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UTILIZATION OF AIRBORNE LIDAR DATASETS IN GIS ENVIRONMENT FOR PROSPECTION OF ARCHAEOLOGICAL SITES IN HIGH ALPINE REGIONS

1. Introduction

Archaeological prospection by airborne laser scanner datasets provides useful methods for the research of potential sites in Alpine regions, because certain geographical properties, e.g., dense vegetation and crude surface, make the ground-based archaeological investigations extremely difficult to apply. For these reasons, several archaeological studies have used airborne LiDAR (Light Detection and Ranging) technologies during the last years (Crutchley 2009). The LiDAR based high resolution Digital Terrain Models (DTMs) can offer new perspectives in the field of the localisation and analysis of archaeological sites on mountain areas.

Furthermore, the number and quality of airborne LiDAR data processing opportunities also increase and develop in a Geographical Information System (GIS) environment (Stal *et al.* 2010). In addition, different visualisation techniques of DTMs can also be applied during the site investigation (McCoy, Asner, Graves 2011). The created geographical databases and maps can be utilised more frequently also by archaeologists in different research projects (Hanke *et al.* 2009). The various results of some helpful visualisation workflows will be discussed and compared in this paper and the practical combination of several archaeological surveys (LiDAR, terrestrial laser scanning and Total Station measurements) will be presented as well. The utilisation of airborne LiDAR datasets was successfully accomplished in two unique archaeological research projects during the last years. At first, some details will be introduced about these studies on the Alpine regions.

1.1 *HiMAT project*

The multidisciplinary "History of Mining Activities in the Tyrol and Adjacent Areas" (HiMAT) programme investigates the history of mining in the Eastern Alps. The University of Innsbruck cooperates with other European universities and with the German Mining Museum within the HiMAT project in order to analyse the mining activities in the region. For example, the impacts of previous activities on the environment and human society are in the focus of the research, because the prehistoric mountain region has changed extensively since the beginning of the extraction of ore and metal in the Alps. There are some specific key areas, e.g. Mauken or Mitterberg in Austria (Fig. 1), which provide possibilities to analyse the expansions and recessions of these mining regions. The Surveying and Geoinformation Unit at the University of Innsbruck contributed to the investigation of those archaeological sites with various methods. For example, the creation of high accuracy DTMs was utilised for archaeological prospection. Furthermore, Terrestrial Laser Scanning (TLS) was applied to the 3D documentation for modelling the excavations and finally, these various datasets were also combined in a GIS environment (Kovacs, Moser, Hanke 2010).

1.2 *APSAT project*

The "Ambiente e Paesaggi dei Siti d'Altura Trentini" (APSAT) project (Environment and Landscapes of Upland Sites of Trentino/2008-2011), funded by the Autonomous Province of Trento in the context of proposals "Grandi Progetti 2006", is focused on the study of upland anthropic system in Trentino area. In particular, it aims at investigating the evolution of antrophic landscape from Prehistory to the Modern Period, seeing landscape as the product of sequences of settlements, communication networks, resources and symbolic places. This project, especially the section on mapping mountain settlements, aims at combining different remote sensing techniques including aerial photography and airborne LiDAR data along with wide archaeological survey in the Trentino area. Traditional remote sensing techniques, for instance aerial photography surveys, are not particularly useful for studying hilltop sites. This is also the case on the Val di Non area, one of the APSAT project's key study sites, since this region is covered by dense vegetation (Fig. 1). For that reason, the application of airborne LiDAR technology has provided the most appropriate solution.

2. Study areas. The Austrian and the Val di Non sites

The regions investigated within these two research projects are located in the Eastern Alps. The Austrian sites, Mauken and Mitterberg are among the key areas of the HiMAT project, as significant mining productions were carried out in these regions in the past. Mauken is a small Bronze Age mining area in Brixlegg in Tyrol, whereas the Mitterberg region, known for its large scale ore production, is located in the federal state of Salzburg.

Val di Non is located North-west of Trentino, and the borders are Alto Adige (North), the Adige valley (South-east) and the Paganella Plateau. This area consists of little plateaux, cross-cutted by many streams and smaller rivers, most dominantly by the Noce. The populated areas, mainly villages, are settled on southern and sunnier terraces, located near the rivers or the artificial lake of Santa Giustina. In the last fifty years, the area was affected by significant changes in agricultural exploitation, which destroyed archaeological traces of human presence, i.e. ancient rural settlements.

Fig. 1 – The map of the study areas: Mauken, Mitterberg and the Val di Non.

3. Methodology

Three various workflows were used in GIS environment during the investigation of these archaeological sites. The combination of different measurements, for example airborne LiDAR and TLS surveys, was applied to create accurate maps of the small mining areas of Mauken. The second workflow was carried out at a larger scale such as in the case of Mitterberg, where different applications were utilised to visualise the mining effects on the surface by high resolution airborne LiDAR datasets. With the third method, slope analysis was used to discover new sites and to identify new structures at the known sites by the government airborne laser scanning surveys within the APSAT project in the Val di Non, Italy.

3.1 *Mapping of small excavation areas by the combination of LiDAR, TLS and Total Station measurements*

The archaeological sites of Mauken E and Mauken F at Brixlegg were documented with additional terrestrial measurements, because the mapping of small relief characteristics was unfeasible by the government LiDAR dataset. The resolution of the airborne laser scanning survey was only 1 point/m^2, furthermore, the horizontal accuracy of these points was within 30 cm and the vertical precision was better than 15 cm. Approximately 1 cm accuracy could be obtained from the terrestrial surveys of these archaeological sites. The TLS point cloud with 3 cm point spacing provided a basis for the combination of other measurements. In these cases, the airborne LiDAR data was used only to hole-filling, since the point cloud of the terrestrial laser scanner was incomplete at some parts of the excavation sites due to the dense vegetation. The break lines of the surface, for instance roads and rifts, were exactly defined by the Total Station measurements. These linear structures could be additionally determined during the surface interpolation. As a result, the high quality DTMs were created after the data fusion in ArcGIS. A mining entrance area was also mapped at the Mauken E site by this technique (Fig. 2, Tav. VI, b). In addition, different objects, like 3D models of excavation layers and ground-penetrating radar measurements could be visualised together with the high resolution DTM of Mauken F site in GIS environment (Fig. 3, Tav. VII, a).

3.2 *Visualisation of the surface's morphological properties by high resolution LiDAR dataset at a large mining region*

A special airborne laser scanning survey was organised approximately on 4 km² at the Mitterberg region in Austria with the average raw point density of 11 points/m². In spite of the dense vegetation coverage, the morphological characteristics of the previous mining activities could be clearly identified based on the DTM (Fig. 4). This work was partially carried out by Michael Doneus and Christian Briese at the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology in Vienna. This highly accurate DTM was created by the Inverse Distance Weighted (IDW) technique in ArcGIS after the import of filtered last echo datasets. The selected size of interpolated raster was 0.5 m, since the average point density of the filtered dataset was only about 1.4 points/m². As a next step, the neighbourhood analysis of the focal statistics tool was applied to smooth the interpolated model. A neighbourhood area was defined by this tool around each raster cell and an average raster value was calculated by adjacent raster information in every grid centre. The created digital terrain model was visualised by the blending of various hillshade results (Kovacs, Moser, Hanke 2010).

3.3 *Slope analysis of hilltop sites in APSAT project*

During the analysis of the LiDAR datasets, the identification of ancient settlements and the mapping of these ruins in the Val di Non key area were the main objectives. The whole area of the Autonomous Province of Trento was documented by an airborne laser scanning survey in 2006 and 2007.

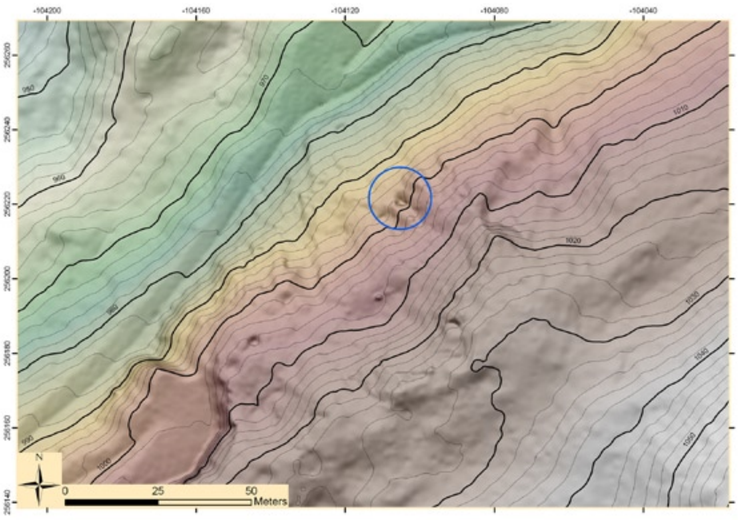

Fig. 2 – High resolution DTM of the Mauken E site: the circle indicates the mining entrance (photo Land Tirol Airborne LiDAR dataset).

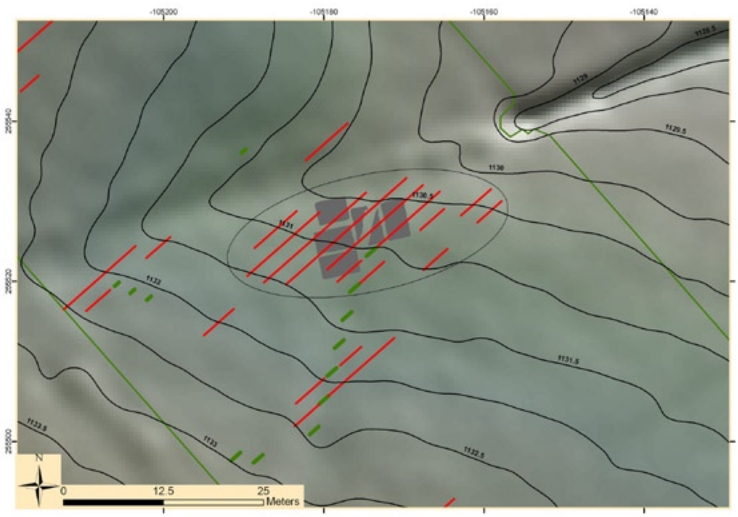

Fig. 3 – GIS based documentation of the Mauken F site: the high resolution 3D digital models of the excavation layers and the result of a ground-penetrating radar measurement (photo Land Tirol Airborne LiDAR dataset).

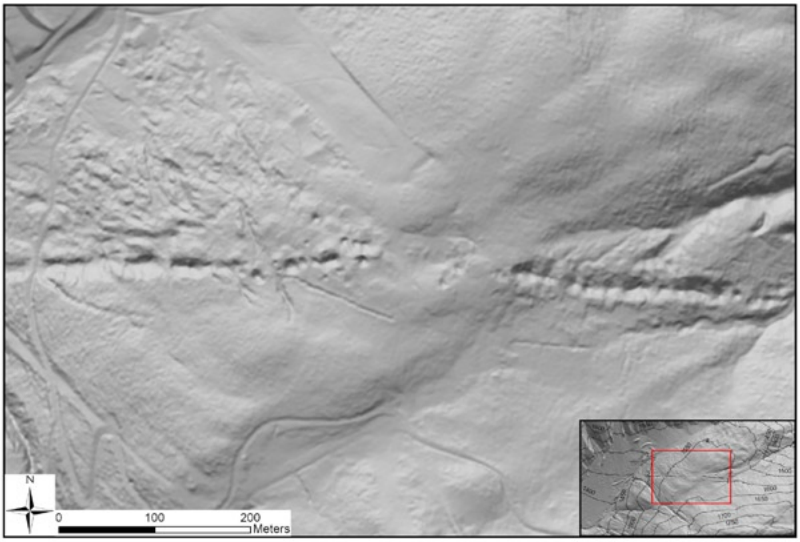

Fig. 4 – Visualisation of the mining extraction impacts in the Mitterberg region.

During this data collection, the average distance between points was 1.5 m in the mountain regions. After this data acquisition, the DTMs and Digital Surface Models (DSMs) were created and these ASCII grids were used by the archaeologists of the APSAT programme. Unfortunately, the mapping and digitising of these structures were not viable only with the hillshade method since the result of this visualisation technique always depends on the position of the illumination source and therefore some features can be hidden (Devereux, Amable, Crow 2008). On the other hand, the regular forms of buildings remains could be successfully detected by the slope analysis of DTMs in ArcGIS. The visualisation of raster's slope values provided an efficient way to discover settlement structures, like walls and roads, because the outline of these objects was completely indicated by the systematic elevation changes of the surface.

3.4 *Specification of other relevant DTM visualisation methods in GIS environment*

The geomorphological patterns can also be mapped by the aspect calculation in GIS environment as the slope direction can provide significant information about some characteristics of the surface. The linear artificial objects covered by soil, for instance wall ruins, can be efficiently visualised by this technique. The main direction changes along the wall can be specified by the various colours of the aspect map. Furthermore, the hydrological modelling helps to investigate geomorphological properties as well. The calculation of flow direction and accumulation offers other methods to analyse the surface, for example, the determination of local watershed can describe morphological edges in small area. In addition, ancient rivers and stream networks can also be identified by the hydrological investigation (Wheatley, Gillings 2002). Calculation of different aspects and hydrological modelling are planned to be applied for future works.

4. Data interpretation in archaeology

4.1 *LiDAR derived models for archaeological interpretation: hill-shading model and slope model*

Surface analysis through LiDAR aims at recognising objects under the vegetation, which could indicate ancient human activities. The DTM resulted by the filtering process shows «a detailed map of the topography with even fain archaeological structures under the forest canopy» (Doneus, Briese 2006). One of the most important airborne LiDAR derived models for archaeological interpretation is the hill-shading model, which simulates the effect of an artificial sun illumination over the terrain. This method uses the properties of altitude (the height above the horizon from which a light source illuminates a surface) and azimuth (the sun's relative position along the horizon) to specify the sun's position. For example, the application of

Archaeological features
Banks
Ditches
Barrows
Trackways Route-ways
Field divisions Drainage channels
Remains of buried or upstanding walls
Pits
Artificial ramparts

Tab. 1 – Common classes of archaeological features.

different altitude and azimuth values provides various hillshade maps at the Romeno-Doss Busen site in the Val di Non area (Fig. 5). On the other hand, some features could be hidden by the utilisation of a single light source (Devereux, Amable, Crow 2008). Consequently, the Mitterberg mining region was visualised by the blending of various hillshade results in the HiMAT project. The positions and structures of the mining extractions were determined by this blending method (Hanke *et al.* 2009; Kovacs, Moser, Hanke 2010).

The visualisation technique by slope analysis can also be applied during the airborne LiDAR based archaeological prospection, which calculates the maximum rate of change in elevation between the raster cell and its neighbours. Different colour ramps (each colour indicates a precise value of slope degree) allow us to recognise steep from flat objects (Challis, Forlin, Kincey 2011). The utilisation of slope analysis at the archaeological site of Romeno-Doss Busen helped us to identify unknown regular depressions along a central road on the hilltop. For example, square features, characterised by steep sides and flat bottom were documented in this case. These objects are probably related to the presence of buildings covered by the soil (Fig. 6, Tav. VII, b).

4.2 *Limits and results of archaeological interpretation*

The exact determination of parameters values in terms of hillshade and slope analysis makes archaeological prospection less difficult (Crutchley, Crow 2009). Furthermore, it is necessary to define forms and extents of features: a regular object is usually an artificial object, but not necessary an archaeological one. We can assign very different types of archaeological features to the main classes of banks and ditches (Tab. 1, Musson, Whimster 1991; Crow 2008; Doneus *et al.* 2008). Unfortunately, airborne LiDAR cannot differentiate between archaeological features and modern features like buildings, roads and infrastructures, forest residue and timber stacks, modern extracting activities, which have sometimes a similar appearance. For this reason, it is important to recognise these modern objects and exclude them in archaeological interpretation (Crow 2008; Crutchley, Crow 2009; Doneus, Briese 2010). Therefore, analysis of airborne LiDAR images must consider other types of information as well, e.g. documentation by terrestrial laser scanner and Total Station, aerial photos, modern and historical maps, archaeological information, historical documents, on-site examination of earthworks.

On-site examination allows the observation of the presence of the structures. However, the survey of archaeological features with GPS, Total Station or terrestrial laserscanner provides the best solution during the documenta-

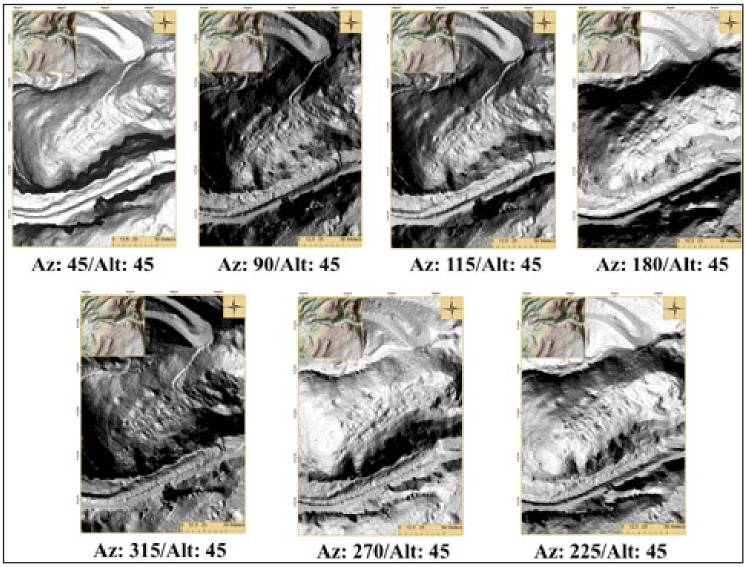

Fig. 5 – Romeno-Doss Busen: different illumination effects in LiDAR derived model (az = azimuth, alt = altitude).

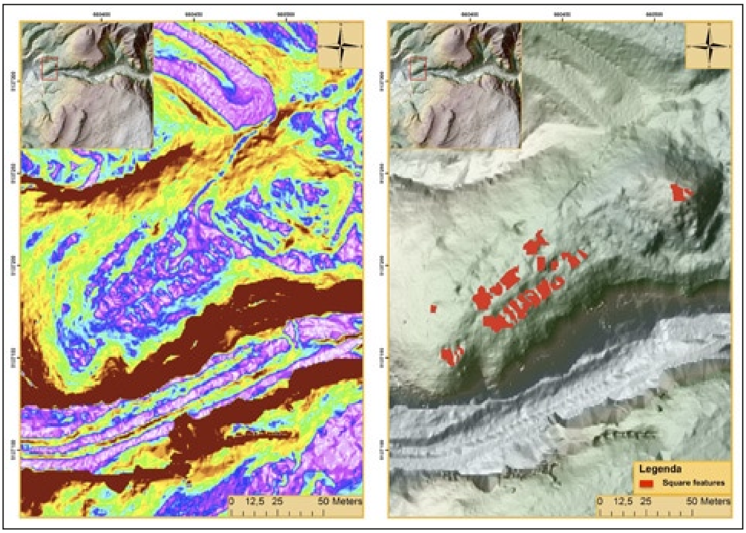

Fig. 6 – Romeno-Doss Busen: slope model and the map of the main archaeological features.

tion process (Doneus *et al*. 2008). Fieldwork on the hilltop of the Romeno-Doss Busen site has helped to clarify the origin of the regular depressions. Some regular ditches were identified during this on-site investigation. The discovered walls were constructed by irregular stone blocks with mortar. No archaeological excavations were carried out at this site, however it may be possible to interpret this as a medieval castle, built in Sanzeno's area and not yet identified with certainty (*dossum unum qui appellatur Tamaçol(us), in partibus Ananie, in plebatu de Sancto Sisinnio … prefati domini fecerunt ex eo dosso cum toto territorio ad eum pertinentem quatuor colonellos, … quod dominus episcopus debet in ilo edificare et facere palacium et turrim*; 1211: *Codex Wangianus*, n. 122).

Airborne LiDAR documentation helped us not only to discover the new site of Romeno-Doss Busen, but also to identify some new structures in the well-known sites. Another study area in the Val di Non is the Vervò Castelaz, which is located at Vervò, not far from the medieval church of St. Martino. Different archaeological finds (from Bronze Age to Early Medieval Age) of Vervò Castelaz were discovered by old agricultural activities; unfortunately, there are no evident remains of walls (Campi 1891-1892; Roberti 1952; Gottardi 1963; Amante Simoni 1984). On the other hand, airborne LiDAR maps have shown a defence wall located on the North side of the hill (Fig. 7, Tav. VIII, a). This could be part of a massive wall, made out of irregular dry-stone blocks, discovered and quickly destroyed by the contruction of a road leading to a modern cemetery (Gottardi 1963).

The other investigated site in the Val di Non area is the Cagnò Castle, which is located on a hill surrounded by St. Giustina Lake. This castle was built before the end of the 13th century (Morizzo, Reich 1907-1915). A map of the Austrian painter and architect Jörg Kölderer (1526) pictures this fortress in the 16th century: two different blocks surrounded by a defensive wall (Fig. 8, Tav. VIII, b). The North block includes the gate and two buildings. Furthermore in the South block, an inner court is enclosed by various buildings, like the *palas*, tower and additional constructions; the round cistern was located West to the castle (Trapp 1961). The two main blocks (N: 20×15; S: 30×20 m) with walls were identified by LiDAR analysis. At present, visible remains of only three different buildings are documented in the South and in Western areas of the fortress.

Airborne LiDAR analysis helped us to map the well-known Austrian mining regions as well. The combination of terrestrial and airborne surveys indicated various mining forms, like a mine entrance in Mauken area. The previous mining activities of the Mitterberg region, like large holes and mining depressions, could also be effectively visualised based on the LiDAR documentation (Kovacs, Moser, Hanke 2010).

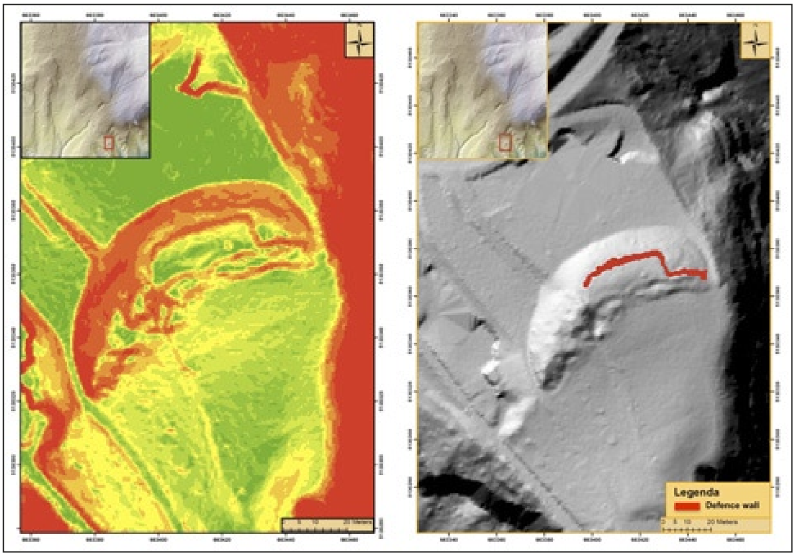

Fig. 7 – Vervò-Castelaz: slope model and the map of the main archaeological features.

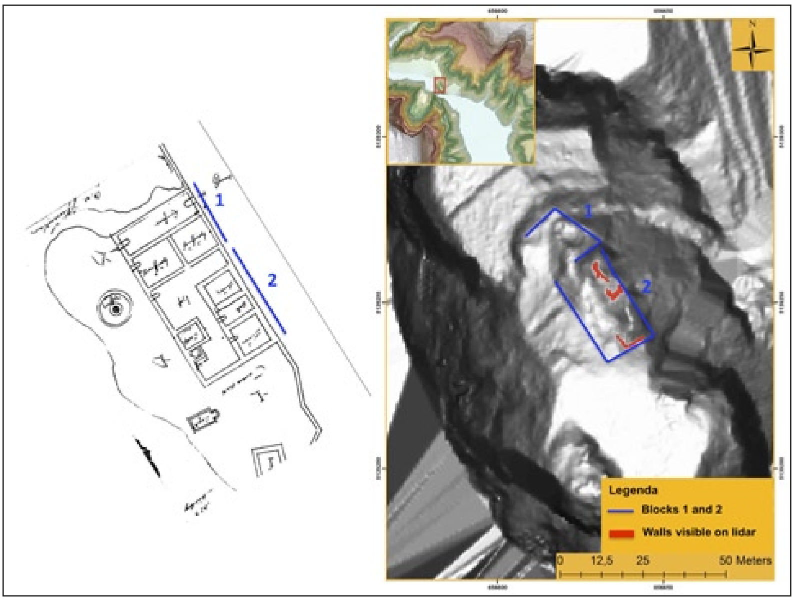

Fig. 8 – Cagnò Castle: map of Jörg Kölderer and map of the main archaeological features.

5. Discussion and conclusion

The airborne LiDAR technology offers several unique research opportunities in the field of archaeological prospection. Three different application methods of airborne laser scanning datasets were applied in the HiMAT and APSAT projects during the last years. The archaeological prospection of hilltop settlements was carried out by slope analysis of governmental LiDAR surveys in the Val di Non area. During the APSAT programme, the remains of unknown buildings could be identified at the Romeno-Doss Busen site and different new structures, e. g. walls, could be documented at the well-known Vervò Castelaz and Cagnò Castle sites in Italy. The second technique was the visualisation of the effects of previous mining works by blending of various hillshade models at a large region. A special high resolution LiDAR survey was utilised to investigate the significant geomorphological characteristics of the Mitterberg mining region in Austria.

In addition, the mapping of the small-sized relief changes could be accomplished only by the combination of airborne, terrestrial laser scanning and Total Station measurements. In this third method, the small mining sites, like Mauken E and Mauken F were documented by the fusion of additional datasets in GIS environment. For example, the exact position of break lines, like roads and edges of mining holes, was surveyed by the high resolution Total Station measurements, since the governmental LiDAR datasets offered only 1 point/m^2 spatial resolution. Furthermore, the results and maps of these three different application methods were visualised and compared with additional information including historical maps and ground-based measurements in GIS environment. Besides, on-site examinations were always required during the archaeological prospection, because the airborne LiDAR documentations could provide incorrect archaeological interpretations as well.

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ABSTRACT

The utilisation of airborne laser scanning (Light Detection And Ranging, LiDAR) technology in archaeological research has developed significantly in recent years. The application of specific algorithms to appropriate software can provide an accurate digital model of the Earth's surface from LiDAR datasets, which helps to identify archaeological objects by the use and comparison of different visualisation techniques of the digital terrain model (DTM). Besides using LiDAR data, the application of various methods (e.g. documentation by terrestrial laser scanner and Total Station, aerial photographs, modern and historical maps, archaeological information, historical documents, on-site examination of earthwork features) helps to assure a more precise identification and interpretation process of the archaeological features. In addition, the Geographical Information System (GIS) offers a good solution for managing together all these various types of information in the same coordinate system. In this paper, the application of LiDAR analysis in GIS environment will be discussed and compared in two different research programmes. The HiMAT programme (History of Mining Activities in the Tyrol and adjacent areas) investigates the history of mining in the Eastern Alps and the APSAT project (Environment and Landscapes of Upland Sites of Trentino) focuses on the study of the upland anthropic system in Trentino area. In both research projects, LiDAR surveys were applied to investigate the archaeological areas such as mining regions and hilltop sites of upland areas. Some of the results from the sites surveyed by LiDAR and additional methods are presented in this paper including the discovery of new sites and the detection of new structures at known sites as well as the mapping of archaeological settings.