



Original Research

Alpine Huts, Built Elements in the Landscape: The Relationship Between Architecture, Nature, and Sustainability in High-Altitude Mountains

Elisa Bernard, Iuav University of Venice, Italy

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Abstract: Alpine huts are territorial outposts built in remote high-altitude locations to support exploring and experiencing hardly accessible sites with remarkable natural and scenic importance. Due to their location in isolated and wild territories, relevant design issues often emerge in the dialogue between these built artifacts and their fragile natural contexts. Given that the Alpine countries acknowledge the Alpine environment and landscape as assets to be protected, this article investigates the means and concrete solutions suggested to support this objective in the design, renovation, and management of Italian Alpine huts. The regional regulations and mountaineering associations' guidelines for hut design are therefore analyzed and evaluated in terms of environmental protection and landscape conservation. The study compares the contents of these documents, highlighting gaps and recurring topics relevant to the design, construction, and management of Alpine huts. The results reveal different levels of attention and sensitivity to environmental and landscape issues. The analysis of the documents highlights that the guidelines offer the most detailed recommendations on these matters, defining objectives, criteria, and actions to undertake. Particular attention is given to the use phase of the building, whereas end-of-life actions are less explored. Simultaneously, a partial vacuum concerning landscape protection emerges. Additionally, the investigation highlights the positive outcomes of collaboration between local authorities and mountaineering associations. It also shows how identifying additional criteria and actions, including those deriving from the architectural practice, could close some of the identified gaps, ensuring that Alpine huts continue to promote access to remote areas while safeguarding the environment and visual integrity.

Keywords: Architectural Approach, Remote Construction, Mountain Hut, Wild Space

Introduction

The Relationship Between Man and High-Altitude Alps over Time

All around the world, high mountain regions are characterized by a considerable amount of unspoiled natural spaces rich in biodiversity, the significance of which stems from the ecosystem services they provide, offering people both direct and indirect benefits (Ioan et al. 2025). Although the verticality and planimetric extension of these natural formations vary across different continents, forming unique and articulated natural landscapes, mountains are characterized by common features—including rugged terrain and steep slopes. In this sense, “their beauty is raw and alluring, but equally forbidding and threatening” (Stahr and

Langenscheidt 2015, 2). The topography of these regions not only defines distinctive landscapes but also creates areas that are both wild and complex. Besides enhancing their aesthetic value, the elevated geographical locations, rugged topography, and extreme weather conditions make these territories difficult to access. Because of their orography, many mountain regions have no road access for cars and can only be accessed by walking several hours along steep and exposed paths. For these reasons, the relationship between man and mountains has always been very complex, and mountains still represent a natural barrier to communication networks and settlements.

Despite the cultural and orographic diversities between the various continents, “the earliest interactions between mountain and man were of religious and mythical nature” (Stahr and Langenscheidt 2015, 2). Their hard-to-reach locations, coupled with the frequent occurrence of intense atmospheric phenomena and climatic conditions deemed incompatible with permanent dwelling, led to the perception of high mountains as dangerous places, often associated with a sacred meaning (Gunzburg and Brady 2022).

Starting from the eighteenth century, a strong interest in the discovery and study of the high altitudes of the European Alps emerged. This phenomenon led to the production and dissemination of paintings and writings celebrating high mountain regions. Over time, authors contributed significantly to the appreciation of Alpine territories, highlighting not only their beauty but also their geomorphological characteristics (Viollet le-Duc 1876; Ruskin 1856), interpreting their forms as a source of inspiration for architecture (Taut 1919) and consolidating the perception of high mountains as sublime places (Bodei 2008). Naturalists, geologists, and nobles began to cross the boundaries of the pastures to explore more elevated regions. During these travels, they used natural rock shelters or temporary tents to rest and protect themselves from weather conditions (De Rossi 2014). Since these earliest explorations, the importance of defining strategic spots along the routes became clear. Over time, the increase in mountaineers and the advent of early tourism led to the construction of structures known as huts.

Today, huts are an integral part of the Alpine landscape (Figure 1) and illustrate the evolution of the relationship between man and these mountains. These structures, which originated as simple shelters for mountaineers and scientists, have gradually evolved into permanent buildings in the Alpine territory (Dini and Girodo 2018). Nowadays, huts are architecture with a historical and cultural value (Salsa 2013; Aschaber et al. 2022) and facilitate access to remote high-altitude locations, offering hospitality to more and more mountaineers and hikers. Nevertheless, the aesthetic value and ecological significance of the Alps are as relevant as their actual and future fragility. Their vulnerability is currently increasing, mainly due to climate change, whose effects are becoming more frequent and intense, especially in high-altitude territories (European Environment Agency 2024; Nigrelli and Chiarle 2023; Adler et al. 2022; Hock et al. 2019; Beniston et al. 2018).



Figure 1: “Chiggiato” Hut, Marmarole (1911 m a.s.l.)

Source: Bernard 2023

The importance of preserving the Alps and their ecosystems is emphasized in National and European protocols that specifically commit to defining the aspects of these areas to be protected and conserved. A growing focus on the implementation of sustainability strategies, particularly regarding resilience to climate change, emerges in recent policies for the European Alps (Hock et al. 2019). Many programs and projects have been developed within this framework, such as the “Alpine Climate Board” (Bornemann et al. 2024). Most of these initiatives are grounded in the political measures outlined by the 1991 Alpine Convention, which is still considered a key document for the Alpine region. The “Nature Protection and Landscape Conservation” (1994), “Spatial Planning and Sustainable Development” (1994), “Tourism” (1998), “Energy” (1998), and “Soil Conservation” (1998) are some of the specific protocols developed based on the Convention. These documents highlight some of the relevant issues shared by the Alpine countries regarding the preservation and sustainable development of mountain areas. Although they address the entire Alpine region, other cooperation outlined specific objectives in a set of distinct altitude ranges—among all, the highest ones.

Mountaineering associations (clubs) contribute significantly to defining specific management and conservation measures for the high-altitude Alps. National Alpine clubs, made up of volunteers, are specifically tasked with the maintenance of these areas. Their primary activities include the coordination and promotion of hiking activities, the management of hiking trails, and the administration of many built structures, such as huts. At the European level, they are represented by the Club Arc Alpin (CAA), which brings together the various Alpine-country associations. Mountaineering, nature conservation, regional development in the Alps, and Alpine culture are the main areas in which the association focuses its efforts to achieve the objectives of the Alpine Convention. To this end, specific guidelines have been developed to guide activities in the various countries in line

with common objectives, particularly regarding environmental protection and landscape conservation. These two aspects are recurring themes in the guidelines that apply to facilities providing accommodation and support for recreational activities in high mountain areas (CAA 2017, 2018)—that is, huts.

In remote and difficult-to-access regions such as the high-altitude Alps, huts illustrate how the complex relationship between man and mountain evolved. Nowadays, their number and distribution across the Alpine chain act as a network of structures facilitating experiencing the mountain, while the architecture embodies significant historical and cultural values. However, these structures are located in a fragile context in which environmental protection and landscape conservation must play a central role. While the presence of huts facilitates people's enjoyment of remote places and learning about unique natural environments, it also impacts on the local territory. It is, therefore, essential to ensure that these structures continue to fulfill their role without compromising the natural and cultural heritage of the Alps. In this perspective, the design, construction, and management of huts in the high Alpine regions are also significant. Currently, this issue is particularly relevant, as many huts need renovation or even reconstruction works to comply with changes in the target users' profiles and structural and safety standards, especially to adapt to the effects of climate change. Permafrost melting represents one of the most significant and discussed problems, as it contributes to the destabilization of infrastructures in high-altitude mountains—including huts (Miczka et al. 2025; Duvillard et al. 2015, 2019; Mair et al. 2011). If all design and construction choices produce long-term environmental impacts, vulnerable and fragile contexts, as the Alpine one, require even more conscious and appropriate evaluations. Therefore, mountain huts should be conceived and designed to minimize their footprint during their whole life cycle.

Italian Mountain Huts' Design in the Current Scenario and the Related Debate

Huts are high-altitude, isolated buildings that provide shelter for mountaineers and hikers. Their spatial distribution follows the morphology of the mountain chain, and, today, more than 770 of them offer overnight accommodation above 1,500 m a.s.l. in the Italian Alps alone (Bernard et al. 2025). Due to their geographical location and altitude, they are generally not connected to primary infrastructure such as roads, water, and electricity networks; therefore, their position brings both advantages and challenges. These structures facilitate experiencing remote places and promote awareness of nature. On the other hand, they generate environmental impacts related to construction activities and natural resources' management, including the use of protected land, interference with local habitats, alterations to the visual and perceptual qualities of the landscape, waste and noise pollution, and water contamination (Trento Province et al. 2013; Aschaber et al. 2022). Therefore, the design, construction, and management of mountain huts are particularly sensitive issues.

The earliest mountain huts in the Italian Alps were constructed in the second half of the nineteenth century, using primarily local materials. Stone, which was available on site, was widely used alongside wood, which is lighter to transport and is easily accessible nearby (Saglio 1964). These structures were simple and functional, consisting of compact shapes and robust walls capable of withstanding extreme weather conditions. Small openings helped limit heat loss. The internal layout responded to the primary needs of efficiency and functionality in line with their purpose as shelters (Dini and Girodo 2018) (Figure 2).

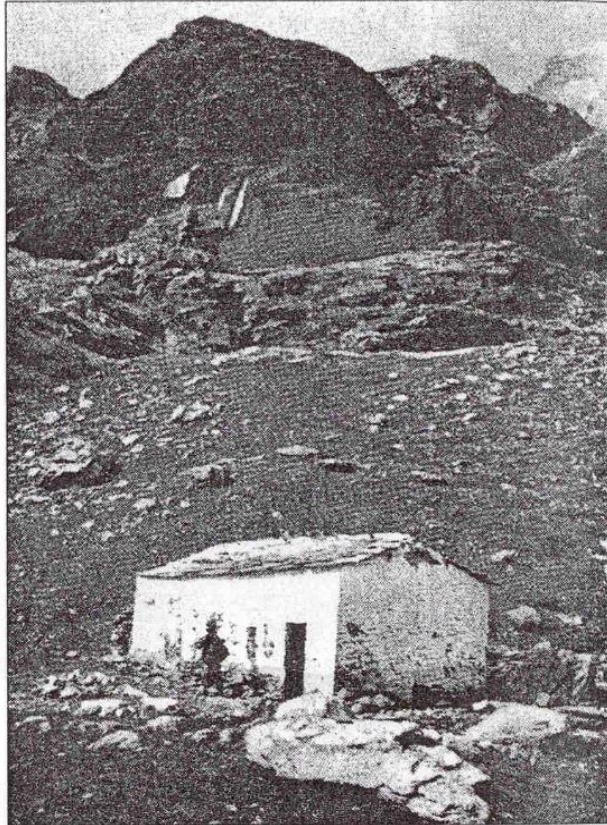


Figure 2: “Dell’Alpetto” Hut, Monviso (2268 m. a.s.l.)¹

Source: Italian Alpine Club Historical Archive

During the twentieth century, high mountains gradually became laboratories for experimentation and technological innovation. New materials and construction techniques were introduced in the architecture of mountain huts (Gibello 2011). The use of helicopters enabled the transport of nonlocal materials to high altitudes. These materials offered better

¹ Built in 1866 by the Italian Alpine Club to support the ascent to Monviso, it is considered the first Italian mountain hut. The building has a load-bearing structure made of local stone. Although it no longer serves its original purpose, the building is now preserved as a museum.

performance and greater resistance to extreme weather conditions. Thus, even in high-altitude contexts, bricks and reinforced concrete became common materials for load-bearing structures, alongside steel and other metal claddings for external shells (Figure 3). Prefabrication also reduced construction time and limited construction workers' exposure to high altitudes (Dini et al. 2018).



Figure 3: "Vittorio Emanuele II" Hut, Gran Paradiso (2735 m a.s.l.)²

Source: Bernard 2019

Currently, most interventions on mountain huts focus on existing buildings rather than new constructions (Salvalai and Gadusso 2024), and aim to make them comply with regulations, improve energy efficiency, and adapt them to the needs of new users. Upgrades often entail lateral extensions and elevations (Giacomelli 2020), clearly showing the hut's transformation phases over time (Figure 4).

² The construction of the hut, completed in 1961, represented the first use of steel as external shell in a hut. Previously, steel had only been used in bivouacs. The building has a load-bearing masonry structure with steel and stone external cladding.



Figure 4: “Maria e Alberto ai Brentei” Hut, Dolomiti di Brenta (2182 m.a.s.l.)³

Source: Umberto Isman, Planet Mountain Website

In other cases, although less common, demolition and reconstruction are chosen. This approach enables the design of internal spatial layouts that comply with current health and safety standards and allows the use of materials and construction techniques that minimize environmental impact and improve energy efficiency.

Both approaches highlight the complexity of design choices, not limited to technical and functional aspects related to nature preservation, but also involving aesthetic and territorial issues. The recent reconstruction of the Santner refuge represents a relevant example (Figure 5). From the outset, the project raised concerns among hikers, architects, and other mountain enthusiasts, yet it was ultimately realized. The most debated issues revolve around the presence and visual impact of contemporary architecture within the Alpine high-altitude landscape, fueling the already animated discussion concerning the approach in the transformation of historic mountain huts (Cantieri d’alta quota 2013).

However, the current debate concerns not only the architectural form of huts, but also how they are built and managed. This includes optimizing water and energy resources, which are essential for minimizing the impact on surrounding ecosystems (Reymond et al. 2024). In this sense, the design of huts is an area where environmental and landscape issues come together, in line with more general considerations on sustainability in mountain territories

³ Completed in 2022, the renovation of this building preserved and adapted the original structure. The dining room was expanded with an addition to the existing structure. A new winter bivouac was constructed in a separate building in front of the hut.

(Dini and Girodo 2018). The issue of sustainability is now central, as highlighted at the 101st conference of the Italian Alpine Club (CAI), “La montagna nell’era del cambiamento climatico” [Mountains in Era of Climate Change], especially given the transformations imposed by climate change (CAI 2024).



Figure 5: “Santner Pass” Hut, Catinaccio (2734 m a.s.l.)⁴

Source: Bernard 2022

Nowadays, mountain huts represent an architecture that engages with significant cultural heritage while embracing innovation and ecological responsibility. Originally built as simple shelters based on vernacular practices, these structures have evolved into buildings that integrate contemporary materials and technologies. However, their presence at high altitudes needs to respect the alpine region and natural landscape, both of which are culturally and ecologically significant, especially in the context of territorial transitions due to climate change scenario (Schickhoff et al. 2021).

⁴ The new building, completed in 2018, replaces the previous hut, which was demolished. The structure has a wooden frame and a steel external shell.

Starting from this premise, the study aims to analyze the existing guidance material supporting the design and management of Alpine huts, in order to determine whether instructions addressing the identified needs are already provided to designers. It also asks: what design approaches, operational measures, and technical solutions are currently suggested for Italian Alpine huts to respect environmental protection and landscape conservation in high-altitude fragile contexts?

Materials and Methods

To address the research question, an analysis of the main regulations specific to these structures and the guidelines provided by mountain associations was carried out. The Italian Alps were chosen as the case study for this analysis; therefore, the examined documents are those related to the Italian Alpine Regions (Figure 6).

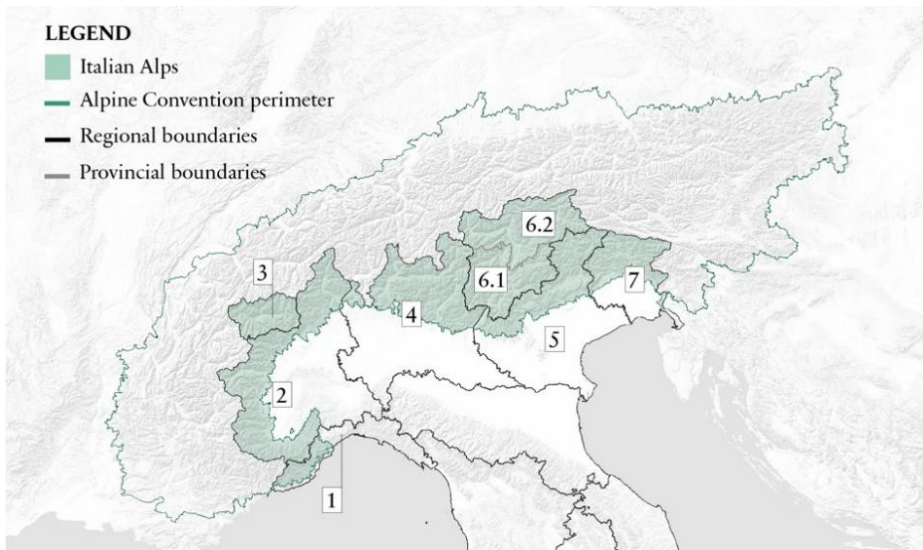


Figure 6: Map of the Italian Alps and Italian Alpine Regions⁵

National and regional regulations are key tools through which public institutions oversee, regulate, and often incentivize the construction and management of huts in accordance with environmental and landscape values. Concurrently, guidelines, despite their nonmandatory nature, are other instruments that suggest design approaches and criteria for evaluating the architectural quality of these buildings, as well as their impact on the territory. These tools assist designers in interpreting and applying regulations consistently within the unique Alpine context.

⁵ The Regions indicated on this map are: (1) Liguria; (2) Piedmont; (3) Aosta Valley; (4) Lombardy; (5) Veneto; (6) Trentino-Alto Adige (6.1. Trento province; 6.2. Bolzano province); and (7) Friuli-Venezia Giulia.

To establish a clear framework for the study, it was necessary to define the structures to be regarded as huts in the context of the research. The Italian “Codice del Turismo” [Tourism Code] (D. lgs. 2011 n.79) categorizes these structures according to their mode of access. The code provides a dual definition of a hut, which is also used in most regional regulations: “rifugio escursionistico” [hiking hut] and “rifugio alpino” [alpine hut]. Hiking huts “are accommodation facilities...suitable for offering hospitality and refreshments to hikers in mountain areas that are favorable for climbing, served by roads or other ordinary vehicles” (D. lgs. 2011 n.79, art.12), while alpine huts are “accommodation facilities located in high mountains, outside urban centers...designed for accommodation, refreshment, and mountain rescue, and must be managed and open to the public for limited periods during the tourist seasons” (D. lgs. 2011 n.79, art.12). Given the investigation interest in structures that facilitate access to remote and difficult-to-reach places, this analysis was carried out on alpine huts as they are located at high altitudes and are not served by roads.

At the national level, apart from the definition of a hut, there are no regulations for the related territory overseeing the construction of huts; the only reference to these structures is the fire protection norms (D.M. 236/1989). From a landscape perspective, Alpine areas located over 1,600 meters above sea level are included among the areas subject to landscape protection (D. lgs 22/2004, n.42, art.142). However, no design provisions are identified for buildings at these heights. More detailed regulations are mainly provided by Regions, which independently establish their own construction and design requirements. As a result, the Italian framework for high-altitude mountain huts is characterized by a complex and fragmented network of regulations (Gibello 2016).

In addition to the Regions, mountaineering associations, especially the CAI, play a key role in coordinating construction and renovation work on mountain huts. The “Regolamento delle strutture ricettive del Club Alpino Italiano” [Regulation for the accommodation facilities of the Italian Alpine Club] (CAI 2021) is the only one relating to alpine huts applied at a national level and includes, in the Annex 2, the “Linee guida per gli interventi di ristrutturazione dei rifugi” [Guidelines for the renovation of mountain huts]. However, this document only applies to structures owned by the CAI and is not mandatory for all mountain huts in Italy, most of which are publicly owned (regional, provincial, or municipal) or privately owned. Additionally, one local authority developed its own guidelines, in cooperation with the “Società Alpinisti Tridentini” (SAT) mountaineering association—the “Linee guida per interventi di ristrutturazione e/o ampliamento di rifugi alpini secondo i criteri di sostenibilità” [Guidelines for the renovation and/or extension of mountain huts according to sustainability criteria] (Trento Province et al. 2013). These guidelines stand out for their completeness, integrating sustainability criteria and providing a detailed reference for renovation and extension projects, applicable even to huts not owned by the CAI.

Given the depicted framework, the present analysis focuses on regional regulations and Alpine Club guidelines (Table 1). This enabled a more comprehensive analysis to understand

how the design and management of mountain huts are addressed, and which strategies, methods, and approaches are explicitly identified to support environmental protection and landscape conservation.

Table 1: List of Regulations and Guidelines Sources

<i>Local Authorities</i>	<i>Document</i>
1. Liguria Region	- Regional Council Decree n.346 del 2017,n. 737 del 2018,n.423 del 2019, and n. 199 del 2022 (<i>Implementing provisions for the regulation of other accommodation facilities as well as furnished apartments for tourist use under l.r. November 12, 2014 no.32</i>) - Implementation rules of the Regional Landscape Plan
2. Piedmont Region	- Regional Regulation, March, 11 2011, n. 1/R. (<i>Requirements and procedures for the operation of mountaineering accommodation facilities as well as technical, building, and sanitation requirements necessary for their operation</i>) - Implementation rules of the Regional Landscape Plan
3. Aosta Valley Region	- Regional Law, del May 29, 1996, n. 11 (<i>Discipline of extra-hotel accommodation facilities</i>) - Regional Law, January 21, 1997 n. 2 (<i>Definition of sanitation requirements, including those related to drinking water supply and discharges, as well as safety requirements</i>) - Territorial Landscape Plan
4. Lombardy Region	- Regional Law, October 1, 2015, n. 27 (<i>Regional policies on tourism and attractiveness of the Lombardy region</i>) - Regional Regulations, August 5, 2016, n. 7 (<i>Definition of services, quality standards, and mandatory minimum equipment of youth hostels, vacation homes, and apartments, Lombardy guesthouses, lodges and bed and breakfasts, as well as structural and hygienic-sanitary requirements of mountaineering and hiking refuges in implementation of Article 37 of Regional Law October 1, 2015, No. 27</i>) - Regional Spatial Plan
5. Veneto Region	- Regional Law, November 4, 2002, n. 33 (BUR n. 109/2002) (<i>Text of regional laws on tourism</i>) - Regional Council Decree nr. 109 del February 5, 2019 allegato A (<i>Unique classification requirements for mountain huts</i>) - Regional Territorial Coordination Plan
6.1 Trento Province	- Provincial President's Decree, October 20, 2008, n. 47 (<i>Ordinance of mountain huts, bivouacs, trails and via ferrata</i>) - Provincial Law, 27 maggio 2008 n.5 (<i>Approval of the regulations for the implementation of Provincial Law No. 8 of March 15, 1993, "Ordinance of mountain huts, bivouacs, trails and via ferrata," as amended by Provincial Law No. 20 of November 15, 2007</i>) - Urbanistic Provincial Plan
6.2 Bolzano Province	- Provincial Law, June 7, 1982, n. 22 (<i>Regulations governing mountain huts—measures to promote the province's mountaineering heritage</i>) - Territory and landscape

7. Friuli-Venezia Giulia Region	▪ Regional Law, December 9, 2016, n. 21 (<i>Regulation of regional policies in the tourism sector and attractiveness of the regional territory, as well as amendments to regional laws on tourism and productive activities</i>) ▪ Provincial President's Decree, April 24, 2018, n.0111/Pres. (<i>Approval of Regional Landscape Plan</i>)
Italian Alpine Club (CAI)	▪ Regulation for the accommodation facilities of the Italian Alpine Club and guidelines for the renovation of mountain huts (2021)
Trento Province, SAT and Habitech	▪ Guidelines for the renovation and/or extension of mountain huts according to sustainability criteria (2013)

Results: Analysis of Italian Existing Regulations and Guidelines

The regional regulations and existing guidelines listed in Table 1 were analyzed to understand if, and how, environmental protection and landscape conservation are included in the provisions for the design of Italian huts in the Alps.

Regional Regulations

Regional regulations for Alpine accommodation facilities set out a series of requirements that can be summarized in three sections (Figure 7):

1. Structural, technological, and minimum equipment requirements. This section lists the minimum services required for the operation and classification of facilities as mountain huts;
2. Health standards, aimed at defining the minimum surface standards that mountain huts must observe to ensure adequate health and well-being conditions;
3. Environmental sustainability requirements, aimed at ensuring respect for the environment in which the facilities are located.

The first section indicates the rooms within the building that are necessary for the structure to be considered as an Alpine hut. All Regions require a kitchen, a space for serving food and beverages, and a sleeping area, but some them require an emergency shelter to be always open, even during the winter season (7/8), an accommodation for the manager (6/8), sanitation facilities (5/8), a space for storing rescue equipment and materials (3/5), and a space and containers for separate waste collection (2/8). In addition to these requirements, other elements are necessary for the hut to function as a safety point, such as first aid equipment (6/8) and a helicopter landing pad (5/8). However, some Regions prioritize having a telephone system (7/8) and an external lamp (3/8) to ensure visibility at night or in difficult weather conditions. Regarding the technological requirements, the ones most mentioned are wastewater treatment systems (5/8), such as septic tanks or phyto-purification systems, and drinkable water (5/8). The latter can be provided by different natural sources, such as springs, surface runoff, lakes, snow or glacier melt, and rainwater collection. If water is not drinkable,

the Aosta Valley Region and the Trento Province require the use of adequate purification systems. Such systems may include automatic chlorination in stainless steel tanks or UV treatment, followed by storage in cisterns or collection tanks. Another requirement is a system for electricity generation (3/8). The Lombardy Region specifies this preference from renewable sources, while the Piedmont Region requires the use of low-noise and low-environmental-impact generators and class A appliances. The Liguria Region includes a requirement for a heating system. The health standards provided in the second section concern lighting in relation to window surfaces and the minimum dimensions of kitchens, toilets, bedrooms, and dining areas.

REGIONAL REGULATION CONTENTS	REGIONS							
	LIGURIA	PIEDMONT	AOSTA VALLEY	LOMBARDY	VENETO	TRENTO PROVINCE	BOLZANO PROVINCE	FRIULI VENEZIA-GIULIA
I. STRUCTURAL, TECHONOLOGICAL AND MINIMUM EQUIPMENT REQUIREMENTS								
Kitchen	●	●	●	●	●	●	●	●
Space for serving food and beverages	●	●	●	●	●	●	●	●
Sleeping area	●	●	●	●	●	●	●	●
Accommodation for manager	●	○	●	●	●	○	●	●
Sanitation	●	○	●	●	●	○	●	○
First-aid equipment	●	●	●	●	●	○	○	●
Space for storing rescue equipment and materials	●	●	○	○	●	○	○	○
Emergency/winter shelter	●	●	●	●	○	●	●	●
Helicopter landing pad	●	●	○	○	●	●	○	●
Outdoor lighting	●	○	○	○	●	○	○	●
Opening/exit in case of snowfall	○	●	○	○	○	○	○	○
Spaces and containers for separate waste collection	○	●	○	●	○	○	○	○
Electricity generation system	●	○	○	●	○	●	○	○
Heating	●	○	○	○	○	○	○	○
Telephone system	●	●	●	●	●	●	○	●
Drinkable water	●	●	●	●	○	●	○	○
Water purification system	○	○	●	○	○	●	○	○
Wastewater treatment system	○	●	●	●	●	○	○	●
II. HEALTH STANDARDS	●	●	●	○	●	●	○	●
III. ENVIRONMENTAL SUSTAINABILITY REQUIREMENTS								
Systems for the Recovery and Reuse of Rainwater	○	●	○	○	○	○	○	○
Grease trap/oil separator upstream of the wastewater treatment system	○	●	○	○	○	○	○	○
Heat recovery systems	○	●	○	○	○	○	○	○
Utilization of eco efficient building materials and techniques	○	●	○	○	○	○	○	○

Figure 7: Summary of Requirements Contained in Regional Regulations

The environmental sustainability requirements for mountain huts, described in the third section, are explicitly defined only by the Piedmont Region, which dedicates a specific section within the regulations for this type of requirement. The Region expressly demands the use of grease traps or oil separators upstream of the wastewater treatment system, as well as rainwater recovery systems that allow its further reuse through storage tanks and suitable devices for filtering rainwater and releasing “overflow.” Regarding electricity production, the use of heat recovery systems is required, with a preference for biomass heat generators. The use of eco-efficient building materials and techniques is also included among the sustainability requirements.

Guidelines

The two guidelines (CAI 2021 and Trento Province et al. 2013) were analyzed separately. The “Linee guida per gli interventi di ristrutturazione dei rifugi” [Guidelines for the renovation of mountain huts] (CAI 2021) identify three specific categories of requirements (Table 2):

- 1. Communication requirements, allowing the identification of huts managed by the association;
- 2. Functional requirements, listing rooms and building spaces recommended for huts to best serve their functions;
- 3. Environmental requirements, aimed at ensuring respect for the environment in which the buildings are located.

Table 2: Summary of Requirements Found Within the Italian Alpine Club Guidelines

<i>Communication Requirements</i>	<i>Functional Requirements</i>	<i>Environmental Requirements</i>
Chromatic reminders of social values	Winter room accessible from outside	Reduction of the use of fossil fuels
	Entrance filter space	Improvement of white and gray water storage
	Storage room for backpacks, boots, and technical materials	Reduction of the environmental impact related to the wastewater disposal cycle
	Availability of at least one toilet per floor	Improving the waste separation and disposal cycle
	Accommodations for manager and employees	

Communication requirements concern the chromatic references to the association’s social values. The functional ones recommend the presence of the following rooms and spaces in the building: a winter room accessible from outside, an entrance filter space, a storage room for backpacks, boots, and technical materials, one toilet per floor, and accommodations

for the manager and employees. As for the environmental requirements, the following measures are suggested for progressive implementation: reducing fossil fuels' use, improving white and gray water storage, reducing the environmental impact of the wastewater disposal cycle, and improving the waste separation and disposal cycle.

The analysis of “Linee guida per gli interventi di ristrutturazione e/o ampliamento di rifugi alpini secondo i criteri di sostenibilità” [Guidelines for the renovation and/or extension of mountain huts according to sustainability criteria] (Trento Province et al. 2013) outlines objectives, criteria to adopt, and the related actions to undertake (Table 3).

Table 3: Summary of the Objectives, Criteria, and Actions Defined in the Guidelines Developed by the Province of Trento in Collaboration with the “Società Alpinisti Tridentini” (SAT) and the Trentino Technology District Habitech

Objectives	Criteria	Actions
O1. Respect for the ecosystem <i>The objective considers aspects of the territory, minimizing the impact on land use and addressing possible impacts resulting from the construction activities and management of the building.</i>	A. Limit changes to the terrain's morphology	a. Avoid digging deep
		b. Design a compact footprint of the building
	B. Prevention of hydrogeological and avalanche risks	a. Design of protective structures
		b. Relocation of buildings
	C. Limit the area of construction activities	a. Minimizing on-site works
		b. Promote downstream processing
	D. Limit the impacts on the territory	a. Minimizing works in high mountains to limit construction time
		b. Choice of construction systems that allow for quick and easy assembly of building components
		c. Use of low-noise generators and machines
	E. Provide a suitable wastewater treatment system	a. Use of long-life technologies
		b. Separate water treatment
		c. Pretreatment with grease/oil separator and sludge separator
		d. Use of dry toilet
		e. Use of septic tank or biological treatment
		f. Treatment and disposal of sludge and solid content
	F. Limit noise impact	g. Where vegetation is present, a secondary treatment system with a drainage well or subirrigation can be provided
		a. Use of low-noise generators, and machines
		b. Raise visitor's awareness
O2. Sustainable provision and management of water	A. Selection of efficient water provision systems	a. Use of flow restrictors for water taps
		b. Use of water timers

<i>The objective focuses on the sustainable management of water, which is a limited resource in high-altitude areas. It emphasizes the importance of conserving, recovering and reusing water, and raising awareness among users.</i>		c. Use of dual flush toilet
		d. Use of dry system
	B. Selection and use of appliances	a. Water-efficient appliances
	C. Recovery and reuse of water	a. Collection of rainwater
		b. Reuse of gray water
	D. Provide a suitable wastewater treatment system	a. Use of long-life technologies
		b. Separate water treatment
		c. Pretreatment with grease/oil separator and sludge separator
		d. Use of dry toilet
		e. Use of septic tank or biological treatment
		f. Treatment and disposal of sludge and solid content
		g. Where vegetation is present, a secondary treatment system with a drainage well or subirrigation can be provided
	E. Raising hiker's awareness about water problems	No action defined
O3. Energy efficiency and selection of renewable energy sources <i>The objective encourages the use of energy-efficient practices and renewable energy sources to reduce consumption of fossil fuel and make remote hut self-sufficient.</i>	A. Decreasing the energy demand	a. Compact shell
		b. Study of shape in relation to orientation and exposure
		c. Study the layout of interior spaces in relation to exposure
		d. Selection of shell materials
		e. Maximizing sunlight exposure
		f. Use low-energy light bulbs
		g. Use of presence light sensors
		h. Use and natural light and of dimming systems
		i. Use energy-efficient appliances and use them correctly
		j. Use of "Greenhouse systems"
		k. Use of heat recovery systems
		l. Reduction in domestic hot water consumption
		m. Correct adjustment of mechanical ventilation
	B. Use of backup energy sources with minimal environmental impact	a. Use of a biomass boiler
	C. Selection of electricity from renewable sources	a. Photovoltaic, small-scale hydroelectric, small-scale wind, solar thermal, and biomass systems
O4. Selection of recycled and recyclable materials at end of life	A. Life cycle assessment of materials	a. Selection of materials that can be reintroduced into a new production cycle
		b. Choosing of durable materials
	B. Selection of sustainable materials	a. Use of local materials

<i>The choice of materials considers sustainability, efficiency, and durability, balancing technical performance with their environmental impact.</i>		b. Use of recycled materials
		c. Use of quickly renewable materials
	C. Selection of materials that are economical to transport (weight and dimensions)	a. Choosing of materials with lower CO ₂ impact during transport
	D. Reuse of site materials	a. Reuse of removed materials, with the same or a new function
O5. Minimization of the environmental impact of demolition <i>The objective encourages the selective demolition of hazardous, recoverable, or recyclable materials in order to reduce environmental impact and promote their reuse as byproducts or secondary raw materials.</i>	A. Choice of accurate selective demolition	a. Removal of hazardous and recyclable materials for reuse or recycling
O6. Minimizing the environmental impact of transport <i>The objective prioritizes construction techniques that facilitate assembly, disassembly, and transport. These techniques reduce the use of helicopters, minimize construction time and costs, and decrease environmental impact.</i>	A. Choice of construction systems that allow for quick and easy assembly of building components	a. Design of modular and dry-assembly systems
O7. Prevention of environmental pollution during management phase of the hut <i>The objective is applying sustainability to the daily management of the hut.</i>	A. Waste management	a. Adoption of preventive measures (avoid single-serving packages and the use of paper. Favor products in reusable containers and large packages)
		b. Raising visitor's awareness
		c. Sort waste
		d. Selection of sustainable products
		e. Decreasing water use
O8. Comfort level suitable for alpine huts <i>The objective is ensuring essential and functional comfort for visitors in alpine huts.</i>	A. Thermal comfort	a. Construction of a performance shell to minimize thermal loss
		b. Design windows with good solar exposure
		c. Use of ventilation systems in common spaces
		d. Design filter zone on the entrances

		e. Heated and ventilated room for drying clothes
	B. Acoustic comfort	a. Use of acoustic insulation in ceilings and walls between rooms
	C. Visual comfort	a. Design large south-facing windows in common areas
		b. Design views of landscape
	D. Healthiness of indoor environments	a. Use of products with low content of volatile organic compounds (VOCs)
O9. Protecting and enhancing the alpine landscape <i>The objective outlines criteria that prioritize landscape protection by harmonizing tradition and modernity. This is achieved through attention to morphology, choice of materials. Renovations and expansions should be limited to actual functional needs and the natural and built environment.</i>	A. In-depth study of the morphology of the site and its lithologies	No action defined
	B. Typological and formal study of existing structures to pursue a coherent integration of restoration or expansion works.	
	C. Selection of materials that are appropriate for the type of building and the surrounding natural environment	
	D. Protection of the natural environment in mountain areas	
	E. Respect for the essence of the Alpine environment and its building culture	
	F. Interpretation of original building types and forms in the context of contemporary architectural language	
	G. Close correspondence between form and function	
	H. Use of current technical expertise for sustainability	
	I. Minimize transformations	
	J. Be mindful of the morphology of the terrain	
	K. Respect for the slopes and lithologies that characterize the surrounding natural landscape	

The objectives, criteria, and actions defined by the guidelines aim to minimize the impact of construction activities on high mountain areas. Respect for the host ecosystem is the first objective identified (O1). The related criteria include: limited changes to the terrain’s morphology, prevention of geohydrologic and avalanche risks, limiting the area of construction activities and the impacts on the territory, providing a suitable wastewater treatment system, and limiting noise impact. The defined actions include avoiding of deep digging, the design of a compact footprint, the design of protective structures and possible relocation of the buildings, the minimization of work in high mountain, the promotion of downstream processing, the choice of construction systems that allow for quick and easy assembly of building components, and the use of low-noise generators and machines to limit the impacts on the territories. Other actions are related to limiting the noise impact with low-noise generators and machines, and with raising visitors’ awareness. The measures for

wastewater treatment are particularly detailed. These include use of long-life technologies, separate water treatment, pretreatment with a grease/oil separator and a sludge separator, use of dry toilets, use of septic tanks or biological treatment, treatment and disposal of sludge and solid content, and subirrigation if vegetation is present near the building.

For the sustainable provision and management of water, the selection of efficient water provision systems, the selection and use of appliances, the recovery and reuse of water, the wastewater treatment system, and raising awareness among hikers about water issues are the identified criteria (O2). Among the actions defined, in addition to those relating to wastewater treatment (the same as in O1E), particular importance is given to the selection of water-efficient appliances and provision systems, while no action is mentioned for raising hikers' awareness. The latter includes the use of flow restrictors for water taps, water timers, dual flush toilets, and dry systems. Other specific actions are the selection of water-efficient appliances and the collection of rainwater and the reuse of gray water.

Energy efficiency and selection of renewable energy sources are another objective described by the guidelines with three criteria (O3). When generators are necessary, they should only be used as backup, with biomass boilers representing a preferred option. To decrease energy demand, actions to implement include the design of a compact shell, the study of shape and layout of the interior in relation to exposure, the selection of shell materials, maximizing of sunlight exposure, the use of energy-efficient appliances, heat recovery systems, mechanical ventilation, the reduction of domestic hot water consumption, and the use of "greenhouse systems." Some other actions are related to lighting specifications such as the use of low-energy light bulbs, the presence of natural light sensors, and dimming systems. The selection of photovoltaic, small-scale hydroelectric, wind, solar thermal, or biomass systems are some options for renewable energy.

When selecting building materials for construction or renovation, priority should be given to recycling and recyclable options (O4). Criteria include life cycle assessment, the use of sustainable materials, and the selection of those that are economical to transport in terms of weight and dimension. The reuse of on-site materials is also included, along with the reuse of removed materials of the previous building, either with the same or a new function, as a defined action. Other actions are the selection of materials that can be reintroduced into a new production cycle and the choice of durable materials. The use of local, recycled, and quickly renewable materials are the options defined related to the selection of sustainable ones, while the selection of materials with lower CO₂ impact is the defined action for minimizing transport impacts.

Additional objectives include minimization of the environmental impact of demolition activities (O5), transport (O6), and prevention of pollution during the management phase of the hut (O7). The choice of accurate selective demolition and the reuse or recycling of on-site materials are the sustainability criteria for Specific Objective 5, where the removal of hazardous and recyclable materials for reuse or recycling is the defined action. The choice of

construction systems that allow for quick and easy assembly of building components is the criterion for Specific Objective 6. Among these actions, the design of modular and dry-assembly systems is a possible solution defined under these guidelines. Objective 7 considers waste management as the most important criterion for the management of mountain huts. Actions to meet it include the adoption of preventive measures, sorting of waste, selection of sustainable products, reducing water use, and raising visitors' awareness.

Another objective concerns achieving a suited level of indoor comfort in Alpine structures (O8). To reach this objective, the control of thermal, acoustic, visual, and indoor parameters is considered. Actions to meet the thermal objective include construction of a performance shell to minimize thermal loss, the use of ventilation systems in common spaces and design windows with good solar exposure, a filter zone on the entrance, and a heated and ventilated room for clothes. The selection and design of the windows are also relevant to the visual objective, while the use of products with a limited volatile organic compounds (VOCs) content is a specific action for indoor parameters. A specific action for an acoustic objective is the use of acoustic insulation on ceilings and walls between rooms.

The protection and enhancement of the Alpine landscape is the objective with the highest number of associated criteria (O9). The latter concern the study of the territory and existing structures, the choice of materials, the design of forms, the protection of natural context, the respect of the essence of the Alpine environment and its building culture, the interaction between contemporary original building types and forms in the context of contemporary architectural language, the close correspondence between forms and function, the use of technical expertise for sustainability, minimizing transformations, being mindful of the morphology of the terrain, and respecting the slope and lithologies that characterize the surrounding natural landscape. However, despite the large number of criteria, no specific action is defined for these criteria.

Discussion

The analysis of regional regulations and guidelines concerning the design of Alpine huts in Italy confirms and highlights even more the complex and fragmented scenario. Regional regulations primarily focus on defining minimum standards, technological and health standards. Although these documents address foundational aspects such as accommodation spaces, sanitation, emergency provision, and basic utilities, their attention to fragile contexts is less common. Only a few regions promote this aspect with explicit environmental sustainability requirements, while other regions lack clear prescriptions on this topic. The gap in regulations is even more pronounced in the landscape field. The analyzed provisions do not include aesthetic, morphological, or chromatic criteria for integrating huts within their natural surroundings, leaving designers with considerable discretion. When such information is present, it is usually limited to the minimum requirements for the

construction of huts in protected areas and the maximum size of any extension work. An example of this information is provided in the Auronzo-Misurina Area Plan (Veneto Region 1999). However, current literature emphasizes the importance of landscape conservation as not only a natural and wild space (Lai 2002) but also as a cultural one (Stahr and Langenscheidt 2015) especially in the current context where mountains are undergoing significant changes due to meteorological and climatic variations, such as the transition from glacial to periglacial areas, which are changing the perception of these places for those who frequent them (Colombo et al. 2016; Schickhoff et al. 2021; Mameno et al. 2022).

On the other hand, the guidelines present a more comprehensive and detailed approach to environmental and landscape protection, although they partly or completely ignore the functional and health requirements of huts. The one developed by the Province of Trento along with SAT mountaineering association and Habitech is among the most comprehensive.

OBJECTIVE/ CRITERIA	O.1: Respect for the ecosystem						O.2: Water provision and management					O.3: Energy efficiency and renewable energy				O.4: Selection of materials				O.5: Demolition impacts		O.6: Transport impacts		O.7: Prevention of pollution		O.8: Comfort			
	A	B	C	D	E	F	A	B	C	D	E	A	B	C	D	A	B	C	D	A	A	A	A	A	B	C	D		
LIFE CYCLE PHASE																													
A1 - A3: Production	○	○	●	○	○							○	○	○		○	○	●	○	○	○		○	○	○	○	○	○	●
A4 - A5: Construction	●	●	●	●	●														●	●	○	●		○					
B1 - B7: Use	○	●	○	●	●	●	●	●	●	●	●	●	●	●	○				○	○		●		○	○	●	●	●	●
C1 - C4: End of Life	○	○		●	○											○	○	○	○	○	○	○	○	○	○	○	○	○	○
D: Beyond the Life Cycle	○	○		●	○									●	○					●			○		○	○	○	○	○

Figure 8: Comparison Between Environmental Criteria from Table 3 and Life Cycle Phases of the Building⁶

They include objectives, criteria, and actions integrating sustainable practices for carrying out the design, construction, management, and deconstruction of these buildings. Drawing from these specifications, it is possible to see (Figure 8) that these guidelines focused mainly on the use stage, while strategies related to the production and end-of-life phase are less explored. Some actions also aim to consider potential benefits extending beyond the life cycle.

Nevertheless, a notable gap persists in landscape preservation, where no specific actions were identified. However, it is important to highlight the large number of criteria that characterize this objective, some of them demonstrating that landscape conservation encompasses not only the preservation of the surrounding natural elements, but also that of the cultural identity embedded in the huts' architecture. From the analysis of the guidelines, it is also possible to note the importance placed on raising visitors' awareness regarding water

⁶ In this diagram, the criteria defined by the guidelines have been traced to the main phases of the building's life cycle with reference to the UNI EN15978:2011: Production (A1–A3), Construction (A4–A5), Use (B1–B5), End of Life (C1–C4), and Beyond the Life Cycle.

and waste management, as well as on noise reduction. This educational focus is essential for the sustainable management of huts, considering their natural context, and for fostering a deeper understanding of the impact of climate change on mountain structures and ecosystems (Adler et al. 2022).

OBJECTIVE/ CRITERIA	ENVIRONMENT																				LANDSCAPE																	
	O.1: Respect for the ecosystem					O.2: Water provision and management					O.3: Energy efficiency and renewable energy					O.4: Selection of materials					O.5: Demolition impacts O.6: Transport impacts O.7: Prevention of pollution					O.8: Comfort					O.9: Protecting and enhancing the alpine landscape							
	A	B	C	D	E	F	A	B	C	D	E	A	B	C	D	A	A	A	A	A	A	B	C	D	A	B	C	D	E	F	G	H	I	J	K			
REGULATIONS																																						
LIGURIA																																						
PIEDMONT																																						
AOSTA VALLEY																																						
LOMBARDY																																						
VENETO																																						
TRENTO PROVINCE																																						
BOLZANO PROVINCE																																						
FRIULI-VENEZIA GIULIA																																						
ITALIAN ALPINE CLUB																																						

Figure 9: Comparison Between the Contents of the Guidelines Drawn Up by the Province of Trento, SAT, and Habitech with Those of the CAI and Italian Regional Regulations

Comparing the specific objectives and sustainability criteria explicated in these guidelines (Trento Province et al. 2013) with the other examined documents results in a graphical interpretation (Figure 9) depicting the aspects most considered for the construction of mountain huts in Italy. It is also possible to identify areas where less information is provided, highlighting the common absence of regional policies addressing the relationship among Alpine huts and landscape.

Environmental protection measures are, in fact, the ones considered by regional legislation. The CAI, along with Piedmont and Lombardy Regions, show greater attention to ecological safeguarding. However, the Liguria Region, like the Trentino and Bolzano provinces, does not include actions in its regulatory instruments. From this comparison, it is also possible to identify recurring criteria considered important for environmental protection, such as providing suitable wastewater treatment systems (O.1.E–O.2.D); the recovery and reuse of water (O.2.A), the generation of electricity from renewable sources (O.3.C), the selection of construction materials (O.4), and waste management (O.7.A). Objectives concerning respect for the host ecosystem, sustainable water provision and management, energy efficiency and solutions of renewable energy sources, the selection of recycled and recyclable materials at the end of life, and the prevention of environmental pollution are therefore significant and commonly shared, even if the criteria deemed essential by the Regions for their implementation are limited. Meanwhile, other objectives, such as minimizing the impact of transport and

demolition activities, are often overlooked. Due to the remote and difficult-to-access locations of most mountain huts, transportation of materials and operational supplies are mostly carried out by helicopter, resulting in substantial ecological and economic effects. Similarly, the demolition phase at high altitudes is complex, and transporting large quantities of materials down the mountain, just like during construction, requires helicopters. Perhaps this aspect should therefore be given greater consideration.

The overall picture emerging from this analysis shows that, despite the growing attention paid to the conservation of nature and landscape, these concerns are not yet central or systematically integrated into the administrative regulations concerning mountain huts. Actually, in some Regions, such references are completely absent. This suggests the opportunity to adopt policies more oriented toward environmental sustainability and the integration of high-altitude mountain huts within the landscape. In this context, mountaineering associations operating in high-altitude mountains could play a key role. Thanks to their direct and deep knowledge of the Alpine region, these organizations can provide useful operational guidelines for a suitable design, construction, and management of structures. Their collaboration with local authorities in developing guidelines has proved particularly effective, generating the most accurate results among the examined documents. Today, these guidelines represent a significant reference for the development of regional regulations and for building constructions in the fragile Alpine contexts. To further improve existing guidance measures, local institutions could welcome architects, engineers, and designers, together with others who work and live in high-altitude contexts, to participate and contribute, as shown by some design and learning experiences (Dallere et al. 2023).

Conclusion

The study presented an analysis of existing guidance measures concerning the design of mountain huts in the Italian Alps, focusing on environmental protection and landscape conservation. The findings show the complex and fragmented situation. Regional regulations and guidelines are the main references for the design, construction, and management of these structures. However, these documents differ in content and in the levels of attention given to the topics of the study. Regulations mainly focus on technical and functional aspects of mountain huts, whereas the guidelines place a greater emphasis on environmental and landscape preservation. The latter defined objectives, criteria, and a range of actions, dedicating more attention to the building's use phase, while leaving the end-of-life objective less explored. This aspect should be explored further, given the uncertain future of huts due to climate change, which requires the reconstruction or removal of some of them. The analysis also highlights some common aspects and notable gaps. Key topics such as water and energy management, wastewater treatment, materials choices, and waste management are addressed in both regional regulations and guidelines, even with different approaches and

levels of detail. However, despite equal importance, landscape conservation generally receives less attention, particularly from a cultural point of view, as also highlighted by other studies on the topic (Bartolomucci 2019). In regional regulations, landscape protection is often vague or completely absent.

At the same time, the study highlights how collaboration between local authorities and mountaineering associations has produced the best results, contributing concretely to the design of these structures, even though some of the actions in the guidelines are generic, without corresponding to specific interventions.

A further step in this research could therefore analyze how designers interpret the concepts of environmental protection and landscape conservation when dealing with Alpine huts in architectural practice. A comparison between the objectives, criteria, and actions that emerged from this analysis, on the one hand, and the design strategies adopted by professionals, on the other, could be carried out. Despite providing insight about the actual compliance with the (not mandatory) guidelines, it may suggest more aspects to be considered and more actions to undertake to promote design approaches consistent with the Alpine environment and landscape. Ultimately, this would help Alpine high-altitude huts facilitate access to remote places without worsening the fragilities of the unique contexts in which they are located.

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Informed Consent

The author declares that informed consent was not required as there were no human participants involved.

Conflict of Interest

The author declares that there is no conflict of interest.

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ABOUT THE AUTHOR

Elisa Bernard: PhD Student in Architecture, Iuav University of Venice, Venice, Italy
Email: ebernard@iuav.it