Feel the Context! *Ex situ* Horizon Reconstruction in Mountain Landscapes for Bioclimatic Design

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Abstract: Bioclimatic design aims to create environmentally harmonious structures by integrating with local climate. This approach relies on passive and active strategies for sustainability, emphasising factors like proper orientation, natural light utilisation, and understanding solar movement. Sun charts assist in analysing the sun's path, crucial for architects and urban planners. Traditional on-site methods using a compass and clinometer are time-consuming, prompting the adoption of digital approaches, such as GIS and 3D modelling. This study proposes an off-site procedure combining QGIS to estimate visibility parameters for nearby and distant obstructions, enhancing accuracy and efficiency, and Grasshopper components to finally plot a Waldram diagram. The workflow, developed and tested in the mountain landscape of the Autonomous Province of Trento (Italy), combines on-site and digital data, underscoring the importance of precise skyline delineation for effective bioclimatic design.

Keywords: Sun chart, horizon shading, DSM, visibility analysis

1 Introduction

Bioclimatic design is an architectural and urban planning approach that focuses on creating buildings and spaces that seamlessly integrate with the local climate and environment (OLGYAY 2015). Its core objective is to harness natural resources, curtail energy consumption, enhance the comfort and well-being of occupants, and simultaneously minimise the ecological footprint. In the pursuit of these goals, bioclimatic design hinges on the prudent use of both passive and active strategies that, collectively, lead to sustainability and energy efficiency. Anchored in this approach are several cardinal principles such as: the correct orientation of buildings, the use of natural light and shading techniques, and a deep understanding of the sun's trajectory across the sky (MAZRIA 1979).

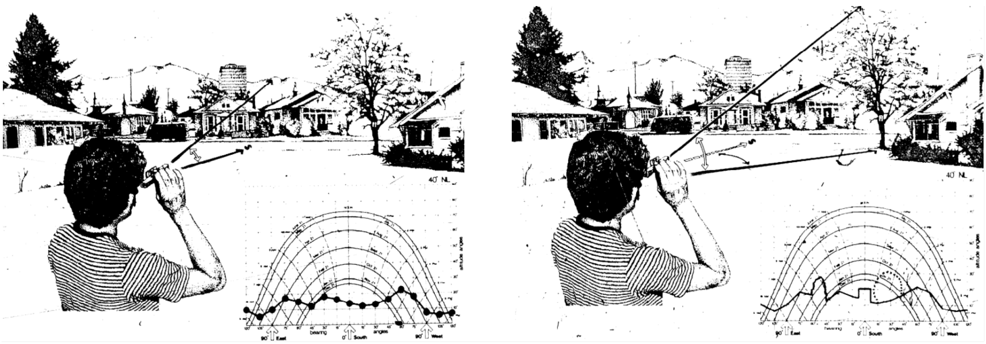

Fig. 1: Plotting the skyline (left) and the obstructions (right) on site (images from MAZRIA 1979)

Journal of Digital Landscape Architecture, 9-2024, pp. 441-448. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-752-6, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537752040.

Specifically, to comprehend the ecliptic of the sun through the sky throughout the year at a particular latitude and identify the skyline and obstructions, sun charts are fundamental tools for practitioners (e. g. architects, urban planners, and energy analysts), delivering location-specific insights to optimise design choices (MARSH 2005, PISELLO et al. 2012, CHAN 2019, DANESHFAR et al. 2022). Traditionally, the task of determining and recording azimuth and altitude angles of visible obstructions to obtain the insolation of a location is fulfilled directly on site respectively with a compass and a clinometer (Fig. 1). However, this procedure can be time-consuming and subject to potential inaccuracies, arising from fluctuating weather conditions and visibility issues. The purpose of this study is indeed to propose a semi-automated workflow, bringing together wide-area GIS representations and localised 3D site representations, to define the obstructions (natural and artificial) without necessarily going to the site with the clinometer and the compass.

2 Background and Aim

With the digital turn, the task of plotting the skyline and obstructions for the studied location can also be achieved with alternative digital approaches (VEGA-GARITA et al. 2023): from the use of hemispherical capturing devices to 3D modelling (both via directly and indirectly acquired data), through GIS analysis (Fig. 2). In particular, *ex situ* workflows for the horizon reconstruction – taking advantage of publicly available geospatial data, such as Digital Surface Models (DSMs) – are promising, also in terms of accuracy (MIRA et al. 2022), and could limit the need for on-site acquisitions when circumstances render visits inefficient or impractical (e. g., early-stage design, inaccessible location). Moreover, satellite or airborne remote sensing data already enable rapid and low-cost 3D digital reconstructions of built and natural environments (CHIONI & FAVARGIOTTI 2023).

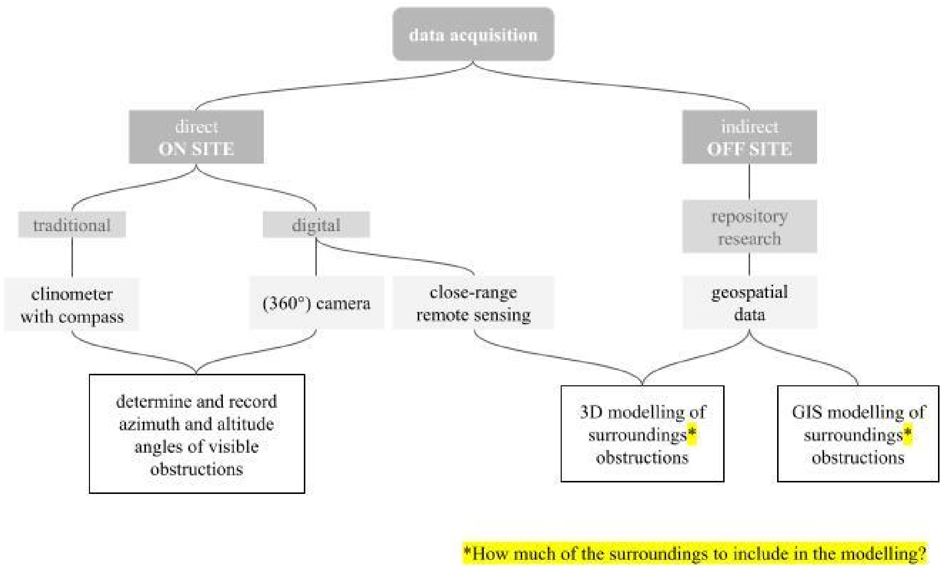

Fig. 2: How to acquire the needed data for horizon reconstructions

The main issues connected to off-site procedures remain the quality of the available data (mainly in terms of resolution and updating) and the uncertainty about how much of the surroundings should be included in the modelling to avoid errors. This last aspect particularly concerns mountain environments, not much investigated in current literature, where topography – even of very distant elements – can greatly affect the simulations.

Indeed, state-of-the-art freely available tools seem to only partially address these concerns as they are developed for specific purposes: the open-source *PVGIS* (Photovoltaic Geographical Information System) online resource, provided by the European Commission (https://re.jrc.ec.europa.eu/pvg_tools/en/, 30 October 2023), calculates the effect of terrain features (e. g., local hills or mountains) on solar radiation using data with up to 90 metres of resolution, not taking into account shadows from nearby objects such as buildings and trees; the *Dynamic Overshadowing* web app (https://drajmarsh.bitbucket.io/shading-box.html, 30 October 2023) generates real-time interactive shading masks based on blocks model. From the same developer, the *Tree Generator* web app (https://drajmarsh.bitbucket.io/tree3d.html, 30 October 2023) simulates dynamic shading effects of growing trees and/or foliage caducity. Both the *PVGIS* and the *Dynamic Overshadowing* allow the user to upload, respectively, their own horizon information and their 3D site model to provide for the lack of data and enrich the output simulation.

Finally, as designers who would like to avoid using third-party tools to manage the simulation themselves, we built for this research a script with Grasshopper (GH) – that leverages *Ladybug Tools* (https://www.food4rhino.com/en/app/ladybug-tools, 09 January 2024) and native GH components – to produce Waldram diagrams for selected locations (Fig. 3). Named after its inventor Percy Waldram, the Waldram diagram is a graphical method to measure daylight and to visually represent the amount of light from the sky at any location (WALSH 1961), i. e. a sun chart plotted on a Cartesian plane, with the addition of obstructions. The basic data needed in input are the topographical surface of the site and the 3D geometry of its buildings, which can be retrieved from OpenStreetMap (OSM) directly in the Rhinoceros environment using, for example, the *Elk* plugin (https://www.food4rhino.com/en/app/elk, 09 January 2024). However, only a limited portion of the surroundings, without buildings and trees, can be downloaded from OSM ultimately resulting in simulation inaccuracies, as in the case of the Autonomous Province of Trento (Italy), a strongly mountainous area in the Alpine landscape; where a restricted 3D model of the terrain returns a distorted scenario of the actual solar radiation (Fig. 3).

Given this framework, the present contribution specifically aims to provide a procedure for cautiously estimating the minimum extent of surroundings that need to be considered to plot both nearby obstructions (such as buildings and trees) and distant ones (such as the skyline) in the sun's path at a given point of interest.

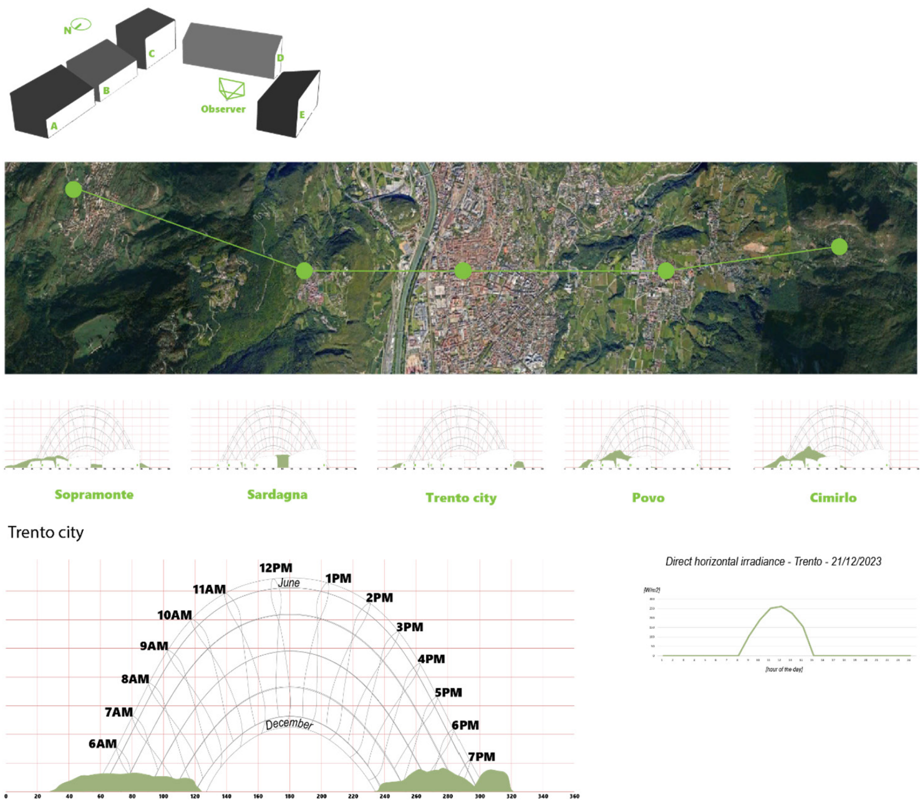

Fig. 3: (Top) Waldram diagrams for selected locations along a cross section of the Adige valley, in Trento; the same set of hypothetical buildings is used to make the different hamlets of the municipality comparable and focus on the changing topography retrieved from OSM. (Down) Taking a closer look at Trento city, without buildings, the Waldram diagram reveals it as very sunny throughout the year, but the irradiance graph shows that the hours in which direct sunlight can be enjoyed are very few, especially during winter.

3 Methodology

The proposed digital approach combines large-scale visibility analysis in a GIS environment with close-scale modelling in a 3D Computer-Aided Design (CAD) interface. It emulates the operation carried out in the field, when recording the profiles of visible obstructions, but utilises already available data, according to the off-site option, to operate visibility analysis on DSM with a popular QGIS plugin, *Visibility Analysis* (https://landscapearchaeology.org/qgis-visibility-analysis/, 30 October 2023). Indeed, all elements visible from a given point are those that cast a shadow on it.

When engaging in horizon studies, it is imperative to account for the range of vision, contingent on various factors, including the observer's elevation, proximity to objects, viewing direction, and atmospheric conditions (NIJHUIS et al. 2011). The arbitrary aspect that we aim to eliminate is the choice of the radius within which to conduct the analysis. The default radius proposed by the plugin is 5000 metres, which corresponds to the distance to the horizon from an average observer at sea level. This distance (d) can be calculated with a well-known formula, derived using the Pythagorean theorem: $d = \sqrt{[(r + h)^2 - r^2]}$, where r is the Earth's radius and h is the observer's height above sea level. In mountain contexts the observer and its surroundings are not at sea level, and thus the visibility radius can increase significantly, but how much?

An iterative approach is proposed, based on the analysis of the global DEM from Copernicus (https://spacedata.copernicus.eu/collections/copernicus-digital-elevation-model, 30 October 2023): if from the studied location the visibility radius of Mount Everest, the extreme shading element as the highest relief on the Earth's surface, actually encounter Mount Everest then this radius (about 340 km) is used for the analysis; otherwise, the highest relief falling within this distance is used to recalculate the radius within which this second relief can be seen. If the second relief still falls outside this radius, the process continues with a third relief, and so on, until the appropriate radius that considers the tallest feature capable of casting a shadow on the studied location is found. This analysis does not have to cover the entire circle defined by the radius but rather a sector determined by the site latitude and the sun path (e. g., in Italy this sector spans approximately 120° east to 120° west) (Fig. 4). Once the suitable area for visibility analysis is identified based on the global DEM, it can be helpful to use a higher resolution 'local' DSM to carry out a more precise analysis. It may be necessary to combine DSMs at various resolutions in order to optimise computation: indeed, it is advisable to have higher resolution in the immediate vicinity of the studied location, to account for nearby buildings and trees, and lower resolution in the distance where only the topographic profile really matters.

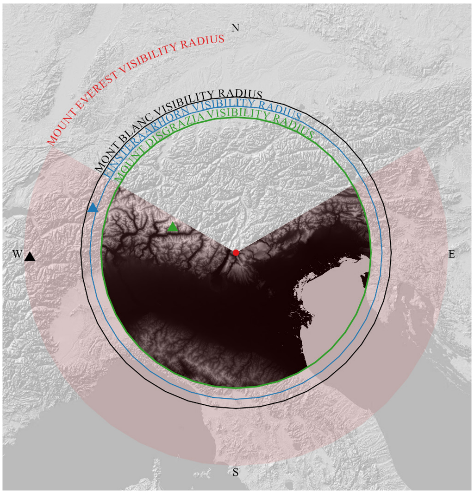

Fig. 4:
Graphic outline of the iterative approach applied to the case study of *Manifattura Tabacchi* in Rovereto (Autonomous Province of Trento, Italy), the red dot. As from the studied location Mount Everest does not fall into its visibility radius, the highest relief falling within this distance is Mount Blanc (the black triangle); this is used to recalculate the new visibility radius, but it still falls outside, as the third relief, Finsteraarhorn (the blue triangle). Only at the fourth iteration, the theoretically appropriate radius that considers the tallest feature capable of casting a shadow on the studied location (Mount Disgrazia, the green triangle) is found.

Once it has been determined what is visible, and therefore casts shadow on the site, it is possible to export the outer edges of the viewshed in, for example, Rhinoceros environment as a base for further bioclimatic analysis. Specifically, it is possible to use the aforementioned GH script (Section 2) to generate Waldram diagrams based on the DSM used for the GIS analysis, without recurring to OSM data.

4 Results

This research exploration was developed and tested in the case study of *Manifattura Tabacchi* in Rovereto (Autonomous Province of Trento, Italy), site already under study by the authors. First, on site data acquisition with a clinometer and a smartphone were performed, allowing to 'conventionally' reconstruct the sun's path for this location; then, after applying the iterative approach to find the appropriate radius, available DSM data with different resolutions from the National Institute of Geophysics and Volcanology (https://tinitaly.pi.ingv.it/Download_Area1_1.html, 30 October 2023) and the Autonomous Province of Trento (http://www.territorio.provincia.tn.it/portal/server.pt/community/lidar/847/lidar/23954, 30 October 2023) were combined and used to perform viewshed analysis (Fig. 5).

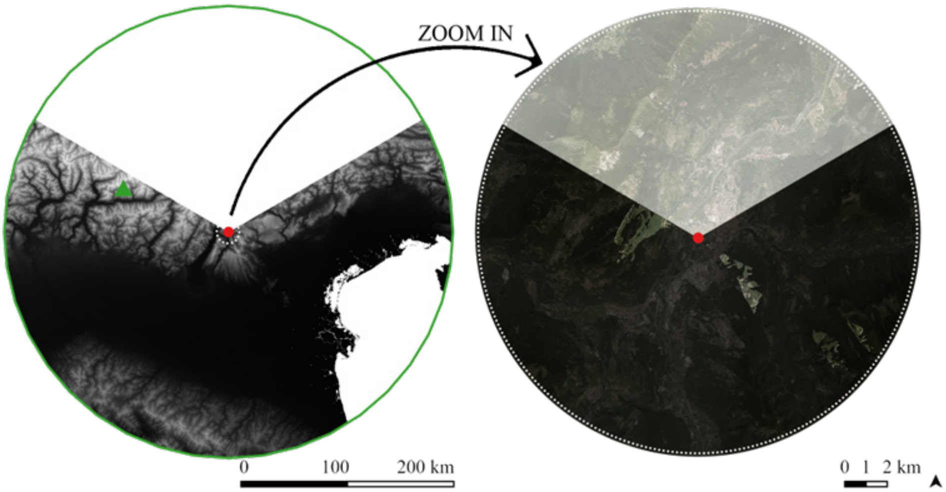

Fig. 5: Viewshed analysis on combined National DEM (with up to 10 metres of resolution) and Provincial DSM (with up to 1 metre of resolution): in the zoom (right), the transparent areas in the dark circular sector are the ones visible from the observer point (the red dot) at *Manifattura Tabacchi*

Finally, through the GH script in Rhinoceros, we produced a completely off site Waldram diagram from the same location in which we acquired data on site so that the results obtained from the two different procedures can be easily compared (Fig. 6). The script in principle also allows to distinguish obstructions between permanent natural elements (topography and evergreen trees), non-permanent natural elements (deciduous trees), and artificial elements (buildings); if the DSM contains this information (as in the case of that provided by the Autonomous Province of Trento), the visible obstructions can be plotted differently in the Waldram diagram to enhance the accuracy of the simulation, as they have different shadowing effects.

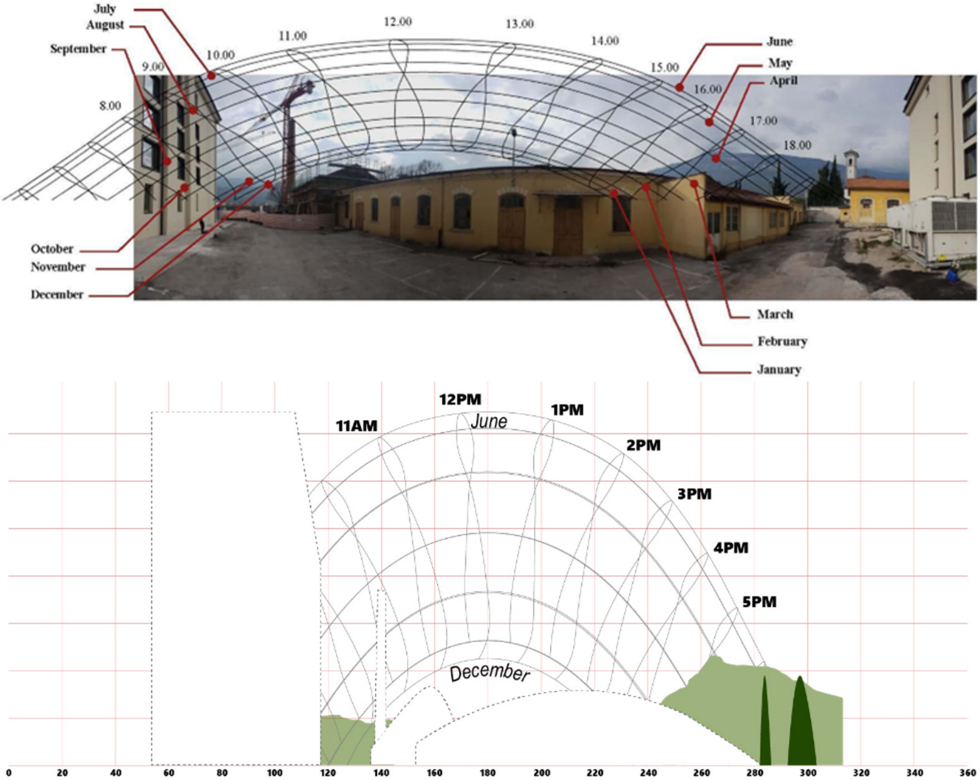

Fig. 6: Waldram diagrams from on site (top) and off-site data (down). The 'stretched' photo shows the obstructions from the observer's location, but also the unfavourable weather conditions during the site visit; the diagram resulting from the *ex situ* digital procedure accounts for all the visible obstructions from the observer's location, differently plotted according to their typologies.

5 Discussion and Outlook

The precise delineation of the skyline and the identification of obstructions (and possibly of their different obscuring characteristics) are essential components in the bioclimatic design toolbox. By embracing sun charts and adopting ex situ reconstructions, the research casts a spotlight on horizon study methods, and their need for precision; this that can be fulfilled through digital procedures using already available geospatial data (aware of their limitations, e. g., resolution and updating, lacking information about vegetation or built environment) and combining tools from different disciplines. Determining the minimum extent of the topographical surface that could affect the simulation in GIS, before modelling terrain, buildings and trees in CAD, saves both time and computational power, without coming at the expense of the final result's accuracy. As shown, considering an arbitrary portion of the terrain, in the off-site 3D digital modelling of the context, can lead to incorrect assumptions for the purposes of bioclimatic design, especially in mountain landscapes (Fig. 3). Future developments can transfer and scale the proposed approach to other mountain contexts in order to compare results from different case studies. Additionally, further developments could be done to make routine workflows merging wide-area GIS and localised 3D site representations, especially in small- or mid-sized professional practices, even if such fusions have become easier as advances in GIS software. Finally, the described semiautomated procedure can be very useful in the initial design phase to define the obstructions (natural and artificial) without going to the site with the clinometer and the compass; however, for effective bioclimatic design it is essential for designers to still visit the site personally, multiple times during various seasons and conditions, ensuring a direct connection with the studied location.

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