, there is a supposed arched niche. There is no data to determine its utility, but it seems realistic either to be one more incomplete/unfinished grave (the only one being sculpted on a level clearly superior to the rest, which indicates certain social differentiation) or a kind of decaying chamber (where the cadaver was exposed to the open air for a particular period before the placement in the grave).

Temple

Even though the exact position of the church has not been discovered yet, there are evidences for 2 possible locations. The first one is located just at the NW of the cliff corner, between the two sectors of the necropolis. Carvings on the rock denote the existence of a construction, which, fairly certainly, had a religious function, since it would be strange for a housing being built so close to the cemetery and so far away from the settlement nucleus. One the other hand, at the NW of Sector II, under a small shelter that creates the rock, appear carved holes, which, even if they are situated at low altitude (2m), indicate the presence of a building.

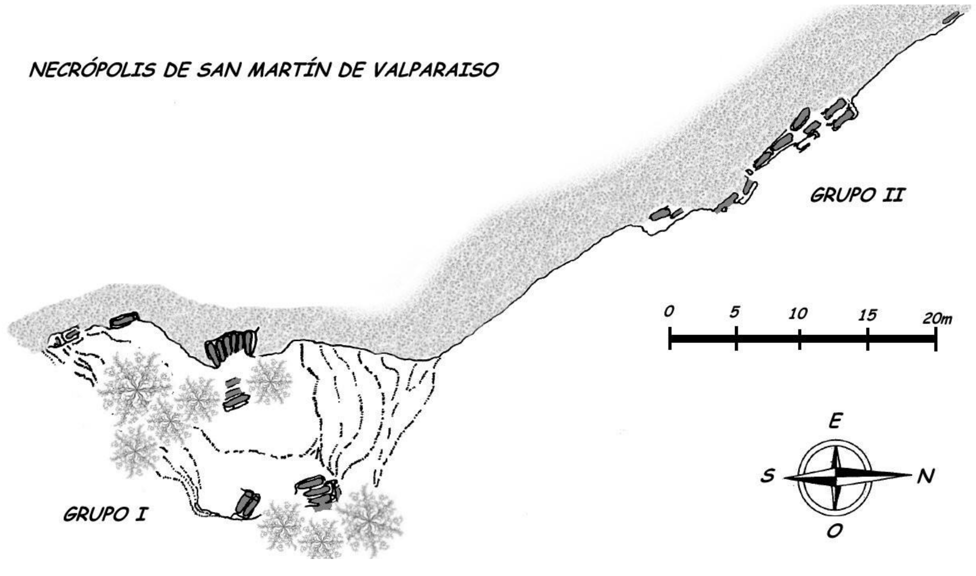


Image 1.4 Necropolis de San Marin de Valparaiso

2. 3D topo

2.1 Data Collection

2.1.1 Preparation

The challenging and extreme, in terms of accessibility, location of the area for documentation is launching photogrammetry to the top of choices for an accurate and integrated geometric documentation. The field work time should have been kept as limited as possible, and therefore a well-organized preparation for field surveying and photo shooting sessions was more than mandatory.

A first visit for reconnaissance of the area of interest was planned, so that a first dataset of images of Sector 2 could be collected. A dataset of about 75 images was acquired and processed in Agisoft Photoscan, so that a draft version of the 3D model of Sector 2 could be created and a documentation planning could be defined. This first draft mapping of Sector 2 indicated the extents of the area that was going to be finally documented. Along with the first images, a set of croquis were also created for the needs of the surveying.

The part of Sector 2 which was chosen for photogrammetric documentation covers an area of approximately 1200 m^2 (Image 2.1).

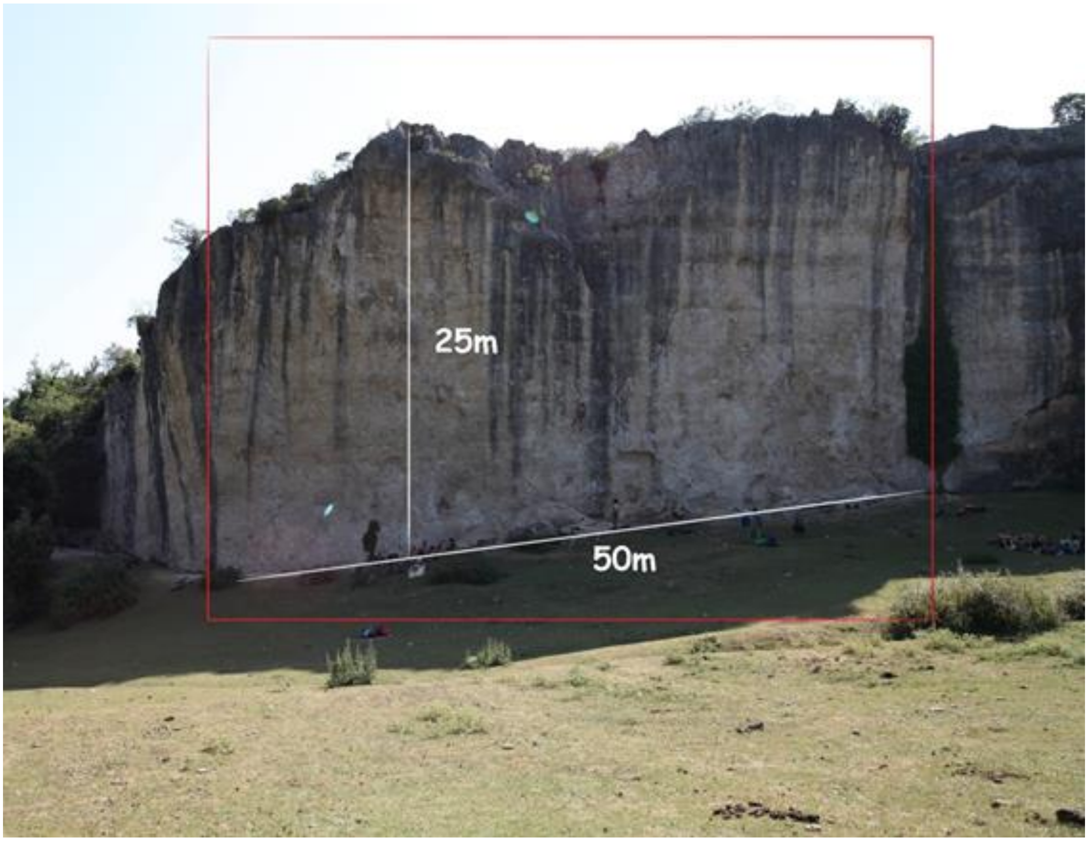


Image 2.1 Documentation Area

2.1.2 Field surveying

During the second visit at the site, the team carried out all needed field work; at first all surveying measurements and secondly photo shooting.

A control points' network was established through the placement or selection of totally 36 control points, spread widely in the area of interest. Four different types of control points were decided to be used, respectively to the accessibility of the site (Image 2.2). Typical 6x6 cm photogrammetric targets were placed at the lower parts of the site in two horizontal strips: 7 of them on the rock surface at about 2 meters height from the ground and 5 more on lower parts or on small rocks in front of the main rock (T_1-T_12). Additionally, permanent points such as bolts and anchors, as well as quickdraws already placed by climbers along existing climbing routes and easily recognizable at the decided image pixel size, were decided to be used as control points for the upper levels (M_1-M_24).

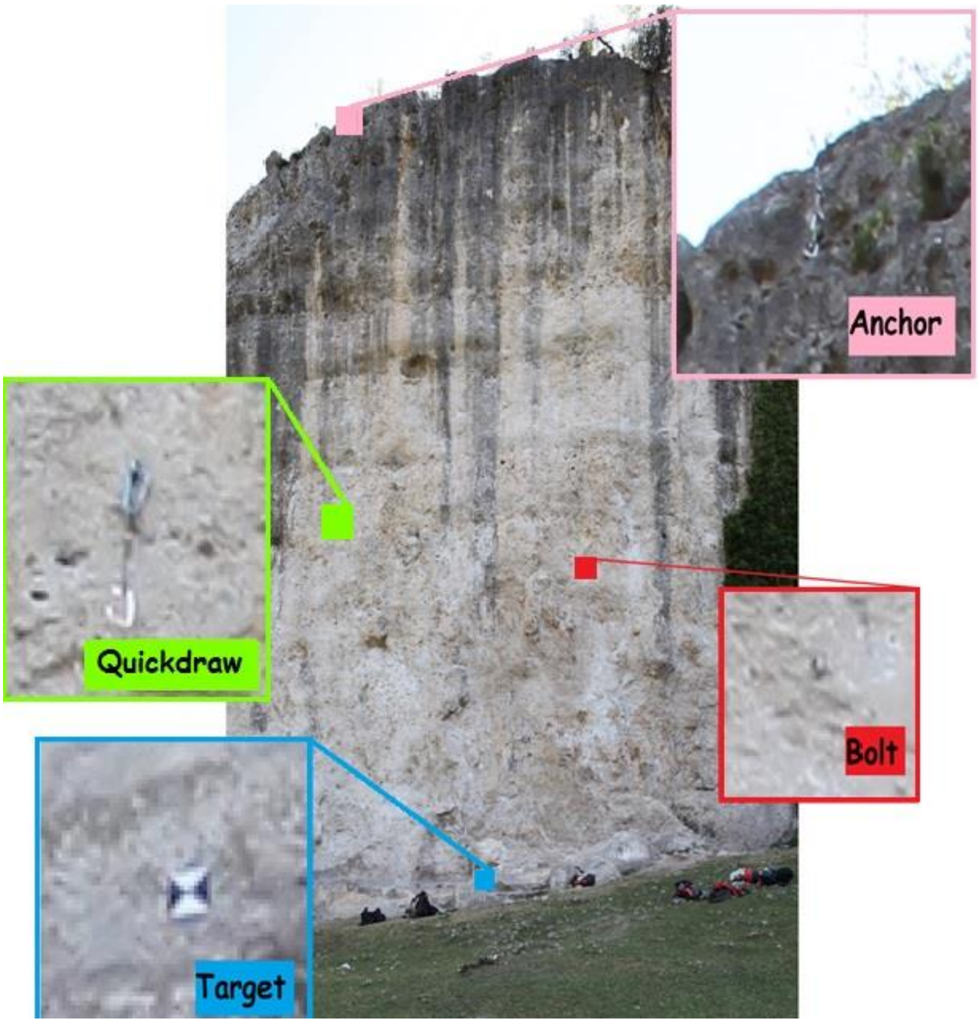


Image 2.2 Type of Targets, pre-marked and existing

For the measuring of the control points' network, a Leica TCR 1205 total station was used, placed at one single location (Image 2.3), thanks to the helpful topography of the site, as a wide, large and smooth meadow lies in front of the rocks.

Image 2.3 Total Station set up station

Although all control point measurements were taken from a single setup, a network of 5 discreet permanent points (Image 2.4) was also established at the site, mostly used as collateral measurements (N_1-N_5). Additionally, it was considered that this 2.5cm nails' network could be useful for future projects.

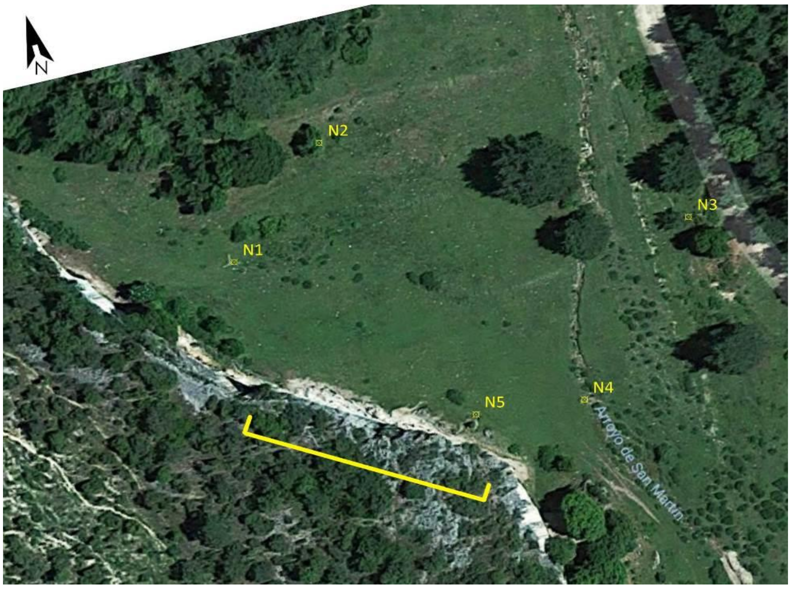


Image 2.4 Permanent points in front of Sector 2

With the use of the Total Station in reflectorless mode, 36 control points were totally measured (Image 2.5), among of which 12 are pre-marked photogrammetric targets and the rest 24 climbing gear details, like anchors, quickdraws and bolts. The amount of 36 points is considered as overabundant for the photogrammetric processing of this particular object, but they are all needed, as they will be divided, at a second stage, to control points and check points. The reference system of the control points network was chosen as local, thus just scaling the object and the north orientation was given with the use of a compass.

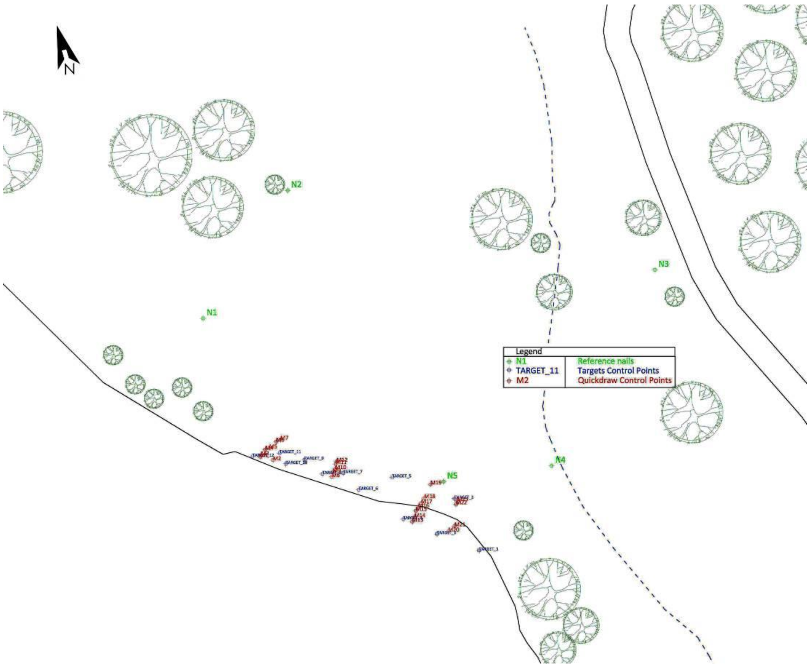


Image 2.5 Field surveying at Sector 2

For closing the measurement process, point N_2 was re-measured for control and the difference was less than 1mm.

Table 5 Measurement Check on point N_2

	X (m)	Y (m)	Z (m)
Measurement 1	963.7847	2006.2100	503.0485
Measurement 2	963.7844	2006.2088	503.0476
Difference	**0.0003**	**0.0012**	**0.0009**

Furthermore, during the field work, 3 sketches were designed respectively to the 3 types of targets (Nails, Typical Targets and Climbing Gear) and useful notes were kept, mostly about the description of the climbing gear and the exact position of the nails.

2.1.3 Image acquisition

On completion of targeting and measuring, two series of close-range images was acquired, with respect to Structure from Motion norms. A Canon EOS MarkII 5D, with an 18 – 24 mm and an 80 mm lens, was used for this purpose. The first round of images was taken with the 21mm lens from a distance of approximately 18 meters from the rock surface and with a 4 meters base, while at the second round of images were taken from 25 meters distance with the 70 - 76 mm lens. Additionally, a series of individual cameras were positioned close (up to 1 m distance) and around the tombs for an extra detailed 3D reconstruction of this area of cultural heritage interest (Image 2.6).

Image 2.6 Close range images of the tombs

Approximately 400 images (5616 x 3744 pixels) were collected from various distances and angles in order to cover the area of documentation adequately (Image 2.7).

Image 2.7 Collected Imagery dataset

Lighting conditions can be characterized as preferable, on the contrary to the climbers' traffic that was quite high during the hours of photo shooting.

2.2 Processing Procedure

2.2.1 Preprocess

After the accomplishment of all field work needed and just before the photogrammetric processing, an important step of the entire workflow is the one of picking and preprocessing the best images of the dataset. All imagery data is examined thoroughly for faulty, i.e. moved, blurred, bad exposed etc. images. A block of 386 images that suit best for the 3D reconstruction of the site was finally created. Apart from picking the best images among all, no corrections were needed to be applied on photos.

For photogrammetric processing, Agisoft Photoscan was chosen. This very popular SfM software gives the user, the possibility of masking images for useless information. Unwanted objects, such as sky, vegetation (Image 2.8), humans (Image 2.9), equipment, clouds etc., can be masked, so that they are not parts of the 3D reconstruction. On this thesis' case 247 out of 386 images were masked for such objects, as e.g. the biggest part of the meadow projected, climbers, sky and vegetation.

Image 2.8 Sky, Vegetation and meadow are masked

Image 2.9 Climbers are masked

2.2.2 Workflow

2.2.2.1 Image orientation

All 386 images, after their masking, were aligned in Agisoft Photoscan, through a matching process. Image matching algorithms inspect all images, so that common features between images can be extracted. By this means and after the implementation of a series of iterative equations and constraints, each image's 3D position can be estimated. The alignment processing was held at its higher accuracy version, something that was more time consuming and computer power demanding but gave the chance of a thorough and more secure image matching. The first result is a sparse textured point cloud (Image 2.10) of the area of documentation.

Image 2.10 Sparse point cloud and images' position

Next step was the georeferencing of the created photogrammetric model. All control points projected on images were imported into Photoscan. Half of 'M' points (mostly bolts and anchors) were not measured on images, so that they could not join the phototriangulation, as they were finally proved as ambiguous targets. Still the dispersion and amount of the rest of control points were satisfying enough for a robust solution (Image 2.11). 25 control points were finally used for the georeferencing of the model, giving the bundle adjustment a final RMS of 0.2 pixels (projection error) and 0.015 m at XYZ error.

Image 2.11 Control points network

Along with the phototriangulation, outliers (trash points) were manually removed and a camera optimization was also applied, so that this kind of self-calibration could reduce the final RMS.

2.2.2.2 Dense and 3D

On completion of the block's bundle adjustment, a dense point cloud was built in Photoscan with the implementation of Multi-Viewpoint Stereo (MVS) algorithms. A textured dense point cloud (Image 2.12), consisted of ≈ 21 million points, was built at a high-quality mode, so that the denser the cloud, the more detailed the reconstruction.

Discreet outliers were manually removed from the dense cloud, which was then triangulated through surfacing algorithms. A wire-frame geometry (mesh) was created, using as surface type the dense point cloud. The 3D surface was finally edited for the removal of disconnected components and the filling of remained holes (Image 2.13).

The last stage of the 3D reconstruction was the texturing of the created 3D model. A texture mosaic-map of the 3D model was calculated by the combination of color information of each image's pixels and the projection of these pixels onto the 3D geometry. The result is a 3D textured model with a photorealistic quality (Image 2.14).

Image 2.12 Dense Point Cloud

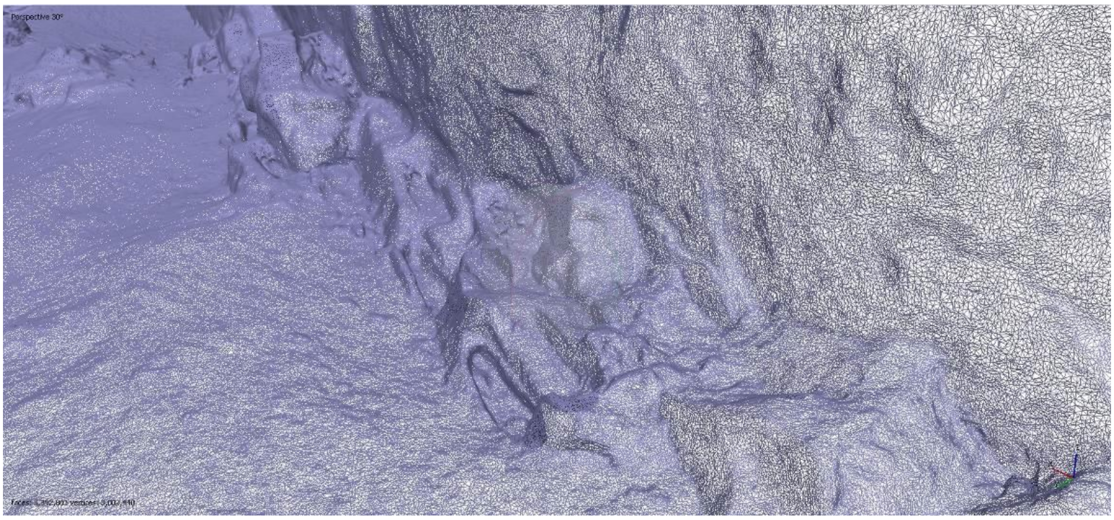


Image 2.13 3D Mesh

Image 2.14 3D textured model

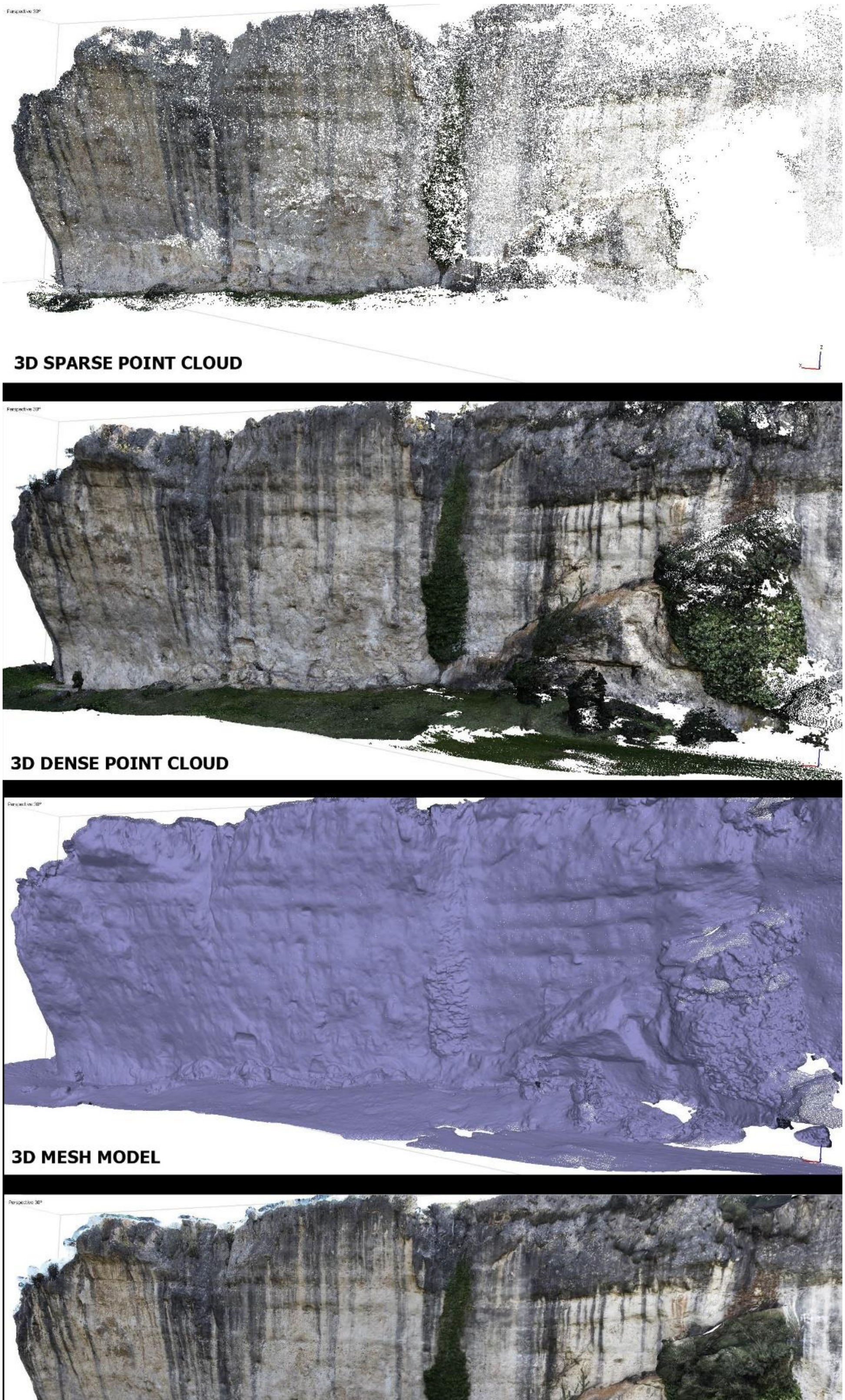


Image 2.15 3D modeling phases

2.2.2.3 Products

The integrated photogrammetric processing resulted in the generation of multiple products with both accurate geometric and photorealistic information.

- 3D textured model of the site in multiple 3D formats
- Orthophoto projected on a vertical plane, that approximates the front view estimated by the control points network, with a ground pixel size of 1cm
- 2D topo (based on the orthophoto)
- 2D drawing of the tombs of Valparaiso

The photogrammetric results are presented in APPENDIX B.

2.3 Concerns and solutions

At this point it was considered necessary to examine the possibility of the 3D production which is the basis for the following procedures without the use of special equipment and commercial software.

2.3.1 Climbing Gear's reliability as GCP

Unlike the anchors and bolts, which were rejected in the targeting process, the quickdraws were distinct and useful, especially for the upper part of the rock where no photogrammetric targets were placed. To study their reliability, a dense point cloud was created with their exclusive use as control points and compared in *Cloud Compare* with a corresponding dense cloud, which was generated from the same data set and with the use of all the GCPs. With most points ranging at about 4 mm and the maximum deviation at 1.5cm, the quickdraws are considered suitable for GCP (Image 2.16).

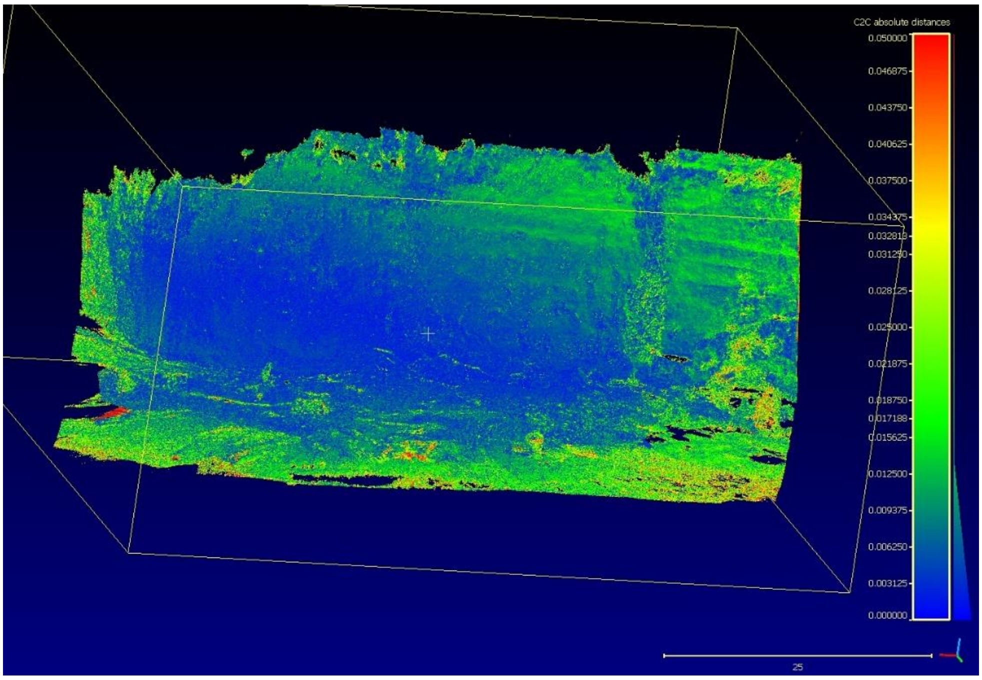


Image 2.16 Cloud compare for GCP reliability.

2.3.2 Scaling with estimated distances

Following the above ascertainment, and in order to study the possibility of avoiding the measurement procedure, a new dense point cloud was created with the use of the scale bar option and 3 distances defined as follows:

- T_1-T_12 : measured during the field work with a tape measure
- M_13-M_19 : roughly calculated as the difference (L-h), where *L* is the route's length and *h* is the distance of M_13 from the ground
- M_8-M_12 : roughly calculated as the difference (L-h), where *L* is the route's length and *h* is the distance of M_8 from the ground

The above cloud was compared to the original at *Cloud Compare* software, using the M3C2 algorithm. With most points ranging at about 5 mm and the maximum deviation at 3.5 cm, even this rough scaling method is acceptable. (Image 2.17) However, it is recommended that all measurements be made by tape measure.

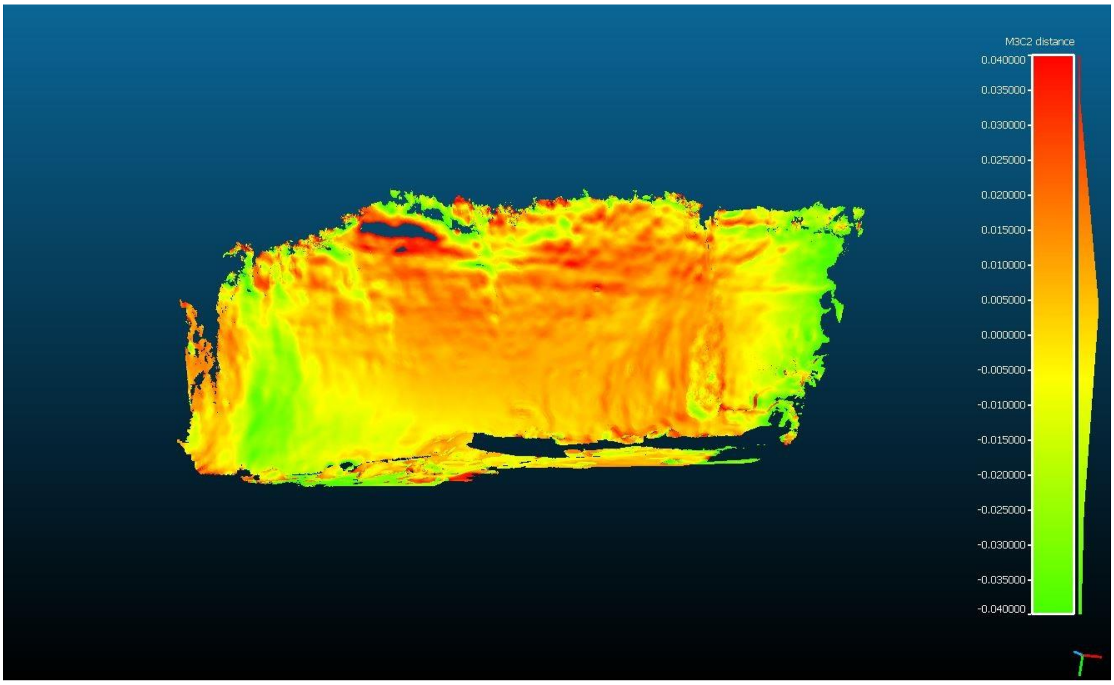


Image 2.17 Cloud Compare for scaling reliability

2.3.3 DS and 3D volume

Considering the system requirements for the processing of a large data set but also the limitations that some of the available 3D creation software bear, it was considered necessary to create a new project with the use of 35 images, and the generated 3D was evaluated as satisfactory for the purposes of this study. In addition, its file size has been reduced to such an extent as to allow the next processes, without cost to the quality of the model.

2.4 3D topos

The creation of the three-dimensional topo is based on the information provided by its corresponding two-dimensional. As the commonly used -for this field- topo is unclear, it was necessary to create a new one: the orthophoto was inserted into an image editing software and each route was designed by following the sequence of the bolts from the ground to the anchor. (image 2.18)

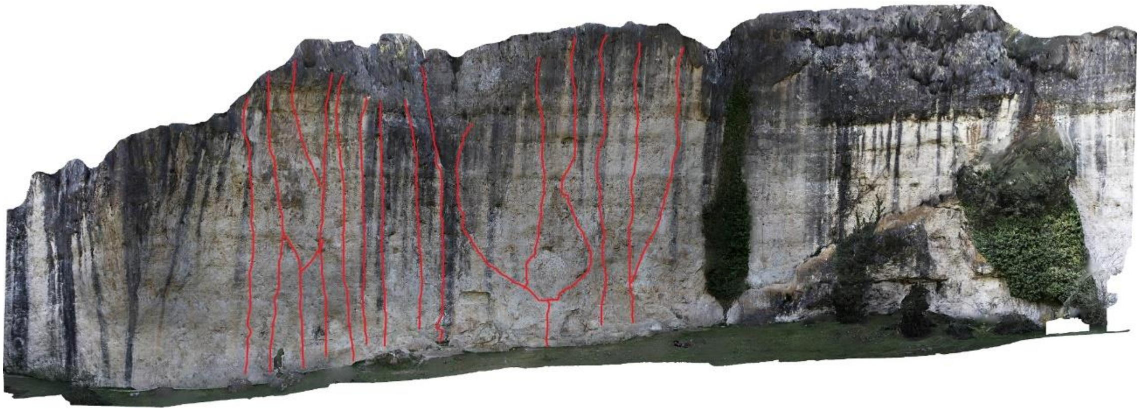


Image 2.18 2D topo based on the orthophoto

Considering the supported file formats, firstly, the 3D was exported as *.obj*. This procedure results a folder which contains an *.obj* file for the mesh, a *.jpg* file for the texture and an *.mtl* file for the definition of the materials.

Autodesk Mudbox student version, which provides texture painting and sculpting tools, was used. As its use is relatively simple, below, the followed process is briefly described.

- Import model (*.obj* file)
- Import layer -> import texture file (*.jpg* file)
- Create new layer
- Routes' design using the paint tool
- Merge layers
- Export visible

The exported file is the new texture of the 3D. As the *.mtl* file defines as texture file the original one, the new file must be renamed properly.

3. Android Application Climbing Guide with 3D topo

To introduce the climbing community to the 3rd dimension of the climbing maps, the development of a complete digital climbing guidebook android application, enriched with a 3D topo, was selected as the most appropriate first approach, after examining several alternatives. Some of them are briefly described below, in order to clarify the reasons why they were rejected.

- The 3D topo was georeferenced in *Sketchup* and exported as *.kmz*. As long as *Google Earth* does not embody custom 3D models in its terrain, each user should have to download the file (probably from a climbing forum) and import it in *Google Earth*, in order to observe the field as a part of its surroundings. (*Image 3.1*)

Image 3.1 3D topo in Google Earth

- In contrast with *Google Earth*, *Google Maps 3D* does permit uploading 3D models' files, the size of which should not be more than 5MB. However, decimating the 3D model down to that limit, causes the loss of so much information, that the topo appears more like a 2D image than a 3D model.

- The user should be registered in several 3D warehouses services and search specifically for the 3D topo.

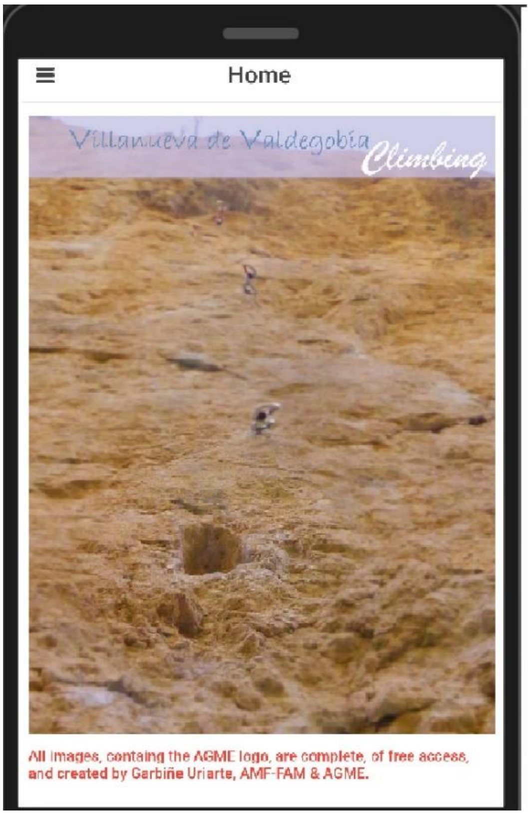
Apart from their particular difficulties and limitations, the main problem of these alternatives is that the user has to be aware that these 3D topos exist. In contrast, downloading an application while searching for a digital guidebook, is more probable, because nowadays the use of them is widespread. Finally, including the 3D topo between the classic climbing topos, makes it even easier for the user to understand the use and the advantages of it.

3.1 Presentation

Firstly, the user must visit *Google Play Store*, download and install the app. When the app is loaded, the *Home* page appears (*Image 3.2, left*). To view the main *Menu*, the button { ≡ }, placed at the upper left corner, must be clicked. A side tab opens (*Image 3.2, right*), where the user can choose between the basic options of the Menu:

- **Home**, to return to the *Home* page
- **Sectors**, to open the *Sectors* sub-menu
- **Info**, to open the *Info* sub Menu.

It should be noticed that the *Menu* Button is anchored at the upper left corner in order to permit user return to the main Menu any time during the navigation within the app.



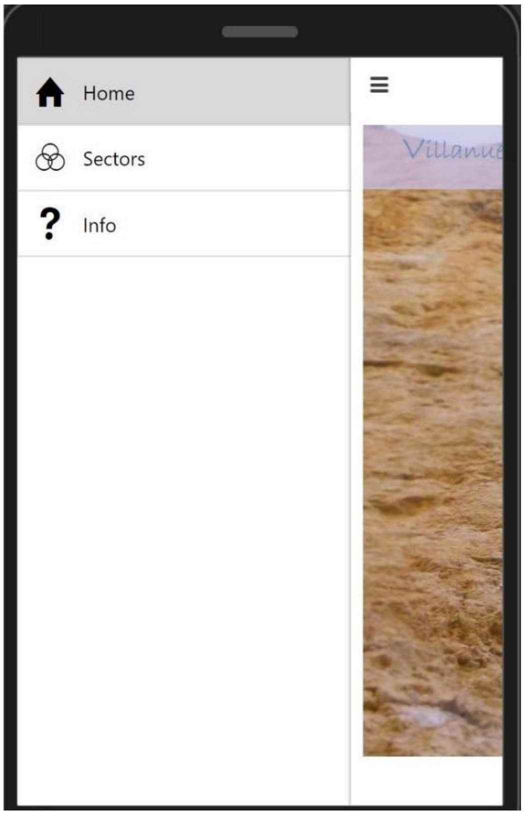
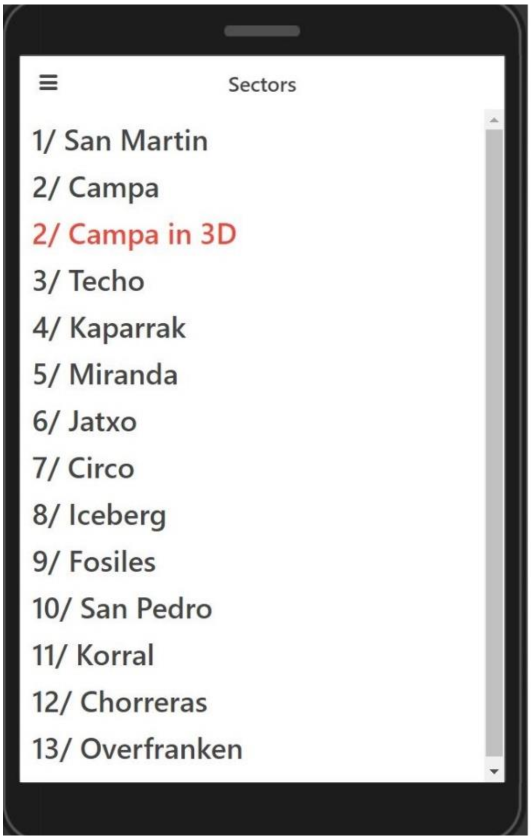


Image 3.2 Home page & side Menu

By tapping on the *Sectors*, a new sub-menu page is loaded, where the sectors of the field are listed (*Image 3.3, left*). Each button includes the number and the name of the sector.

By tapping on the *Info* area of the Menu, a new sub-menu page is loaded, where additional information about the field is divided in 4 categories. Each one of the 4 buttons includes the name and a brief description of the kind of information that is provided (*Image 3.3, right*).



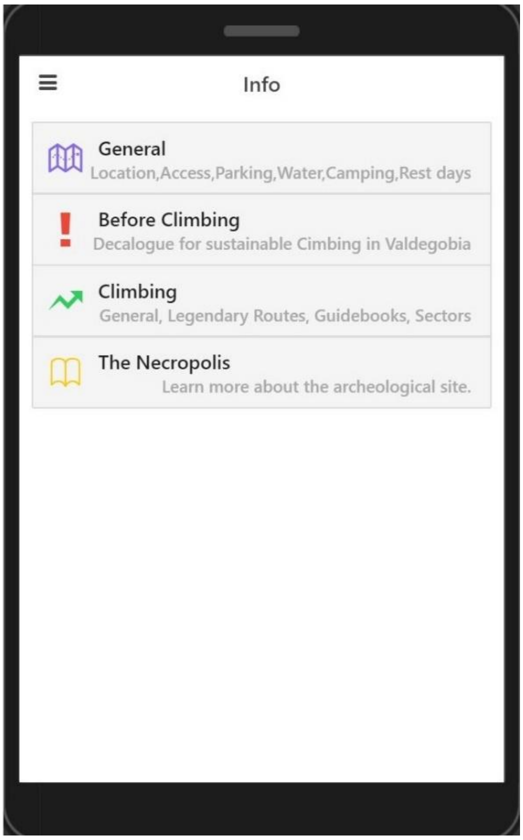


Image 3.3 Sectors and Info submenus

3.1.1 Sectors Menu

Each button of the *Sectors* sub-menu corresponds to a separate page, that contains the basic info of each sector, respectively; a sketch and a table with the number, the name and the grade of each route (*Image 3.4, Image 3.5*).

Image 3.4 Sector 4 page

Image 3.5: Sector pages

Moreover, for the sectors that are divided in sub-sectors, the sub-sectors are placed in separate boxes, that slide horizontally. (*Image 3.6, Image 3.7*) The dots at the bottom of the screen are as much as the slide boxes.

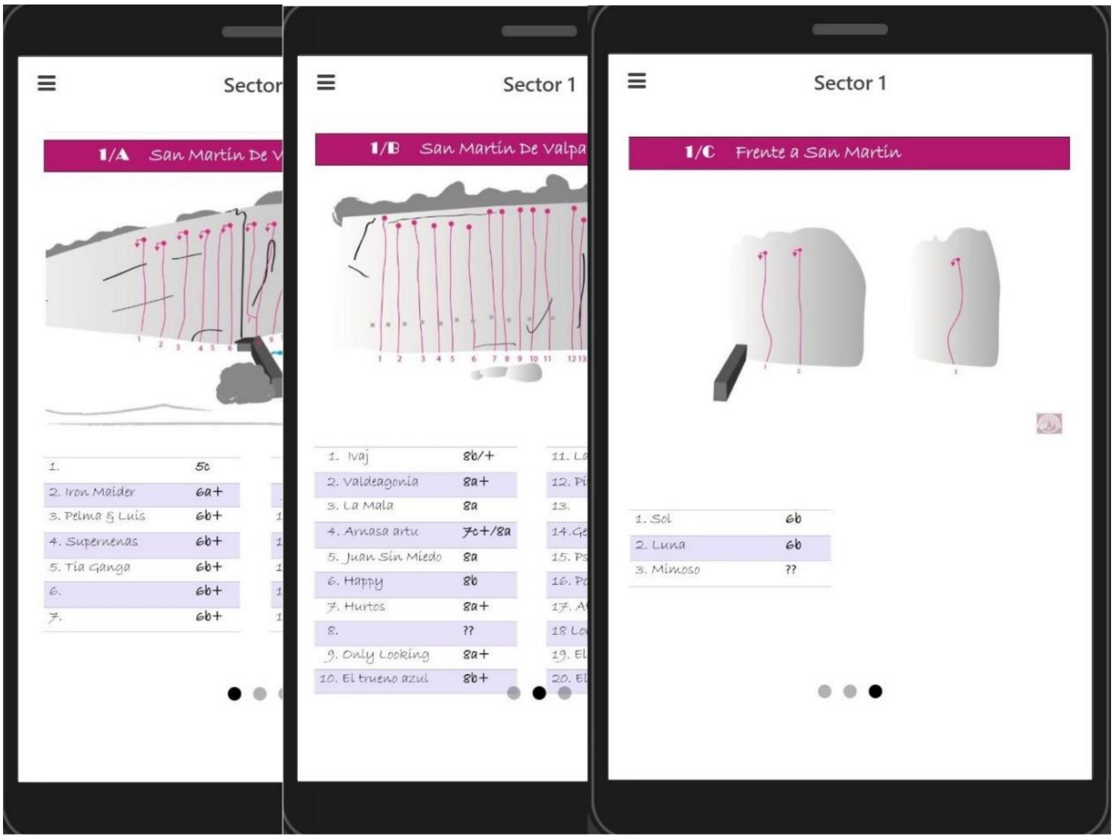


Image 3.6 Sector 1 page with slide boxes

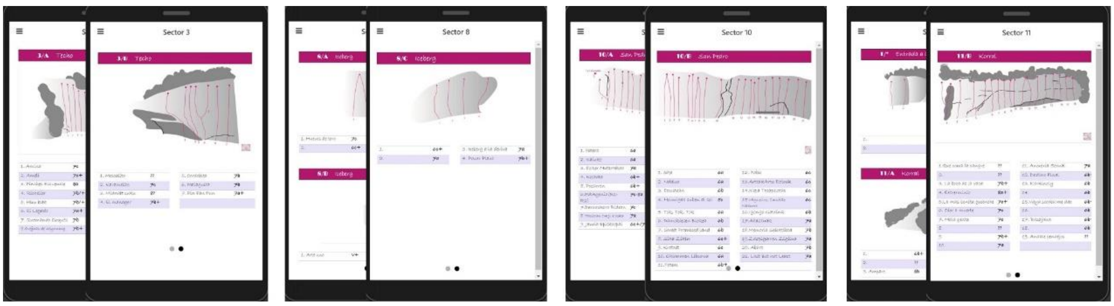


Image 3.7 Sectors with slide boxes

Exceptionally, for Sector 2-Campa, except from the standard presentation of the sector *(2/ Campa*), there is an additional choice (*2/ Campa in 3D*), where, instead of the sketch, a 3D viewer window appears. (*Image 3.8, left*) In order to start loading the 3D model of the sector, the user just has to tap on the play button of the 3D viewer window, and a loading bar appears (*Image 3.8, right*).

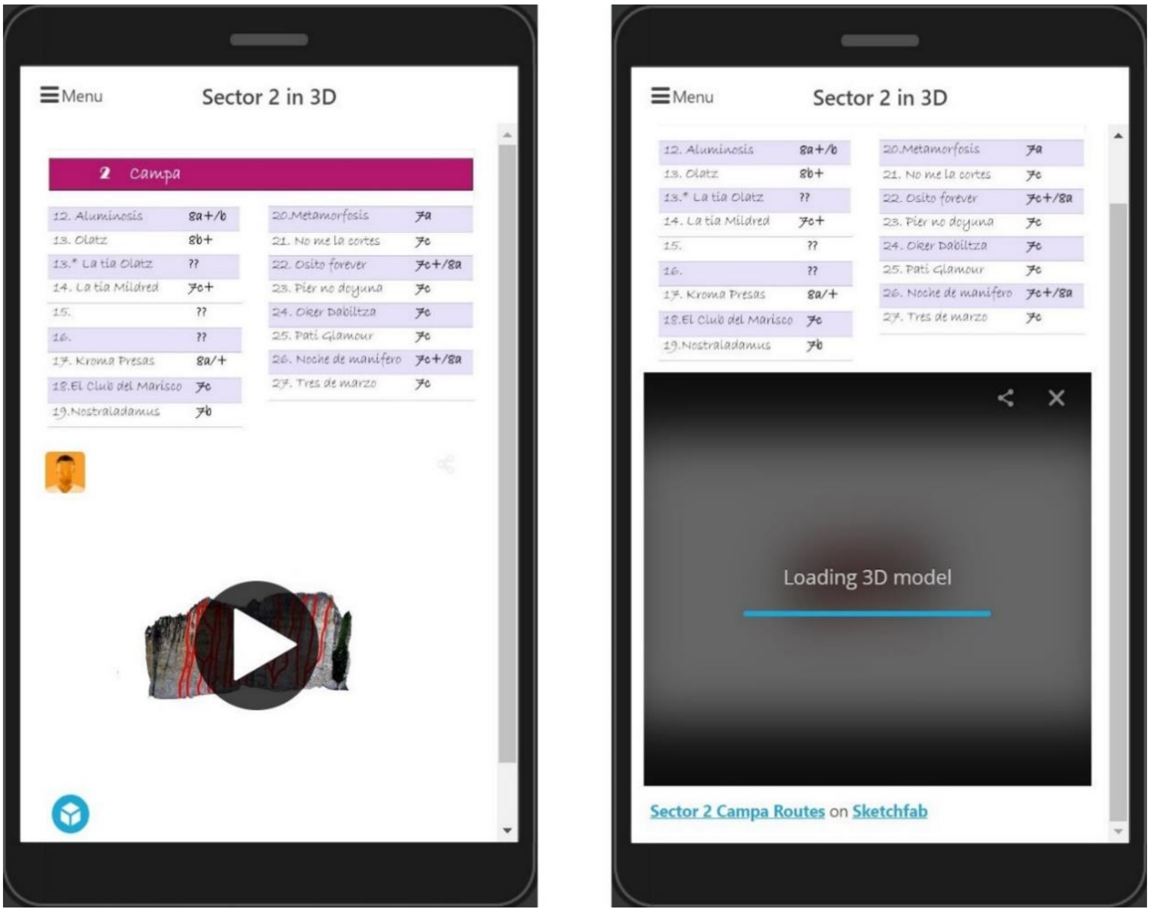
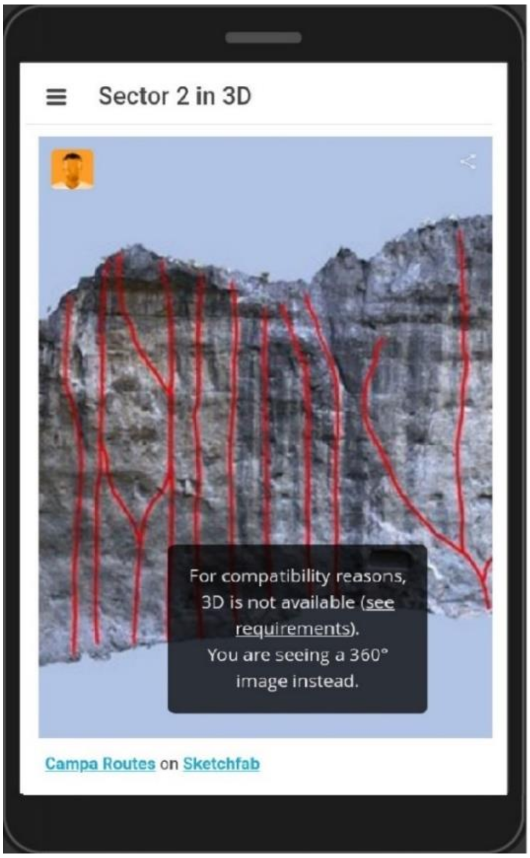


Image 3.8 3D viewer & loading bar

If the device does not support the 3D navigation within the application (*Image 3.9, left*) the user is advised to click on a link that redirects him to an external browser which displays the 3D viewing. (*Image 3.9, right*)



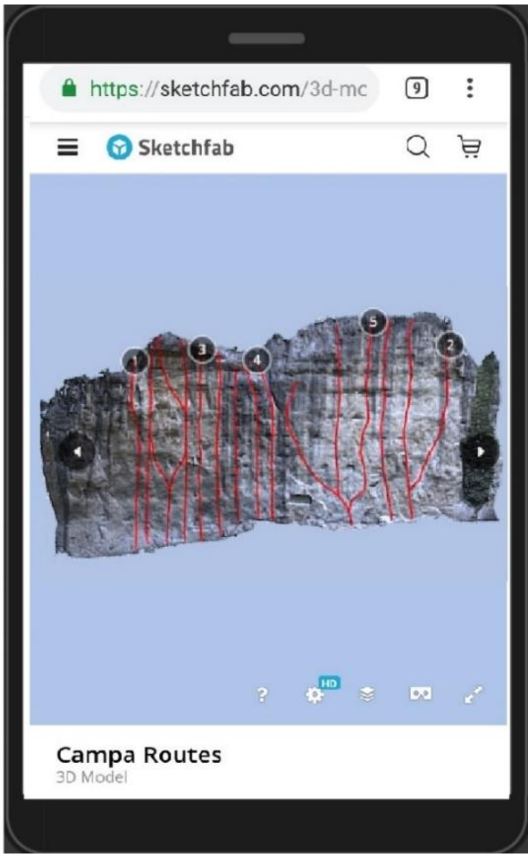


Image 3.9 Error message & External browser display

In both cases the 3D model of the field can be viewed in standard 3D viewer size or full screen size. Additionally, the basic options of zoom in / out and rotation are functioning normally (*Image 3.10)*.

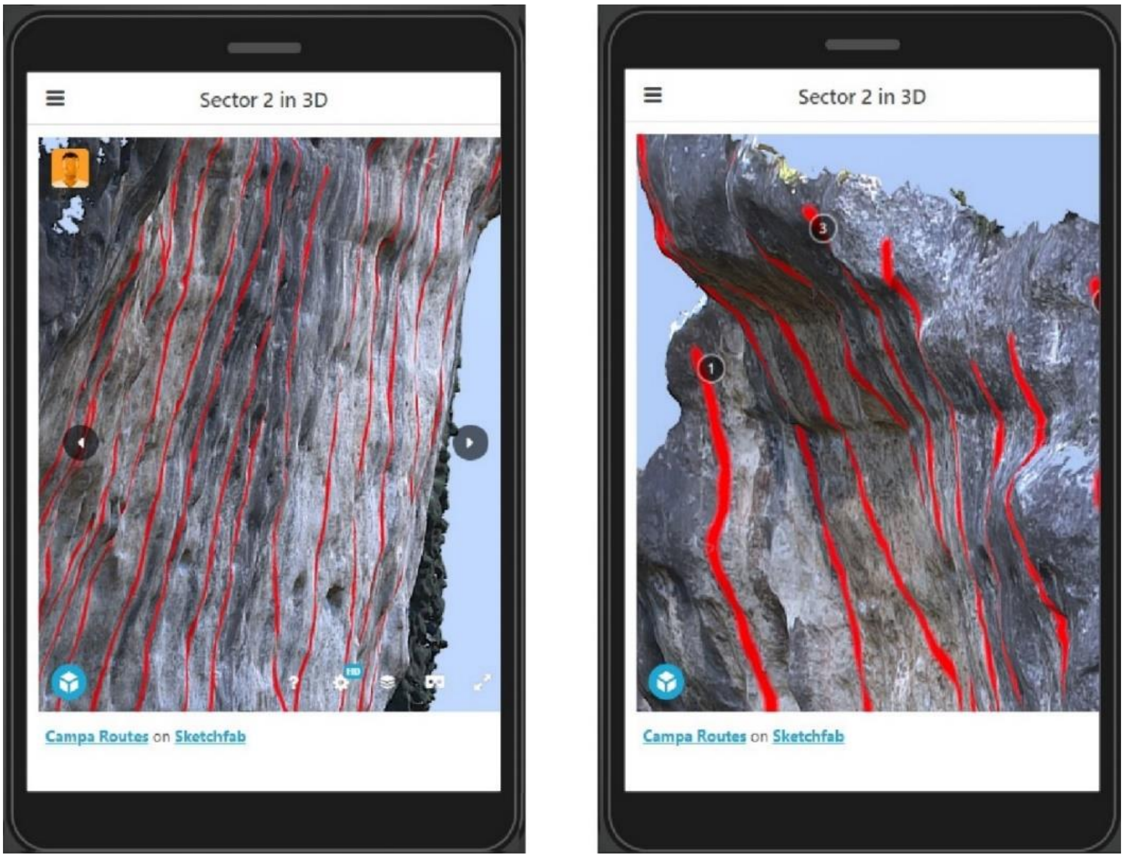


Image 3.10 Full screen, zoom-in and rotation

3.1.2 Info Menu

Each button of the *Info* sub-menu corresponds to a separate page, which contains the corresponding to each category information. Each page contains slide-boxes and scroll down bar, to ease the navigation. More specific:

The *General* page (*Image 3.11*), as the headings indicate, incudes:

- The Location of the field (1st screen)
- The access from the village to the sectors (1st screen)
- Parking and water in the village (2nd screen)
- Camping area (2nd screen)
- Rest days proposals (2nd screen)

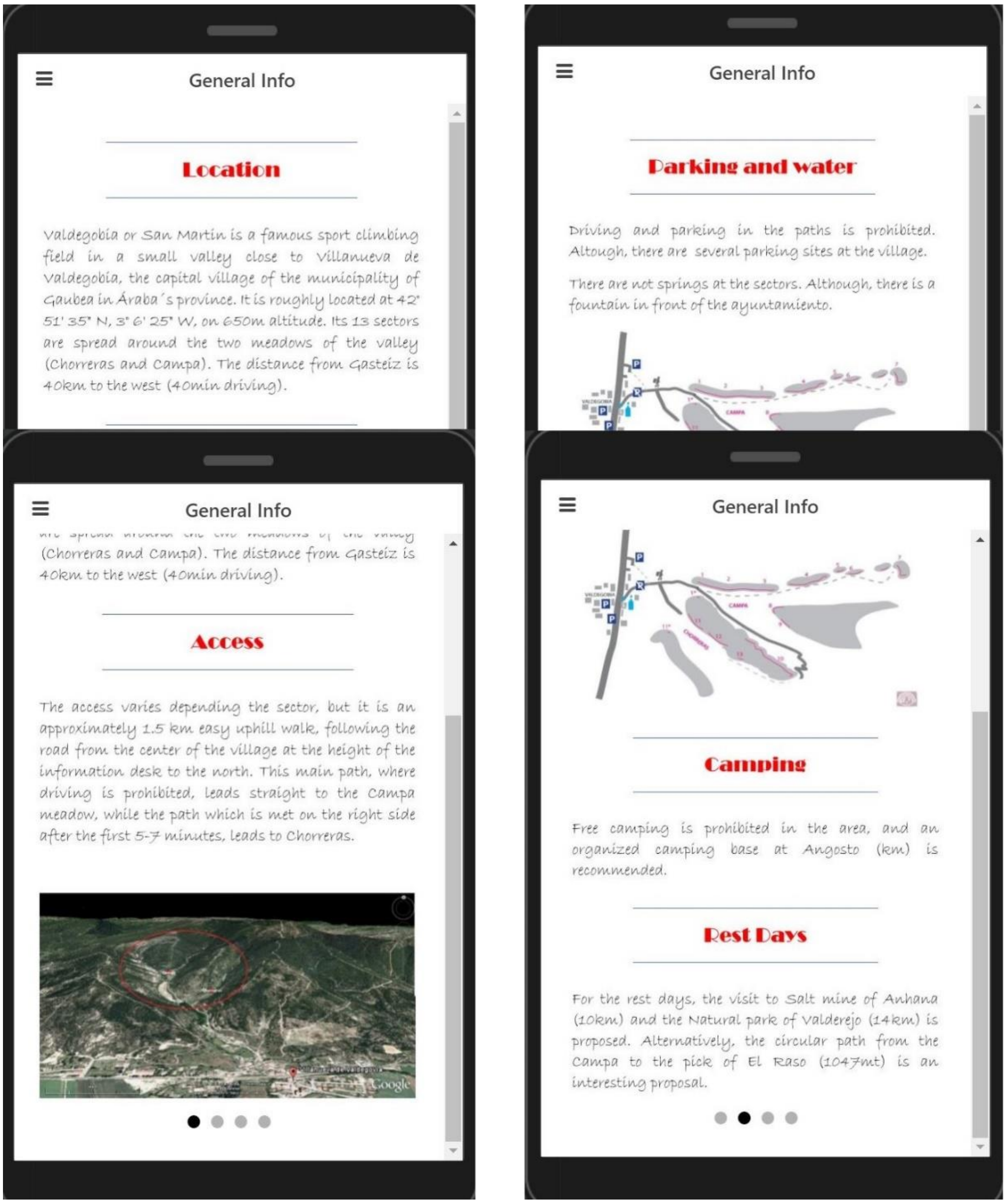


Image 3.11: General page

I. The *Before Climbing* page (*Image 3.12*) informs the climbers about the restrictions in the area.

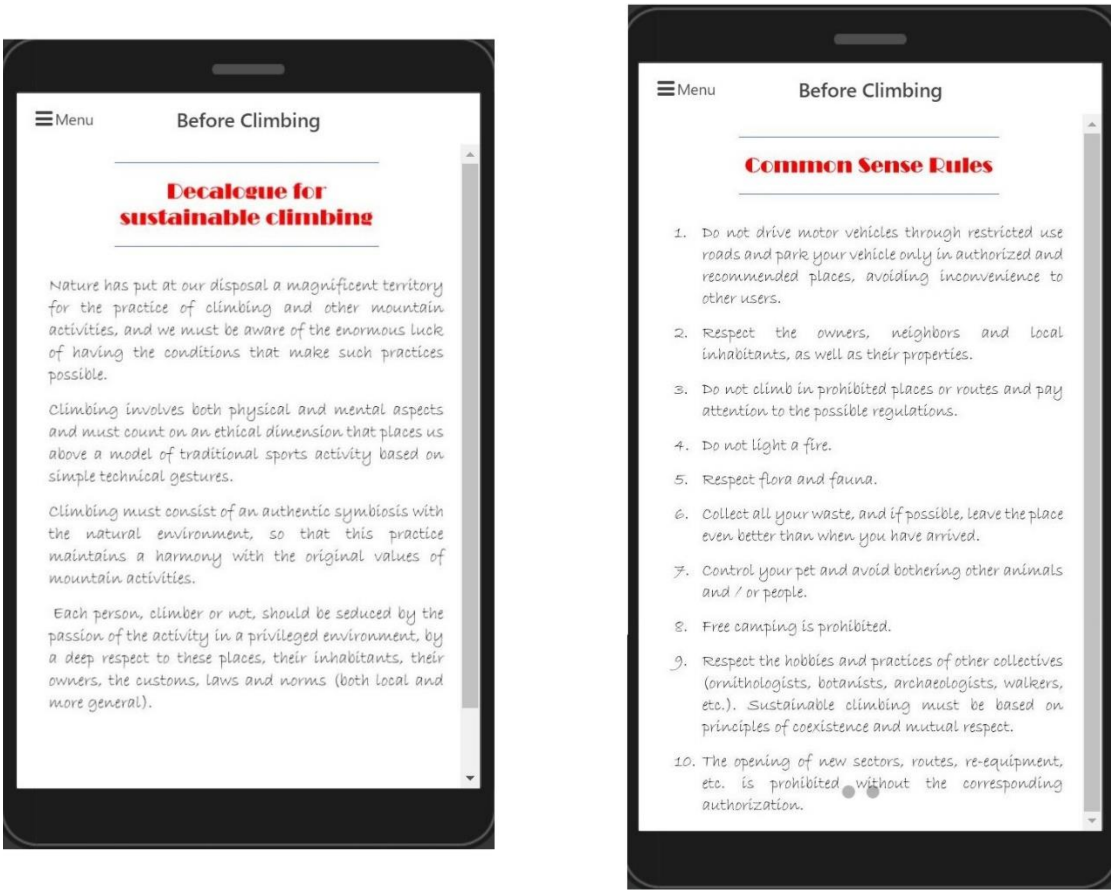


Image 3.12: Before Climbing page

II. The *Climbing* page (*Image 3.13*) contains climbing information for the particular field, legendary routes and guidebooks. Moreover, the second screen includes the sketch of the sectors and a table with the name of the sector, number of routes and the range of the grade.

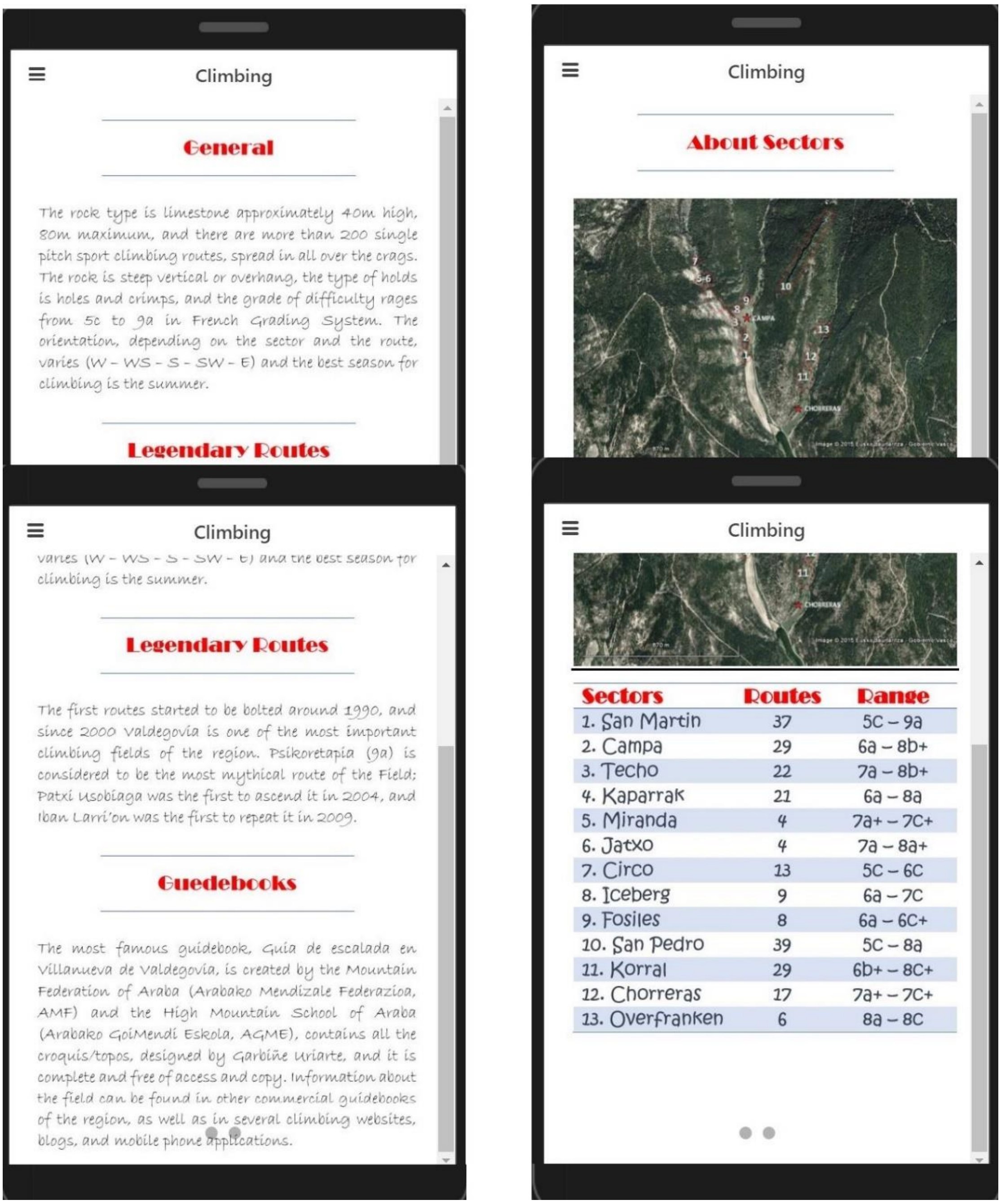


Image 3.13 Climbing page

III. The *Necropolis* page (*Image 3.14*) was created for those who want to learn details about the archeological site of the Necropolis de San Martin.

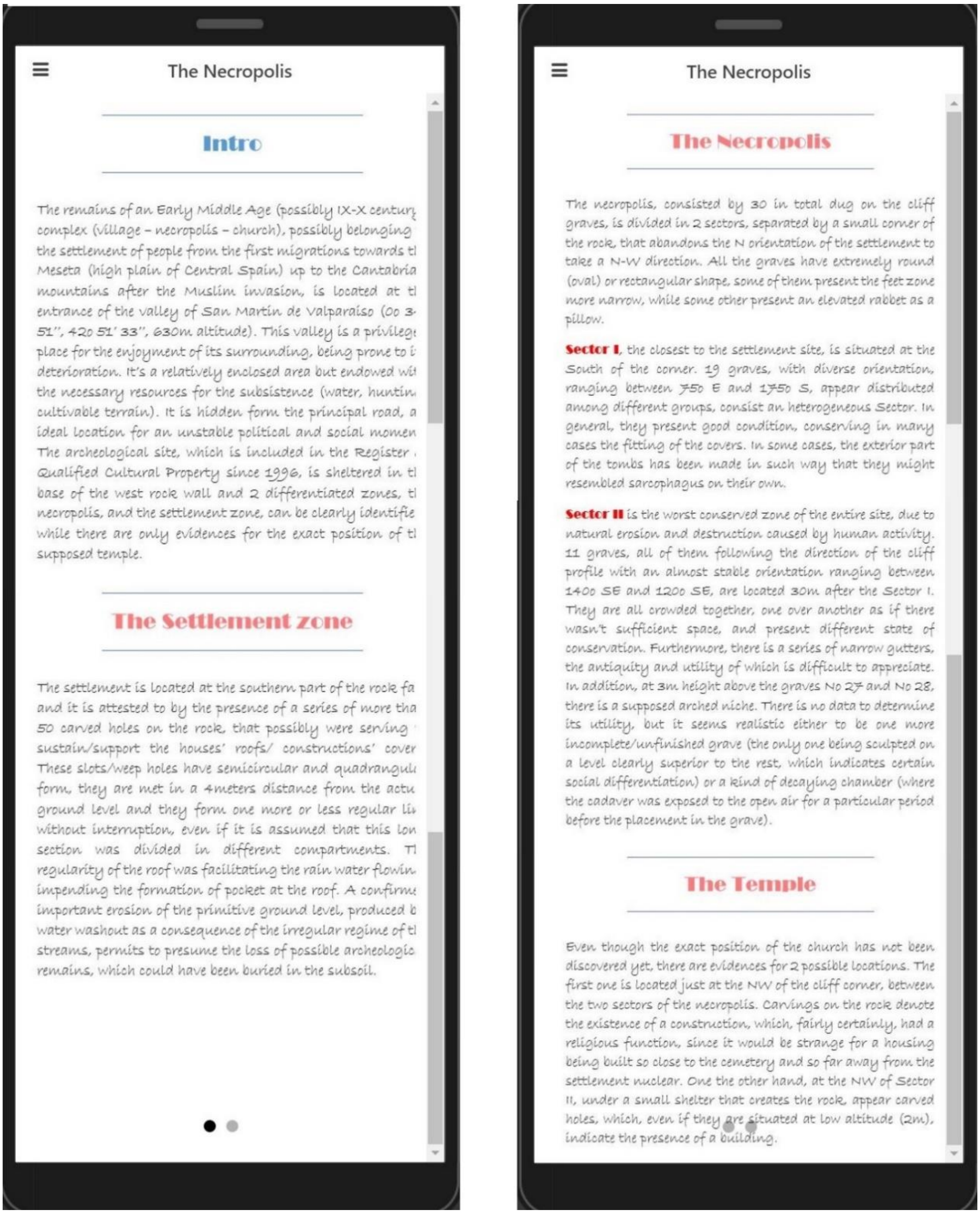


Image 3.14 The Necropolis page

3.2 App Building Process

Appery.io is a cloud-based platform, designed for the development of hybrid and web mobile apps. Moreover, it is a commercial platform, with several pricing plans; for the trial version, which was selected for this project, a registration on the platform is required. Additionally, it's a low-code platform, which eases the creation of an app via a series of tools; even users without programming experience can create simple apps with the drag-and-drop process. As for the programmers, there is always the option of stepping in the code, either by changing it or by adding scripts. Furthermore, there is the option of native app testing, which allows the application test without installing it. Due to this feature, the user not only has complete control of the application's operation before releasing it, but as well is permitted to locate and correct possible errors during the whole development process. Finally, the application can be exported as *.apk* or *.ipa*, in order to be released on *Google Play* or *Apple Store*, respectively.

3.2.1 Structure

The design of the appliation's structure, before the developing process, was necessary in order to clarify the basic elements (pages), directories and the dependencies (*Diagram 1*).

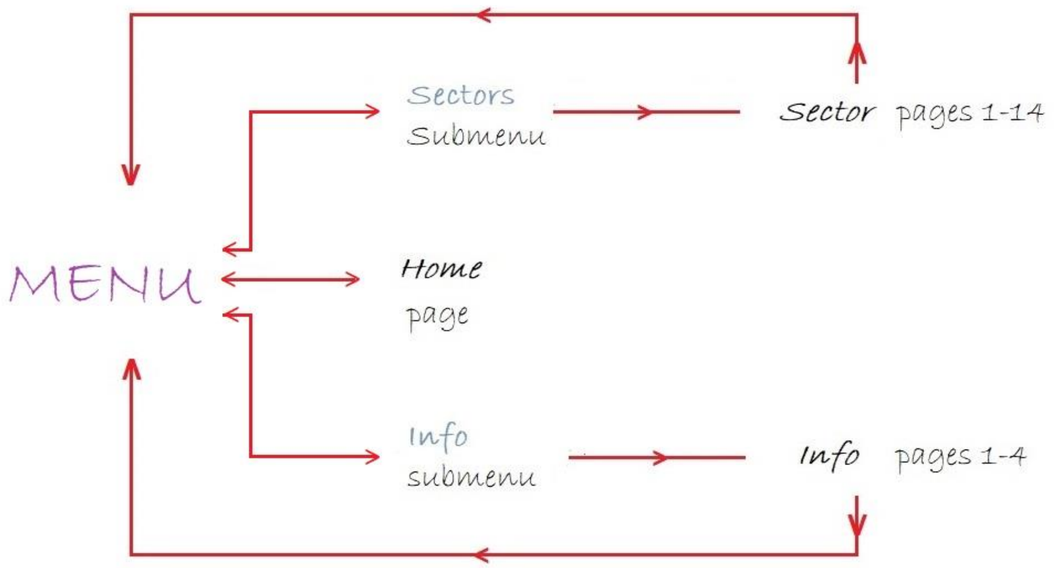


Diagram 1: Application's Structure

Transferring this structure to the editor's environment, 22 in total pages were created at "pages" directory;

- 18 guidebook pages
- 1 Home Page
- 2 submenu Pages
- 1 index

Next, at the same directory, 2 folders, corresponding to the sub menus, were added and the 18 guidebook pages were divided into them, according to their content/context.

For all the pages, the option of the parallel creation of navigation route was selected in order to ease the routing process.

The page template structure comes with header, content and footer. Though the footer was decided to be disactivated, the header was considered as useful; apart from the side (main) menu button, contains the heading of the page as well. In order to activate the heading visibility, the ***active-Screen*** attribute was used, giving the attribute value the name of each page.

3.2.2 Home page

The *Home* Page contains an image item with custom image, that was uploaded using the media manager. In order to adjust to fit the screen size automatically, the directive ***Responsive*** was set as *True* at the *image properties* tab.

3.2.3 Guide pages

Both *Info* and *Sector* Pages, present guidebook information, that had previously been concentrated in a text processor, exported as *.pdf* and finally edited as images. Hence these pages were faced similarly to the *Home* Page. Additionally, the scroll and slide box items were used where the content was larger than screen size.

Exceptionally, for the *Sector 2 in 3D* page, the <***html***> item was used. At the *properties* tab, the html was replaced by the embed code (*Image* 3.*15*) that was previously copied from *Sketchfab*.

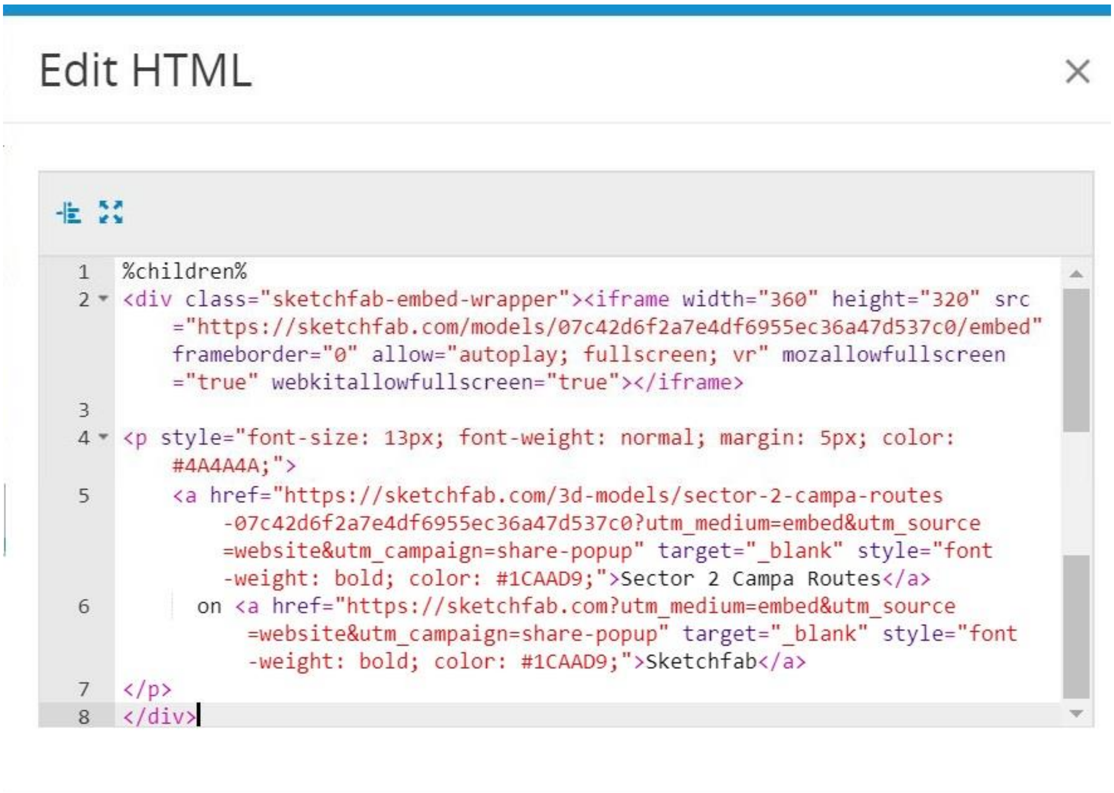


Image 3.15: The <HTML> tool with the Sketchfab embed code

3.2.4 Sub Menus

A submenu contains a list of categories, each of which redirects to a particular page if selected. Firstly, the **list item** was selected, and they were added as much item boxes as the number of the categories. For each box-category, the name and a brief description were typed at the ***text*** and ***item note*** variable, respectively. Moreover, avatars were selected from the ***left-icon*** option of *properties* tab.

In order to activate the redirection from a list item to its equal page, the ***Navigate-to*** function was called for each item. As all pages have navigation route, the path to each page was set by giving attribute value the route page name, using the default routing.

3.2.5 Index

The *Index* page contains the common structure and elements of all the pages. Every page is consisted of a *content* and a *header*. While the *content* is set for every page separately as described above, the *header* has 2 common elements for all of them; a button and a heading. The heading changes correspondingly to the page properties, due the combination of ***ng-view*** directive and ***{{activeScreen.name}}*** attribute of the *Index* properties. For the *Menu* **button**, the ***menu-toggle*** and ***ng-click*** directives were used in order to show the side menu when clicking it.

The properties of the side menu were managed at the *outline* tab of the index page. Specifically, each page contains a side menu (page-> side menu set as true), anchored at the left side (page->side menu-> side set as left), which contains a list of link items (page-> side menu-> list-> type set as link). For each list item the following settings were edited at the *properties* tab;

- Left icon-> style, to manage the categories avatars
- Text-> Home, Sectors and Info, to set the name of each category shown in the list
- Menu-close directive, to close the menu tab when navigated to the selected category
- navigate-to -> route page, to enable the redirection from the menu to the selected category
- ng-class-> {active: activeScreen.name === "ATTRIBUTE"}, to activate the heading change from "HOME" to the category's one

The default options of the template side Menu are *Home*, *Profile* and *Info*. However, for this project, instead of *Profile,* a *Sectors* options should appear. Hence the *Profile* page was deleted, such from the pages directory as from the routing as well and replaced by the *Sectors* page.

3.3 Release

Although the present application has not been released yet, it is available for native testing. Once the Appery.io tester application is downloaded and installed, the code **513-616-119** must be entered.

PART III Conclusions

This study presents a complete proposal for the creation of 3D topo for fields of sport climbing, and the development of a climbing guide android application that utilizes it. With the aim of allowing their creation by climbers themselves, considering that these tools are exclusively used by the climbing community, the examination of simplifying the individual processes is included. At the same time, although the Campa Sector, is an idealized case of climbing field for study, the peculiarities of a climbing rock as the actual object of documentation are considered, parameters are set and choices are made aiming at a generalized proposal.

The main concern is the choice of a method free from special equipment. The photogrammetric method is chosen firstly for its applicability to any rock type, including marble). The use of climbing equipment as GCP is being examined; quickdraws are considered to be appropriate, as opposed to bolts and anchors, for which further investigation is proposed. Scaling using estimated distances is also examined and proved to be satisfactory, but it is suggested that they be measured with a measuring. The combination of the above, relieves the process from need to use of specialized equipment.

Although image acquisition is made from such positions that allow the rock to be displayed throughout its height, the use of a drone would give a better result to the upper part of the rock. Moreover, it is the only solution for fields whose height exceeds the typical maximum (25m) or the morphology of the surrounding area does not allow for terrestrial image acquisition.

Although the archaeological site situated at the base of the rock is beyond the scope of the study, it is considered important to be included in the study and to be documented in detail as an element of cultural heritage and an integral part of the history of the field. For this purpose a large data set is created, demanding the use of commercial software and powerful hardware, resulting in a large 3D file, from which the documentation of the burial site is utilized. In order to approach better the study object and focus on the parameters that have been set (system requirements, software limitations, product quality and size) it is ultimately decided to exclude them from the photogrammetric process, and a new project of 35 photos is created. The generated and finally used 3D is shown to be satisfactory concerning quality and appropriate to file size restrictions.

In order to map the routes on 3D and convert it into 3D topo, a 3D editing software is selected. Although relatively simple to use, it could have been avoided altogether if all routes were fitted with ropes during the image shooting.

The 3D warehouse free version limitation on the file size is not a problem, since the dimensions of the case study object are representative of the sport climbing fields. Besides, using a larger 3D file would make it harder to display it through the application, given the processing power of the average mobile device today. However, the use of the pro version is proposed, as it allows the addition of information on the routes, in order to embed the legend directly on the 3D topo.

In conjunction with the topo-guide relation, the development of a climbing guide android application is chosen to display the 3D topo. The use of a drag-and-drop method is chosen, so that climbers themselves may be able to develop it.

The developed application is a complete digital guide of the climbing field of Villanueva de Valdegobia. However, in order to convert it to an exclusively 3D topo guide application, the creation and inclusion of a 3D topo for each sector will follow and then it will be released in the Google Play Store.

Thereafter, the entire proposal will be published in climbing websites to assess the ease of use of the proposed procedures. Interaction with the climbing community may lead to more conclusions and parameters to be explored.

The existence of global climbing guide applications highlights the need of a comprehensive database, so their enrichment with the 3D topos is proposed. Moreover a possible option to upload images could divide tasks and speed up the process altogether.

Utilizing AR Technologies, the development of an application that will use the camera to read the 2D map and project the 3D topo on the screen, is suggested. In addition, it would be interesting to study the real time projection on screen of the routes on the rock while scanning it with the mobile camera, as well as the potential use of the 3D topo as a base model or the quickdraws as trigger points.

Bibliography

1. Buchroithner M., 2002, "Creating the Virtual Eiger North Face." ISPRS of Photogrammetry and Remote Sensing, Geomatics in Mountainous Areas – The International Year of the Mountains, 2002, 57, no.1 (Nov. 1, 2002): 114-25. *https://doi.org/10.1016/S0924-2716(02)00109-0.*

2. Gruen A., Roditakis A. 2003, "Visualization and animation of Mt Everest." *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXIV-5/W10

3. Rabatel A., Deline Ph., Jaillet S., Ravanel L., 2008, "Rock falls in high-alpine rock walls quantified by terrestrial lidar measurements: A case study in the Mont Blanc area." *Geophysical Research Letters*, Vol. 35, L10502. https://doi.org/10.1029/2008GL033424, 200

4. Kolecka N., 2011. "High-Resolution Mapping and Visualization of a Climbing Wall." *True-3D in Cartography*, 323–37. Lecture Notes in Geoinformation and Cartography. Springer, Berlin, Heidelberg, 2011. https://doi.org/10.1007/978-3-642-12272-9_22.

5. Kajastila R., Hamalainen P., 2014, "Benefits of 3D topos for information sharing and planning in rock climbing", *Sports Technology*, Research article, Routledge, 2014 http://dx.doi.org/10.1080/19346182.2014.968249

6. Whiting E., Ouf N., Makatura L., Mousas C., Shu Z., Kavan L., 2017. "Environment-Scale Fabrication: Replicating Outdoor Climbing Experiences" *CHI 2017*, May 6–11, 2017, Denver, CO, USA http://dx.doi.org/10.1145/3025453.3025465

7. Kosmalla F., Zenner A., Speicher M., Daiber F., Herbig N., Krüger, 2017. "Exploring Rock Climbing in Mixed Reality Environments" *CHI'17* Extended Abstracts, May 06-11, 2017, Denver, CO, USA http://dx.doi.org/10.1145/3027063.3053110

8. Hale A., Fisher A., Hutchinson J., Jeffrey S., Jones S., Maxwell M., Watson J.S., 2017. "Disrupting the heritage of place: practising counter-archaeologies at Dumby, Scotland" *World Archaeology*, 49:3, 372-387, http://dx.doi.org/10.1080/00438243.2017.1333923

9. Putnam R., Glazner A., Coleman D., Kylander-Clark A., Pavelsky T., Abbot M., 2015. *"*Plutonism in Three Dimensions: Field and Geochemical Relations on the Southeast Face of El Capitan, Yosemite National Park, California." *Geosphere* 11, no. 4 (August 1, 2015): 1133–57. https://doi.org/10.1130/GES01133.1.

10. Matasci B., Carrea D., Jaboyedoff M., Metzger R., Stock G., Putman R., 2013 "Rock face stability analysis and 3D geological mapping in Yosemite Valley (California): new remote sensin methods" *Geophysical Research Abstracts* Vol. 15, EGU2013-1518, 2013

11. Stock G., Bawden G., Green J., Downing G., Hanson E., Collins B., Bond S., Leslar M., 2011. "High-resolution three-dimensional imaging and analysis of rock falls in Yosemite Valley, California" *Geosphere*; April 2011; v. 7; no. 2; p. 573–581, http://dx.doi.org/10.1130/GES00617.1.

12. Stock G., Guerin A., Matasci B., Jaboyedoff M., Derron M.H., Collins B, 2017. "Quantifying 40 years of rockfall activity in Yosemite Valley with Structure-from-motion and Terrestrial Lidar analyses" *GSA Annual Meeting in Seattle*, Washington, USA – 2017, *Geological Society of America Abstracts with Programs*. Vol. 49, No. 6. http://dx.doi.org/10.1130/abs/2017AM-299103

13. Wiehr F., Daiber, F., Kosmala F., Kruger A., 2017, "ARTopos - Augmented Reality Terrain Map Visualization for Collaborative Route Planning" *UbiComp/ISWC'17 Adjunct* , September 11–15, 2017, Maui, HI, USA ACM 978-1-4503-5190-4/17/09. https://doi.org/10.1145/3123024.3124446

14. Aldighieri B., Testa B., Bertini A., 2015, "3D Exploration of the San Lucano Valley: Virtual Geo-routes for Everyone Who Would Like to Understand the Landscape of the Dolomites*"* *Geoheritage* http://dx.doi.org/10.1007/s12371-015-0164-x

15. AMF-FAM, Mendian, AGME, Garbine Uriarte, 2011, "Guía de escalada en Villanueva de Valdegobia", *AMF-FAM*

Stock G., Downing G., Hanson E., 2010. "High-Resolution Imaging of Rock Falls in Yosemite National Park*"* *Proceedings of the Fine International Conference on Gigapixel Imaging for Science*, November 11–13 2010.

Stock, G.M., Luco, Nicolas, Collins, B.D., Harp, E.L., Reichenbach, Paola, and Frankel, K.L., 2014, "Quantitative rock-fall hazard and risk assessment for Yosemite Valley, Yosemite National Park, California" *U.S. Geological Survey Scientific Investigations* Report 2014–5129, 52 p., http://dx.doi.org/10.3133/sir20145129.

Matasci B., Stock G., Jaboyedoff M., Carrea D., Collins B., Guérin A.,Matasci G., Ravanel L., 2017. "Assessing rockfall susceptibility in steep and overhanging slopes using three-dimensional analysis of failure mechanisms" http://dx.doi.org/10.1007/s10346-017-0911-y

Wiehr, Frederik, Felix Kosmalla, Florian Daiber, and Antonio Krüger. "*BetaCube: Enhancing Training for Climbing by a Self-Calibrating Camera-Projection Unit*." In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 1998–2004. CHI EA '16. New York, NY, USA: ACM, 2016. https://doi.org/10.1145/2851581.2892393

Redweik P., Marques F., Matildes R., 2008. “A strategy for Detection and measurement of the cliff retreat in the coast of Algarve (Portugal) by photogrammetry” *EARSeL eProceedings* 7, 2/2008

Rieke-Zapp D. H., Bommer-Denss B., Ernst D, 2010. “Small format digital photogrammetry for application in the earth sciences” *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVIII, Part 5 Commission V Symposium, Newcastle upon Tyne, UK. 2010

Wangensteen B., Eiken T., Ødegård R., Sollid J.L., 2007. “Measuring coastal cliff retreat in the Kongsfjorden area, Svalbard, using terrestrial photogrammetry” *Polar Research* (2007) 14–21.https://doi.org/10.1111/j.1751-8369.2007.00002.x

Gates W. C. B., Haneberg W.C., 2012. “Comparison of Standard Structural Mapping Results to 3-D Photogrammetric Model Results: Boundary Transformer Banks Rockfall Mitigation Project, Metaline Falls, Washington” *46th US Rock Mechanics / Geomechanics Symposium*, Chicago, IL, USA, 24-27 June 2012.

Vidal Royo O., 2010, “3D Reconstruction and modelling of the Sierras Exteriores Aragonesas (Southern Pyrenees, Spain)”. *University of Barcelona*

Buchroithner M., Gaisecker D., Gaisecker T., Österreich H., 2009. “Terrestrial Laser Scanning for the Visualization of a Complex Dome in an Extreme Alpine Cave System” *Photogrammetrie - Fernerkundung - Geoinformation* 4/2009, S.329–339, https://doi.org/10.1127/1432-8364/2009/0025

Haneberg W., 2007. “Directional roughness profiles from three-dimensional photogrammetric or laser scanner point clouds” *Rock Mechanics: Meeting Society’s Challenges and Demands: Proceedings*, 1st Canada-U.S. Rock Mechanics Symposium, Vancouver, May 27-31, 2007, p.101-106.

Abellan A., Vilaplana J.M., Calvet J., Garcia-Selles J., Asensio E., 2010. “Rockfall monitoring by Terrestrial Laser Scanning – case study of the basaltic rock face at Castellfollit de la Roca (Catalonia, Spain)” *Nat. Hazards Earth Syst. Sci*., 11, 829-841, 2011. https://doi.org/10.5194/nhess-11-829-2011

Alonso J.F., Castellet S., Fernandez E., 1993. “La Necropolis de San Martin de Valparaiso (Villanueva de Valdegobia), Alava” *KOBIE (Serie Paleoantropología)*, Bilbao Bizkaiko Foru Aldundia-Diputación Foral de Bizkaia N.º XX, 1992/93

Μαρτζούκος Γεώργιος, 2007, «Ορειβασία: Ιστορία και Ιστορίες» εκδ. Ανάβαση

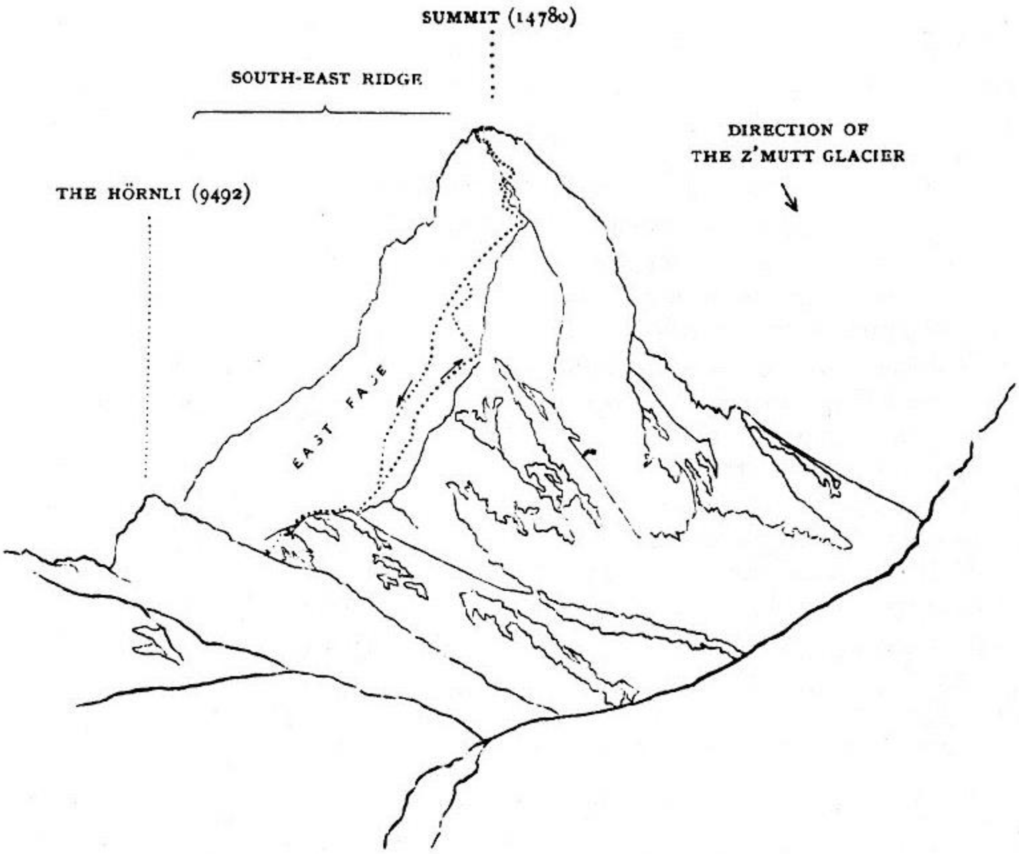
Κάραλης Δ., Θεοδωρόπουλος Ά., 2007, «Ορειβασία: Αναλυτικό τεχνικό εγχειρίδιο» ΕΟΣ ΑΧΑΡΝΩΝ

Links

https://en.wikipedia.org/w/index.php?title=Climbing&oldid=822209480.
https://en.wikipedia.org/wiki/Glossary_of_climbing_terms.
https://www.thoughtco.com/types-of-climbing-755874.
https://www.britannica.com/sports/mountaineering.
http://www.alpineinstitute.com/articles/expert-tips/rock-climbing-terms-styles-and-techniques/.
http://climbingschool.org/types-of-climbing.
https://www.snowguide.gr/anarrixisi/item/i-istoria-tis-anarrixisis.
http://www.oreivatein.com/oreivatein/page/library/b_orei_his.htm.
https://blogs.agu.org/landslideblog/2015/08/29/tour-ronde-1/.
http://ubimount.rocks/static/papers/drones.pdf.
https://wp.unil.ch/risk/battista-matasci/.
http://www.planetmountain.com/english/News/shownews1.lasso%3Fl%3D2%26keyid=42417.
http://www.xrez.com/yose_proj/Yose_idea.html.
https://www.yosemite-17-gigapixels.com/.
https://www.wired.com/2008/10/geology-20-20-g/.
http://www.en.openalp3d.it/.
https://climbingaway.fr/en/tools/climb-articles/184-ceuese-the-whole-digital-guidebook.
http://climbaround.com/.
https://www.vertical-life.info.
https://play.google.com/store/apps/details?id=com.crags27.crags27.
https://27crags.com/create_topo.
https://climbingaway.fr/en/.
https://play.google.com/store/apps/details?id=com.mountainproject.android.
https://play.google.com/store/apps/details?id=com.rakkup.rakkup&hl=el.
https://climbingaway.fr/en/rock-climbing-areas/and-on-your-smartphone/ios-application.
https://www.climbing.com/gear/6-must-have-climbing-apps/.
https://27crags.com/.
https://play.google.com/store/apps/details?id=com.thesend.kalymnos&hl=en_GB.
https://itunes.apple.com/us/app/climbingaway/id408499277?mt=8.
http://www.artofvfx.com/everest-dadi-einarsson-vfx-supervisor-rvx/.
http://www.solfar.com/everest-vr/.
http://store.steampowered.com/app/384750/EVEREST_VR/.
https://www.roadtovr.com/everest-vr-review/.
https://www.youtube.com/watch?time_continue=4&v=olhRKlDUAnA.
http://www.solo.maxmediacorp.com/site/.
http://gameranx.com/updates/id/45811/article/crytek-has-a-new-video-for-their-vr-rock-climbing-game-the-climb/.
https://www.engadget.com/2015/12/17/vr-climbing-brain-hacks/.
http://www.theclimbgame.com/

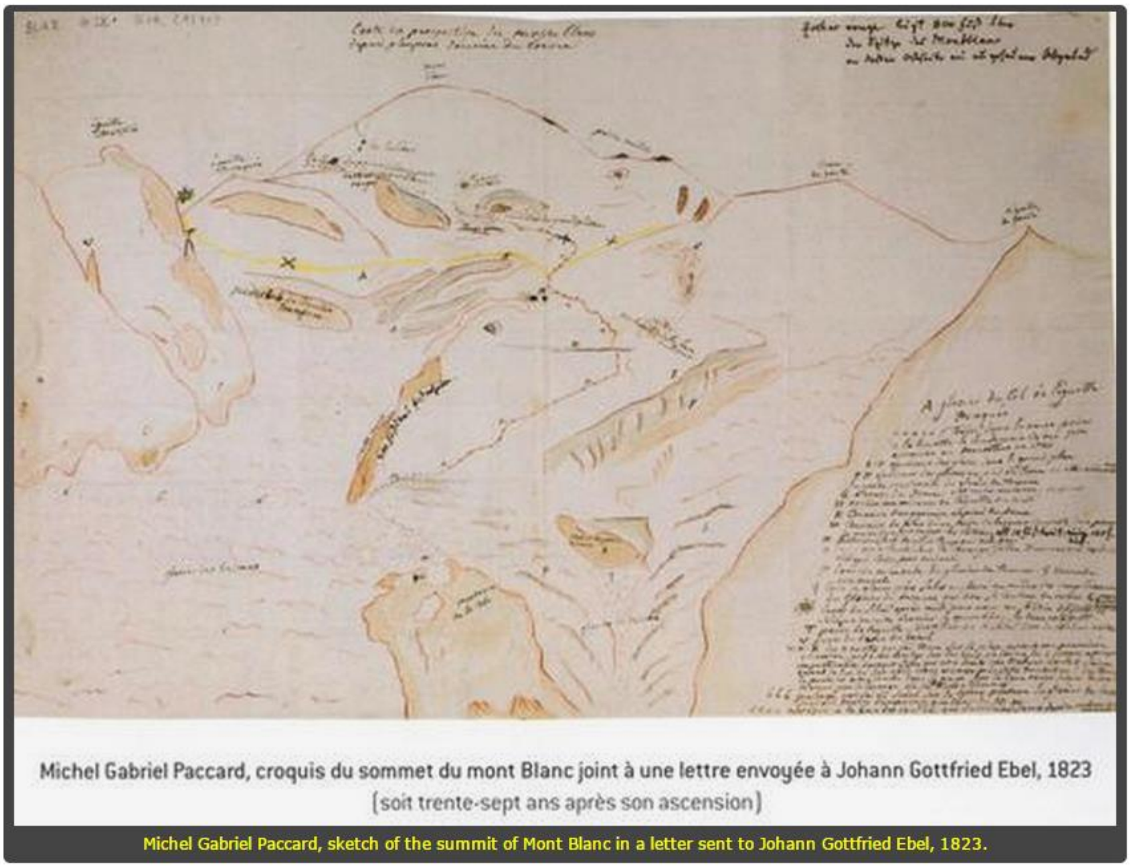
APPENDIX A

Topos



THE MATTERHORN FROM THE NORTH-EAST.

Ilustración 1.1 Old Topo Of Matterhorn



Michel Gabriel Paccard, croquis du sommet du mont Blanc joint à une lettre envoyée à Johann Gottfried Ebel, 1823
(soit trente-sept ans après son ascension)

Michel Gabriel Paccard, sketch of the summit of Mont Blanc in a letter sent to Johann Gottfried Ebel, 1823.

Ilustración 1. 2 Old Topo Of Mont Blanc

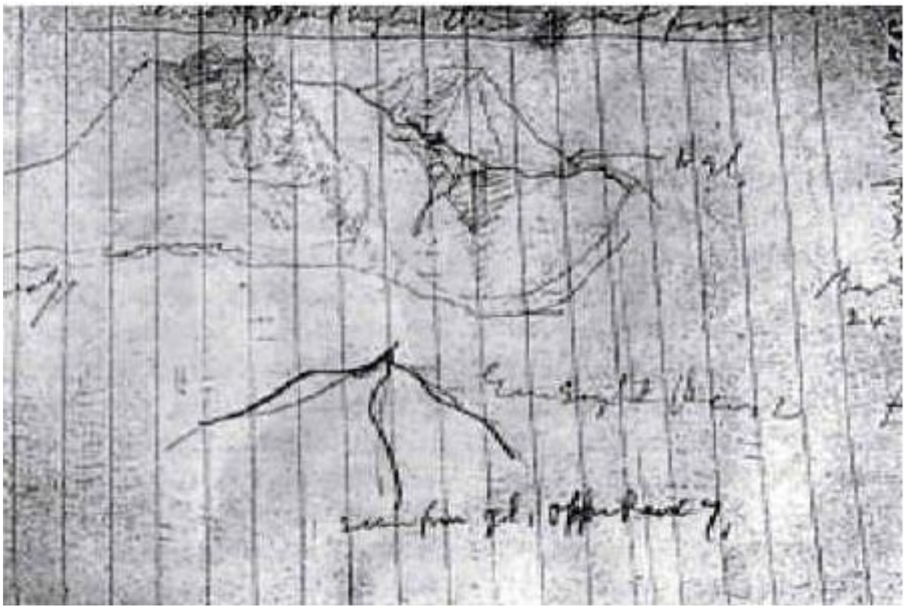


Ilustración 1. 3 Old Topo Of McKinley

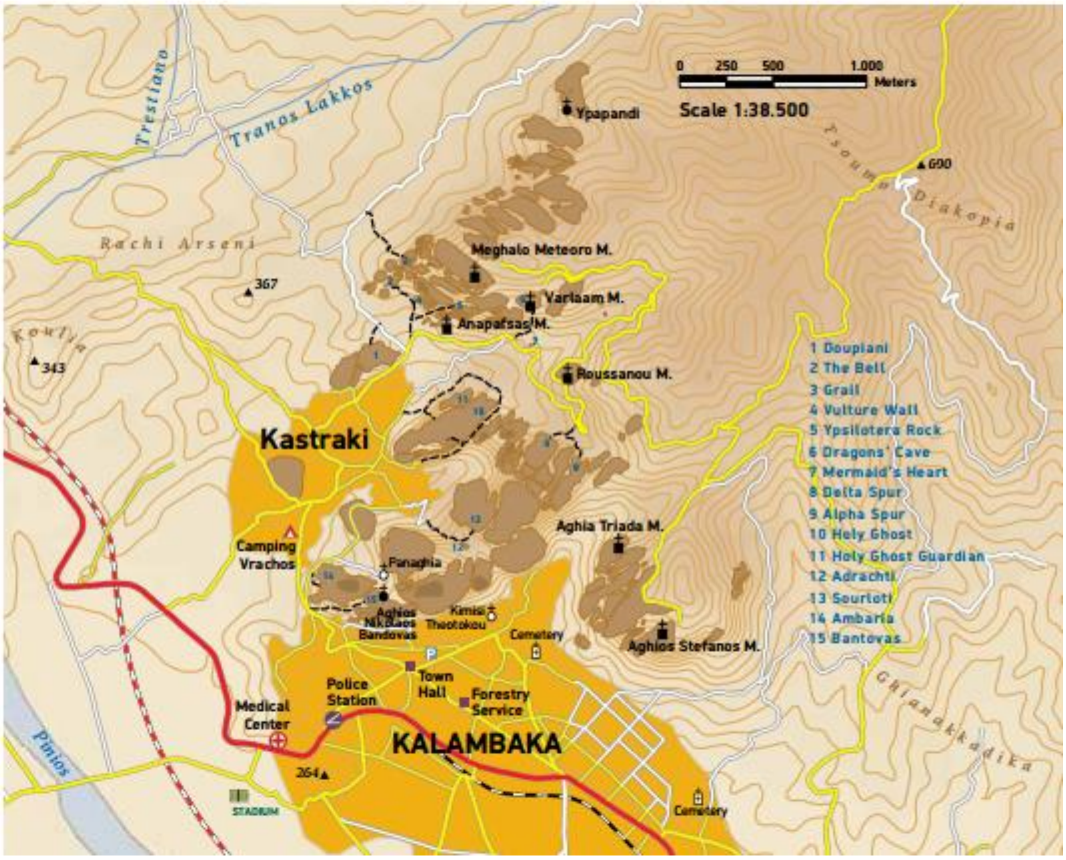


Ilustración 2.1 Horizontal Topo of Meteora

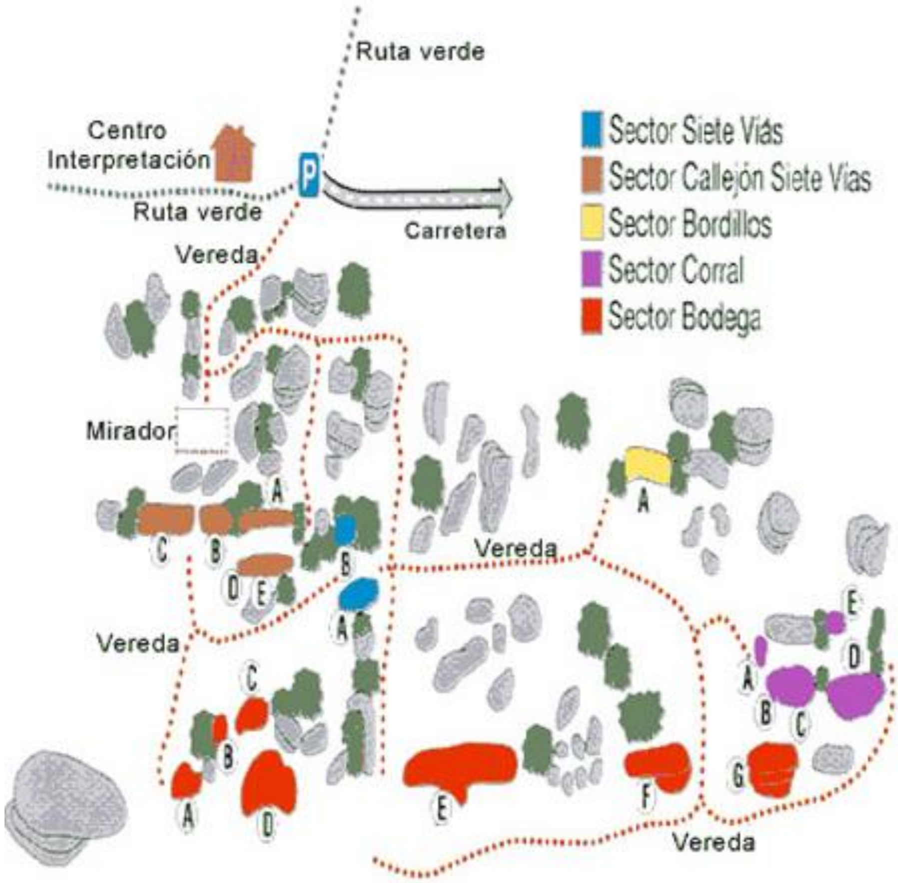


Ilustración 2.2 Horizontal Topo Of Torcal De Antequera

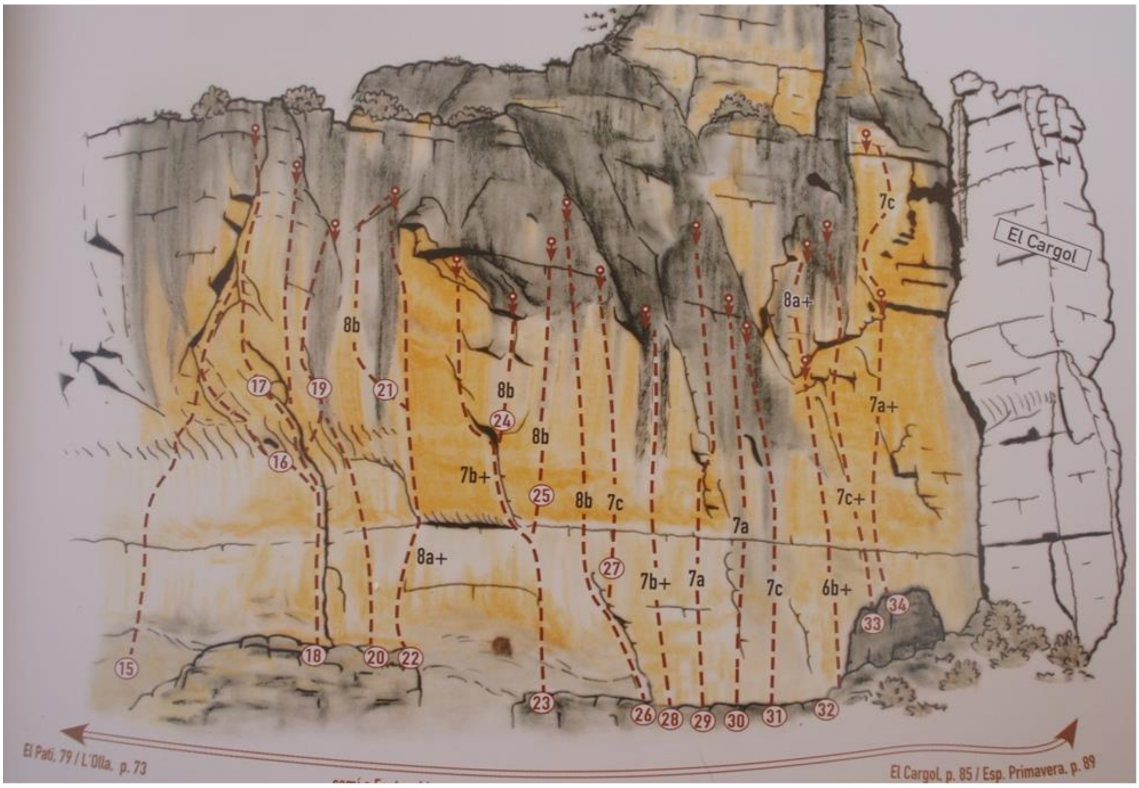


Ilustración 3.1 Vertical Drawing Topo Of Siurana

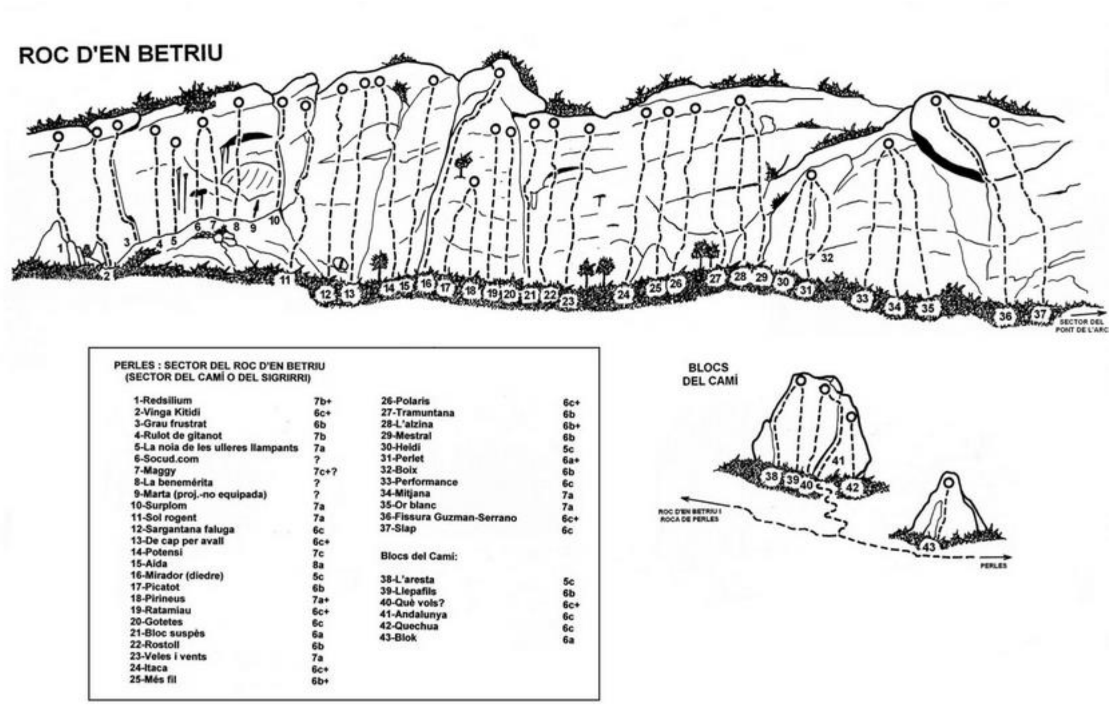


Ilustración 3.2.Vertical Sketch Topo Of Roc D´ En Betriu

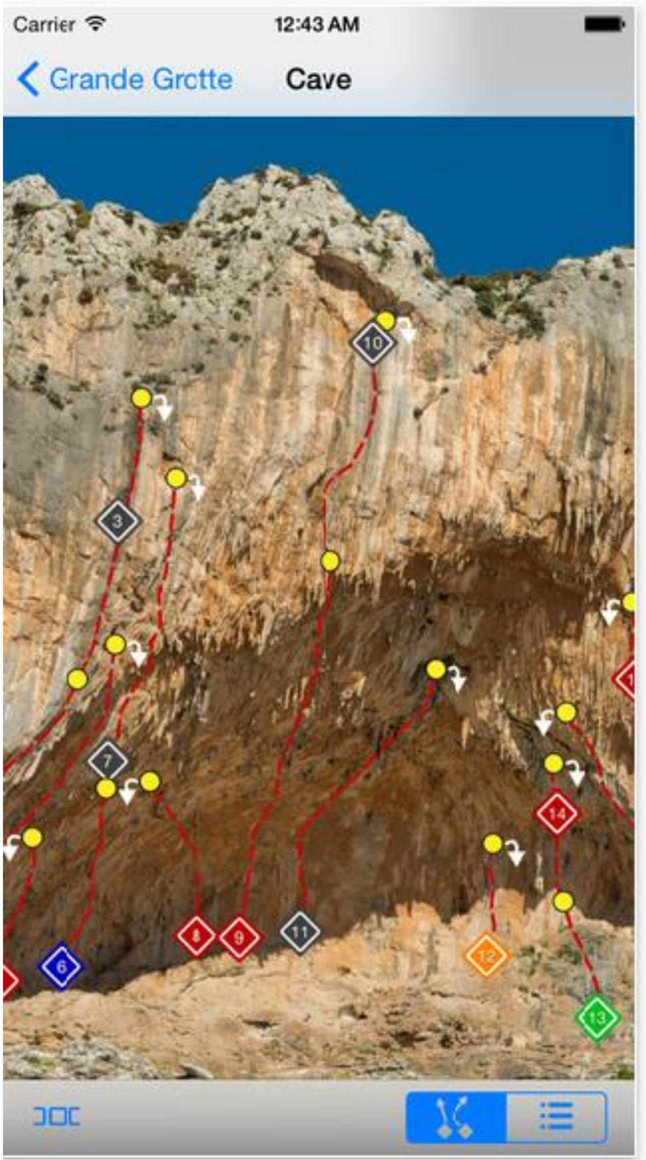
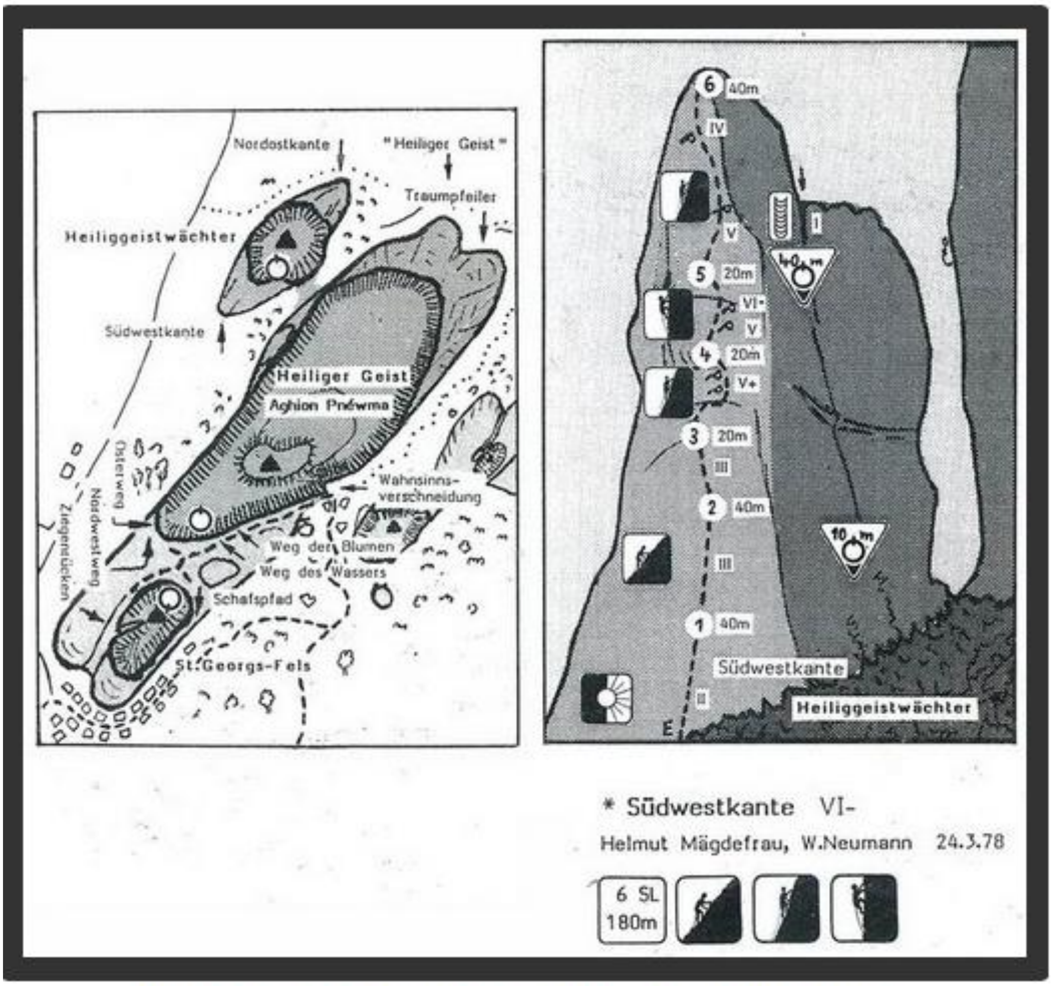


Ilustración 3.3.Vertical Application Topo of Kalymnos



Sudwestkante, Meteora climbing & Hiking, H.L.Stutte, D.Hasse

Ilustración 4.1 Horizontal and Vertical Topo of Meteroa

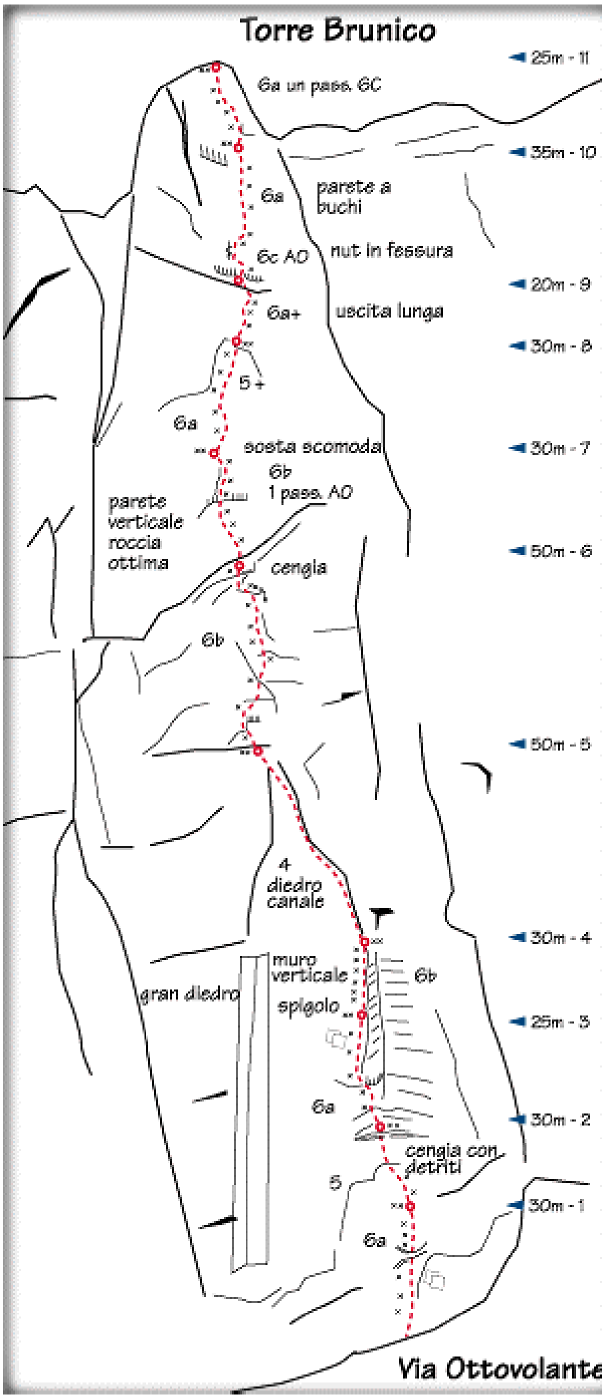


Ilustración 5.1 Vertical Topo Of Ottovolante Multipitch route

Ilustración 5.4 Vertical Topo of El Toro Multich

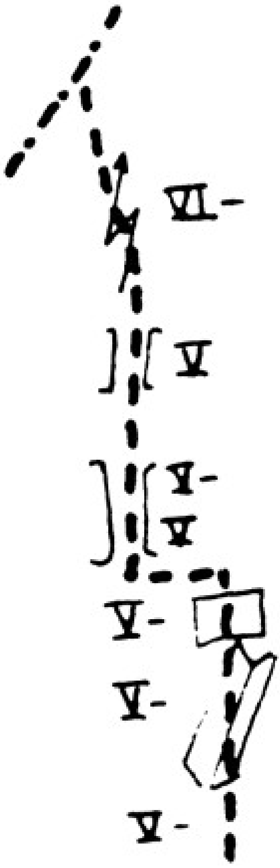


Ilustración 5.2 Vertical Schetch topo of Tsatsaragou/Adamakopouloou/Harzir-vasani route in Giona

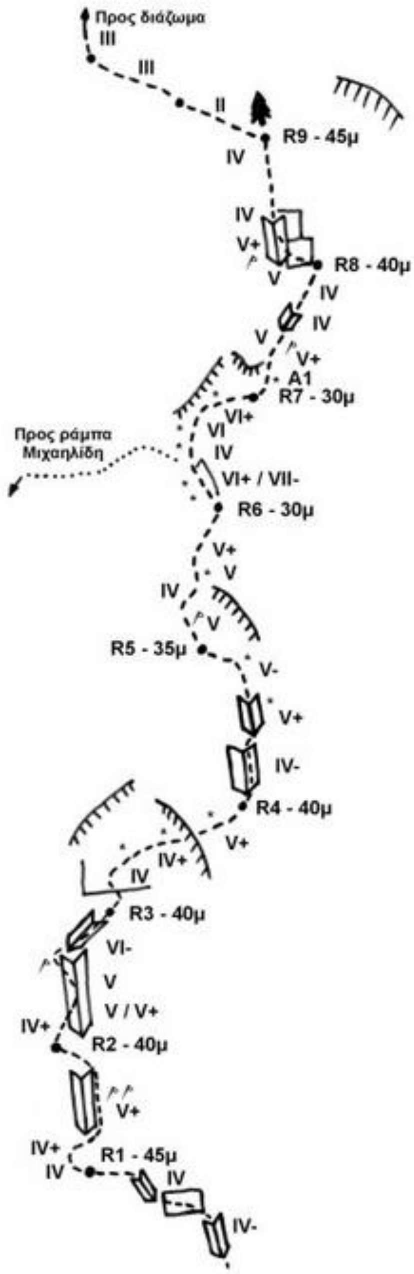
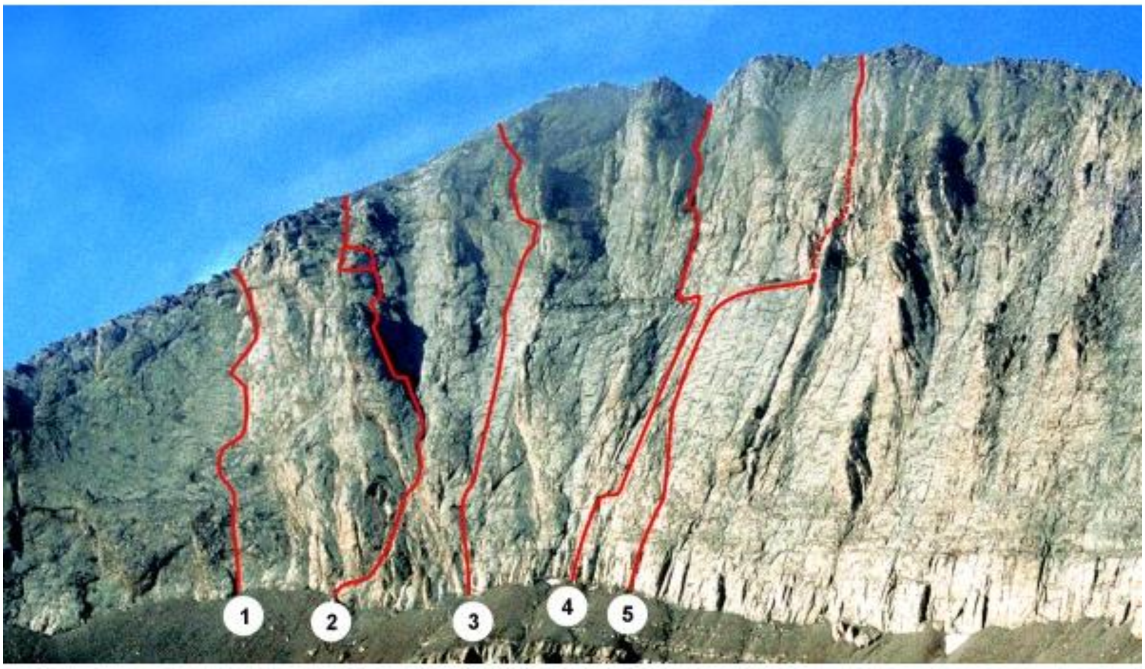


Ilustración 5.3 Vertical Scetch topo of Esthis-eon Route in Gkiona

Olympos - Stefani - E. Face



[1] "Mpoteli - Zarra", [2] "Ahladi", [3] "Nefeli", [4] "Comici - Escher", [5] "Schwab - Agliardi"

Ilustración 6.1 Panoramic Topo of Stefani in Olympos

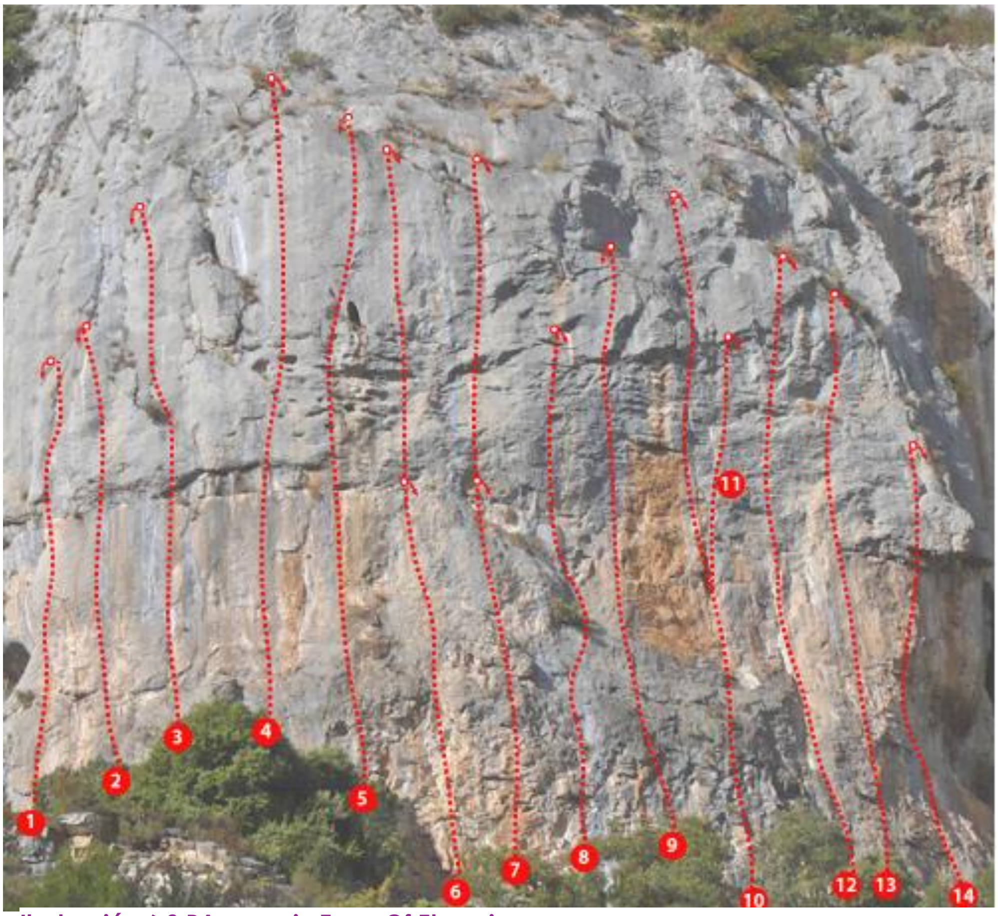


Ilustración 6.3 PAnoramic Topo Of Etxauri

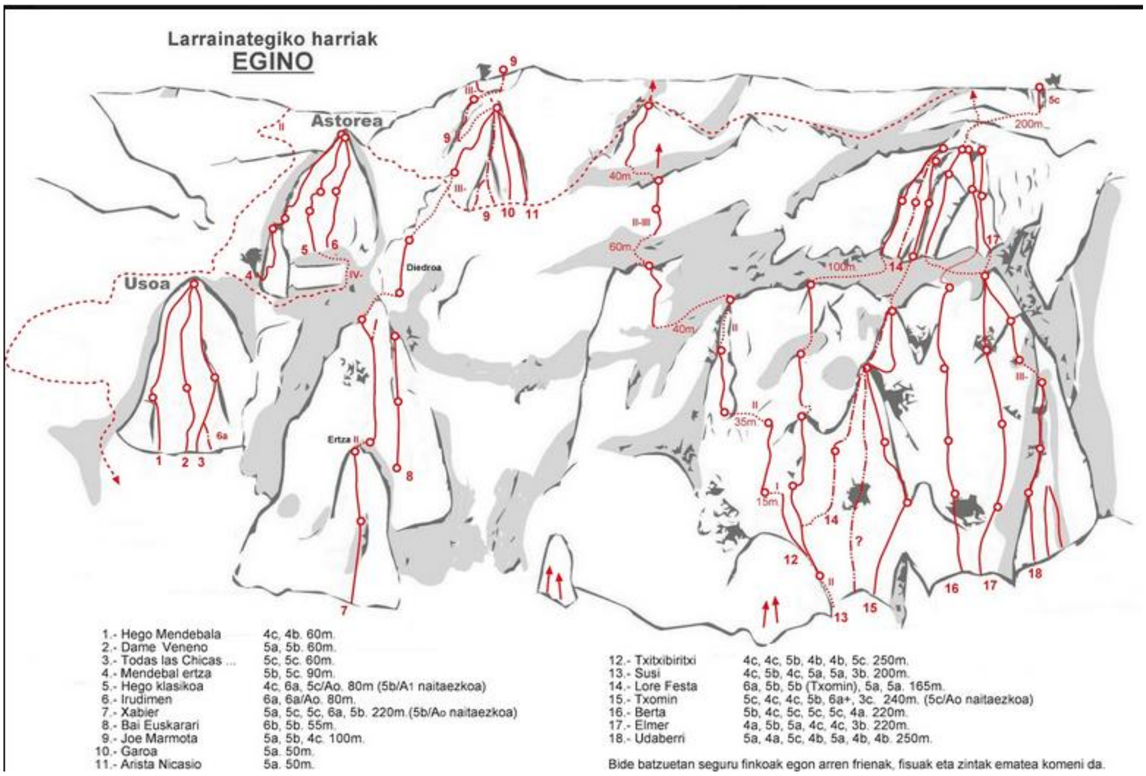


Ilustración 6.4 Panoramic Sketch Of Egino

Ilustración 6.2 Panoramic Topo of Half Dome

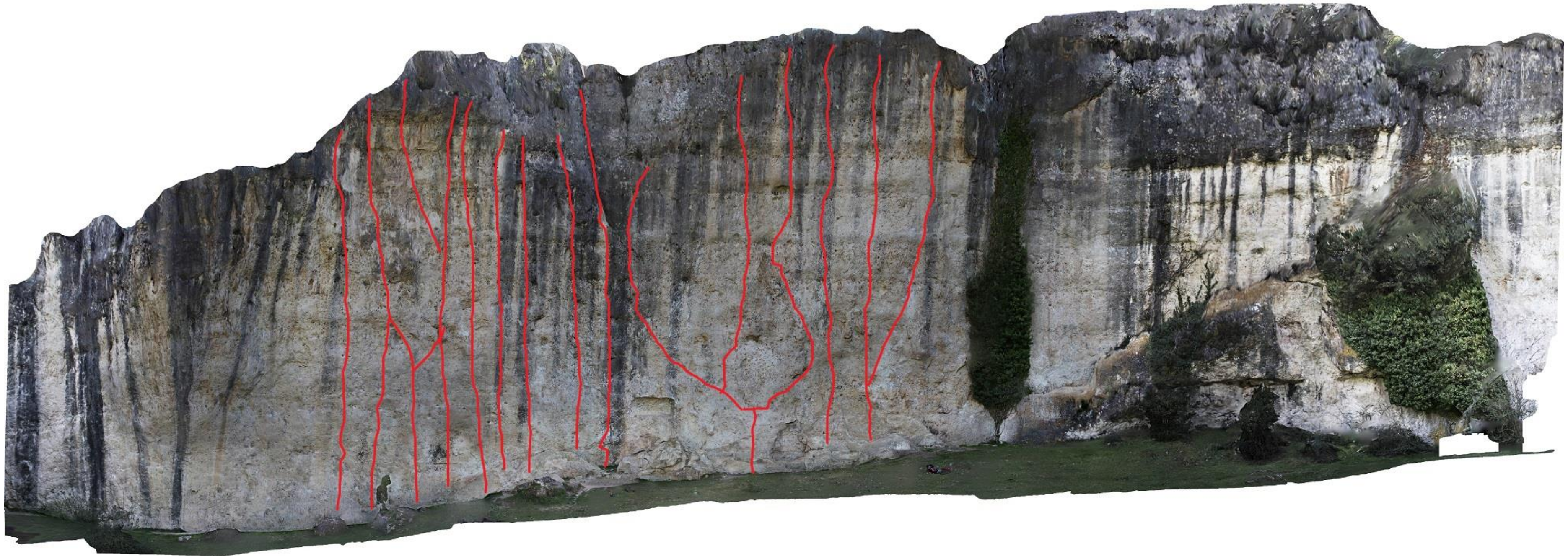
1.1.Old_topo_Matterhorn	http://www.gutenberg.org/files/41234/41234-h/41234-h.html
1.2.Old_Topo_MontBlanc	http://www.summitpost.org/the-1rst-ascent-of-mont-blanc/850467
1.3.Old_topo_McKinley	http://www.frederickcooksociety.org/mckinley.htm
2.1.H_Topo_Meteora	http://www.petzl-roctrip.com/sites/www.petzl-roctrip.com/files/basecamps/pdf/topos/me-teora-petzl-small.pdf
2.2.H_Topo_TorcalDeAntequera	http://www.en.enlavertical.com/es-cuelas/view/334
3.1.V_Topo_Draw_Siurana	https://tomball83.word-press.com/2011/11/17/the-curious-incident-of-the-pig-at-night-time/
3.3.V_Topo_App_Kalymnos	https://itunes.apple.com/us/app/kalymnos-rock-climbing-topo/id924883293?mt=8
3.2.V_Topo_Schetch_RocD´EnBetriu	http://climbinspain.com/2009/11/perles/
4.1.H&V_Topo_Meterora	http://www.summitpost.org/sudwest-kante/795724
5.1.V_Topo_Multi_Ottovo-lante	http://www.planetmountain.com/eng-lish/Rock/dolomites/sella/Ottovolante/Ottovo-lante2.html
5.2.V_Topo_Gkiona	http://www.routes.gr/?Page=en/Climbing/Routes/TsatsaragouAdamakopoulouHatzirvasani
5.3.V_Topo_Gkiona	http://www.routes.gr/?Page=en/Climbing/Routes/Aisthiseon
5.4.V_Topo_ElToro	http://vertiquality.blogspot.com.es/2008_10_01_archive.html
6.1.Pan_Topo_Olympos	http://www.routes.gr/?Page=en/Climbing/Panoramas/Olympos-Stefani-E
6.2.Pan_Topo_HalfDome	http://www.supertopo.com/tr/Hey-Coz-Sure-would-like-to-hear-the-story-of-Southern-Belle/t271n.html
6.3.Pan_Topo_Etxauri.png	http://www.planetmountain.com/english/Rock/crags/settore.html?idfalesia=138&idsettore=1
6.4.Pan_Topo_Egino.png	http://ametsek.blogspot.com.es/2013/07/vias-egino-actualizada.html

APPENDIX B

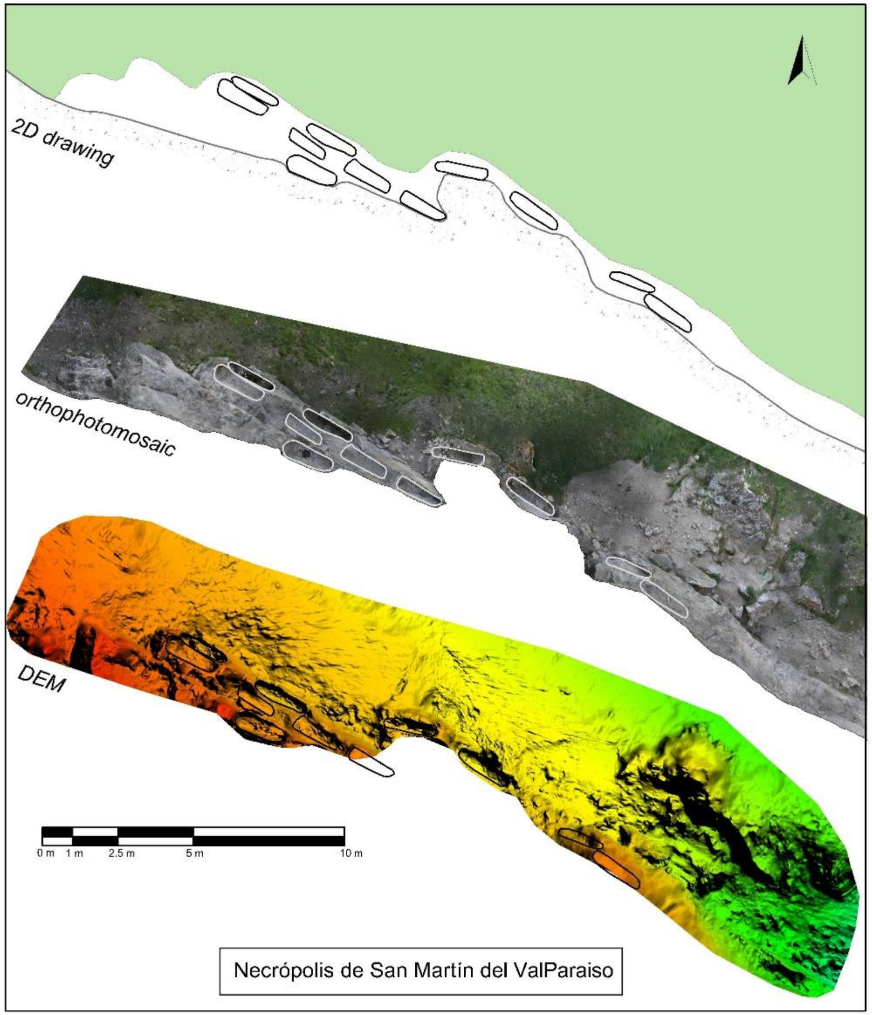
Products

Product 1 Photorealistic 3D model

Product 2 Orthophoto



Product 2 2D topo



Product 3 Tombs 2D drawing