Digital Representation of Marginal Landscapes: 'Agile' 3D Modeling Workflows for an Italian Inner Valley

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Abstract: Nowadays, the urban design, planning and environmental management of areas suffering territorial imbalances require exploiting the ever-increasing availability of data about the natural and built environments, while promoting stakeholder engagement and empowering local communities. In the framework of an ongoing doctoral thesis, this paper contributes to the topic of digital representation of marginal landscapes, presenting three rapid and low-cost 3D modeling workflows relying on available data from different sources. The case study for this experimentation is the Val di Sole, an Italian inner mountain valley in the Trentino-Alto Adige region, whose multidimensional representation could support information management activities relevant to landscape planning and urban design towards the enhancement of its social-spatial resilience.

Keywords: Territorial imbalances, inner areas, landscape representation, digital modeling

1 Introduction

An overview of the landscape planning and design tools in Europe – comparing those countries that have adopted the principles of the European Landscape Convention (2000) for their territorial policies – reveals that the prescriptions of the Landscape Plans are represented in static documents such as the Landscape Charters (SALA et al. 2014). Despite their name, the current 'charters' are no longer drawn on paper, but, although digital, they still take the form of bidimensional maps usually implemented in a Web-Geographic Information System (GIS) environment, in compliance with cartographic symbolization and generalization conventions. Costly to update, the Landscape Charters crystallize the territory's assets, mirroring the long gestation period of the Landscape Plans. The long-term ambition of this research is to promote a shift from the 'traditional' 2D Landscape Charter concept towards the use of dynamic and responsive 3D landscape representations to support truly informed and participating decision-making processes, envisioning future territorial design at different levels of engagement.

Nevertheless, several researchers (ERVIN 2001, NESSEL 2013, ZHANG 2021) have identified an enduring gap between mainstream tools used for landscape design and industry-standard mapping and modeling technologies – such as Landscape Information Modeling (LIM) –, capable of producing meaningful information about the natural and the built environments, at different scales and levels of detail. Indeed, the idea of a 'smart', 'responsive' or even 'sensory' landscape (ERVIN 2018) is still in its infancy, also because of two relevant challenges (MOSHREFZADEH et al. 2020): the networking of distributed information resources (i. e., Big Data in ROYDS 2018; or even 'Enormous' Data in ERVIN 2020), and the integration of real-time information in virtual landscape models, even in raw environmental conditions (i. e., poor Internet connectivity, lack of sensors, digital divide, etc.). Indeed, the smart development of natural and built environments are divided into two sets of frameworks: the urban

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framework, already well established (i. e., Helsinki's 3D city models, Rotterdam 3D, Virtual Singapore); and the intermediate, rural and mountain framework which have only recently gained momentum, but mainly lack technical innovations (i. e., Smart Villages in ZAVRATNIK et al. 2018).

However, the latter is not residual (Figure 1), hosting 58% of the European population for living and working issues (EUROPEAN UNION 2020) and being the target of the last (2014-2020) and current (2021-2027) European Cohesion Policies that call for its smart, sustainable, and inclusive growth. Indeed, climate and inherent social-spatial vulnerabilities bring uncertainty about the capacity of intermediate, rural and mountain areas to achieve sustainable development. The prevalence of exploratory studies related to territorially imbalanced areas, mainly concentrated in Asia and in Europe, is reflected in the use of a variety of adjectives – as 'peripheral', 'marginal', 'inner' and 'inland' – to refer to these (OPPIDO et al. 2020). Specifically in Italy (the second most active country globally, and first in Europe, in researching practices), the National Strategy for Inner Areas (SNAI) – an innovative territorial cohesion policy which has recently benefited from new funds from the 2021 National Recovery and Resilience Plan (PNRR) and the current European Cohesion Policy – aims to counteract the marginalization and demographic decline of these contexts, fostering a sensitive, respectful, and sustainable design-driven approach not to compromise their territorial resources, knowledge, artifacts, and potential uses.

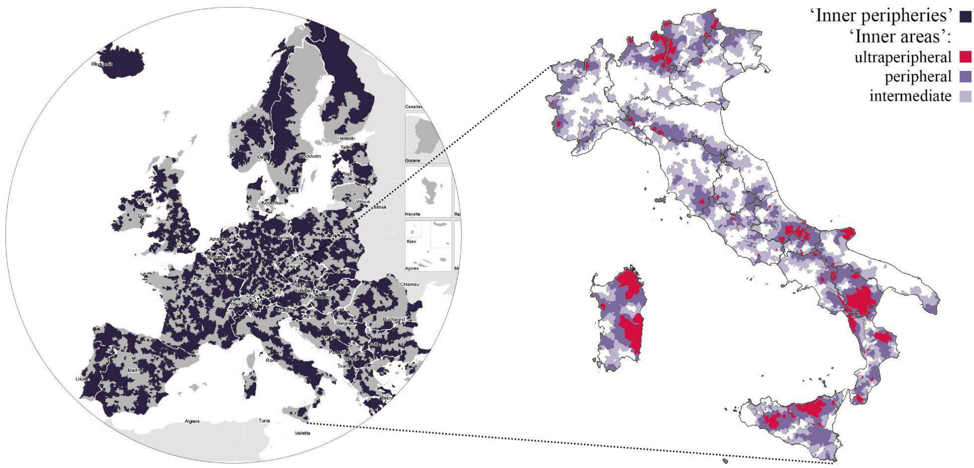

Fig. 1: Left, Inner Peripheries in Europe; right, map of the Italian Inner Areas, with different degrees of peripherality (FAVARGIOTTI et al. 2022)

On the one hand, these areas need the support of digitalization to overcome their territorial imbalances and go beyond their infrastructural marginalization. On the other hand, they lack human and service support to address the most technologically advanced tools. The methodological and operational proposal of this study moves in this critical gap by contributing to identify and test rapid and low-cost workflows for 3D landscape reconstructions in marginal areas: the exploitation of available data from different sources can provide realistic visualizations of these territories to support information management activities and help democratize decision-making.

2 Materials and Methods for the Val di Sole Case Study

Within the framework of an ongoing doctoral thesis and the research project of national interest "B4R Branding4Resilience. Tourist infrastructure as a tool to enhance small villages by drawing resilient communities and new open habitats" (FERRETTI et al. 2022), the authors are investigating the digital multidimensional representation of marginal landscapes, relying on available data from different sources. One of the four pilot areas of B4R, the Val di Sole – an Italian inner valley in the Alpine context of Trento Autonomous Province – is also the testing ground for our investigation towards the development of a cross-sectoral approach for a virtual-physical system supporting landscape planning and design decision-making, promoting stakeholder engagement and public empowerment.

2.1 The Quali-quantitative B4R Database

Since the representation of landscapes, an interdisciplinary theme cutting across STEM and Humanities disciplines, requires the processing of geo-data as well as the depiction of sensory information (SALERNO 2019), a preliminary quali-quantitative exploration of the valley – coinciding with the first phase of the B4R project – was oriented to gather and reorganize the existing distributed information resources on it, also aiming to solve interoperability gaps. The process was conducted from November 2020 to June 2021 via the collection, categorization, and spatialization of open-source and collaborative data from different databases at various geographic scales and levels of detail (European, national, provincial, valley community, and municipal) within four main dimensions (infrastructure, landscape, and ecosystems; built and cultural heritage, and settlements dynamics; economies and values; networks and services, community and governance models) to create a digital multi-domain information profile for the valley, developed in a GIS environment (FAVARGIOTTI et al. 2022). The result is an under-construction atlas of thematic digital maps, diagrams, and cross-cutting indicators to comprehend, store, and transmit, among others, the environmental resources of such a marginal territory – one above all, the thermal water resource (PASQUALI et al. 2022) –, identifying landscape heritage values and assets. The outputs of the digital mapping supported the activities of the four-days co-design workshop in the Val di Sole held in February 2022 – coinciding with the second phase of the B4R project – during which the participants proposed real answers to local design challenges mainly related to maintaining a balance between the protection of valuable natural resources and their fruition during mass seasonal flows of tourists (FAVARGIOTTI et al. 2022).

Recalling the premises of this contribution, even if the GIS environment is nowadays the preferred way to manage information layers about landscape in the Italian practice, from the operative point of view of the landscape planning and design, other approaches must be addressed (i. e., the 'cloudism' in GIROT 2020), and different software packages and workflows are required for iteratively modelling, rendering and testing the various design solutions (WISSEN HAYEK et al. 2011). To advance from the 2.5D visualizations of the valley's Digital Terrain Model (DTM), with other data 'projected' on it, in the current GIS environment (obtained, for example, with the Qgis2threejs plugin for QGIS software) towards the quali-quantitative B4R database implemented in a proper 3D environment – and thus to support the last co-visioning phase of the B4R project –, a landscape truly 'intelligent' model of the Val di Sole is necessary. Namely, it has to promote the use of technology to develop micro-actions in accordance with local conditions and citizens demands (CERRETA & FUSCO 2016).

2.2 Three 'Agile' 3D Modeling Workflows

Primarily, the updating of the valley topography data is necessary as a base because the digital models (i. e., the Digital Terrain Model, the Digital Surface Model, and the Digital Building Model with a pitch of 1x1 m or 2x2 m, depending on the area) freely distributed by the Autonomous Province of Trento were acquired with airborne LiDAR technologies in 2014 and integrated with other flights in 2018. Also, the digital orthophoto (a 4-band RGBI orthophotomosaic with a ground resolution of 0.2 m) made available by the province was acquired through an aero-photogrammetric survey in 2014-2015-2016. Since now extensive and resource-consuming survey campaigns to acquire current data are not an option for the valley community nor for the province, the solution is to identify expeditious and inexpensive – both in terms of economic resources and computational power – workflows for updated 3D landscape reconstructions, relying on already available data from different sources.

Three relatively rapid and low-cost 3D geometric modeling workflows have been identified and tested for virtually reconstructing portions of Peio municipality, in the upper Val di Sole. The first two procedures rely on globally available and periodically updated satellite data, while the third procedure uses data acquired on a one-off basis and for an originally different purpose. As a result of all three procedures, a textured 3D mesh surface is obtained.

1) 'Automatic' geometric modeling from the cloud by importing elevation data (i. e., terrain, buildings) of the selected location through the Lands Design plugin for Rhinoceros software and obtaining a textured mesh surface with 3D buildings (Figure 2a). This workflow requires an internet connection and about ten minutes of time; the main limitation is the extension of the exported rectangle of data whose long side can not exceed 10 km. The source and details of the data can be directly set from the Lands Design tab 'Import Earth's elevation data' (in this case, a satellite image from Jaxa, with accuracy 100 and distance 10 m/sample – for both parameters, the highest possible values were selected); the date of satellite image acquisition is not clearly declared, we can assume that it is updated to 05/01/2022 at the latest, when it was imported.
2) Image-based geometric modeling from Google Earth data by acquiring a video tour of the selected location through Google Earth Pro software, processing frames in cloud with Autodesk ReCap Photo software, and obtaining a textured mesh surface to be imported in a proper 3D environment (Figure 2b). This workflow requires an internet connection and about one hour of time, but this may vary depending on the number of frames to be processed and the desired output quality (in this case, 97 frames – extracted one frame per second from the video tour – were processed with default setting in Autodesk ReCap Photo). The source and details of the data used is clear from Google Earth Pro (in this case, a satellite image from Landsat/Copernicus, acquired on 24/09/2021). Note that, to date, Google Earth can be used for research purposes without needing permission but its Terms of Service generally forbid to use its output to reconstruct 3D models.
3) Image-based geometric modeling from UAV video by processing frames with Metashape software and obtaining a textured mesh surface to be imported in a proper 3D environment (Figure 3). This workflow required about one half an hour of time, but this may vary depending on the number of frames to be processed and the desired output quality (in this case, 30 frames – extracted one frame per second from the video – were processed with default setting in Metashape). The data were acquired by the B4R project's official photographer, Mr. Nicola Cagol, on 05/11/2021 during his photographic campaign.

Fig. 2: 3D textured mesh surfaces of the same portion of Peio municipality (pink-colored, in the upper Val di Sole) from rapid satellite image processing, according to the first workflow on the left (a) and to the second workflow on the right (b). To facilitate the visual comparison between these two outputs, the 3D mesh obtained from the second workflow was cropped according to the same rectangle of the first.

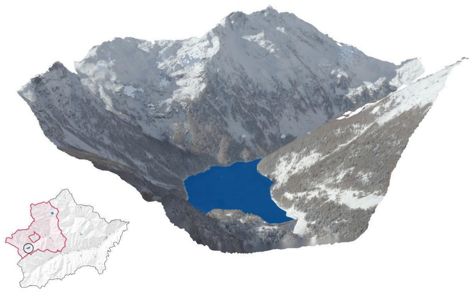

Fig. 3:
3D textured mesh surface of Pian Palù lake in Peio municipality (pink-colored in the upper Val di Sole) from UAV image data. The lake surface was digitally filled with a blue color in the post-production of the figure.

3 Discussion

Although some of the presented techniques were originally developed for photogrammetric applications (i. e., the image-based geometric modeling), this contribution focuses on their ability to support the updated 3D documentation of the Val di Sole and improve the visualization of information from existing databases and available sensors, rather than on the accuracy of the result.

Indeed, the textured 3D mesh surfaces of valley's portions are obtained without conducting professional survey campaigns and could now be managed in a proper 3D environment (as Rhinoceros software, having many specific plugins for the purpose) for iteratively modelling, rendering, and testing various landscape design solutions. These digital models are relatively easy to obtain because, as illustrated, the procedures involve few steps and software commonly used in the field of digital landscape architecture (i. e., Lands Design, Rhinoceros); also, regarding the use of specific photogrammetric reconstruction software that may be less familiar (i. e., Autodesk Recap Photo and Metashape), the proposed workflows follow a standard procedure – loading photos, aligning photos, building dense point cloud, building mesh, building model texture – with default setting. Finally, in the case study of the Val di Sole's inner area, the resulting models benefit from more up-to-date data than those distributed by the province, although they do not reach that level of detail and control. Nevertheless, since the requirements of quality and metric precision for the output can sometimes be more relaxed in landscape planning and design applications, the actualization of information technologies' affordances in intermediate, rural and mountain areas may rely also on citizen participation that would ensure extra data and information, as in the third presented workflow in which data acquired during a documentary photographic campaign were used for modelling purposes.

Since this investigation about landscape 'intelligent' models is still ongoing as part of a doctoral thesis, the 3D mesh surfaces generated with the proposed workflows are not yet linked to the semantic information stored in the quali-quantitative B4R database, mainly because of the open issues related to Landscape Information Modeling (LIM). However, the digital mapping, oriented at increasing awareness of individuals and organizations about the use of environmental resources in the Val di Sole, proved to be an effective information tool – both during and after the B4R co-design phase – by prompting the inclusion of the (thermal) water element in the communication about the valley by territorial promotion agencies.

4 Conclusion and Outlook

Novel opportunities are emerging due to the ongoing digital transformation and the rise of smart technologies, which promise the implementation of 'intelligent' solutions for landscape planning and urban design, even in areas suffering from territorial imbalances. However, in complex and poorly infrastructured systems as inner areas a smart development has to follow local conditions, knowledge and needs because of the lack of adequate technological tools, networks, and structures. This contribution illustrated how the digital mapping and modelling of marginal landscapes can effectively rely on already available data from different sources, in addition to the official data provided by public administrations which here are often outdated: specifically, elevation data (i. e., terrain, buildings) from remotely sensed images can be used in expeditious and inexpensive workflows for 3D landscape reconstructions. Moreover, the global availability of smartphones, cameras and drones has transformed even non-professionals citizens into 'sensors': images collected and shared by tourists could be used to improve results obtained using remotely sensed images by integrating different point-cloud models from collaborative photogrammetry, also enabling the monitoring of places, with particular regard to local resources exposed to hazards.

The long-term vision of this research goes towards the application of the Digital Twin (DT) paradigm (Batty 2018) to marginal landscapes: beyond the buzzword, a loop in which data collected in real-time from the real world are processed to inform a virtual counterpart and, at its highest level of 'maturity', allow autonomous operations. Originally born in the field of production engineering, DTs are now applied to towns, cities, and even nations. The idea of a Territorial Digital Twin (TDT) – both a three-dimensional queryable repository of knowledge (i. e., an information system), and a simulator (i. e., a model) of more resilient futures for the Val di Sole – requires further development but would contribute to closing gaps in strategic planning and process management at the landscape scale, also overcoming issues connected to the digital divide. It could support operative actions in collaborative decision-making sessions towards the management and design of complex territorial transformations from a truly holistic and integrated perspective. Indeed, by improving accessibility of distributed data and making the fruition of information more intuitive and interactive, in future research TDT could assist understanding of risk-related components in the territory by local stakeholders, prompt concerted spatial planning actions, and help assess if investments are risk-informed.

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