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Terrestrial-Aerial-SfM and TLS data fusion for agricultural terrace surveys in complex topographic and land cover conditions

Sara Cucchiaro[1], Daniel J. Fallu[2], He Zhang[3], Kevin Walsh[4], Kristof Van Oost[3], Antony G. Brown[2,5], and Paolo Tarolli[1]

[1]University of Padova, Land, Environment, Agriculture and Forestry, Italy (sara.cucchiaro@unipd.it) (paolo.tarolli@unipd.it)
[2]Tromso University Museum, UiT The Artic University of Norway, Tromsø, Norway (daniel.j.fallu@uit.no) (antony.g.brown@uit.no)
[3]Earth and Life Institute, Université Catholique de Louvain, Louvain-la-Neuve, Belgium (he.zhang@uclouvain.be) (kristof.vanoost@uclouvain.be)
[4]Department of Archaeology, The Kings Manor, University of York, UK (kevin.walsh@york.ac.uk)
[5]Geography and Environmental Science, University of Southampton, UK (antony.g.brown@uit.no)

In the last two decades, important developments in High-Resolution Topographic (HRT) techniques, methods, sensors, and platforms has greatly improved our ability and opportunities for the characterization of landscapes through sub-metric DTMs (Digital Terrain Models). The choice of the most appropriate platform for HRT surveys must consider the required resolution, the spatial extent, and the features present in the analysed area. In complex topography, inaccessible areas and vegetated environments, the use of a single HRT technique is constrained by several factors. Therefore, data fusion from different acquisition platforms can be a useful solution if we design appropriate workflows for survey planning, data acquisition, post-processing, and uncertainty assessment. We tested this approach in the production of detailed DTMs of ancient agricultural terracing on two sites, Soave (North-east of Italy) and Martelberg in Saint-Martens-Voeren (East Belgium); case study sites for the TerrACE archaeological research project (ERC-2017-ADG: 787790, 2018-2023; https://www.terrace.no/). Both sites presented complex topographic and landcover conditions: the presence of vegetation (common in ancient, often abandoned, terraces) that cover parts of the sub-vertical surfaces (e.g., vertical walls of terraces), steep slopes and large survey areas. Therefore, we carefully designed the data fusion of HRT techniques in order to overcome all these constraints and thereby represent detailed 3D-views of the study sites. An integrated approach employing ground-based and UAV Structure from Motion (SfM) photogrammetry was used to preserve fine-grained topographic detail (via ground-based photos) and capture flat terrace zones at large spatial scale (via UAV images); while terrestrial Laser Scanner (TLS) permitted the accurate survey of the highly vegetated areas and vertical terrace walls. In order to create the point-cloud fusion, a key aspect for consideration when planning the survey planning was the location and distribution of the Ground Control Points (GCPs) for SfM and TLS targets. These are essential for georeferencing and co-registering of the aggregate data during the final merge. In the inaccessible zones of the studied areas, where was impossible to locate the GCPs, we tested the direct georeferencing of the UAV images with

differential GNSS, such as PPK (post-processing kinematic). The SfM-TLS technologies allowed us to accurately recognize the topographic features of the entire terrace areas. This point-clouds merge was impossible to obtain without post-processing steps as co-registration process and uncertainty analysis. Even if several studies highlight how co-registration is essential in order to correctly merge HRT data, it is often not addressed in post-processing workflows. In this study, we demonstrated how survey planning and co-registration were fundamental phases for data fusion and allowed us to obtained proper and reliable DTMs. These high-resolution DTMs provided a high level of detail of landscape that was useful to extract valuable information about ancient terrace complexes: morphological features, profiles, sections and scaled plans, simplifying and speeding the archaeologist's field and laboratory work.