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DISCOVERING TERRACED AREAS IN SLOVENIA: RELIABLE DETECTION WITH LIDAR

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ABSTRACT

LIDAR data offer an unprecedented accurate new interpretation tool for detecting terraced landscapes. The boundaries of terraced areas in Slovenia cannot be clearly defined without the help of a field survey even when the configuration of the terrain makes surveys difficult. The segmentation of point cloud data into various classes of foliage, ground, buildings, and so on makes previously hidden earthwork structures (including abandoned terraces) instantly recognizable. The conceptual shift is that the LIDAR slope analysis layer is more revealing and instructive for discovering terraces areas than orthophoto images ever were. Although LIDAR data are a new tool in the search for terraced areas, orthophotos remain important but are nevertheless only a contextual aid. A quantitative comparison between the old and new methods shows no difference in three pilot areas, shows only a minor difference in two cases, and reveals major differences in three pilot areas. The quantitative differences in some of the pilot areas are compelling. However, the most significant feature of the new method is its reliability for detecting the exact boundaries of terraced areas.

Keywords: terraced areas, terraces, LIDAR, digital terrain model, Slovenia

LOCALIZZAZIONE DI AREE TERRAZZATE IN SLOVENIA: RILEVAMENTO ATTENDIBILE CON IL LIDAR

SINTESI

I dati prodotti con la tecnologia LIDAR si presentano come un preciso strumento interpretativo, nuovo e senza precedenti nella localizzazione di paesaggi terrazzati. In Slovenia, l'identificazione dei confini di aree terrazzate richiede sistematicamente l'aiuto di indagini sul campo, anche quando la configurazione del terreno rende tali indagini difficili. Con la segmentazione dei dati a nuvola di punti nelle categorie del fogliame, suolo, edifici ecc. le strutture di terrapieno precedentemente nascoste (incluso terrazze abbandonate) risultano subito riconoscibili. L'innovazione concettuale del LIDAR sta nel fatto che il suo livello delle analisi di pendenze è più rivelatore e informativo per la localizzazione di terrazze di quanto non lo siano mai state le immagini ortofoto. Ciò non toglie che le ortofoto rimangono un aiuto importante nella ricerca di aree terrazzate, anche se meramente contestuale. In tre delle aree pilota in cui sono stati eseguiti i rilevamenti, i risultati non hanno evidenziato nessuna differenza quantitativa tra il vecchio e il nuovo metodo, in due aree si è osservata una minima divergenza, mentre in tre aree pilota le differenze sono state notevoli, in alcuni casi straordinarie. Comunque, la funzionalità distintiva del nuovo metodo sta nell'attendibilità della localizzazione dei precisi confini di aree terrazzate.

Parole chiave: aree terrazzate, terrazze, LIDAR, modello digitale del terreno, Slovenia

INTRODUCTION

In recent years, growing local and international attention to terraced systems has stimulated the demand for GIS to map the size and distribution of terraces (Varotto, 2014, 295). Research on terraced areas is also gaining momentum in Slovenia. A crucial year in terrace research was 2005, with the start of the transnational EU project INTERREG IIIB, titled Terraced Landscapes in the Alpine Arc (or ALPTER). The Slovenian partner was the University of Ljubljana's Faculty of Architecture.

The research project contributed to the comprehensive development of various methods for cataloging and studying terraced areas. Some of the partners were already using advanced methods of cataloging and analyzing terraced areas. For studying countermeasures against erosion and terrace collapses in Italy's Brenta Valley, the researchers used a point cloud, which they obtained from LIDAR data (Nimfo, 2008) as early as 2002. At the time, this was an advanced technique for gathering data. The researchers had to deal with data interpretation, high equipment costs, time-consuming computations, and undeveloped algorithms for cleaning the point cloud. The data were acquired in an area where the terraces are partially abandoned but still very recognizable in the landscape because of the dry-wall construction that defines them. The final digital elevation plan is a clear and precisely drawn map that shows the geometry of the terraces in the pilot area. This confirmed the technology's ability and advantages for studying terraced areas.

"LIDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system— generate precise, three-dimensional information about the shape of the Earth and its surface characteristics. A LIDAR instrument principally consists of a laser, a scanner, and a specialized GPS receiver. When an airborne laser is pointed at a targeted area on the ground, the beam of light is reflected by the surface it encounters. A sensor records this reflected light to measure a range. When laser ranges are combined with position and orientation data generated from integrated GPS and Inertial Measurement Unit systems, scan angles, and calibration data, the result is a dense, detail-rich group of elevation points, called a "point cloud." Each point in the point cloud has three-dimensional spatial coordinates (latitude, longitude, and height) that correspond to a particular point on the Earth's surface from which a laser pulse was reflected. The point clouds are used to generate other geospatial products, such as digital elevation models, canopy models, building models, and contours. Two types of LIDAR are topographic and bathymetric. Topographic LIDAR typically uses a near-infrared laser to map the land, while bathymetric lidar uses water-penetrating green light to also measure seafloor and riverbed elevations" (Internet 4).

The publication *Terraced Landscapes of the Alps: Atlas, Alpter Project* (Scaramellini, Varotto, 2008) included the paper "Mapping and Geological Classification of Terraced Landscapes: Problems and Proposals" (Varotto, Ferrarese, 2008), in which the authors sought to introduce a new term: *terracing size index*. In the study, the researchers cite a previous classification of terraced areas by size (Scramellini, 2005). Scramellini divided terraced landscape into the following ranges: 1) micro-terraced landscapes (0–0.33 hectares), 2) mezzo-terraced landscapes (0.33–0.66 hectares), and 3) macro-terraced landscapes (0.66–1 hectares). On this basis, Varotto and Ferrares created an additional classification of the intensity of terraced landscapes based on the relation to drywall per hectare, and they obtained the following classes: low intensity (5–200 m/ha), medium intensity (200–800 m/ha), and high intensity (> 800 m/ha). The authors concluded that this research has a number of limitations. The first and the most significant limitation is that this classification method works only with areas already catalogued and is prone to oversimplification of results. It also focuses exclusively on terraces with drywall construction. Moreover, it does not take into consideration terraces made of earth and it does not take into account the sizes of terrace surfaces.

One of the most important results of the ALPTER project is the design of a platform for a content-based database of catalogued terraced areas. The database was devised in such a way that contributions would be part of a private-public partnership with a detailed structure. It works at two levels. The first level (the Datasheet for Analysis of Terraced Areas) is meant to accommodate large areas and has a larger territorial scale of 1:25,000. The second level is at a more detailed 1:5,000 scale. A number of different criteria are introduced: location, historical data, land use, the structure of terraced areas, and several others.

The data prepared in this way were also part of the publication *Terraced Landscapes of the Alps: Atlas: Alpter project* (Scaramellini, Varotto, 2008). The structure of the database was ambitiously set. In its complete form, it is complex and therefore intended for research purposes. Only its most basic parts are intended for gathering data through public participation. The most important part of this data gathering is defining the exact borders of terraced areas. The basic underlay for visual definition through a web interface is aerial images. These are flat and do not contain any elevation data, and so they are prone to the interpretation of the individual participant in the survey. The exact borders of terraced areas based on orthophoto images can then be anyone's guess.

For the scientific study of terraced areas, exact and systematic data input is essential. The team from the University of Ljubljana surveyed terraced areas in the

Municipality of Brda, which has an area of 72 km², from 2006 to 2008. The area is composed of fifteen cadastral units further divided into forty-five settlements. This was the first time that the researchers processed data with such content in such a wide region in Slovenia. Unlike today, GIS technologies and the techniques for gathering and processing large amounts of spatial data were relatively unknown. The base layers were inconsistent and therefore a field survey was required. The most important underlay was a grayscale Ortofoto image: a series of geometrically corrected aerial images with a resolution of 0.5 m by 0.5 m. During the project, a color orthophoto became available and was used to complete the project.

The extent of the municipality consisted of thirty-four geo-positioned orthophoto images at a scale of 1:5,000, each covering an area of 2.25 km by 3 km. With this data as the main underlay, the first digital vector layer of potential terraced areas was defined. The chosen area is intensely agriculturally developed, consisting mostly of vineyards, orchards, and olive groves, creating a uniform landscape pattern. The basic orthophoto layer does not provide all of the data needed to accurately determine the boundaries of the terraces. Because of the lack of precise elevation data, the new layer of potential terraced areas needed to be verified through fieldwork. The terrain configuration and intensity of agricultural production made almost all of the terraced areas in the southern and central part of the municipality easily discernible and readily accessible. The northern part of the municipality was more challenging due to its dynamic terrain profile being less agriculturally developed and less easily accessible. Most of the terrain of the municipality consists of hills covered in terraces; the rare flat areas contain vineyards without terraces. Fieldwork confirmed or rejected the interpreted boundaries in the draft layer. In the end, this process resulted in a highly accurate representation of the extent of terraced areas in the municipality. The fieldwork turned out to be very time-consuming and took a team of four more than two years to complete. Although a variety of other GIS layers were collected, none were used for determining terraced areas.

The first World Conference on Terraced Landscapes took place in Honghe, Yunnan (China) in 2010, at which the Honghe declaration on the protection and development of terraces was signed. At the same time, the ITLA (International Terraced Landscapes Alliance) umbrella organization was established (Ažman Momirski, Kladnik, 2015), which gathers together all researchers and activists interested in cooperating to protect, study, and develop terraced areas globally. The second World Conference on Terraced Landscapes took place in Peru in 2014. At the conference, Mario Varotto presented the study "From GIS to Participatory GIS for Trans-Local Cooperation: The Terraces Project for Mapping, Shar-

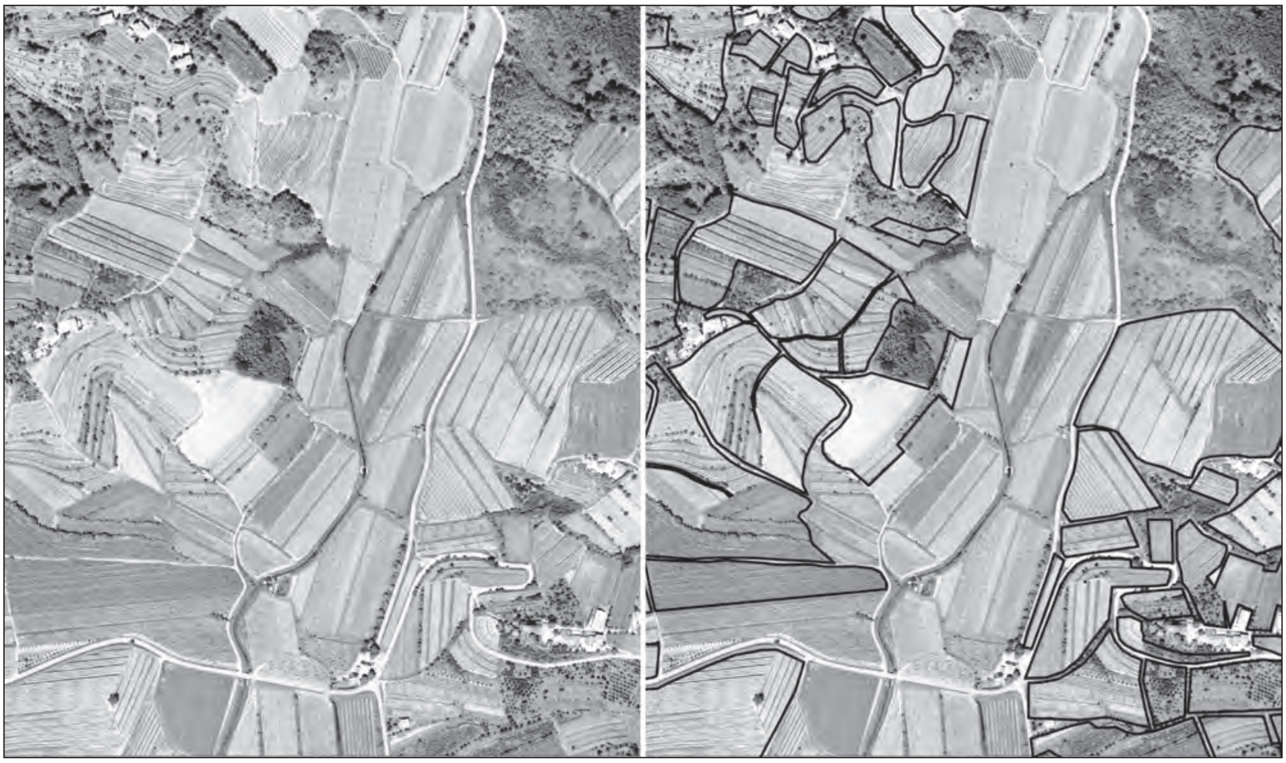

Figure 1: Orthophoto image with terraced landscape boundary in the Municipality of Brda (2008). The uniform landscape pattern does not indicate which areas are flat and which are terraced.

ing, and Sustaining Terraced Landscapes." The activity is considered an improvement and implementation of the project results of the ALPTER-based development platform for recording terraced areas. As Varotto states, the platform is the first P-GIS (Participatory Geographic Information System) platform of this kind. It aims to form trans-local connections and will initially be introduced as a trial in Italy under the Italian ITLA. After the initial local implementation, the authors are seeking global support. It is a social network of terraced landscapes and it is striving to attract all owners of terraced areas to create their own profile, enroll, and input their data. In this way, terraced areas can be enriched with various content to obtain information for local authorities, agricultural agencies, universities, tourism, and shops. Public participation in the database should be limited only to the substantive component because it turns out that, due to the influence of many factors, the exact boundaries of terraced areas cannot be determined without a predetermined method. Even the content is problematic in terms of privacy. Another issue for these databases is who will monitor the public data entered to ensure that it is precise.

A reasonable step would be for the terraced landscape attribute to become a constant in the land-use database. This would truly be a significant step forward because it offers an additional perspective on influences that it has on the surrounding landscape, such as erosion, food production, and tourism.

After the ALPTER project, knowledge expanded and various technology became more widely used for analyzing, identifying, and cataloging terraced areas. LIDAR technology in particular became widely available and widely used. "Developed just a few years ago, LIDAR

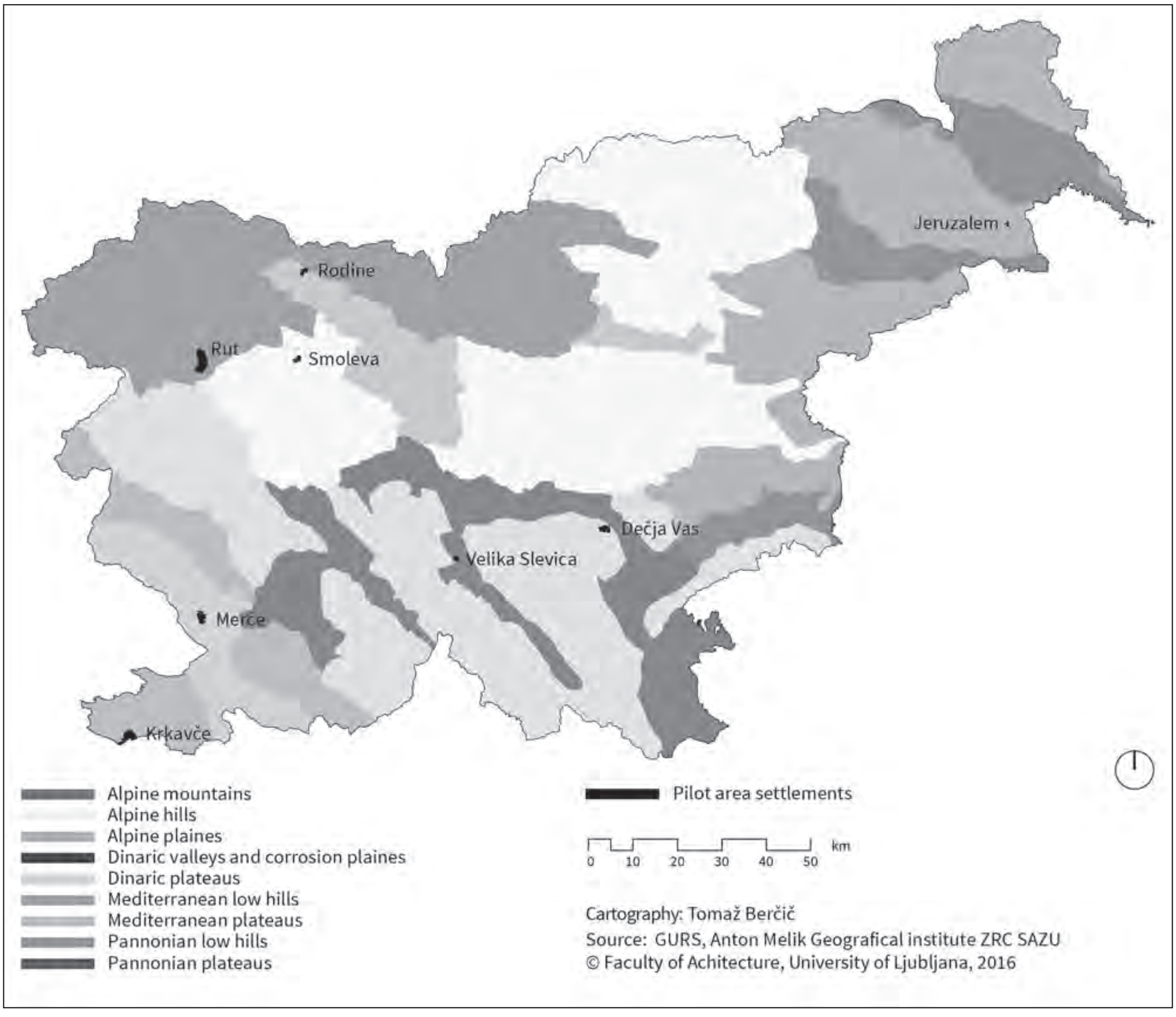

Figure 2: Slovenian territory divided into nine natural landscape types with names of selected pilot settlements.

technology has aroused great interest among those involved in the study or management of the territory" (Ninfo, 2008, 28). The density of the data gathered and used by Italian researchers in 2002 was from one to 1.5 points per square meter. Along with relatively weak data, these researchers also had difficulty with problems of pure processing ability and underutilized algorithms for cleaning the point cloud data. In the meantime, the technology matured in both aspects. In 2011, Slovenian government agencies commissioned the laser scanning of the country's territory with a resolution between two and ten points per square meter. However, this was only a dry run because only a few areas were processed and available for research purposes in the southwest Mediterranean part of Slovenia and in the northeast, near Maribor. In cooperation with the Ministry of the Environment and Spatial Planning, the Slovenian Environment Agency commissioned LIDAR data for the entire territory of Slovenia and publicly released this information for public use in 2015 (Internet 1). For capturing LIDAR data, the latest technology was used, which is able to capture up to twenty-four points per square meter. "The state of the art of airborne laser scanning (ALS) used along with LIDAR (light detection and ranging) is known by the speed of gathering data, high accuracy and high resolution. This method brought a real revolution in the field of a topographical survey" (Mongus et al., 2013, 245).

As with any project, the input data are extremely important and must be accurate to achieve the highest quality and best results possible. The basis of research for all projects connected with terraced areas involves inventorying terraced areas in the field. There is a common method that is used but has some drawbacks that can significantly reduce the quality of the data needed for studying terraced landscapes. The new method described here addresses these drawbacks and offers a new workflow for reliably detecting terraced areas. What is interesting are the quantitative differences of results when following the new and the old methods and the scope of difference between them.

METHODOLOGY

The University of Ljubljana's Faculty of Architecture was a project partner in the Slovenian research project Terraced Landscapes in Slovenia as Cultural Values between 2011 and 2014. The survey included the entire territory of the country, or 20,273 km², consisting of 2,716 cadastral units and 6,031 settlements. One of the university team's accomplishments was a comprehensive GIS analysis of the selected pilot areas.

After 2014, the Faculty of Architecture continued its own research, based on the conclusion that the photo interpretation model works in combination with a field survey to convey reliable results, but has one major weakness. The procedure offers no data making it possible to recognize abandoned terraced areas. Generating accurate results requires a great deal of time and labor. The goal was to improve on the existing method for defining terraced areas, which will offer improved accuracy, less fieldwork, and a shorter timeframe for acquiring a greater amount of data.

Among the nine natural landscape type in Slovenia, we searched for suitable areas that contain terraced areas. Among a number of candidates for each natural landscape type, the suitable pilot areas in the form of settlements were selected for analysis (Figure 2).

Definitions

Definition of a terrace

A terrace is a natural or artificial flat or slightly inclined flat surface cut into a slope with a constant incline. "A cultivated agricultural terrace is a more or less flat surface that people carved into a steep slope to obtain arable land or increase its extent, aid or intensify agricultural production, alleviate soil erosion, increase soil moisture, and in some cases make gravitational irrigation possible. A terrace is composed of two basic elements: the terrace surface and terrace slope. The width of the terrace surface depends on the slope inclination, crops grown, and land cultivation" (Ažman Momirski, 2008). Instead of a terrace slope, the soil can be also held back with a wall.

Definition of a terraced area

The terraced areas in this context are cultural terraces intended for agricultural production. Terraced areas may also be used for building purposes or be part of road other transport networks, anti-erosion measures, various infrastructure purposes, or a combination of multiple purposes. The terraced areas are landscapes in which a distinctive uniform pattern of two or more terrace surfaces are present. The terrace surfaces are divided by a slope or wall. Terraced areas can be comprised of active or inactive terraces, or a combination of both, and have a clear boundary.

Defining the boundary of a terraced area

The terraced areas on a detailed 3D grayscale representation of the surface are not difficult to recognize. The difficult part is when the boundaries of the terraces must actually be drawn and the borders must be defined. The flat terrace surfaces and the slopes or walls of the terraces follow the terrain contours. Each terrace has a lower and an upper boundary that follows the terrain contours. The terraced area has two additional borders at the narrow ends of the terrace that connect the ends of the upper and lower border of the terrace.

Defining the highest point of the terraced area

The first task is to define the general direction of the terrain with the elevation extremes of the terrain. The first terrace at the top starts with the beginning of the flat

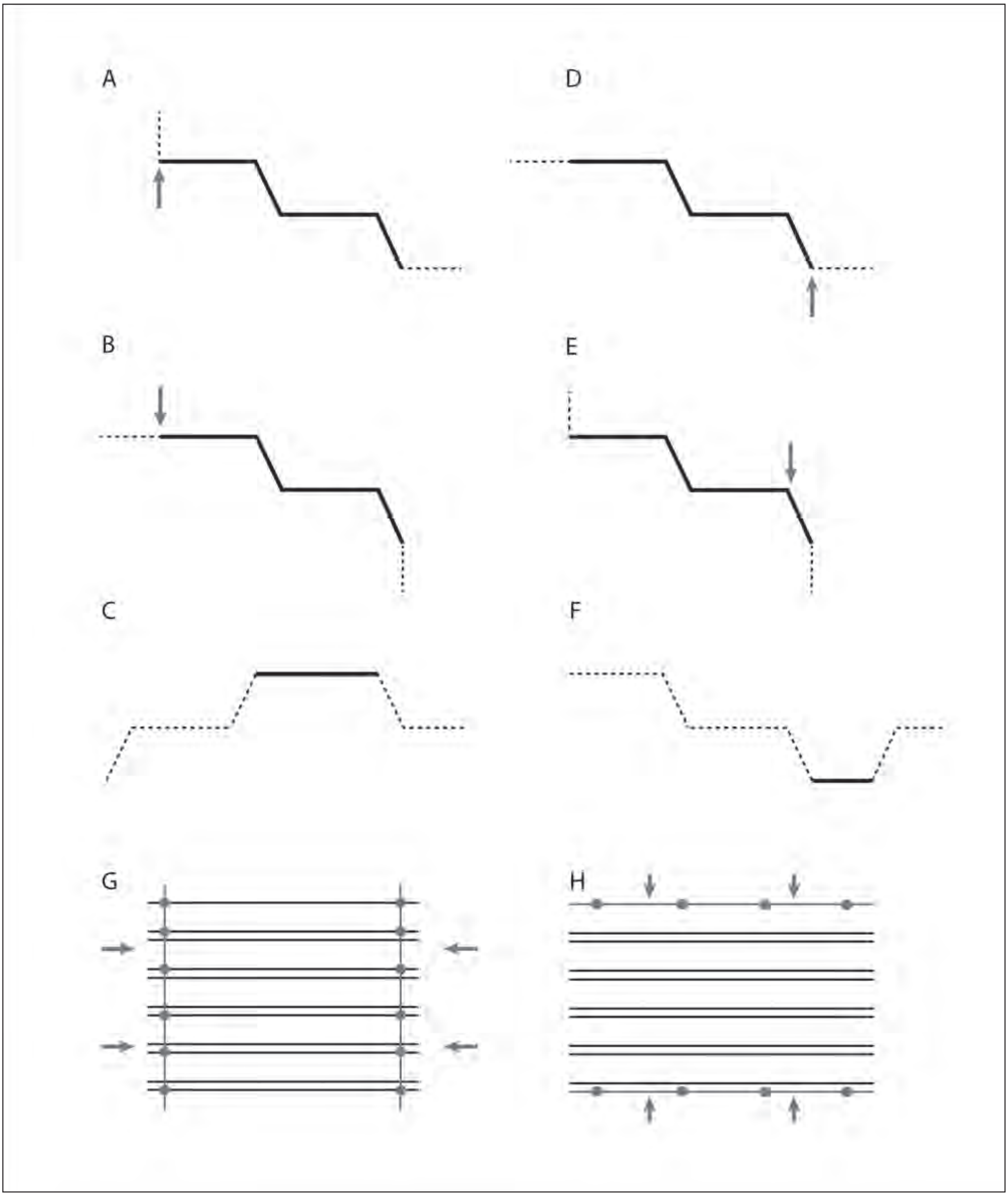

Figure 3: Schematic drawings determining the borders of a terraced area. A) Start of the boundary of the terraced area when the terrain rises above the terraces, B) Defining the boundary when the terrain is flat at the top, C) Situation when everything around the top is terraced landscape, D) Defining boundary at the bottom when the terrain becomes flat, E) Defining bottom boundary when the terrain recedes beyond the terraced area, F) Everything above the bottom is terraced landscape, G) Finding the points that determine the boundaries left and right, H) Defining the top and bottom boundaries.

part of the terrace. There are generally three possible scenarios. If one takes a terraced area as a whole, it is necessary to determine what happens beyond the highest point of the area. The terrain may continue upwards, the terrain may become flat, or the terrain may descend in the opposite direction. If the terrain continues upwards, which is the most common situation, the start of the terraced area is at the base of the incline. With all the other situations, the land-use must be taken into account to determine the bounds of the terraced area. If terrain descends and there are no terraces on the downward slope and the entire flat of the area is agriculturally cultivated, the boundary is on the threshold between the flat surface and downward slope. If the flat part is not completely cultivated, the boundary is at the end of a cultivated area. To determine the bottom edge of the terraced area, the procedure is similar. If the terrain ends in a flat area (which is most common), the end of the terraced area is at the base of the last terrace slope or wall. If the terrain continues downwards but there is no more visible terracing, the terrace ends at the end of the flat part of the terrace just before it continues downward.

In some cases, a field survey is still necessary, but it is not always the most reliable. Sometimes, especially with dynamic terrain with low inclinations, lush foliage, and stone piles between the plots, appearances can be deceiving. The photo interpretation method is still a reliable way of determining terraced areas, but it is time-consuming, difficult in bad weather conditions, and even dangerous in steep rocky terrain.

Digital data sources

DOF050 orthophoto images are the primary underlay and are a collection of georeferenced images available through the Surveying and Mapping Authority of the Republic of Slovenia (Digitalni ortofoto posnetki 5×5m, 2011–2015**)**. The raster data resolution cell size is 0.5 m. For some areas, a greater resolution was available with a cell size of 0.25 m, but this was not used because of the sheer scope of the data. The raster data is geometrically ortho-corrected so that the scale is uniform throughout the image and is thus like a map. The layer is the base layer for making a base photointerpretation map of terraced areas.

The digital elevation model (DEM5) has a resolution of 5 m and a height accuracy of 1 m in open areas and 3 m on overgrown and mountain areas. The layer cannot be directly used for recognizing terraced areas because is too coarse. The point cloud is too dispersed and the terraced features are too small to be recognized in the layer. The planar accuracy is too unrefined and too interpolated. The terrace dimensions are below the physical level of recognition. DEM5 is an important analytical tool for representing and interpreting the elevation maps of larger landscapes of cadastral units, settlements, and other localities (spatial administrative units) with a scale larger than 1:5,000.

Land use is a digital database available through a webpage (Internet 2) of the Ministry of Agriculture, Forestry, and Food and is a detailed database with frequent updates, also offering a comprehensive look at changes in land use through time. The data format is polygons and these are photo-interpreted through a comprehensive set of rules over the natural boundaries as seen on the orthophoto images and in fieldwork. The land use is regularly updated and has a well-defined key (Interpretacijski ključ, 2013) and structured attributes (Podatki o dejanski rabi tal, 2015).

The data for current land use are defined by:

- A computer-supported photo interpretation method for orthophoto images;
- The use of other records, which allow significant improvement of current land-use data;
- Field surveys and measurements.

The smallest area considered for uniform agricultural land use is 1,000 m². Exceptions include vineyards (500 m²), olive groves (500 m²), plant nurseries (500 m²), other permanent groves (500 m²), other permanent crops (500 m²), greenhouses (250 m²), agricultural land located within the built-up area, and similar land and forest areas larger than 5,000 m². The polygons may be even smaller, especially if they are part of the Registers of Agricultural Holdings. Land-use polygons are defined by natural boundaries as seen on orthophoto images or on the basis of fieldwork where available or required. The types of land use are defined in the Regulation of Current Land-Use Records of Agricultural and Woodland Plots. From the “arable land and gardens,” “permanent crops,” and “grassland,” we eliminated all plots that fit under “build-up land” or “water” and are larger than 25 m². We also eliminated all plots larger than 100 m² that fit under “other agricultural land,” “forest,” and “other non-agricultural land,” as well as all transport infrastructure wider than 2 m, unless defined differently in a detailed instructions guide for defining each type of land use.

The “permanent crops on arable land” (ID no. 1180), “other permanent groves” (ID no. 1240), “plantations of forest trees” (ID no. 1420), and “forest tree nurseries” (ID no. 1212) are more difficult to determine on the basis of orthophoto interpretation, and this is why we used the data from the Registers of Agricultural Holdings and the field survey. In the case of mixed land use with “permanent groves” (e.g., olives and fruit trees) the prevailing land use is set (Interpretation key, 2013).

It was seen that the land-use layer in combination with other data is an outstanding tool for defining the boundaries of active terraced areas. Unfortunately, abandoned terraced areas are indiscernible with this method, but they can be anticipated with a comparison between current and historical land-use analysis.

The Franciscan Cadaster, (Sheets AS-176, L/L175, AS-176, L/L45, AS-176, N/N214, AS-176, N/N93, AS-177, M/F/M476, AS-179, G/FJ/G131, AS-179, G/FJ/G64, AST-

179, I/FJ/I43) produced under Emperor Francis I, were used to analyze the historical land use of the pilot areas. The historical land use is important for defining and verifying potential locations of abandoned terraces. The accuracy of the historical data source is very good, but there are no data about the relief. The terraced areas are usually very well recognizable because of geometrization of the landscape and subsequent parcellation. The archive material of the Franciscan Cadaster is comprised of paper prints measuring 655 mm by 525 mm at a scale of 1:2,880. Most of them are digitized, but because of their age, various storage conditions, and various kinds of paper, they have stretched and contracted over time, becoming deformed. The separate sheets of paper were assembled into a larger mosaic of the cadastral units they represent, georeferenced, and then cropped to the size of the pilot areas.

The historical land-use correlation key is an adjustment and improvement of the table made by Franci Petek for the correlation between historical and current land use (Petek, 2008, 73).

LIDAR is point cloud data achieved through aerial laser scanning, and it has been provided for public use in raw and other refined formats, each intended for a specific use (Projekt 'Lasersko skeniranje in aerofotografiranje 2011' za določitev poplavnih območij, 2011). One of the most important end results of this kind of scanning is a DEM of the landscape in high resolution, which even surpasses the photogrammetrically derived DEM (Podobnikar, 2008). For the analysis, LIDAR DEM data were used, based on interpolated OTR points, transcribed in a grid measuring 1 m by 1 m available in an ASCII file. The LIDAR DTM (digital terrain model) used is twenty-five times more accurate than the DEM5 used in a previous analysis. The main advantage of LIDAR technology is that radar signals pass through the foliage and bounce off the ground. In this way, the overgrown terraced terrain features become visible. This is one of the most significant advancements in anthropological landscape study in recent times.

Workflow

This workflow was processed using ESRI ArcMap 10 software, but it can be recreated using any other available GIS analysis software tools. For the chosen pilot area, we prepared a digital file database consisting of available data. We started with an orthophoto image for reference and clipped it to the pilot area boundary. The orthophoto is overlaid with current land use, which is also clipped down to the particular boundary of interest. From the complete land-use layer, we removed all the attributes that correspond to "built up land" (ID code 3000) and "water" (ID code 7000). We also eliminated all plots that fit under "other agricultural land," "forest," and "other non-agricultural land", as well as all land use for which the numbers are greater than 1400 (except for 1600, which designates unused agricultural land). With this procedure, we obtained areas of disjointed clumps of polygons with a variety of land uses. A version was saved in a separate file for further reference. The copy of the modified land-use data layer was then merged to form a unified boundary of functioning agricultural land that contains a smaller domain of active terraces.

The next step was the use of LIDAR DEM data with a cell density of 1 m. This level of accuracy in the DEM is detailed enough that, when put through 3D Analyst tools in the Raster Surface subset and the slope analysis tool is used, the geometric pattern of terraces emerges. It is an essential interpretational tool that can accurately define the boundaries of terraced areas. When the interpreted layer with borders of terraces is clipped with the modified land-use layer from the previous step, a very accurate final layer of boundaries of active terraces is derived. The remainder of visible terraced pattern are overgrown inactive terraced surfaces. The final results of active terraces are checked against the orthophoto image to eliminate any possible lapse in data. The abandoned terrace layer is matched against the historic land-use layer derived from the Franciscan Cadaster.

Terrain analysis requires its own set of analysis. The first terrain analysis is the terrain aspect. The basis for this is 3D terrain elevation data in the form of point cloud coordinates, DEM, or LIDAR DEM data sets. For this we used the Raster Surface Aspect tool from the 3D Analyst tool subset. This tool requires an input raster and identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of –1 (ESRI Knowledge Base). It is an essential tool for defining terrain orientation, which is essential for various purposes such as agricultural production, biodiversity, environmental impact on building placement, and many others. The methodology for the particular analysis is a division into eight classes: north, northeast, east, southeast, south, southwest, west, and northwest. In addition to the four basic orientations, four more were added for a more meaningful result.

The most important analysis in this study is a terrain slope analysis. Slope represents the rate of change of elevation for each DEM cell. It is the first derivative of a DEM. For each cell, the Slope tool calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell.

The methodology developed for detecting flat and steep areas of the terraced landscape is such that the slope is divided into five classes or categories. The inclination can be calculated in degrees or output as per-

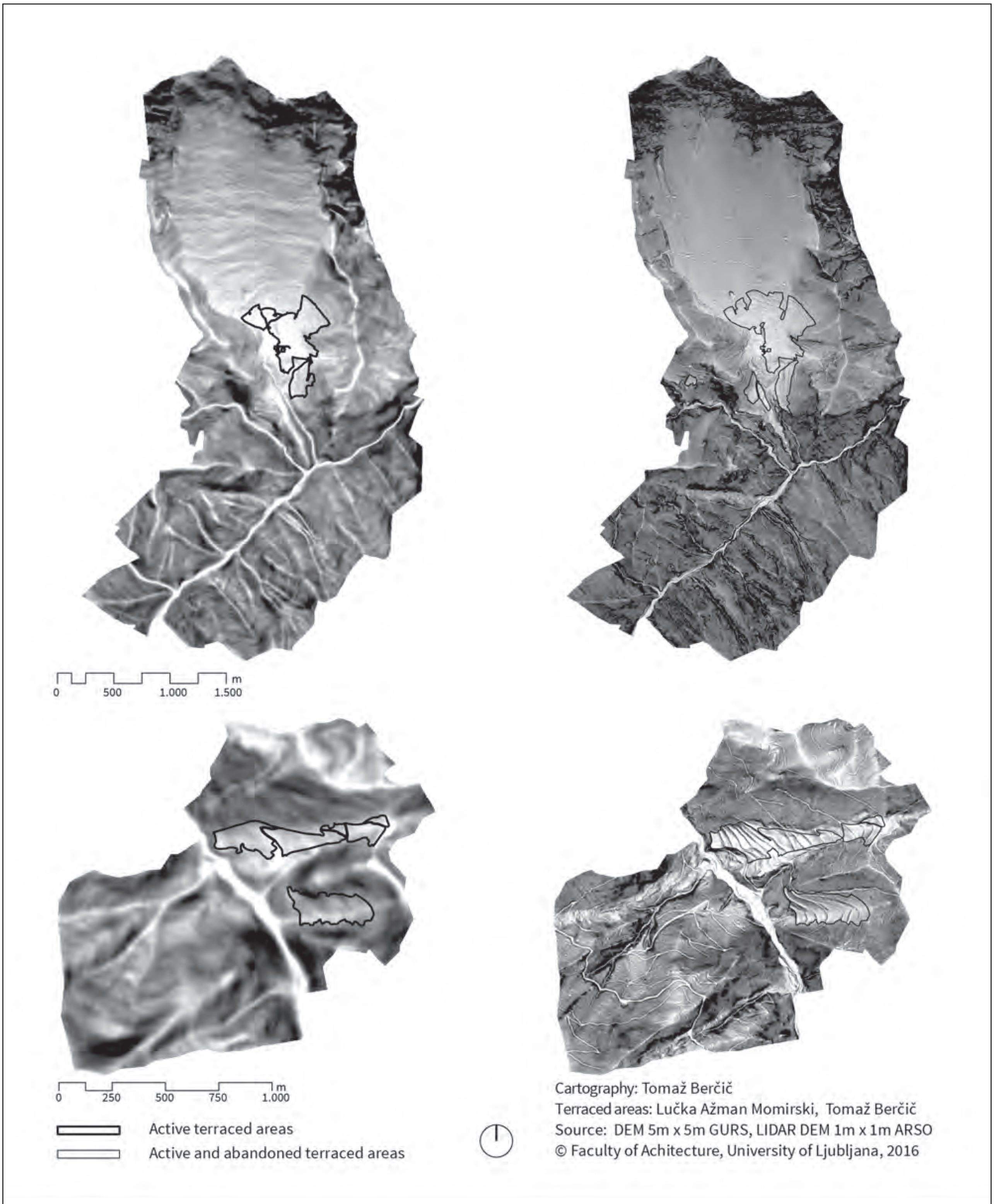

Figure 4: The top left image shows DEM5 slope data with an active terrace overlay for the settlement of Rut. The top right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area. The bottom left image shows the DEM5 slope data with an active terrace overlay for the settlement of Smoleva. The bottom right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area.

centage values. The first category ranges from 0 to 15% (0–8.5°), the second from 15 to 30% (8.5–16.7°), the third from 30 to 50% (16.7–26.6°), the fourth from 50 to 70% (26.6–35°), and the fifth is over 70% (35°). By default, the slope appears as a grayscale image. A colormap function can be added to specify a particular color scheme.

RESULTS

The first representative of Slovenian natural landscape types is the Alpine mountains, with the first pilot settlement chosen: Rut in the Bače Gorge. It is part of the Municipality of Tolmin. The settlement of Rut is a remote and poorly accessible village. It has a unique position on the southern side of Slovenian Julian Alps. Its area is the largest of the selected case studies, at 1,017 hectares, mainly on account of the mountainous terrain in the northern part. It is also the second-smallest by population, with a population of only forty-two (SURS, 2015). The lowest elevation in the settlement is 371 m and the highest is 1,967 m. The part of the village where the only cluster of the buildings is located is at 676 m. Around the cluster towards the north, east, and south in a fanlike pattern the terraces are spread out, with an average elevation of 695 m. The orientation of the settlement at first glance is predominantly southern, which the aspect analysis confirms. Southern orientations encompass more than half of the settlement's territory (SE 15%, S 28%, and SW 14%, plus NW 7%, N 4%, and NE 9%.) The impassable terrain to the north and on the edges of the settlement is represented in the slope analysis where terrain with a slope greater than 50% (45 degrees) consists of more than 80% of the area of the settlement. Gentle slopes are few (altogether 20%; first category 2%, second category 4%, and third category 13%). According to LIDAR analysis, terraced areas encompass thirty-six hectares, which is 5% of the settlement area. According to the old method of analysis carried out with DEM5, the terraced areas were fewer, or twenty-six hectares. The difference in values is the difference between active and abandoned terraced areas. The elevation extents of the terraced areas are 598 m at the lowest and 786 m at the highest. The orientation of the terraced areas is even more revealing. A northern orientation does not exist, and the southern orientations reach 81% of the total terraced areas (SE 17%, S 31%, and SW 33%). The slope analysis of the terraced areas shows that the majority of terraced areas are in the second category (51%; plus first category 15% and third 27%).

The settlement of Smoleva is representative of the Alpine hills. The settlement boundary is contained within the cadastral unit of Martinj Vrh in the Municipality of Železniki. The settlement consists of two oppositely oriented hillsides with Lower Smoleva Creek (Sln. *Prednja Smoleva*) separating them in the middle. For the settlement and agricultural land, the incline below Špik Hill (882 m) with a favorable orientation is utilized. The opposite-facing mountainside below Mount Vancovec (1,085 m) is entirely forested. The settlement area is 183 hectares and has a population of fifty-seven. The lowest elevation of the settlement is 484 m, and the highest is 1,080 m. The average elevation of the settlement is 719 m. The settlement has two clusters of buildings: one is in the valley, and the other is on the hill. Considering that the settlement consists of two opposing inclines, the orientation aspect is evenly distributed (NE 17%, E 12%, SE 10%, S 10%, SW 16%, W 8%, and NW 11%). Interestingly, the values of the average slope categories are the same as in the settlement of Rut, discussed above. However, the slope values of the terraced areas in Smoleva differ greatly. According to the LIDAR data, terraced areas comprise twelve hectares, which is 7% of the settlement's area. There is no difference between the LIDAR and DEM5 data. No abandoned terraces were detected. All terraced areas are active and in use. The minimum elevation of the terraced areas is 521 m, the maximum 779 m, and the average 633 m. There are no terraced areas oriented towards the north, northeast, east, and southeast. The majority of terraces are oriented toward the southwest (63%; others orientations are S 9%, W 20%, and NW 7%). Based on the slope of the terraced areas, they are all evenly distributed among the categories; the middle three slope categories contain 80% of all the terraced areas.

Rodine is a small settlement in the Municipality of Žirovnica. It is surrounded by three large urban areas in the Upper Carniola region: Bled, Žirovnica, and Begunje. Rodine belongs to natural landscape type of Alpine plains. They lie on the southern foot of Mount Begunščica and, like all Alpine localities, they have a distinct south and southwest orientation. The settlement size is 180 hectares and it has a population of 116 (SURS, 2015). The minimum elevation is 521 m, and the highest is 960 m, averaging around 960 m. The buildings are clustered in the western part of the settlement. The settlement landscape faces south (16%), southwest (42%), and west (20%). The slopes of the settlement, as part of the Alpine plains, are on the low side (first category 44%, second category 20%, third category 15%, fourth category 11%, and fifth category 10%). Eighty percent of the slopes fall into the first three categories under the 50% limit. There are twenty-four hectares of terraced landscape, which corresponds to 13% of the settlement area. The lowest elevation for the terraces is 533 m, and the highest is 590 m. The average elevation is 522 m. The terraces oriented toward the north, northeast, east, and southeast are insignificant in size. Sixty-nine percent of them face southwest, 17% south, and 11% due west. The terraced areas lie in the flat part of the settlement.

The settlement of Velika Slevica lies in the Municipality of Velike Lašče and is part of the Dinaric valleys and corrosion plains, according to the natural landscape types of Slovenia. It is located on a small mound with a predominantly southern orientation. The size of the settlement is 113 hectares, the lowest elevation is 522 m, the highest elevation is 655 m, and the average elevation is 585 m. The village has a population of fifty-seven (SURS, 2015). Based on the shape of the terrain, aspect

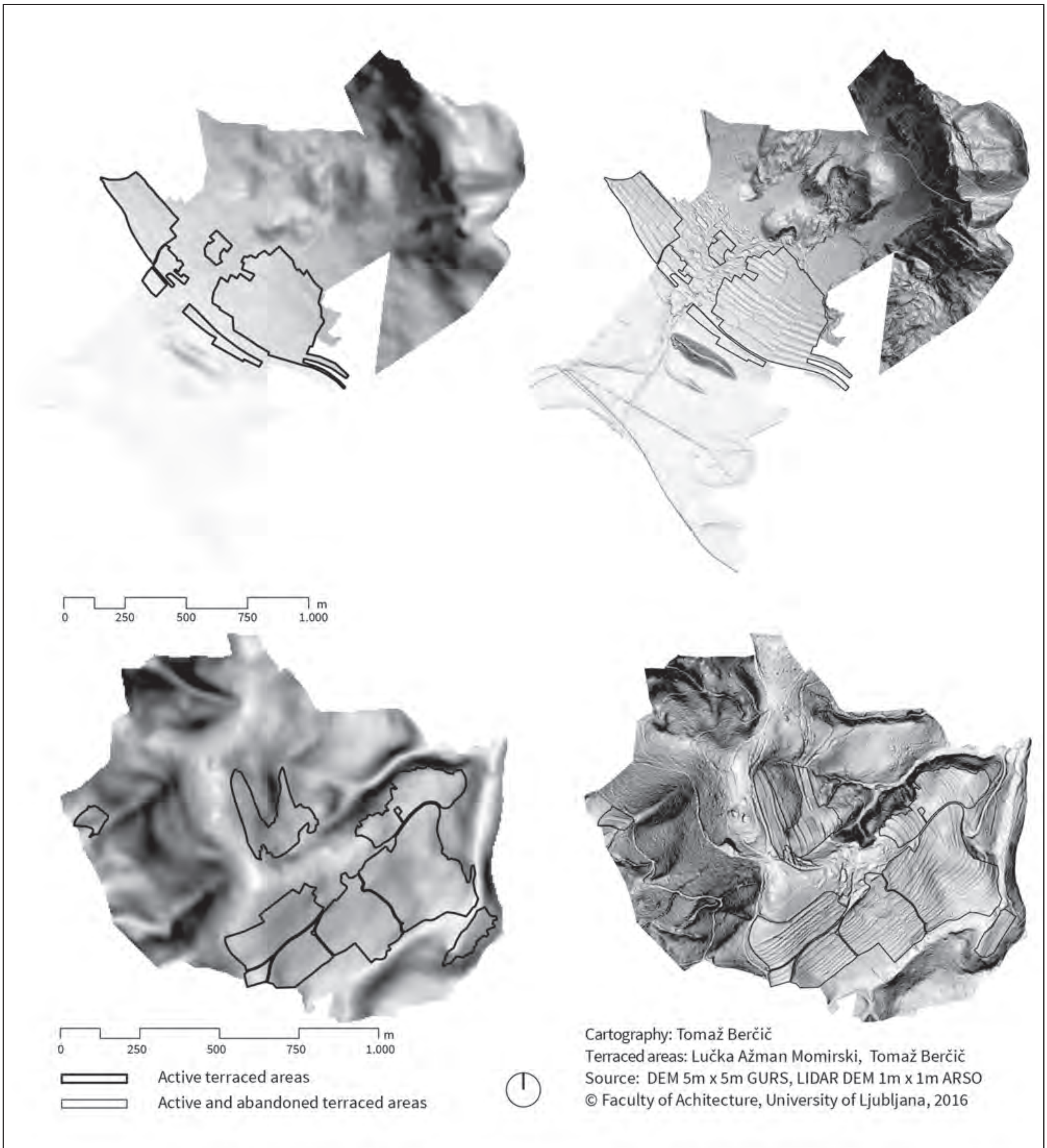

Figure 5: The top left image shows the DEM5 slope data with the active terrace overlay for the settlement of Rodine. The top right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area. The bottom left image shows the DEM5 slope data with the active terrace overlay for the settlement of Velika Slevica. The bottom right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area.

analysis shows equally distributed terrain orientations with an emphasis on regions facing east and southeast (other terrain aspect values are N 11%, NE 8%, E 17%, SE 22%, S 9%, SW 10%, W 13%, and NW 10%). Slope analysis shows that the inclination is predominantly in the first three categories (first category 26%, second category 36%, third category 29%, fourth category 8%, fifth category 1%). The terraced area covers twenty-seven hectares of the settlement area, or 1% less than a quarter of the entire settlement area. The lowest elevation of the terraced areas is 530 m, the highest is 643 m, and the average is 580 m. There is no difference be-

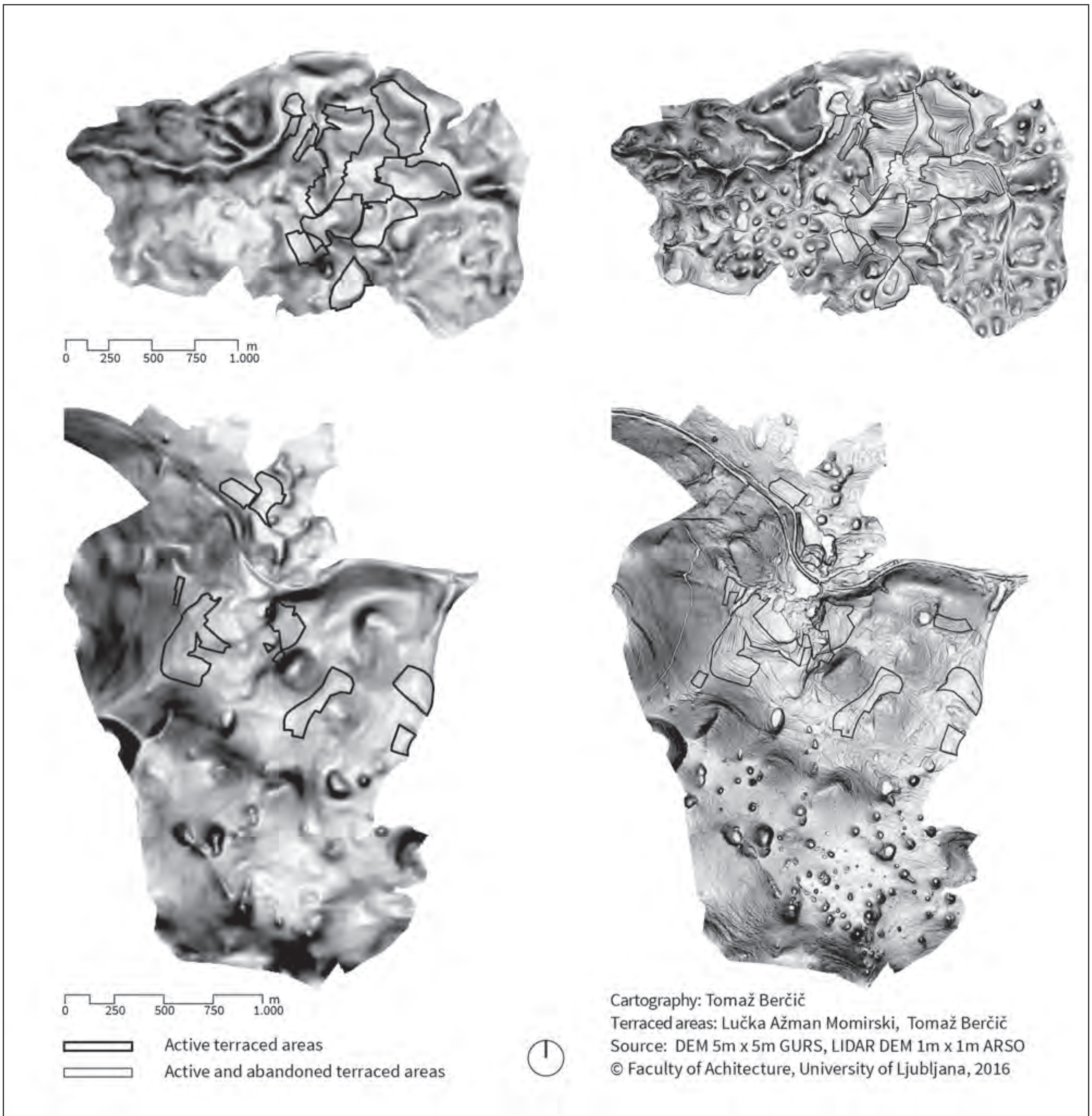

Figure 6: The top left image shows the DEM5 slope data with the active terrace overlay for the settlement of Dečja Vas. The top right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area. The bottom left image shows the DEM5 slope data with the active terrace overlay for the settlement of Merče. The bottom right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area.

tween the LIDAR and DEM5 data, which means that no difference was detected between active and abandoned terraces. The terrace orientation follows the general orientation of the entire settlement (N 4%, NE 9%, E 28%,

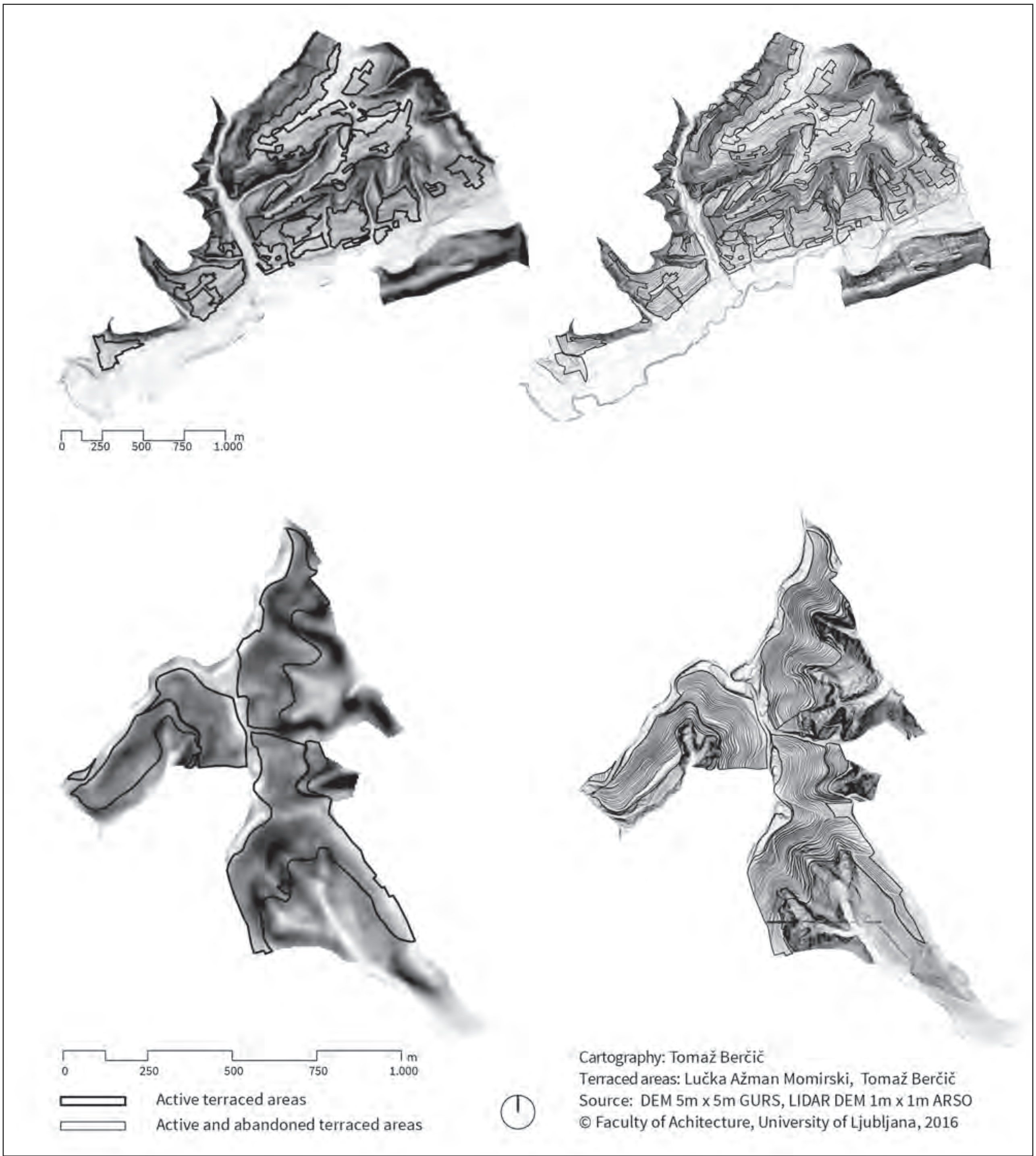

Figure 7: The top left image shows the DEM5 slope data with the active terrace overlay for the settlement of Krkavče. The top right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area. The bottom left image shows the DEM5 slope data with the active terrace overlay for the settlement of Jeruzalem. The bottom right image shows LIDAR data with detected active and abandoned terraced areas for the same pilot area.

SE 43%, S 10%, SW 1%, W 1%, and NW 4%) with an emphasis on the southeast and east regions. The slope analysis of the terraced areas is predominantly in the first two categories (first category 38%, second category 49%, third category 12%, fourth category 1%, and fifth category 0%).

The village of Dečja Vas is part of the Dinaric plateaus according to the natural landscape types of Slo-

TABLE 1	NATURAL LANDSCAPE TYPE	POPULATION 2015	SETTLEMENT AREA / PERSON ha	TERRACES / PERSON ha	MIN ELEV. m.a.s.l.	MAX ELEV. m.a.s.l.	AVERAGE ELEV. m.a.s.l.	TA ELEV. MIN m.a.s.l.	TA ELEV. MAX m.a.s.l.	TA ELEV. AVERAGE m.a.s.l.
RUT	Alpine mountains	42	24.22	0.63	371.55	1967	854	598	786	695
SMOLEVA	Alpine hills	57	3.21	0.22	483.95	1080	719	521	779	633
RODINE	Alpine plaines	116	1.56	0.2	521.25	960	641	533	590	552
VELIKA SLEVICA	Dinaric valleys and corrosion plaines	57	1.99	0.47	522.16	655	585	530	643	580
DEČJA VAS	Dinaric plateaus	65	4.7	0.77	287.89	475	353	307	382	340
MERČE	Mediterranean plateaus	108	3.63	0.22	341.76	575	424	362	440	403
KRKAVČE	Mediterranean low hills	304	2.13	0.45	14.95	275	114	23	268	142
JERUZALEM	Pannonian low hills	33	1.81	0.85	232.98	345	292	264	343	309

TABLE 2	ASPECT	N	NE	E	SE	S	SW	W	NW	SLOPE	0 - 15%	15% - 30%	30% - 50%	50% - 70%	>70 %
RUT		4%	10%	9%	15%	28%	14%	10%	7%		2%	4%	13%	27%	53%
RUT TA		0%	0%	5%	17%	31%	33%	14%	0%		15%	51%	27%	5%	1%
SMOLEVA		16%	17%	12%	10%	10%	16%	8%	11%		2%	4%	13%	28%	53%
SMOLEVA TA		0%	0%	0%	0%	9%	63%	20%	7%		5%	17%	36%	25%	17%
RODINE		4%	4%	3%	4%	16%	42%	20%	6%		44%	20%	15%	11%	10%
RODINE TA		0%	0%	0%	1%	17%	69%	11%	1%		67%	29%	3%	0%	0%
VELIKA SLEVICA		11%	8%	17%	22%	9%	10%	13%	10%		26%	36%	29%	8%	1%
VELIKA SLEVICA TA		4%	9%	28%	43%	10%	1%	1%	4%		38%	49%	12%	1%	0%
DEČJA VAS		12%	13%	15%	16%	16%	11%	8%	9%		37%	38%	21%	4%	1%
DEČJA VAS TA		12%	11%	14%	12%	15%	16%	9%	11%		58%	34%	5%	2%	1%
MERČE		16%	19%	23%	15%	7%	5%	6%	9%		45%	34%	17%	3%	1%
MERČE TA		11%	15%	25%	16%	7%	6%	10%	10%		69%	22%	8%	2%	0%
KRKAVČE		9%	7%	9%	19%	18%	12%	11%	14%		40%	17%	17%	15%	11%
KRKAVČE TA		3%	3%	7%	27%	28%	10%	10%	11%		41%	26%	16%	10%	7%
JERUZALEM		5%	11%	20%	25%	16%	15%	5%	4%		24%	30%	27%	13%	5%
JERUZALEM TA		2%	7%	24%	34%	14%	12%	5%	2%		15%	35%	33%	13%	3%

TABLE 3	AREA ha	TA DMV5 ha	TA DMV5 %	TA LIDAR ha	TA LIDAR %	CHANGE ha	CHANGE %
RUT	1017	26	3	36	4	10	- 27
SMOLEVA	183	12	7	12	7	0	0
RODINE	181	23	13	24	13	1	- 5
VELIKA SLEVICA	114	27	24	27	24	0	0
DEČJA VAS	306	50	16	51	17	1	- 3
MERČE	392	23	6	26	7	3	- 12
KRKAVČE	647	135	21	167	26	32	- 19
JERUZALEM	60	28	47	26	44	-2	6

* **TA** - terraced areas * **ELEV** - elevation

Figure 8: Statistics for the pilot areas.

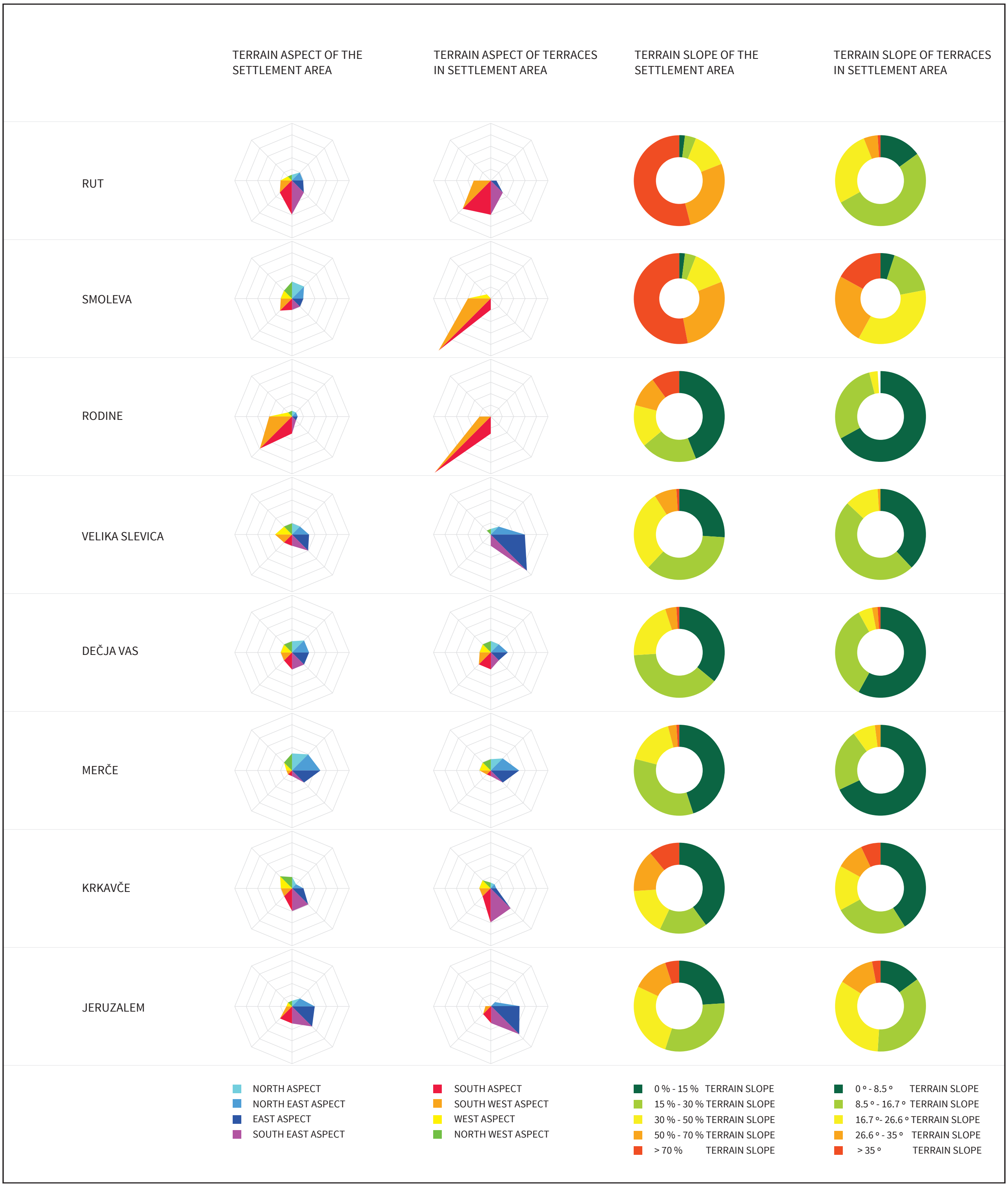

Figure 9: Graphic representation of the statistics of terrain aspect and terrain slope for the settlements and pilot areas.

venia. It is part of the cadastral unit of Ponikve in the Municipality of Trebnje. The settlement area is 306 hectares and has a population of sixty-five (SURS, 2015). The lowest elevation in the settlement is 288 m, the highest is 475 m, and the average is 353 m. The aspect analysis of the terrain of the settlement is mixed (N 12%, NE 13%, E 15%, SE 16%, S 16%, SW 11%, W 8%, and NW 9%) and the slopes are as follows: first category 37%, second category 38%, third category 21%, fourth category 4%, and fifth category 1%. According to the LIDAR data analysis, terraces cover fifty-one hectares, which corresponds to 17% of the settlement's area. The terraced elevation extremes lie at a minimum of 307 m, a maximum of 382 m, and an average of 340 m. Active terraces consist of fifty hectares, which correspond to 16% of the territory. The difference between the active and abandoned terraces is only one hectare. The aspect analysis of the terraced areas is mixed (N 12%, NE 11%, E 14%, SE 12%, S 15%, SW 16%, W 9%, and NW 11%). The slope analysis offers no surprises, considering that the low-lying terrain is mostly in the first two categories (first category 58%, second category 34%, third category 5%, fourth category 2%, and fifth category 1%).

The settlement of Merče in the Municipality of Sežana is part of the Mediterranean plateaus. The area of the settlement is 392 hectares and it has a population of 108 (SURS, 2015). The lowest elevation in the territory is 342 m, the highest is 575 m, and the average is 424 m. The aspect analysis of the entire settlement is mixed (N 16%, NE 19%, E 23%, SE 15%, S 7%, SW 5%, W 6%, and NW 9%) and the slopes are as follows: first category 45%, second category 34%, third category 17%, fourth category 3%, and fifth category 1%. There is twenty-six hectares of terraced landscape in the settlement, which corresponds to 7% of the territory. Because of the specific terrain configuration and Karst landscape, the terraces are extremely difficult to read both in the LIDAR model and in the field. The lowest elevation of the terraced area is 362 m, the highest is 439 m, and the average is 403 m. According to DEM5 data analysis, there are twenty-three hectares of active terraced areas, which corresponds to 6% of the area of the settlement. The aspect analysis of the terraced areas is mixed (N 11%, NE 15%, E 25%, SE 16%, S 7%, SW 6%, W 10%, NW 10%) and the slope is as follows: first category 69%, second category 22%, third category 8%, and fourth category 2%.

The settlement of Krkavče is part of the Mediterranean low hills and has a population of 304. The lowest elevation in the settlement is 15 m, the highest 275 m, and the average 114 m. The orientation of the territory is mixed (N 9%, NE 7%, E 9%, SE 19%, S 18%, SW 12%, W 11%, and NW 14%) and the slopes are as follows: first category 40%, second category 17%, third category 17%, fourth category 15%, and fifth category 11%. Terraced areas cover one-quarter (167 hectares) of the settlement's land. The lowest elevation of the terraces is 23 m, the highest is 268 m, and the average 142 m. The aspect of the terraced areas is mixed (N 3%, NE 3%, E 7%, SE 27%, S 28%, SW 10%, W 10%, and NW 11%) and the slopes are as follows: first category 41%, second category 26%, third category 16%, fourth category 10%, and fifth category

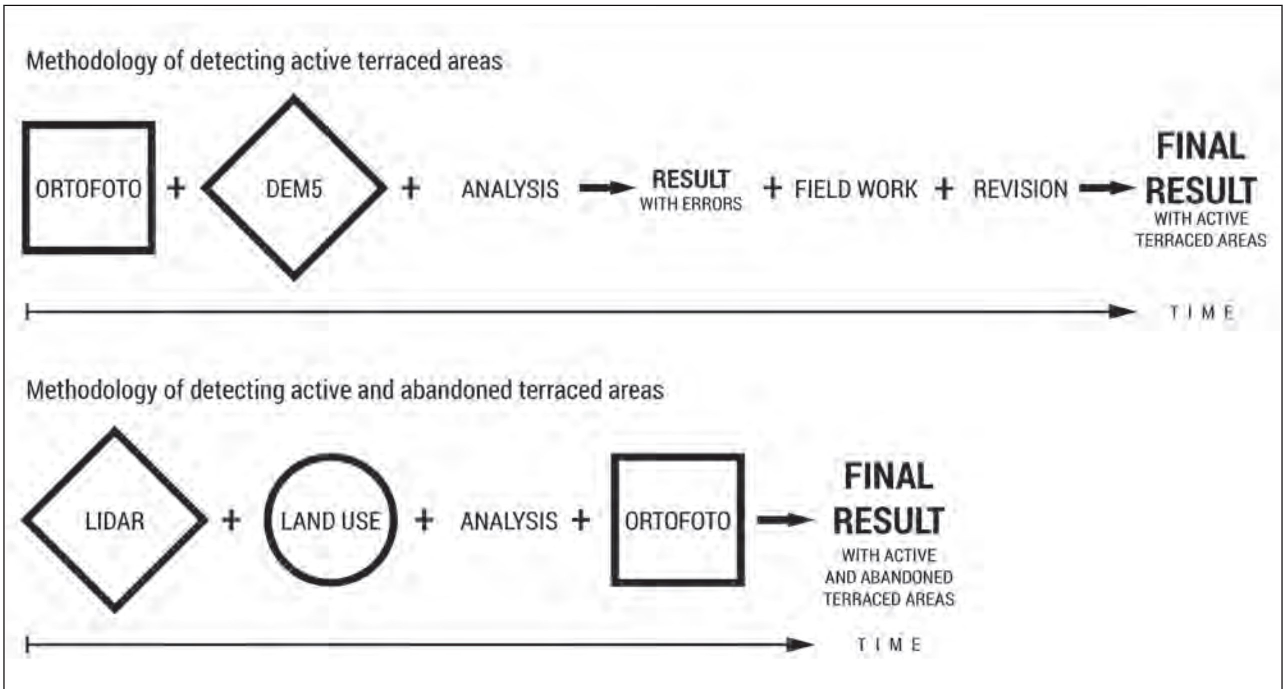

Figure 10: The workflow difference between analysis with and without the detailed LIDAR dataset. The first final result shows only active terraced areas. The second less time-consuming and more precise approach indicates not only active terraces but also abandoned terraced areas.

7%. In this case, there is a significant difference between active and abandoned terraces. According to DMV5 data, there is over 135 hectares of active terraces in more remote and difficult-to-access parts of the settlement. As much as 19% of terraces detected with LIDAR data areas are abandoned, totaling thirty-two hectares.

The settlement of Jeruzalem is part of the cadastral unit of Plešivica in the Municipality of Ljutomer and is part of the Pannonian low hills. The area of the settlement is sixty hectares. The lowest elevation in the settlement is 233 m, the highest 345 m, and the average 292 m. The aspect of the terrain analysis of the entire territory is mixed (N 5%, SE 11%, E 20%, SE 25%, S 16%, SW 15%, W 5%, and SW 4%) and the slopes are as follows: first category 24%, second category 30%, third category 27%, fourth category 13%, and fifth category 5%. Jeruzalem in an extremely terraced settlement, with terraces comprising an astonishing twenty-six hectares, or 44% of the entire settlement area. The lowest elevation of the terraced areas is 264 m, the highest 343 m, and the average 309 m. The method with DEM5 data suggested that terraces cover an even greater area, or 47% of the settlement. However, because of the difficult accessibility of some parts of the terrain in the field, there was no way of determining the exact boundaries of the terraced areas. Again, this is a testament to the value of LIDAR data, without which the definition of the boundary of the terraced areas would be impossible in this case, or at least extremely difficult. The aspect analysis of terraced areas is mixed (N 2%, NE 7%, E 24%, SE 34%, S 14%, SW 12%, W 5%, and NW 2%) and the slopes are as follows: first category 15%, second category 35%, third category 33%, fourth category 13%, and fifth category 3%.

DISCUSSION

This research project has shown that, overall, terraced landscapes are frequent in Slovenian territory. Terraced areas are usually found in small settlements with less population, and this is why they are most frequent where urbanization has not left a permanent footprint. Where the influence of urbanization is more apparent, terraces have succumbed to construction pressure because they are flat and offer a good view. Terraced areas remain where the population is low, the agricultural production on terraces has added value, and the terraces are a significant or main source of people's income.

With the introduction and public availability of LIDAR data for the entire territory of Slovenia, it is now possible to discover the historic underlay of the development of terraced landscapes, especially in remote and difficult-to-access parts of the country. On the basis of historical analysis and without automated statistical geoprocessing, these data can accurately reveal where there were areas suitable for living and agricultural production in the past, which is especially valuable because the positions were based on observation and experience over an extended time period.

The results of the analysis of the pilot areas show that there is no significant difference in extent between active and abandoned terraced areas (ranging between 1% and 3%), and they show that the positions of the terraces have remained more or less the same. The differences emerge on the fringes, on the edge between cultivated areas and natural areas, where access was most difficult. The areas closest to building clusters closer to the center of the settlements remain active and functional. The pilot area settlements of Rodine and Krkavče, where the wish to build up the terraces is the greatest, are under strong urban pressure. In the case of Rodine in the Upper Carniola region, which is close to large urban centers, this pressure is most evident. From the building pattern, there is an easily discernible deliberate change of land use on the terraced areas from agricultural to built-up land. Directly south of the terraces, the remains of a Roman countryside villa (*villa rustica*) were discovered in 1959. The archaeological data show that it was active from the first century AD to the end of the Roman state in the fifth century (Internet 3). Similar increases in built-up land at the expense of terraces were observed in Krkavče because of the warm Mediterranean climate and the proximity to the sea.

Natural landscape types are undeniably a major factor that influences the shape, type, and extent of the terraced areas in a certain landscape. Further terraces are determined by local micro-conditions such as terrain inclination, orientation, soil, elevation, and a combination of these and other aspects.

With certainty, it can be claimed that in the past terraced landscapes were more extensive and that they have been preserved on a large scale where agricultural production is at the forefront of economic development. It is also certain the terraced areas were more extensive in the past in all but one of the pilot areas; however, it can hardly be claimed that terraces' agricultural output has shrunk because of new farming techniques, new cultivars, and new farming equipment. Terraced areas are heavily influenced by weather, erosion, and other climate factors that threaten their existence. It is difficult to say for certain how much of the terraced landscape has disappeared over the centuries.

Paradigm shift

When LIDAR data are processed and run through a slope analysis tool, this offers an unprecedented accurate new interpretation tool for detecting terraced landscapes. The boundaries of terraced areas can now be clearly defined without the help of a field survey, even where the configuration of the terrain made surveys difficult. Because of the nature of LIDAR itself, the segmentation of point cloud data into different classes of foliage, ground, buildings, and so on turns previously hidden earthwork structures (including abandoned terraces) into something instantly recognizable. The shift in thinking is that the LIDAR slope analysis layer is more informative for discovering terraces areas than orthophoto images were. This is why LIDAR data are the new paradigm in the search for terraced areas. The orthophoto remains just as important, but nevertheless only a contextual aid.

CONCLUSION

The impact of LIDAR technology on anthropological landscape exploration is immense and not only has importance for research, but also has economic effects. Because of greater precision over older DEM5 models, it offers an interpretation of the terrain without a field survey, significant time savings, quick reaction times for quick terrain checks, and historical terrain monitoring if the measurements are periodically updated. The future offers the possibility of further resolution upgrades for even better results because terraced areas would benefit from even denser point cloud scans, which would represent an additional step forward in landscape analysis. DEM5 data source will remain as historical data, which served its purpose well, but LIDAR has surpassed it and has become the most important platform for landscape research, monitoring, and management, landscape archaeology, and landscape anthropology.

A quantitative comparison between the old and the new methods shows no difference in the three pilot areas, shows only a minor difference in two cases, and reveals major differences in three pilot areas. The quantitative differences in some of the pilot areas are compelling. However, the most significant feature of the new method is its reliability for detecting the exact boundaries of terraced areas.

In Smoleva and Velika Slevica there are no differences between the LIDAR and DEM5 data, which means that no difference was detected between active and abandoned terraces. According to the LIDAR and DEM 5 data analysis in Rodine, Dečja Vas, and Jeruzalem, there are small differences in detecting terrace coverage in the settlement. In Rodine there is a 5% difference, in Dečja Vas a 3% difference, and in Jeruzalem a 6% difference. Because of the specific terrain configuration and karst landscape, the terraces in Merče are extremely difficult to read both in the LIDAR model and in the field. There is only a three-hectare difference, but because of the small settlement areas this corresponds to a 12% difference. According to DMV5 data, active terraces cover over 135 hectares in Krkavče in more remote and difficult-to-access parts of the settlement. As much as 19% of terraces detected with LIDAR data areas are abandoned, totaling thirty-two hectares. According to LIDAR, terraced areas cover one-quarter (167 hectares) of the settlement's land. This is the second-largest difference, at 19%, and is due to detection of abandoned terraced areas. The greatest difference detected in coverage of terraced areas is in the largest pilot area of Rut, where the DEM5 method yielded twenty-six hectares of terraces and the LIDAR method thirty-six hectares of terraced areas, which is a massive 27% difference.

The basis of research for all projects connected with terraced areas involves inventorying terraced areas in the field. The results show that input data are extremely important and must be highly accurate to achieve the highest quality and best results possible.

With the introduction of LIDAR technology, recognized terraced areas increased significantly. The most important consequence is a new means of detecting terraces and terraced landscapes. On the basis of LIDAR DEMs, it is now possible to detect and define the terrace range, size, and boundary very quickly and with great accuracy. With this kind of accurate terrain measurement, the field survey is becomes redundant—or, when necessary, extremely limited. The anthropological component of LIDAR has extremely important research value in discovering abandoned overgrown landscape features, which was previously not possible without a great deal of fieldwork and enormous amounts of time.

The change of paradigm lies in the fact that orthophoto imagery is the most important underlay for interpreting terraced features and is essential for discovering terrace patterns in the landscape. With the implementation of better computer-processing algorithms, the introduction of neural networks and machine learning even automated detection is not far away in the future.

TERASIRANA OBMOČJA V SLOVENIJI: ZANESLJIVOST ODKRIVANJA Z LIDARJEM

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POVZETEK

Slovenija je država raznolikih tipov pokrajin. Terasirane pokrajine imajo med njimi zagotovo pomembno mesto. Ta privlačna območja niso naravnega izvora, ampak so delo človeških rok. Terase se med seboj razlikujejo po tipologiji in namenu. Najdemo jih na skoraj celotnem ozemlju Republike Slovenije. Sistematična obravnava terasirane pokrajine je še vedno zapostavljena. Predstavljeno delo je korak k boljšemu razumevanju tega pojava. Za izbrana pilotna območja, ki so bila analizirana z GIS orodji, so bile poleg natančnega obsega teras, analiz osončenja in naklona terena izdelane tudi karte zgodovinske analize rabe tal, na podlagi katerih je mogoča primerjava obsega terasiranih območij v preteklosti in v sodobnosti. V prispevku so opredeljeni osnovni pojmi in njihove razlage, ki so pomembni za identifikacijo območij s terasami. Vhodni podatki vsake raziskave imajo izjemen pomen in morajo biti zelo natančni, da lahko dosežemo najboljše rezultate. Osnova vseh raziskav, ki se ukvarjajo s terasami, je inventarizacija terasiranih območij na terenu. Pri tem se uporablja navadna metoda fotointerpretacije, ki ima nekatere slabosti. Slednje vplivajo na (ne)natančnost vhodnih podatkov pri raziskavah terasiranih območij. V študiji smo opisali osnovno metodo in potek dela za določanje terasiranih območij. Na podlagi novih LIDAR podatkov je prikazana prilagojena interpretacijska metoda določanja terasiranih območij. Rezultati stare in nove metode se v treh izbranih primerih ne razlikujejo, v dveh primerih so le nekoliko drugačni, v treh primerih pa je prišlo do bistvenih razlik.

Ključne besede: terasirana pokrajina, terase, LIDAR, digitalni model terena, Slovenija

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