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Reuse of Vernacular Architecture in Minor Alpine Settlements: A Multi-Attribute Model for Sustainability Appraisal

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Abstract: In the marginal areas of the Alps, there is a huge built heritage expressed by local communities, resulting in an architectural model that is sustainable in terms of its material use, resource exploitation, and landscape coherence. Although buildings in these small settlements have been largely protected from transformation, currently this heritage is largely underused. Thus, it is desirable to consider reuse and enhancement actions that can combine both economic viability and the protection of historic, cultural and architectural values. This paper presents a multi-attribute model for the evaluation of sustainability in reuse projects concerning traditional buildings in the Italian Alpine settlements. For the appraisal of sustainability, the model uses relevant parameters aggregated into three macro-indicators. The model was calibrated by an expert panel and tested on reuse projects in Sauris, in north-eastern Italy, where residential building type is characterized by specific techniques that are expressions of community traditions. The main results show that the attributes aggregation function is predominantly andness in all nodes. A short range in sustainability assessment is a predictable result, as the buildings used for the model's application give a common judgment in some attributes. Finally, activities for widespread hospitality generate a greater expected return compared to commercial services.

Keywords: economic sustainability; vernacular architectural heritage; multi-attribute model; sustainability appraisal; reuse project

1. Introduction

If the most widespread definition of the concept of sustainability refers to environmental, social, and economic aspects, it follows that the purpose of a requalification intervention, designed to achieve sustainability goals, should be an attempt to increase the quality of life of the community by developing local resources, thus pursuing an objective with a multidimensional nature [1]. The aim of this study is to establish a value function that can summarize the most relevant issues in the choice of intervention options for the reuse of traditional buildings, based on the knowledge of local communities in Alpine cultural region. Integration is required between issues related to economic and social sustainability and the more established issues concerning intervention sustainability at the typological and technical levels. This is a complex process that is not easily measurable with a strictly quantitative approach.

Within this scope, the concept and value of sustainability includes two aspects: first, the sustainability of the renovation of building materials and typology; second, the sustainability of the new function inherent in the reuse, a transformation that can involve consolidation, integration or even a replacement that can change the perception and understanding of the original building. In interventions performed on Alpine architecture, the sustainability target requires a balance between reuse and conservation. In other words, it is necessary to perform a rehabilitation, which is defined as a process that provides the compatible use of a building through repairs, alterations and additions, while preserving functional solutions, features and materials that convey the historical, cultural and architectural values of the community [2]. Moreover, the main cause of the degradation of traditional Alpine buildings and artefacts lies in the absence of a function, leading to their abandonment and ruin, particularly in areas not interested in the considerable exploitation of Alpine tourism, which has occurred in the second half of the last century [3–5].

A study conducted in Sauris, north-eastern Italy, which is a small settlement in the Carnic Alps notable for the homogeneous typology found in most of its buildings and artefacts, is suitable for testing a multi-attribute model for assessing the sustainability of reuse. In fact, the preservation of architecture based on functional criteria, such as the use of raw materials available in situ, is strictly linked with the protection of the community that has expressed it through the introduction of new functions compatible with its typological, formal and material features. This approach can contrast heritage loss with the values of which it is the bearer. The European Charter for Architectural Heritage has previously considered the social and economic implications of restoration and recovery: integrated conservation is defined as the integration of built heritage into community life through the introduction of appropriate intended uses, that are capable of respecting the architecture and ensuring its safeguard [6]. The architecture of Sauris offers a built heritage comprising peculiar key elements, requiring congruous protection given the renewed trends in permanent resettlement and the development of more conscious Alpine tourism.

2. Sustainability Evaluation in the Reuse of Mountain Architecture

The vernacular architectural heritage in mountain contexts represents the answer to habitability needs developed by a community in a specific geographic and climatic situation. This is the result of a historical evolution, reflected by the adoption and progressive development of distributive, functional and technological solutions derived from the rational exploitation of the material resources available in situ [7].

The reuse of mountain architecture is an operation with three different targets, which should concur. The first involves the counteraction of the non-use and subsequent ruin of artefacts through the identification of new sustainable uses that are functional for the maintenance and preservation of community values, according to the principles of social and economic sustainability. The second involves the adaptation of functionality and performance to the current standards of safety, reliability and comfort. Finally, the third target is the preservation of historical and cultural values found in the individual artefacts and, from a wider perspective, in the whole community that has conveyed them over time.

In the theoretical framework concerning adaptive reuse and conservation, reuse projects certainly do not fall within the scope of integral conservation [8]. Attributing new functions, the conservation of original construction materials and techniques is often not possible due to necessary consolidation and replacement works. Moreover, the choice for non-use often leads to the loss of an artefact's intrinsic values, resulting from abandonment and ruin. Incompatible use, similarly, leads to the same loss [9].

The rehabilitation of this heritage, particularly for an intervention that contemplates a new intended use, must comply with the features of mountain architecture: specifically, the use of local materials and the typology of the community housing. This occurs in accordance with the vision of mountain architecture as an application of sustainability principles that involves the exploitation of local resources, coherence in the development of settlements in the landscape, and the evolution of livability solutions that are gradually refined over time.

Traditional buildings in the Friuli historic region evidence a remarkable variety of local architectural typologies that cannot be summarized in the physical boundaries of the artefacts. It requires the investigation of traditional features, technical knowhow and local experience, welded together and deeply blended with the landscapes. Mountain architecture displays the knowledge of its master-builders adapting to a place, respecting the landscape, and addressing the social and cultural identity of territories [10].

In the scope of mountain architecture in the Friuli historic region, this vision is effectively highlighted in the regulations enacted for the management of the seismic events of 1976. Regional Law No. 30/1977 concerns the housing needs in areas affected by earthquakes, establishing the functional and static recovery of existing buildings while considering the protection and preservation of the local architecture. In addition, Regional Law No. 63/1977 regulates the reconstruction process based on the extent of aid granted to the owners of destroyed dwellings. The need to re-functionalize existing buildings is accompanied by the need to acknowledge original materials and construction techniques, combining heritage recovery with the preservation of these features in small settlements [11]. Moreover, different sustainability visions are reflected in the studies concerning the Sauris municipality: initially, we see the cultural specificity of the population of German origin, followed by the methods of settlement arising from the geographical site, which is located at more than 1200 m above sea level and lacked stable communication connections until 1934. On the other hand, most recent studies concern the reconstruction of this architectural heritage according to an approach that respects the artefacts' features, and leave open the debate on the sustainability of renovation interventions [12,13].

The state of degradation and ruin of some buildings and settlements, together with the extent of the transformation of the original features, imposes limits on the sustainability of reuse interventions, in both the historical-architectural and socio-cultural contexts. On one hand, it is economically unsustainable to encourage the recovery of buildings that are so damaged that they require a replacement of entire parts and systems; on the other hand, the socio-economic limit of sustainability depends on the conditions under which expenditure and the public contribution to preservation is acceptable [14,15]. The inclusion of socio-economic aspects, such as intangible heritage, in sustainability evaluations can allow for the recognition of community values that are to be protected [16].

Defining the attributes that can be used to assess sustainability in reuse interventions is, thus, a multi-attribute problem. In the literature, there are several methods that approach multi-attribute problems, including outclassing methods, such as the ELECTRE family [17,18], interactive approaches, and the multi-attribute value approach (MAVT) [19]. The first, which is of French origin, aims to build a relationship of superiority that represents the preferences established by the decision maker, given the available information. The second is characterized by the alternation of calculation phases and interaction phases. Finally, MAVTs, which are of American inspiration, are based on the value function, and rank the achievement of alternatives by attributing to each a score synthesized by an aggregation operator, given a finite and discrete set of alternative options [20]. The most common aggregation operator is the weighted average function, which consists of the weighted average of the values provided by the attributes. Multi-attribute assessment models are often used for economic assessments in different areas, such as in the assessment of benefits arising from urban or environmental regeneration [21–23].

In most complex decision-making problems, owing to the presence of conflicting or synergistic information, there are important interactions between attributes. This means that the combined effect of two criteria is greater or lesser than the sum of the effects of each attribute considered separately; thus, the linearity is lost. However, it is possible to implement multilinear structures for aggregation that are capable of capturing the interactions among criteria. For example, considering the i-th alternative, and assuming the existence of only two criteria with values of c_1 and c_2, the multi-linear value function can be expressed as follows:

$$C = w_1 c_1 + w_2 c_2 + w_{12} c_1 c_2 \quad (1)$$

where w_i are the weights given to the individual attributes and their combinations.

Sustainability indicators can derive from relative points of view, e.g., from a specific historical, architectural or aesthetic sensibility [9,24,25]. Moreover, the sustainability attributes of the reuse interventions are subject to changes over time, depending on the cultural and economic conditions of the involved community, or even the context in which these conditions are determined. The attributes proposed in this study could be useful in limiting the subjectivity involved in the critical interpretation of an artefact and the reuse intervention to be performed.

3. Methodology for Attribute Definition and Calibration

The model presented in this study concerns the application of MAVT for a sustainable reuse of mountain vernacular buildings and artefacts. Thus, the set of attributes and its organization in a structured framework aspires to the specific characterization of minor settlements' architecture in Alpine regions. Compared to historical buildings relevant to art and history, the latter expresses a different function for decorative apparatus and finishing works, and, as mentioned above, a sensibility for the use of natural material resources.

3.1. Sustainability Attributes and Key Performance Indicators

The operational phase of this study has thus focused on the definition of attributes, expressed according to appropriate indicators, which allow for an assessment of the sustainability level of alternative reuse projects carried out on the Friuli mountain architecture.

The framework adopts a hierarchical approach, which can be traced to international rating systems that are prevalent at a national level in Italy. The framework consists of synthetic attributes capable of reflecting the features comprising reuse projects, and can describe the sustainability level of the intervention itself. The framework structure is shown in Figure 1, while the attributes considering reuse intervention effects are divided into three evaluation areas. Attributes are grouped by operative scopes and, at the higher level, by evaluation areas; only the first area, at an intermediate level, is sub-divided into categories.

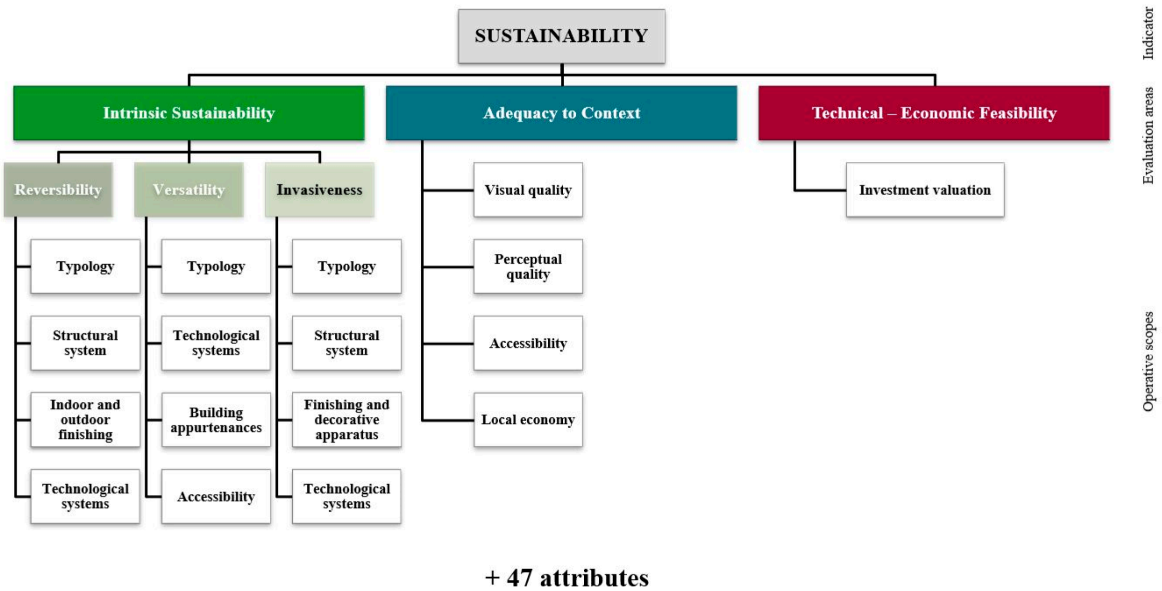

Figure 1. Structure of the framework for sustainability appraisal of reuse intervention in Alpine mountain architecture.

The Intrinsic Sustainability evaluation area (Table 1) consists of 36 attributes that allow for an assessment of the capability of the intervention as regards the preservation of the building's architectural and historical features, from the point of view of both the construction techniques and materials used. In turn, the Intrinsic Sustainability area is further divided into three categories to characterize the need for artefact preservation with greater precision. The first category, Reversibility, is intended to reflect the potential for restoring the status quo ante of the building as a result of any additions provided for the reuse; the second, Versatility, refers to the potential for future modifications of the project's intended use, without resorting to further substantial transformation works; the third, Invasiveness, is an estimation of the degree of interference of the reuse with the building's material components.

The Adequacy to Context evaluation area (Table 2) consists of seven attributes reflecting the capacity of the reuse project to enhance the environmental, social and economic context and, therefore, evaluating its potential for preserving or enhancing the identity of the local community.

The Technical and Economic Feasibility evaluation area (Table 3) consists of four attributes capable of assessing the reuse project in terms of financial management of the intervention and the subsequent management of the planned activity.

The definition of attributes aims to highlight the role of built heritage rehabilitation in preserving the well-being of the local population, in ensuring an overall economic development capable of attracting qualified human resources; these positive effects can be reached, preserving the authenticity of the territory, through the exploitation of existing cultural assets and considering activities that can be perceived as authentic and coherent with the context both by the local community and tourists [26].

Each attribute is identified by an alphanumeric code that consists of the evaluation area code (IS; AC; TEF), the category code only for Intrinsic Sustainability area (R; V; I), the progressive number for operative scopes and, at the lower level, the number of the attribute.

A value of between 0 and 1 can be assigned to each attribute. This assignment depends on a quantitative approach for 25 of the attributes, identifying within a set of possible scenarios the one that best describes the specific connotation of the reuse project. For each of the remaining 22 attributes, it is possible to define a Key Performance Indicator (hereafter KPI) in the initial model testing step; each KPI expresses synthetically the value of the attribute within a benchmark scale. Identified scales serve to guide the evaluator in the expression of judgments.

The assessment of Intrinsic Sustainability is based on a simplified breakdown of the building; it essentially considers the ability to retain the typological and functional scheme, the reversibility and compatibility of works on load-bearing structures, the finishing or decorative apparatuses, and the appropriateness of the introduction of new technological systems. This assessment is intended to avoid works that may affect the authenticity of material and architectural features. Moreover, the framework analyzes the presence of pre-existing outdoor areas and ancillary spaces that could provide valuable locations for the installation of new technological systems. Table 4 shows the KPIs, thresholds and scenarios used to structure the judgments in Intrinsic Sustainability area attributes.

For the assessment of Intrinsic Sustainability, there are up to three possible choices in the optioneering of each attribute judgment in the IS.R.2 and IS.3 categories. The final judgment derives from the simple average of Reversibility and Invasiveness Indexes, as defined in Formulas (2) and (3), so as to allow one to take into account multiple different intervention types.

The attributes included in the Adequacy to Context assessment allow for an evaluation of the impacts on the surrounding context by determining the degree of compatibility of the intervention with the perception of the building as expressed by the local community, as well as its effects on the circulation and local economy.

Table 1. Articulation of the attributes included in the Intrinsic Sustainability evaluation area.

Valuation Levels of a Reuse Project—Intrinsic Sustainability (IS)		
Categories	**Operative Scopes**	**Attributes**
Reversibility (R)	1. Typology	1. Retaining of the existing volume 2. Plotting of indoor space 3. Construction of adherent new volumes 4. Retaining the original use of spaces
	2. Structural system	1. Reversibility of groundwork reinforcements 2. Reversibility of vertical structure reinforcements 3. Reversibility of slab and floor reinforcements 4. Reversibility of roofing reinforcements
	3. Indoor and outdoor finishing	1. Reversibility of flooring integration/replacement 2. Reversibility of facing integration/replacement 3. Reversibility of frame and shutter integration/replacement 4. Reversibility of door stone and cornice integration/replacement
	4. Technological systems	1. Placement optimization 2. Decoration preservation
Versatility (V)	1. Typology	1. Flexibility in spatial distribution 2. Movability of indoor partitions 3. Provision of vertical connections
	2. Technological systems	1. Indoor comfort 2. Adequacy of terminal units
	3. Building appurtenances	1. Annex volumes eligible for reuse 2. Outdoor areas eligible for reuse
	4. Accessibility	1. Driveway availability 2. Accessibility to public transportation 3. Potential for private parking 4. Accessibility for weak users

Table 1. *Cont.*

Valuation Levels of a Reuse Project—Intrinsic Sustainability (IS)		
Categories	**Operative Scopes**	**Attributes**
Invasiveness (I)	1. Typology	1. Readability of original typology 2. Reuse compatibility
	2. Structural system	1. Recognizability of integration 2. Use of materials similar to the originals 3. Awareness in removal of degradation pathologies
	3. Finishing and decorative apparatus	1. Recognizability of integrations 2. Preservation of original features 3. Awareness in removal of degradation pathologies
	4. Technological systems	1. Visual impact 2. Control of system loss factor 3. Use of annex volumes and low-value spaces

Table 2. Articulation of the attributes included in the Adequacy to Context evaluation area.

Valuation Levels of a Reuse Project—Adequacy to Context (AC)	
Operative scopes	**Attributes**
1. Visual quality	1. Landscape quality preservation 2. Aesthetic quality preservation
2. Perceptual quality	1. Use shared by the community 2. Public fruition of the reuse
3. Accessibility	1. Integration with pedestrian/cycle paths
4. Local economy	1. Introduction of new economic activities 2. Differentiation of economic activities

Table 3. Articulation of attributes included in the Technical and Economic Feasibility evaluation area.

Valuation Levels of a Reuse Project—Technical and Economic Feasibility (TEF)	
Operative scopes	**Attributes**
1. Investment valuation	1. Expected return 2. Risk evaluation 3. Eligibility 4. Management costs

Attributes included in Adequacy to Context evaluation area are defined by means of services provided by the new activity, in terms of a function shared with the community, innovation, and integration of the activity into a scenic or cultural path. For private artefacts embedding an activity open to the public, i.e., craftsmanship, the percentage of floor surface deputed to the activity is set as a KPI. Detailed information is provided in Table 5.

Finally, the attributes included in the Technical and Economic Feasibility assessment allow the evaluation of the reuse project based on aspects aimed at verifying the financial autonomy of the intended activity, and the presence of income flows sufficient for making maintenance actions sustainable.

Technical and Economic Feasibility attributes are evaluated via the KPIs to consider different scenarios of the economic activity planned in the reuse project, i.e., private house, hospitality, craftsmanship activity, provision of a new service not originally available in the settlement, or provision of a competitor activity in an already existing service. The definition of possible choices considers on one hand the process that led to the formation of the architectural heritage, involving master-builders and craftsmen; on the other hand, it pursues the generation of appropriate work opportunities and the achievement of sustainable tourism in order to increase the social expectations of the community, embedded in a wide sustainability strategy [27]. The valorization of possible optional Technical and Economic Feasibility attributes is shown in Table 6.

The attributes concerning the reversibility and invasiveness of works (Intrinsic Sustainability evaluation area, Reversibility and Invasiveness categories) have been treated in such a way as to provide a semi-quantitative evaluation. A documented abacus inherent in the methodologies of interventions into technical elements typical of mountain architecture allows for the definition of a set of specific actions on these elements, in accordance with the simplified breakdown of the building adopted in the definition of the attributes [12,13].

Table 4. KPIs and thresholds/scenarios chosen for Intrinsic Sustainability evaluation area.

Valuation Levels of a Reuse Project—Intrinsic Sustainability (IS)			
Attribute	**KPI**	**Judgment Structure**	
IS.R.1.1	r_{VM}: percentage of original gross volume maintained by reuse project	$J = 1 - \frac{r_{VM}}{100}$	
IS.R.1.2	N_s: ratio between the number of new spaces and number of original spaces	$J = 1 - (0.5 \cdot \lvert 1 - N_s \rvert)$	
IS.R.1.3	r_{NV}: percentage of added volume compared to original gross volume	$J = 1 - 0.5 \cdot \frac{r_{NV}}{100}$	
IS.R.1.4	r_{OU}: percentage of indoor space that maintains its original intended use	If $r_{OU} < 25\%$, $J = 0.50$ If $r_{OU} < 40\%$, $J = 0.60$ If $r_{OU} < 55\%$, $J = 0.70$ If $r_{OU} < 70\%$, $J = 0.80$ If $r_{OU} < 85\%$, $J = 0.90$ If $r_{OU} > 85\%$, $J = 1.00$	
IS.R.2.1	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.2.2	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.2.3	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.2.4	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.3.1	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.3.2	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.3.3	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.3.4	Reversibility Index, as defined in (2)	Average R_I of applicable options	
IS.R.4.1	Integration scenarios in distribution and emission subsystems	New chases on walls and floors Non-removable superfetation Removable superfetation Use of original chases	$J = 0.00$ $J = 0.30$ $J = 0.80$ $J = 1.00$
IS.R.4.2	Interaction scenarios between decorations and technical distributions	Decoration removal and new application Superimposed distributions No interaction	$J = 0.20$ $J = 0.40$ $J = 1.00$

Table 4. *Cont.*

Valuation Levels of a Reuse Project—Intrinsic Sustainability (IS)			
Attribute	**KPI**	**Judgment Structure**	
IS.V.1.1	Floor clear depth (D_{fc}) Average net indoor height (H_{ani})	If $D_{fc} < 3.0$, $J_1 = 0.30$ If $D_{fc} < 3.5$, $J_1 = 0.40$ If $D_{fc} < 4.0$, $J_1 = 0.50$ If $D_{fc} > 4.0$, $J_1 = 0.60$	If $H_{ani} < 2.5$, $J_2 = 0.10$ If $H_{ani} < 2.7$, $J_2 = 0.20$ If $H_{ani} < 3.0$, $J_2 = 0.30$ If $H_{ani} > 3.0$, $J_2 = 0.40$
		Attribute judgment: $J = J_1 + J_2$	
IS.V.1.2	Typology of new vertical (V) and horizontal (H) internal partitions	Use of hydraulic binders (V)	$J_1 = 0.20$
		Use of mechanic links (V)	$J_1 = 0.80$
		No new vertical partitions	$J_1 = 1.00$
		Use of hydraulic binders (H)	$J_2 = 0.30$
		Use of mechanic links (H)	$J_2 = 0.70$
		No new horizontal partitions	$J_2 = 1.00$
		Attribute judgment: $J = \frac{(J_1+J_2)}{2}$	
IS.V.1.3	Width (L) and slope (p) of vertical connections	If L < 0.8 m, $J_1 = 0.30$ If L < 1.0 m, $J_1 = 0.40$ If L < 1.2 m, $J_1 = 0.60$ If L > 1.2 m, $J_1 = 0.70$	If $p > 65\%$, $J_2 = 0.10$ If $p > 55\%$, $J_2 = 0.20$ If $p < 55\%$, $J_2 = 0.30$
		Attribute judgment: $J = J_1 + J_2$	
IS.V.2.1	Predicted Mean Vote (UNI EN 7730) Daylight Factor (UNI EN 15193)	If PMV > 0.7, $J_1 = 0.10$ If PMV > 0.5, $J_1 = 0.20$ If PMV > 0.2, $J_1 = 0.40$ If PMV < 0.2, $J_1 = 0.50$	If DF < 1.5%, $J_2 = 0.10$ If DF < 2.0%, $J_2 = 0.30$ If DF < 2.5%, $J_2 = 0.40$ If DF > 2.5%, $J_2 = 0.50$
		Attribute judgment: $J = J_1 + J_2$	
IS.V.2.2	Scenarios about technical systems typologies	High-temperature heating	$J_1 = 0.20$
		Low-temperature heating	$J_1 = 0.30$
		Low temperature + direct expansion heating	$J_1 = 0.40$
		Low temperature heating + Controlled Mechanical Ventilation	$J_1 = 0.50$
		No BACS	$J_2 = 0.20$
		Class C BACS (UNI EN 15232)	$J_2 = 0.40$
		Class B BACS (UNI EN 15232)	$J_2 = 0.50$
		Attribute judgment: $J = J_1 + J_2$	

Table 4. *Cont.*

Valuation Levels of a Reuse Project—Intrinsic Sustainability (IS)			
Attribute	**KPI**	**Judgment Structure**	
IS.V.3.1	Eligibility of appurtenances	No ancillary functions Facility/plant core (scenario A) As scenario A + larder (scenario B) As scenario B + storage space (C) As scenario C + laundry	$J = 0.10$ $J = 0.40$ $J = 0.60$ $J = 0.80$ $J = 1.00$
IS.V.3.2	Eligibility of outdoor areas	No ancillary functions/no areas Ancillary functions New annexes or enlargements	$J = 0.40$ $J = 0.70$ $J = 1.00$
IS.V.4.1	Width (L) and slope (p) of driveway access	If L < 2.5 m, $J_1 = 0.00$ If L < 3.5 m, $J_1 = 0.20$ If L < 4.5 m, $J_1 = 0.30$ If L > 4.5 m, $J_1 = 0.40$ Attribute judgment: $J = J_1 + J_2$	If $p > 12\%$, $J_2 = 0.10$ If $p < 12\%$, $J_2 = 0.30$ If $p < 8\%$, $J_2 = 0.50$ If $p < 4\%$, $J_2 = 0.60$
IS.V.4.2	(*) Number of daily trips in 7–9 and 17–19 time slots (N_{dt}) Distance between building and access point to transportation (d_{at})	$J = \frac{30}{\left[0.5\cdot\left(\frac{60\cdot 4}{N_{dt}}\right)+\frac{d_{at}}{80}\right]}$	
IS.V.4.3.	Scenarios about spaces available for private parking	No availability 1 stall/100 m^2 gross area (A) 2 stall/100 m^2 gross area (B) As scenario A + weak users As scenario B + weak users	$J = 0.00$ $J = 0.70$ $J = 0.90$ $J = 0.90$ $J = 1.00$
IS.V.4.4	Scenarios concerning spaces accessible to weak users depending on private (A) or public (B) nature of the building	A. No accessibility A. Accessibility to common spaces A. Partial accessibility + adaptability A. Full accessibility B. No accessibility B. Accessibility to common spaces B. Partial accessibility + adaptability B. Full accessibility	$J = 0.30$ $J = 0.60$ $J = 0.80$ $J = 1.00$ $J = 0.00$ $J = 0.20$ $J = 0.40$ $J = 1.00$

Table 4. *Cont.*

Valuation Levels of a Reuse Project—Intrinsic Sustainability (IS)			
Attribute	**KPI**	**Judgment Structure**	
IS.I.1.1	Difference between project and original roofing slope (Δs) Difference between project and original glazing surface (Δg)	If Δs > 6%, $J_1 = 0.30$ If Δs > 4%, $J_1 = 0.40$ If Δs > 2%, $J_1 = 0.60$ If Δs < 2%, $J_1 = 0.70$ Attribute judgment: $J = J_1 + J_2$	If Δg > 15%, $J_2 = 0.00$ If Δg > 10%, $J_2 = 0.10$ If Δg > 3%, $J_2 = 0.30$ If Δg < 3%, $J_2 = 0.50$
IS.I.1.2	Comparison between original and reuse project activity	Pairwise comparison among private house, service activity, craftmanship activity, hospitality, cultural activity	
IS.I.2.1	Invasiveness Index, as defined in (3)	Average I_I of applicable options	
IS.I.2.2	Number of technological units described in IS.R.2 operative scope that use materials (N_{OM}) similar to original ones and (N_{KM}) obtained within 100 km of building site	If $N_{OM} = 0$, $J_1 = 0.00$ If $N_{OM} = 1$, $J_1 = 0.20$ If $N_{OM} = 2$, $J_1 = 0.30$ If $N_{OM} = 3$, $J_1 = 0.40$ If $N_{OM} = 4$, $J_1 = 0.60$ Attribute judgment: $J = J_1 + J_2$	If $N_{KM} = 0$, $J_2 = 0.00$ If $N_{KM} = 1$, $J_2 = 0.10$ If $N_{KM} = 2$, $J_2 = 0.20$ If $N_{KM} = 3$, $J_2 = 0.30$ If $N_{KM} = 4$, $J_2 = 0.40$
IS.I.2.3	Invasiveness Index, as defined in (3)	Average I_I of applicable options	
IS.I.3.1	Invasiveness Index, as defined in (3)	Average I_I of applicable options	
IS.I.3.2	Number of technological units described in IS.R.3 operative scope that use materials (N_{OM}) similar to original ones and (N_{KM}) obtained within 100 km of building site	If $N_{OM} = 0$, $J_1 = 0.00$ If $N_{OM} = 1$, $J_1 = 0.20$ If $N_{OM} = 2$, $J_1 = 0.30$ If $N_{OM} = 3$, $J_1 = 0.40$ If $N_{OM} = 4$, $J_1 = 0.60$ Attribute judgment: $J = J_1 + J_2$	If $N_{KM} = 0$, $J_2 = 0.00$ If $N_{KM} = 1$, $J_2 = 0.10$ If $N_{KM} = 2$, $J_2 = 0.20$ If $N_{KM} = 3$, $J_2 = 0.30$ If $N_{KM} = 4$, $J_2 = 0.40$
IS.I.3.3	Invasiveness Index, as defined in (3)	Average I_I of applicable options	
IS.I.4.1	r_{VS}: Percentage of elements in distribution and emission subsystems left visible after reuse	$J = 1 - \frac{r_{VS}}{100}$	
IS.I.4.2	Plant Loss Factor, percentage of project gross volume used for plant installations	If PLF > 16%, $J = 0.40$ If PLF < 16%, $J = 0.60$ If PLF < 12%, $J = 0.80$ If PLF < 8%, $J = 1.00$	
IS.I.4.3	Scenarios about the use of annexes and outdoor areas	Derived by judgments in IS.V.3.1 and IS.V.3.2	

(*) The judgment formulation was inspired by Reference Practice UNI/PdR 13.1:2019, criterion A.1.6.

Table 5. KPIs and thresholds/scenarios chosen for Adequacy to Context evaluation area.

Valuation Levels of a Reuse Project—Adequacy to Context (AC).			
Attribute	**KPI**	**Judgment Structure**	
AC.1.1	Scenarios about the landscaping quality of the context after reuse	Derived by judgments in IS.R.1.3, IS.I.1.1, and IS.I.3.2	
AC.1.2	Scenarios about morphology and visual quality after reuse	Derived by judgments in IS.R.2.2, IS.R.2.4, IS.R.3.3 and IS.R.3.4	
AC.2.1	Scenarios about the level of sharing with community in reuse activity	Private house Hospitality Private house open to public Local craftsmanship activity Training craftsmanship activity Building with exposition space Service activity Cultural activity	$J = 0.00$ $J = 0.10$ $J = 0.20$ $J = 0.40$ $J = 0.60$ $J = 0.70$ $J = 0.80$ $J = 1.00$
AC.2.2	r_{OS}: Percentage of gross surface open to public	If r_{OS} = 0%, $J = 0.40$ If r_{OS} < 15%, $J = 0.50$ If r_{OS} < 50%, $J = 0.70$ If r_{OS} > 50%, $J = 1.00$	
AC.3.1	Scenarios about pedestrian/cycling paths	Private access only Proximity to cultural/landscape path Integration within cultural/landscape path	$J_1 = 0.00$ $J_2 = 0.60$ $J_2 = 1.00$
AC.4.1	Typology of reuse activity	Private house Hospitality Competent service activity Local craftsmanship activity New service activity	$J = 0.00$ $J = 0.00$ $J = 0.30$ $J = 0.50$ $J = 1.00$
AC.4.2	Innovation in economic activity	No economic activity Competent activity Innovative activity	$J = 0.00$ $J = 0.30$ $J = 1.00$

Table 6. KPIs and thresholds/scenarios chosen for Technical and Economic Feasibility evaluation area.

Valuation Levels of a Reuse Project—Technical and Economic Feasibility (TEF)			
Attribute	**KPI**	**Judgment Structure**	
TEF.1.1	Scenarios about the expected return of investment in reuse project	Private house	$J = 0.40$
		Hospitality	$J = 0.80$
		New service activity	$J = 0.50$
		Existing service activity	$J = 0.50$
		Craftsmanship activity	$J = 0.60$
		Restaurant/catering activity	$J = 1.00$
TEF.1.2	Scenarios about the risk evaluation of investment in reuse project	Private house	$J = 0.00$
		Hospitality	$J = 0.50$
		New service activity	$J = 1.00$
		Existing service activity	$J = 0.10$
		Craftsmanship activity	$J = 0.50$
		Restaurant/catering activity	$J = 0.50$
TEF.1.3	Scenarios about the eligibility of investment in reuse project	Private house	$J = 0.80$
		Hospitality	$J = 1.00$
		New service activity	$J = 0.20$
		Existing service activity	$J = 0.80$
		Craftsmanship activity	$J = 0.50$
		Restaurant/catering activity	$J = 1.00$
TEF.1.4	Scenarios about the management costs of activity in reuse project	Private house	$J = 0.00$
		Hospitality	$J = 0.80$
		New service activity	$J = 0.50$
		Existing service activity	$J = 0.50$
		Craftsmanship activity	$J = 0.50$
		Restaurant/catering activity	$J = 1.00$

An expert approach allows an appropriate set of parameters capable of expressing the degrees of reversibility and invasiveness of the intervention works to be defined and weighed. For reversibility, with reference to a potential restoration of the status quo ante from the condition of the reuse project, the technical feasibility, damage caused by restoration works, and residual restoration traces are considered as parameters. For the *i*-th intervention work documented in the abacus, the judgment of reversibility R_i is given by a weighted sum that gives priority to the reversibility of restoration action to the status quo ante:

$$R_i = 0.2 \cdot f_i + 0.3 \cdot d_i + 0.5 \cdot t_i \quad (2)$$

where f_i, d_i and t_i are the part coefficients of technical feasibility, damage caused by restoration, and residual traces, respectively.

For invasiveness, the parameter of damage due to restoration works on technical elements, with reference to the status quo ante, is considered a significant parameter. Thus, for the *i*-th intervention work, the judgment of invasiveness I_i is given by:

$$I_i = d_i \quad (3)$$

For each attribute included in the IS.R.2 and IS.R.3 operative scopes, it is possible to choose several options, as described in Table 7 for the structural system's scope. The average of these choices provides the KPI for the Intrinsic Sustainability evaluation area, the Reversibility and Invasiveness categories, and scopes concerning the structural system, finishing and decorative apparatuses. All parameters are defined on a threshold scale according to a quantitative judgment, as per Table 8 [28]. The abaci for the intervention methods are composed according to the information available in the literature for the recovery and restoration of existing valuable buildings, identifying the most relevant construction techniques, and intervention criteria for the reuse of mountain architecture [29–31].

Table 7. Semi-quantitative evaluation of attributes concerning reversibility and invasiveness; assumed numeric judgments are reported for each intervention work.

Evaluation of Attributes for Reversibility and Invasiveness—Operative Scope: Structural System			
Attributes	**Option Description**	**R**	**I**
1. Reversibility in groundworks reinforcement	Laying of concrete slab	0.87	1.00
	Laying of concrete slab anchored with steel bars	0.80	0.75
	Foundation footing	0.55	0.50
	Underpinning provision	0.00	0.00
	Reinforcement through side micropiles	0.00	0.00
	Reinforcement through crossing micropiles	0.00	0.00
	Provision of ground floor loose stone foundation	0.80	0.75
2. Reversibility in vertical structure reinforcement	Masonry: Provision of a dehumidification chemical barrier	0.00	0.00
	Masonry: Reinforcement by binder injection	0.00	0.00
	Masonry: Reinforcement by steel-fiber bands	0.57	0.75
	Masonry: Hollow joint sealing	0.55	0.25
	Masonry: Reinforcement by indenting operation	0.15	0.00
	Masonry: Reinforcement with restraint crossing steel bars	0.67	0.50
	Masonry: Banding with composite materials	0.57	0.75
	Masonry: Facing connection by helicoidal steel bars	0.57	0.75
	Masonry: Insertion of tie bars	0.87	1.00
	Concrete: Reconstruction, reinforcement insertion, and section enlargement	0.20	0.25
	Concrete: Crack repair by shim and binder injection	0.32	0.50
	Concrete: Beam and column plating with composite material nets	0.57	0.75
	Wood/timber: Pin insertion at connections	0.60	0.50
	Wood/timber: Insertion of steel frame substructure	1.00	1.00
	Wood/timber: Wooden element substitution	0.50	1.00
	Wood/timber: Anti-insect treatment	0.60	0.75
	Wood/timber: Antifungal treatment	0.52	0.50

Table 7. *Cont.*

Evaluation of Attributes for Reversibility and Invasiveness—Operative Scope: Structural System			
Attributes	**Option Description**	**R**	**I**
3. Reversibility in slab and floor reinforcement	Masonry: Provision of new concrete side-beams	0.15	0.50
	Concrete: Batten stiffening plating at intrados of reinforced concrete and hollow tile mixed floor	0.70	0.75
	Concrete: Extrados stiffening with reinforcement addition	0.52	0.75
	Concrete: Rigid connection between column and slab	0.07	0.25
	Concrete: Plating with steel-fiber textiles	0.50	0.50
	Concrete: Prevention of sloughing off with biaxial fiber net	0.57	0.75
	Wood/Timber: Plank stiffening with associated slab	0.37	0.25
	Wood/Timber: Plank stiffening with iron straps	0.62	0.75
	Wood/Timber: Plank stiffening with diagonal wooden battens	0.80	0.75
	Wood/Timber: Provision of new auxiliary wooden beams	0.55	0.50
	Masonry vault: Stiffening by reinforced slab	0.45	0.50
4. Reversibility in roofing reinforcement	Wood/timber: Provision of new summit side-beam	0.92	0.75
	Wood/timber: Insertion of tie bars	0.75	0.75
	Wood/timber: Connection with steel profiles	0.75	0.75
	Wood/timber: Retrofit by waterproofing and thermal insulation	0.80	0.75
	Wood/timber: Provision of steel braces at pitches	0.55	0.50
	Wood/timber: Stiffening by provision of a second wooden plank with interposition of thermal insulation	0.80	0.75
	Wood/timber: Substitution of degraded elements	0.20	0.25
No intervention	1.00	0.00	

Table 8. Parameters for judgments in Reversibility and Invasiveness categories [28].

Operative Scopes	Threshold Scale for f_i, d_i, and t_i				
	0.00	**0.25**	**0.50**	**0.75**	**1.00**
Technical feasibility of restoration works	not executable	complex	moderate	acceptable	excellent
Damage caused by restoration works	large	noticeable	limited	negligible	absent
Residual restoration traces	large	noticeable	limited	negligible	absent

The KPIs for judgments on the reversibility of interventions affecting the typological scheme are based on threshold evaluation of the new volume added, or the existing volume demolished, compared to the original building volume; the versatility evaluation of the typological scheme is based on such KPIs as the net indoor height, distance between load-bearing vertical structures, and width and slope of stairs. The evaluation of building site accessibility depends on the width and pendency of vehicular access, distance from public transportation access points, service frequency, and availability of parking areas. For weak users, we distinguish non-accessible buildings, buildings with only common and public spaces that are accessible, adaptable buildings, and fully accessible buildings, with a progressively increasing judgment for each scenario. The judgments concerning the installation of new technical plants consider the plant loss factor, intended to reflect the volume dedicated to the placement of plants and facilities compared to the building gross volume. Finally, visible terminals of electric and heating plants are penalized in the visual impact evaluation, because in the original vernacular buildings only a fireplace was present as the precursor to a modern heating system.

The definition of the framework for the sustainability assessment in reuse interventions has been based on the objectivity and repeatability of the evaluation of each attribute, and on the compliance of the attributes with the architectural object being evaluated. In particular, the definition of attributes evaluable by scenarios, as an alternative to the widespread use of KPIs, overcomes the risk of a different judgment being given to the same attribute by different evaluators working in the same scope.

3.2. Framework Weighting Procedure

Once the structure of the assessment framework has been described, each evaluation area, category and attribute are given a weight that defines their contribution in terms of sustainability. Attribute weights are estimated according to a hybrid procedure that implements the edges and the Simos methods [32], as revised by Figueira and Roy [33], and is finally applied through a simplified process proposed for the scope of multicriteria evaluations [34].

The first step is to configure the scenarios characterized by the combination of very bad and very good evaluations. The decision maker orders the scenarios and calculates the non-normalized weights as follows:

1. The scenarios are ordered from the least to most important, including ex-aequo, defining the r positions and c_r scenarios in the r-th position.
2. Blank cards are inserted.
3. Values (v_r) are assigned based on the positions of scenarios.
4. Positions containing blank cards are deleted. In this way, the value assigned to each position, v_r, represents an initial non-normalized judgment of the relative importance of each scenario.
5. The importance ratio, z, between the least and most important scenarios is defined.
6. The weight, ${p^z}_r$, is calculated through linear interpolation to obtain a ratio between the weights associated with the most and least important scenarios, z.

$$p_r^z = \frac{v_r \cdot (z-1)}{(v_{rmax} - v_{rmin})} + \frac{(v_{rmax} - z \cdot v_{rmin})}{(v_{rmax} - v_{rmin})} \quad (4)$$

7. All weights ${p^z}_r$ are scaled from 0 to 100 and normalized to achieve w_r, taking into account the interactions between the scenario parameters.

Three scenario levels are distinguished, including first-order scenarios,

$$w_1 = \frac{p^z_{r,100}\ \{c_1\}}{100} \tag{5}$$

$$w_2 = \frac{p^z_{r,100}\ \{c_2\}}{100} \tag{6}$$

$$w_3 = \frac{p^z_{r,100}\ \{c_3\}}{100} \tag{7}$$

second-order scenarios,

$$w_{12} = \frac{p^z_{r,100}\ \{c_1,\ c_2\}}{100} - (w_1 + w_2) \tag{8}$$

$$w_{13} = \frac{p^z_{r,100}\ \{c_1,\ c_3\}}{100} - (w_1 + w_3) \tag{9}$$

$$w_{23} = \frac{p^z_{r,100}\ \{c_2,\ c_3\}}{100} - (w_2 + w_3) \tag{10}$$

and third-order scenarios,

$$w_{123} = \frac{p^z_{r,100}\ \{c_1,\ c_2,\ c_3\}}{100} - (w_1 + w_2 + w_3 + w_{12} + w_{13} + w_{23}) \tag{11}$$

The procedure can easily be extended to higher orders depending on the number of areas, categories and attributes involved.

While the decision maker assigns a rating [0;1] to each attribute, which is then multiplied by its weight, an aggregation operator is calculated at each single node. The synthetic sustainability indicator, V, is formulated as follows:

$$\begin{aligned} \mathrm{V}(\mathrm{c}_1, \mathrm{c}_2, \ldots \mathrm{c}_n) = & \sum_{i}^{n} \mathrm{w}_i \mathrm{c}_i + \sum_{i_1=1}^{n} \sum_{i_2=i_1+1}^{n} \mathrm{w}_{i_1 i_2} \mathrm{c}_1 \mathrm{c}_2 + \ldots \\ & + \sum_{i_1=1}^{n} \sum_{i_2=i_1+1}^{n} \ldots \sum_{i_n=i_{n-1}+1}^{n} \mathrm{w}_{i_1 i_2 \ldots i_n} \mathrm{c}_1 \mathrm{c}_2 \ldots \mathrm{c}_n \end{aligned} \tag{12}$$

where c_i are attributes in first-order scenarios, categories in second-order scenarios, and evaluation areas in third-order ones; and w_i are the weights applied for each scenario.

Moreover, the model provides indices capable of assessing the degree of conservativeness of the value function at each node. These orness, *O*, and andness, *A*, indices vary between 0 and 1, and are defined as follows:

$$O = \frac{1}{n-1} \sum_{T \subseteq N} \frac{n-t}{t+1} w(T) \tag{13}$$

$$A = 1 - O \tag{14}$$

where n represents the number of attributes, categories, or areas depending on the hierarchical order at which *O* and *A* are evaluated; t is the hierarchical order; and *w* is the expression for the weights.

In Tables 9 and 10, an excerpt of the weighting process is reported. The example considers the Reversibility category, as a third-level set of operational scopes, and the Intrinsic Sustainability area as a second-level set of categories. The highlighted sets are characterized by a different number of inputs, and consequently more combinations must be considered according to the edges method.

Table 9. Scenarios weighting in Intrinsic Sustainability second level area. The attribution of each value judgment, VJ, depends on the valorization of the applicable KPI.

Intrinsic Sustainability								
IS.R.1	**IS.R.2**	**IS.R.3**	**IS.R.4**	v_r	c_r	$p^z_{r,100}$	**w**	**VJ**
low	low	low	low	0	0	0.00	0.00	-
high	low	low	low	3	3.00	15.00	0.15	0.863
low	high	low	low	6	1.00	30.00	0.30	0.593
low	low	high	low	3	3.00	15.00	0.15	0.606
low	low	low	high	3	3.00	15.00	0.15	0.700
high	high	low	low	13	1.00	65.00	0.20	0.512
high	low	high	low	10	3.00	50.00	0.20	0.523
high	low	low	high	8	2.00	40.00	0.10	0.604
low	high	high	low	10	3.00	50.00	0.05	0.360
low	high	low	high	10	3.00	50.00	0.05	0.415
low	low	high	high	8	2.00	40.00	0.10	0.424
high	high	high	low	16	2.00	80.00	−0.25	0.310
high	high	low	high	18	1.00	90.00	−0.05	0.358
high	low	high	high	15	1.00	75.00	−0.10	0.366
low	high	high	high	16	2.00	80.00	0.00	0.252
high	high	high	high	20	1.00	100.00	−0.05	0.217
Z	6.66						1.00	0.709
						ORNESS		0.497
						ANDNESS		0.503

Table 10. Scenarios weighting in Reversibility third level category.

Intrinsic Sustainability								
IS.R	**IS.V**	**IS.I**	**-**	v_r	c_r	$p^z_{r,100}$	**w**	**VJ**
low	low	high		0	0	0.00	0.00	-
high	low	high		3	2.00	30.00	0.30	0.709
low	high	high		2	1.00	20.00	0.20	0.650
low	low	low		3	2.00	30.00	0.30	0.585
high	high	high		6	2.00	60.00	0.10	0.461
high	low	low		8	1.00	80.00	0.20	0.415
low	high	low		6	2.00	60.00	0.10	0.380
-	-	-		-	-	-	-	-
-	-	-		-	-	-	-	-
-	-	-		-	-	-	-	-
-	-	-		-	-	-	-	-
-	-	-		-	-	-	-	-
-	-	-		-	-	-	-	-
-	-	-		-	-	-	-	-
high	high	low		10	1.00	100.00	−0.20	0.269
Z	5.00						1.00	0.631
						ORNESS		0.467
						ANDNESS		0.533

A total andness measure (O = 0; A = 1) means that at least one attribute is high enough to result in a high aggregate rating, regardless of the value of the other attributes; in the case of a total orness measure (O = 1; A = 0), all attributes must be high in order to produce a high rating. Finally, a simple additive measure means that the rating is given by the sum of the scores assigned to KPI, without considering any synergy among them (O = 0.5; A = 0.5).

In this way, it is possible to consider and mediate different approaches to reuse projects for mountain architecture. The sorting of scenarios, carried out according to the Simos method, can vary depending on the cultural training of the expert performing the valuation. It is therefore possible to treat this different sensibility through a composition of scenarios determined by an expert panel. In the beginning, each expert expresses a value order that defines a weight vector, through the Simos method; subsequently, the average weights obtained by each expert evaluation allows for a determination of the andness and orness indices inherent to the degree of conservativeness. As shown in Figure 2, a variation in the O index modifies the value of the sustainability indicator, V, while retaining the same judgments expressed for the attributes.

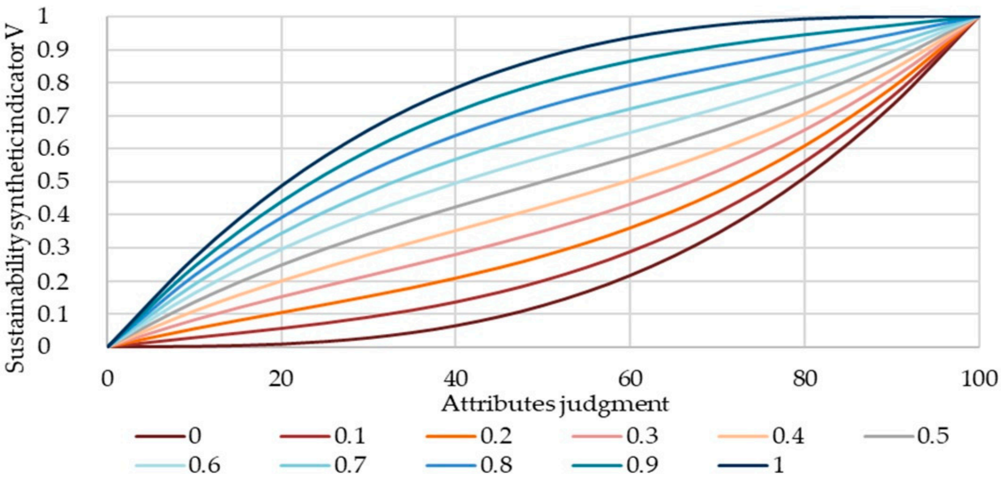

Figure 2. Variation in the sustainability indicator, V (in ordinates), for curves corresponding to different O index values; the values given to the attributes are shown on the abscissae.

4. Case Study for Model Application

The vernacular architecture considered in this study is widespread throughout the Sauris Municipality in the historic region of Carnia in Friuli–Venezia Giulia. The municipality consists of three main settlements: Sauris di Sotto (seat of the town hall), Sauris di Sopra and Lateis (Figure 3).

Figure 3. Location of Sauris and general view of the settlements.

In Sauris architecture, the careful use of local natural resources can be observed, in which the building material supply satisfies the control criteria of rationality and availability; in this way, construction techniques seek optimal performance in association with a minimum consumption of virgin materials, such as wood and stone, although these are of large availability. Moreover, a remarkable value of this architecture lies in its sustainable exploitation of territory, as settlements occur in the most suitable location depending on sunlight and shelter from cold winter winds.

These conditions have led to the progressive development of a homogeneous building type that characterizes the buildings in terms of the distribution of functional spaces and common construction techniques. The matrix type of Alpine wooden house has a rectangular plan delimited by load-bearing walls built using the blockbau technique, in which squared overlapping trunks are carved and interlocked at the corners.

The evolution of Sauris houses shows a diversification in looks through an evolution, leading to the distinction of living and bedroom areas through a distribution atrium accessible from the main front (Figure 4). Thus, the factors that characterize this residential type are the position of the entrance, the orientation of the roof pitches relative to the North–South direction, and the relationship of the built volume to the variable land slope. The ground floor, partially underground, is built in river-stone and pebbles, keeping the first floor above the maximum winter blanket [7].

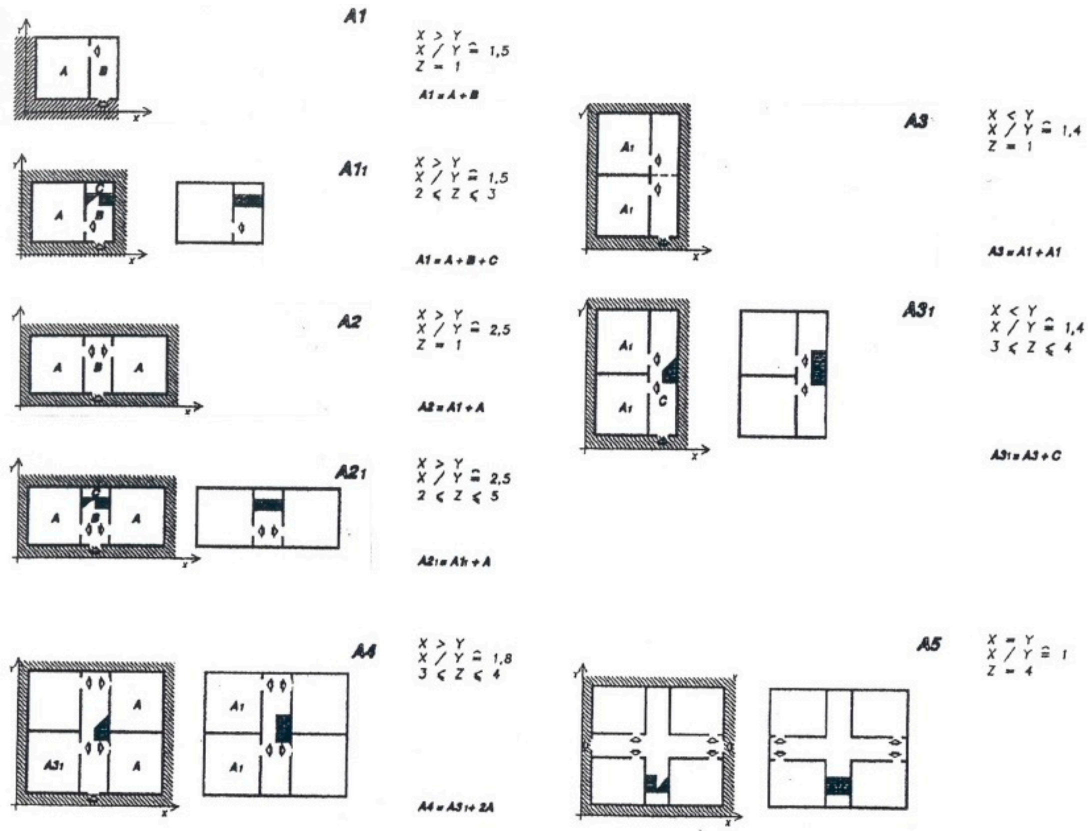

Figure 4. Building types in Sauris territory. The abacus shows the main activity spaces (A) and distribution spaces (B), combined in a single story in types A1, A2 and A3, and in two stories in the remaining types. Types A2 and A3 represent a single module house, while A4 and A5 represent a double module house [13].

On the ground floor, living rooms are located on the southern front, at a lower height than the north-facing front. In plots where the ground has a significant slope, a transversal position of the distribution atrium is preferred, with consequent double access to the house from opposite sides.

Bedrooms are usually located on the first floor, characterized by the use of the blockbau wooden technique; access is granted by internal stairs, and the access extends to the balcony as well (Figure 5).

The transformation of Sauris residential types has also involved technical elements, which are the result of a continuous evolution from entirely wooden construction to mixed construction with wood and river-stone; the most recent buildings are constructed entirely of hydraulically bound stone. Sauris' vernacular architecture covers the range of specific housing answers developed by the local community, evolving from a matrix-type through continuous revisions and improvements.

Figure 5. Examples of different load-bearing structural systems in Sauris di Sopra settlement—image taken by the authors.

The proposed multi-attribute model was tested on four Sauris buildings. A brief description of each building is provided in Tables 11–14; for case No. 1, the evaluation was carried out ex-ante on the reuse project documents, while the remaining cases were analyzed based on the reuse interventions already performed.

Table 11. Description of case study No. 1 for multi-attribute model application—image taken by the authors.

Identification	Features	Description
Case study No. 1	Location	Sauris di Sotto
	Intended reuse	Residential, with annexed commercial activity
	Floor plan	Mono-family single module and ancillary volume
	Gross area	160 m^2 (commercial activity) 305 m^2 (residential spaces)
	Elevation	Two floors above ground, one underground level
	Structure	Concrete walls (underground) blockbau walls with steel frame reinforcement, wooden planks, roofing in wooden shingles
	Project description	Seismic adjustment through a new foundation slab at the basement, structural reinforcement by a new steel frame, roofing retrofit, and envelope thermal insulation

Table 12. Description of case study No. 2—image taken by the authors.

Identification	Features	Description
Case study No. 2	Location	Sauris di Sotto
	Intended reuse	Bed and Breakfast
	Floor plan	Semi-detached double module and ancillary volume
	Gross area	561 m^2
	Elevation	Three floors above ground, basement
	Structure	River-stone walls (basement and ground floor), blockbau walls (1st, 2nd floors), wooden planks, roofing in wooden shingles
	Project description	Replacement of degraded wooden elements, window replacement, roofing thermal insulation and waterproofing

Table 13. Description of case study No. 3—image taken by the authors.

Identification	Features	Description
Case study No. 3	Location	Sauris di Sopra
	Intended reuse	Primary residence
	Floor plan	Semi-detached (double module)
	Gross area	429 m^2
	Elevation	Two floors above ground, basement
	Structure	River-stone walls (basement and ground floor), blockbau walls with steel frame reinforcement (1st, 2nd floors), wooden planks, roofing in wooden shingles
	Project description	Stone wall strengthening with new concrete side-beams, second wooden plank, stiffening with diagonal battens, steel bracing reinforcement and thermal insulation of blockbau, roofing thermal insulation

Table 14. Description of case study No. 4—image taken by the authors.

Identification	Features	Description
Case study No. 4	Location	Sauris di Sopra
	Intended reuse	Widespread hospitality, 3 rooms (Albergo Diffuso)
	Floor plan	Mono-family single module, later enlarged
	Gross area	280 m^2
	Elevation	Two floors above ground, basement
	Structure	River-stone walls (basement), blockbau walls (above ground), wooden planks, roofing with waterproof membrane
	Project description	Replacement of degraded wooden elements, roofing renovation, internal thermal insulation of vertical envelope

5. Results and Discussion

As stated above, the andness and orness indices used in the model are derived through an expert approach (Figure 6). First, the results show that the aggregation function of attribute judgments, after mediation based on expert-based indications, is predominantly andness in all aggregation nodes. As an example, for a theoretical intervention in which a value 0.5 is given to all attributes, the aggregation function provides a sustainability indicator of V = 0.363 (Figures 7–10). This means that on one hand, a reuse project can be said to be sustainable when several categories and attributes receive a high judgment. However, on the other hand, that reuse project must not only be respectful of the features of which Sauris vernacular architecture is the bearer, but also must be economically sustainable, with particular attention paid to its relationship with the local context.

The overall sustainability assessment for each case study considered fluctuates in the range of 0.449–0.616, which is a predictable result as the buildings subjected to these reuse projects are in the same context and, therefore, will have a common judgment in some attributes.

In this regard, the attribute of Accessibility to public transportation (Intrinsic Sustainability area, Versatility category, Accessibility scope, attribute 2) is used as an example. In considering the distance between the study building and the public transportation access point, the value is penalized in all cases by the low frequency of the public transportation service, giving a judgment varying between 0.22 and 0.26. In addition, the methodologies adopted for the retrofit of structures and architectural envelopes have a limited set of possible actions, thus generating a short list of judgments that can be attributed.

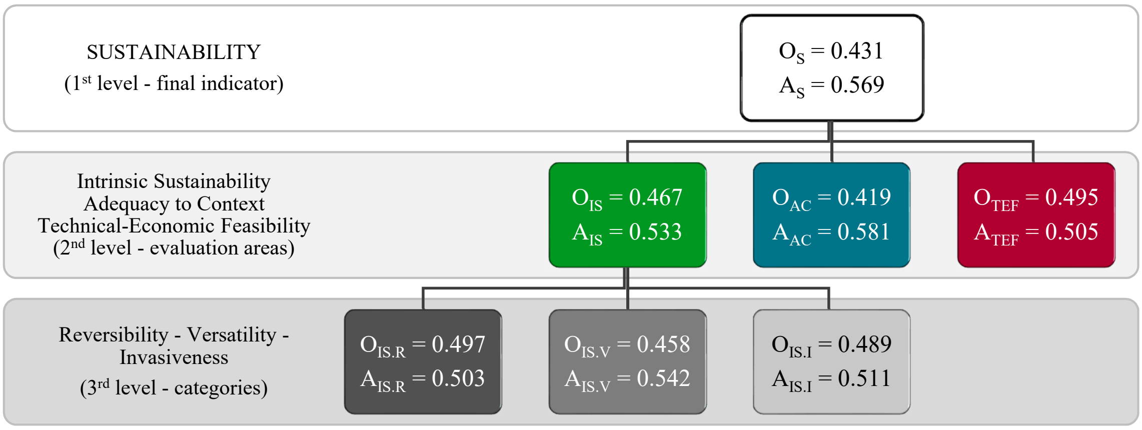

Figure 6. Andness and Orness indices at the different nodes of the evaluation, obtained according to the Simos method as revised by Figueira and Roy [33].

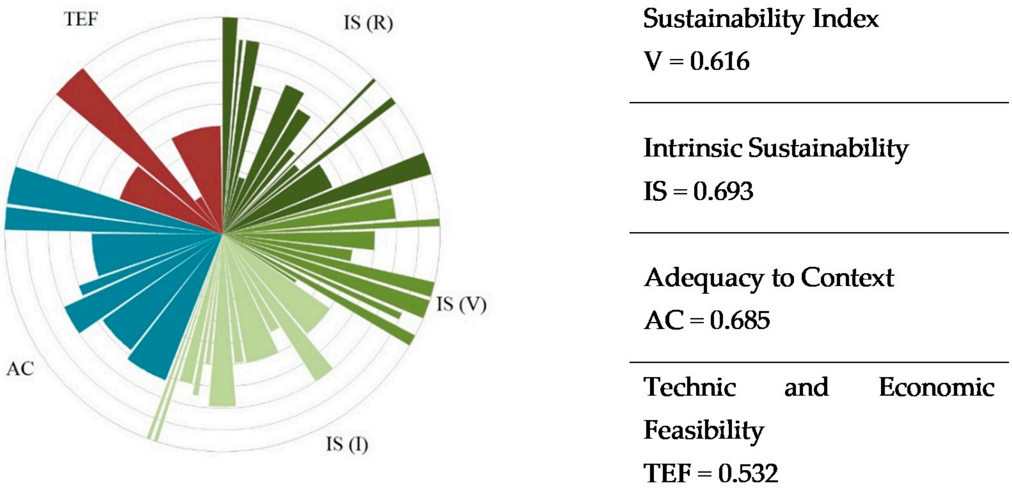

Figure 7. Attribute judgment and aggregated indicators for case study No. 1.

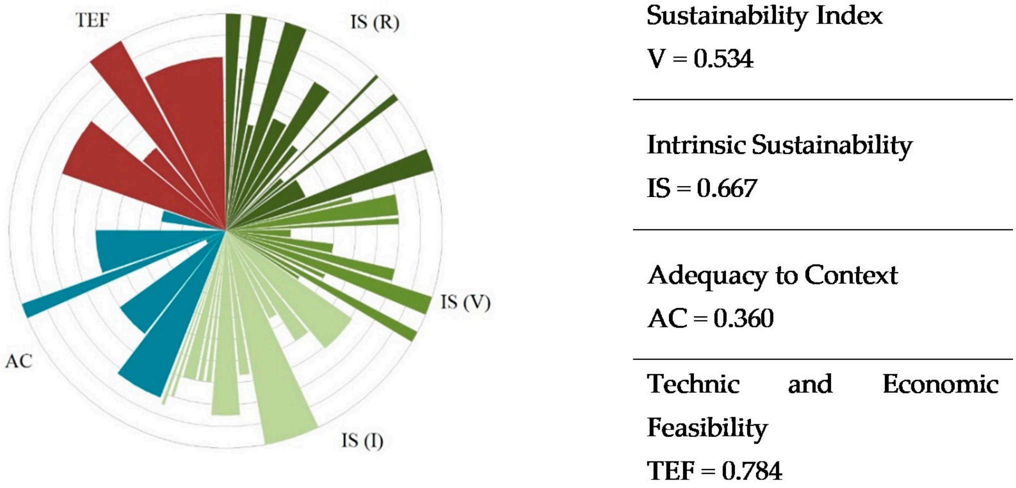

Figure 8. Attribute judgment and aggregated indicators for case study No. 2.

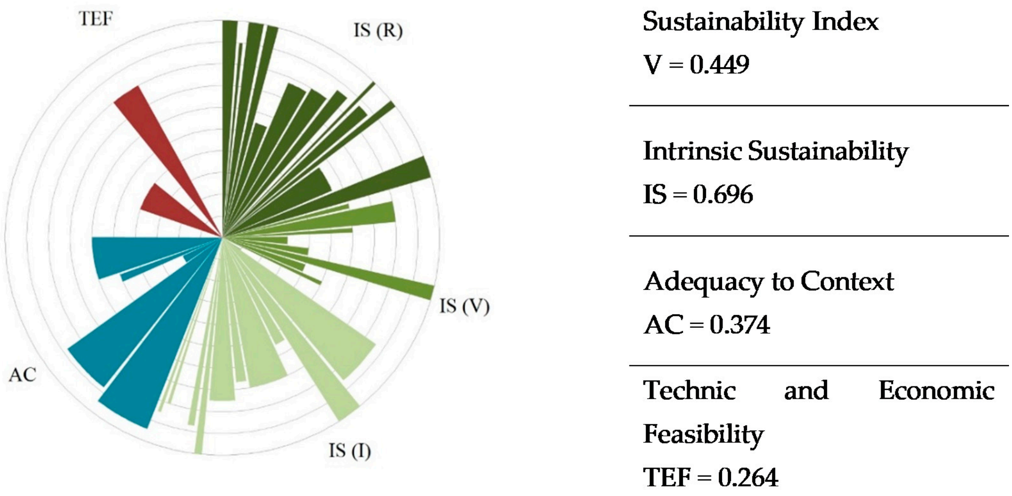

Figure 9. Attribute judgment and aggregated indicators for case study No. 3.

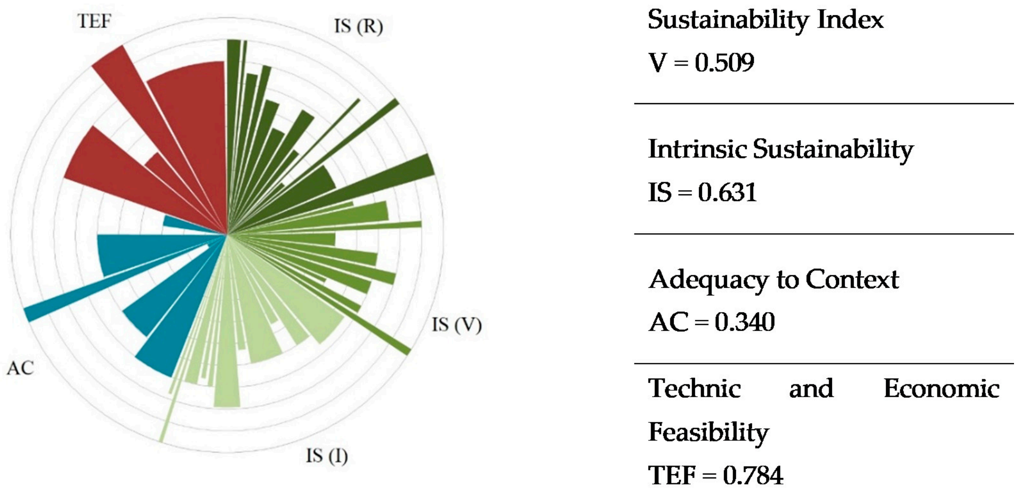

Figure 10. Attribute judgment and aggregated indicators for case study No. 4.

The assessment of individual reuse projects provides results that are generally sufficient, giving a simple average of attribute judgments that is greater than 0.6 in all case studies. Case No. 3 is penalized for a low performance in the Technical and Economic Feasibility evaluation area, as the intervention is aimed at restoring the function of a private house, with modest effects on the economic profile and potential activity sharing by the community. All of the reuse interventions exhibit good performances in terms of the intrinsic sustainability, which is aimed at the conservation of the geometric and material aspects of the buildings. It should be noted that the proposed interventions must comply with the requirements of the Typological Standards of the Municipality General Development Plan.

The highest ratings in the Technical and Economic Feasibility evaluation area are achieved for activities of widespread hospitality, such as Albergo Diffuso and Bed and Breakfast, as these are capable of generating a greater than expected return compared to commercial services or dwellings, while being embedded in a service typology already present in the Sauris community.

6. Conclusions

The multi-attribute model proposed in this paper aims to define an organized set of attributes capable of evaluating the sustainability of reuse projects for mountain architecture, specifically the vernacular architecture of mountain settlements in the Friuli historic region in north-eastern Italy. The proposed model has been tested in the context of Sauris, which is characterized by building types that trace the historical evolution of the settlements.

With respect to experience obtained from the literature, the attributes were organized in a hierarchical framework and further calibrated to capture the needs connoting the reuse of these specific buildings.

Considering the remarkable homogeneity that characterizes the settled portion of Alpine territory in terms of architectural expression, material culture and landscape organization, the model's construction allows for future development of the research, i.e., by applying the model to other mountain contexts. In this way, it could be possible to overcome current limitations, such as the evaluation of several attributes by qualitative scenarios. Moreover, the study of a context different in terms of construction materials and techniques can lead to a more objective classification of actions performable in building refurbishment in terms of technical feasibility, induced damage and residual traces.

Thus, a future objective is the implementation of scenario evaluations, with a desired improvement in the specifications comprising the Reversibility and Invasiveness abaci, and a strengthening of the weighting system through an updating of the requirements for the protection and reuse of mountain cultural heritage.

The synthesis of such complex assessments in a single sustainability indicator does not catch all the peculiarities of the various projects assessed. The use of a model based on synthetic numerical judgments also entailed the need to set the judgment of some qualitative attributes according to scenario evaluation, leading to the possibility that no scenario among those proposed is able to describe the qualities of the evaluated alternative.

The semiquantitative approach at the basis of the judgments in the Reversibility and Invasiveness abaci allows one to update and—where appropriate—correct the model. The description of scenarios related to technical feasibility, damages and residual traces, according to qualitative, clear parameters as per Tables 7 and 8, can broaden the set of intervention works related to reuse projects, and help in appropriately considering the technological developments made in the field of building refurbishment.

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