Multiscale Digital Landscape Reconstructions for Resilient Mountain Inner Areas

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Abstract. Lacking, declining, marginal, inner areas overlap worldwide with intermediate, rural and mountain territories where climate change and inherent social-spatial vulnerabilities inhibit a smart, sustainable, and inclusive development. Within this framework, the present contribution addresses the lack of methodologies for engaging and empowering community resilience in the case of Italian mountain inner areas by investigating the integrated application of digital tools, technologies and techniques for their planning, design, and management.

In a landscape-scale perspective, this work adopts an interdisciplinary and multiscale approach towards the development of rapid and low-cost workflows for 3D reconstructions to support information management activities. Connecting a wide range of methods and tools (i.e., GIS mapping, photogrammetry, point cloud modeling), two research explorations conducted in the Autonomous Province of Trento (Italy) are presented as complementary approaches towards the digital representation of fragile landscapes at different spatial scales of action: the territorial scale of municipal planning in Val di Sole, where 2.5D visualizations of cartographic information in a GIS environment and 3D models relying on satellite data are identified; and the tree scale of forest management in the Mesiano University park, where low-cost alternatives for under-storey vegetation 3D mapping (i.e., Apple iPad Pro with LiDAR sensor and Ricoh Theta V 360° camera) are tested.

Keywords: Inner Areas · Community Resilience · Landscape Representation · Digital Modeling

1 Introduction

1.1 A 'Glocal' Framework: Areas Suffering from Territorial Imbalances

'Inner areas' is the Italian terminological declination [1] of the internationally debated issue concerning territorial imbalances and spatial inequalities [2]. In the framework of the current (2021–2027) European Cohesion Policy, the new season of the Italian National Strategy for Inner Areas (SNAI) – which has also been funded by the 2021 National Recovery and Resilience Plan (PNRR) – aims to counteract the marginalization and demographic decline of 114 'reservoirs of resilience' [3], corresponding to almost 4,000 municipalities covering the 58.8% of the national territory [4].

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Worldwide, lacking, declining, marginal, or 'peripheral' [5] areas – regardless of the various classification methodologies, if any – overlap with intermediate, rural and mountain territories where climate change and inherent social-spatial vulnerabilities inhibit a smart, sustainable, and inclusive development.

Trying to go beyond standardized definitions, the ongoing research project of national interest "B4R Branding4Resilience. Tourist infrastructure as a tool to enhance small villages by drawing resilient communities and new open habitats" (B4R) proposes an interdisciplinary and multiscale methodological approach which integrates different qualitative and quantitative tools (i.e., data analyses and mapping, territorial portraits, stakeholder analysis, a collaborative platform) to explore inner territories, interact with local actors (i.e., public and private institutions, and associations), and support them in designing future strategic scenarios [6]. Specifically, the B4R research unit of the University of Trento, focusing on the Val di Sole inner area in the Autonomous Province of Trento (Italy), aims to create a territorial branding strategy on the value of (thermal) water resources by promoting the enhancement of the natural capital through co-designed spatial transformations, also in response to the medium-high level of risk [7] (Fig. 1).

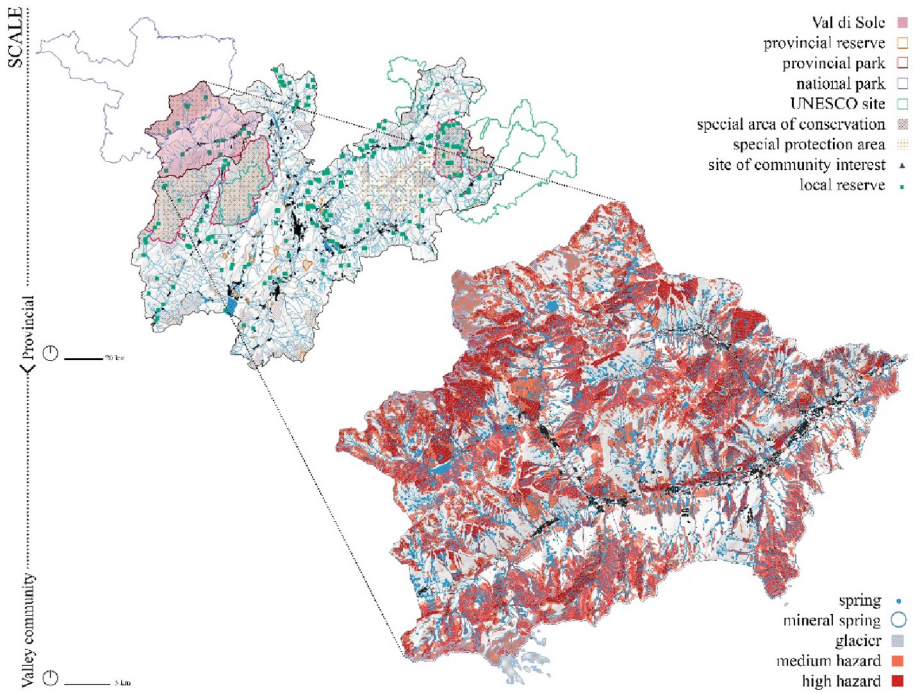

Fig. 1. Left: location of the Val di Sole in the Autonomous Province of Trento (Italy), and the protected natural sites. Right: medium-high multi-hazard risk (hydrogeological, avalanche, seismic and forest fire) and hydrological resources in the valley. Image from [8].

Within this 'glocal' (i.e., simultaneously 'global' and 'local') framework [9], the present contribution addresses the lack of methodologies for engaging and empowering

resilience in society, focusing on the paradigmatic case of Italian mountain inner areas which are nodes of larger social, political, and economic frameworks [10]. Acknowledging that the term 'resilience' is used in different disciplinary fields, in the following the author will refer to 'community resilience', as embedded in the broader social-ecological resilience perspective (i.e., implying consideration of spatial aspects, environmental features of built and natural environments, and issues of equity, inclusion, and justice) [11]. Accordingly, in mountain areas, the existing gaps should be addressed by relying on local knowledge and co-creating solutions with communities [12].

1.2 A Landscape-Scale Perspective for Resilient Mountain Inner Areas

For the management, planning, and design of mountain inner areas, this study, as part of an ongoing PhD research, adopts a landscape-scale perspective: since landscape derives from the actions and the interrelationships of human and natural factors [13], encompassing multiscale ecosystems from the territory to the single tree (and beyond), it seems the suitable spatial unit to be addressed in order to meet both the global Sustainable Development Goals (i.e., Goal 9, 'Industry, innovation and infrastructure'; Goal 10, 'Reduced inequalities'; and Goal 11, 'Sustainable cities and communities') and the local SNAI objectives, and to achieve the 'twin' green and digital transitions in the long-term future [14].

However, focusing on digital tools, technologies and techniques, there is an enduring gap between the mainstream approaches in landscape management, planning, and design [15], and the industry-standard mapping and modeling for the architectural and urban scales (Fig. 2).

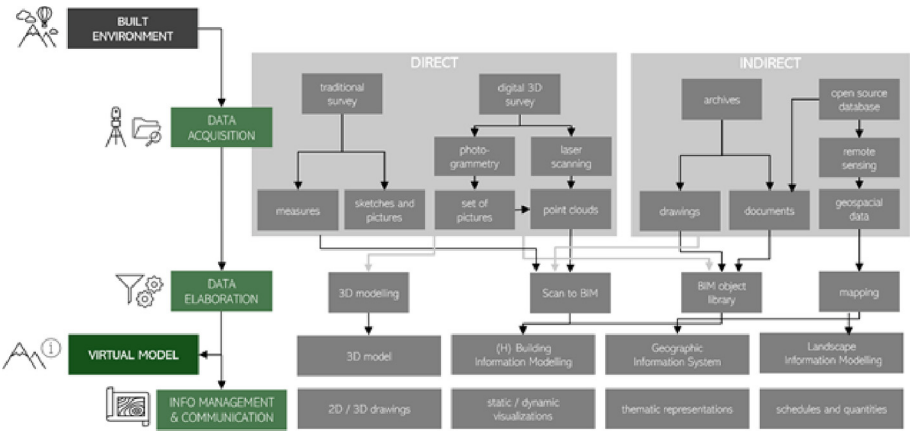

Fig. 2. Each scale of study privileges different data acquisition techniques and returns information in different shapes, which can be mixed, integrated, and adapted depending on the specific object of investigation, the purposes of the analysis, and the project. Image from [16].

Indeed, at the landscape scale, digital reconstructions are generally based on a Geographic Information System (GIS) approach, drawing data from cartography or remotely

sensed images, but there is an increasing interest in adopting the Building Information Modeling (BIM) paradigm – as demonstrated by the relatively new term Landscape Information Modeling (LIM) [17, 18], that could be approached also as an integration of BIM and GIS – or the 'cloudism' methodology, where landscape design is driven by point cloud modeling [19].

Moving in this critical gap, exacerbated in 'infrastructurally' raw systems as inner areas (because of poor Internet connectivity, lack of sensors, etc.), the methodological and operational proposal of this contribution investigates the integrated application of digital tools, technologies and techniques (especially if rapid and low-cost) in the landscape management, planning, and design of resilient mountain inner areas to support information management activities and help democratize decision-making also towards the overcoming of digital divide and lack of digital literacy.

2 Materials and Methods

The research design adopts an inherently interdisciplinary and multiscale approach towards the development of rapid and low-cost workflows for digital landscape reconstructions; respectively, it integrates landscape planning and design with survey and digital modeling disciplines and investigates micro (single tree) and macro (territorial) spatial scales (translating into landscape the concept "From the Spoon to the City", lit. "Dal Cucchiaio alla Città", by Ernesto Nathan Rogers). In completion of the B4R methodological framework based on 'Research by Design' [6, 20], this research also adopts a 'Learning by Doing' approach [21] to further investigate the use of digital data acquisition and representation tools in landscape architecture.

In the following, selected results from two self-contained applied research explorations in the Autonomous Province of Trento are presented. Addressing different scale-related problems in digital landscape reconstruction, they both connect a wide range of methods and tools (i.e., GIS mapping, photogrammetry, point cloud modeling) to tackle different steps of information management activities oriented at landscape planning and design (i.e., data acquisition and transformation, data elaboration and results' visualization) [22, 23].

The first exploration, applied to a portion of Peio municipality in the upper Val di Sole, concerns the representation of marginal landscapes at a territorial scale: ranging from the 2.5D visualizations of cartographic information in a GIS environment to 3D models from globally available and periodically updated satellite data [24]. The second exploration, conducted in a plot of the Mesiano University park in Trento, regards 3D mapping of trees with low-cost sensors (i.e., Apple iPad Pro with integrated LiDAR [25], and Ricoh Theta V 360° camera [26]).

The two case studies are not compared, rather they are presented as complementary approaches (Table 1) towards the development of digital 'twins' of the landscape at different scales of action – from the territorial scale of municipal planning [27] to the tree scale of forest management [28] – in order to support the spatial decision-making, ultimately promoting stakeholder engagement and public empowerment from a community resilience perspective [8].

Table 1. Summary information about the workflows for 3D reconstructions in the two applied research explorations.

Case study	Peio municipality in the upper Val di Sole		Mesiano University park in Trento	
Workflow	'Automatic' image-based modeling from the web	Image-based modeling from Google Earth	Point cloud modeling from LiDAR sensor	Image-based modeling from a panoramic camera
Data input	Satellite image (from Jaxa)	Satellite image (from Landsat/Copernicus)	Point clouds	360° video
Method	-	Photogrammetry	Point cloud modeling	Spherical photogrammetry
Tool(s)	Dell Inspiron 16 Plus 7620 (personal laptop)	Dell Inspiron 16 Plus 7620 (personal laptop)	Apple iPad Pro WI-FI 12.9", Dell Inspiron 16 Plus 7620 (personal laptop)	Ricoh Theta V 360° camera, Dell Inspiron 16 Plus 7620 (personal laptop)
Software	Lands Design plugin for Rhinoceros	Google Earth Pro, Autodesk ReCap Photo	3D Scanner App, CloudCompare	Agisoft Metashape
Data output	Textured mesh surface with 3D buildings	Textured mesh surface	Textured point cloud	Textured point cloud

3 Results

3.1 Territorial Scale: Digital Reconstructions from 'Indirect' Data

In the case of Val di Sole, the B4R research unit of the University of Trento conducted a preliminary quali-quantitative exploration to gather and reorganize the existing distributed information resources in thematic maps, diagrams, and plots of cross-cutting indicators [7]. Among the open data retrieved from the Autonomous Province of Trento, the Digital Terrain Model (DTM) acquired with airborne LiDAR technologies in 2014 (and integrated in 2018), and the digital orthophoto (i.e., a 4-band RGBI orthophoto-mosaic) acquired through an aero-photogrammetric survey between 2014 and 2016, were used in this study to produce textured 2.5D visualizations of portions of Peio municipality in a GIS environment with the Qgis2threejs plugin for QGIS software.

Without conducting new extensive and resource-consuming survey campaigns to acquire more updated data, 'agile' (i.e., expeditious and inexpensive – both in terms of economic resources and computational power) 3D geometric digital modeling workflows, relying on current available online satellite data, have been tested for virtually reconstructing portions of Peio municipality [24]. A textured mesh surface with 3D buildings is obtained with an 'automatic' geometric modeling from the cloud by importing

elevation data of the selected location through the Lands Design plugin for Rhinoceros software; similarly, but without elevation data for buildings, a textured mesh surface is generated with an image-based geometric modeling from Google Earth data by acquiring a video tour of the selected location through Google Earth Pro software and processing frames in cloud with Autodesk ReCap Photo software (Fig. 3).

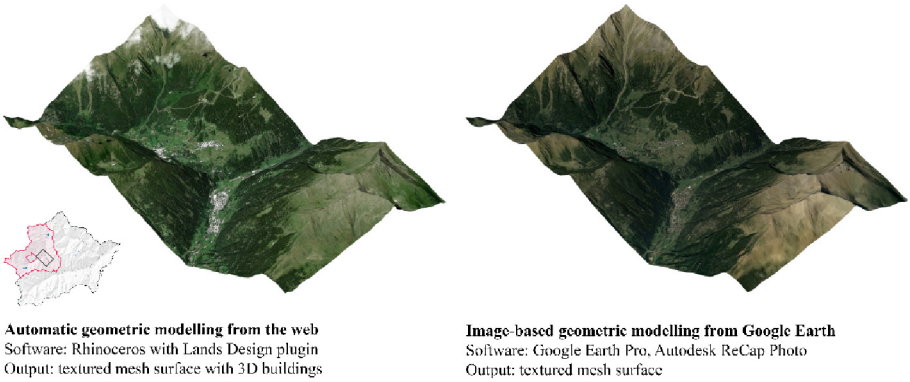

Fig. 3. 3D textured mesh surfaces of the same portion of Peio municipality (pink-colored, in the upper Val di Sole) from rapid satellite image processing. Left: result from the 'automatic' geometric modeling workflow (~ ten minutes); right: result from the image-based geometric modeling workflow (~ one hour). Image from [24].

3.2 Tree Scale: Digital Reconstructions from 'Direct' Data

In the case of a plot of the Mesiano University park in Trento, two low-cost sensors (i.e., the Apple iPad Pro WI-FI 12.9" with LiDAR sensor, and the Ricoh Theta V 360° camera) are explored and compared (in terms of data acquisition time, processing and modeling, and the overall visual fidelity of the results) to close-range photogrammetry (conducted with the Canon EOS600D 18 mm camera) and terrestrial laser scanning (conducted with the Leica ScanStation 2 scanner) which currently is the gold standard for 3D reconstructions in forestry [29]. The description of workflows for the point clouds generation by means of classical photogrammetry and terrestrial laser scanning are overlooked in the following because belong to an established practice.

Following the current best practices to scan with iPad [30] and aware that the range of its sensor is approximately 5 m, the data acquisition was conducted by the author using the 3D Scanner App (between the most suitable for this application), slowly circling each tree in the plot and trying not to scan the same area twice (~ half an hour). After the first processing of the scans directly in the app, the generated point clouds were exported in a XYZ file format and imported into CloudCompare software for the alignment through the targets (~ one hour) (Fig. 4).

With regards to spherical video acquisitions with the Ricoh Theta V, they were acquired by the author again walking around the study plot, circling each tree slowly (~



Fig. 4. 3D textured point cloud of the study plot in the Mesiano University park acquired with the Apple iPad Pro with LiDAR sensor.

fifteen minutes). With the software Agisoft Metashape, first the frames (i.e., panoramic images) were split and oriented using the spherical camera model, then the point cloud was obtained via dense matching. Unlike the point clouds generated with the iPad, the textured 3D model derived from spherical photogrammetry needed to be scaled (through the targets) and oriented in space (~ two hours) (Fig. 5).

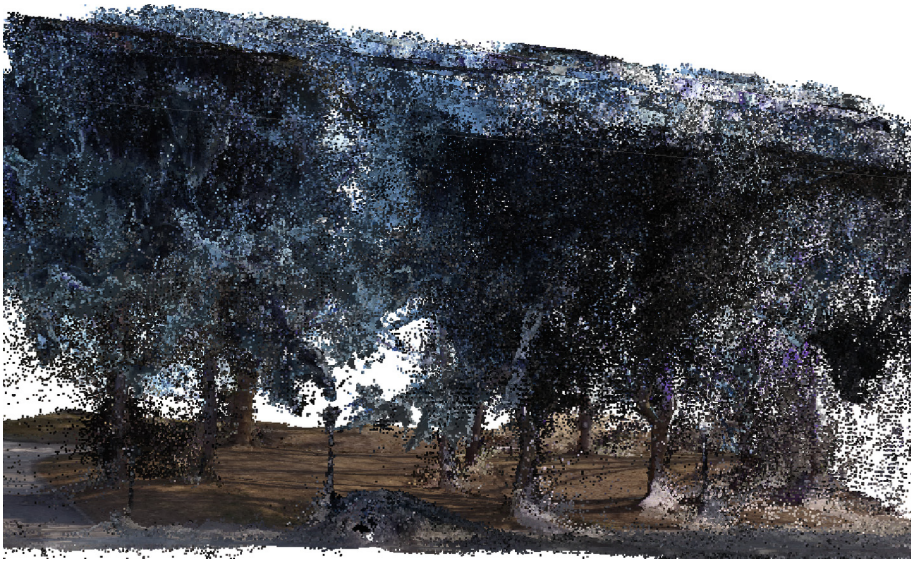

Fig. 5. 3D textured point cloud of the study plot in the Mesiano University park generated from the acquisition with the Ricoh Theta V 360° camera.

4 Discussion and Conclusion

The presented range of methods and tools (i.e., GIS mapping, photogrammetry, point cloud modeling) have been investigated to evaluate their capacity to support rapid and inexpensive 3D digital reconstructions of landscapes at different scales of action, from municipal planning and design to forest management.

Both the research explorations aim to make the acquisition, elaboration, and/or fruition of technical information more intuitive and interactive: in the case of a portion of Peio municipality in the upper Val di Sole, mapping and modeling processes based on cartography and remotely sensed images are oriented at improving accessibility of scattered geospatial data towards the management and design of territorial transformations; in the case of a plot of the Mesiano University park in Trento, because the crown canopy hinders the above-measurements of the below-foliage stem part, a direct 3D mapping of the under-storey vegetation is oriented to support the low-cost monitoring, analysis and visualization of forest development.

While the geometric accuracy of the results may be challenged, the overall visual outputs of these 3D digital reconstructions are satisfactory for their purposes, given the limited time and expense required to generate them.

The long-term goal of this PhD research is to outline a process that connects and operationalizes existing distributed information resources by enabling real-time/regularly updated data integration into Territorial Digital Twins – of which Forest Digital Twins would be essential components – as 3D virtual copies of that landscape to ultimately promote stakeholder engagement and public empowerment.

Indeed, because of the global availability of smartphones and the increasing popularity of cameras and drones even among non-professionals, the actualization of information technologies' affordances for landscape planning and design in mountain inner areas could rely also on citizens as prosumers (i.e., both consumers and producers) of data. While combining crowdsourced street-level and/or aerial imagery with other data sources requires further research on integrating citizen science inputs into data collection and elaboration processes, low-cost sensors promise to significantly reduce the future costs of 3D digital documentation campaigns. The research still needs to verify how and whether, through the presented workflows, the citizens can be placed at the center of the project, sharing criticalities and results with them.

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