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Circular Economy strategies for Adaptive Reuse of Borgo San Leonardo in Carlentini

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Highlights

- Adaptive reuse of rural heritage supports circular economy by extending building life cycles.
- The case study of Borgo San Leonardo applies a participatory Multi-Criteria Decision Analysis (MCDA).
- The approach enhances local identity by preserving productive culture and traditions and the proposed strategies activate new development scenarios in high-value landscapes.

Abstract

Reuse of the built heritage is a strategy for enhancing the architectural heritage, designed to start virtuous development processes with positive impacts on the landscape. Adaptive reuse is a significant approach in circular economy practices to extend the life cycle of building by lengthening the use and delaying the end of life. As a result, the reuse of abandoned buildings can enhance the surrounding contexts, achieving ecological benefits and implementing social responsible economic growth. Borgo San Leonardo in Carlentini (Italy) is an example of disused rural heritage in a context of high landscape value and development potential, characterised by a common type of dwelling in the Syracuse area. The area has been declared of outstanding public interest and still retains its perceptual-cultural, morphological-dimensional, and material-constructive values. The regeneration of rural heritage seeks to place communities at the centre of decision-making processes in these territories, aiming to preserve the local productive culture and traditions while activating new development processes. The case study describes the decision-making process related to the definition of new uses, through a multi-criteria and participatory approach. The outcomes are guidelines to choose new compatible uses for old buildings, able to activate circular development processes. This will be achieved through a Multi-Criteria Decision Analysis (MCDA), in order to compare adaptive reuse alternatives, considering the impacts on the environmental, cultural, social and economic systems.

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1. Introduction

Circular economy approaches in construction and urban systems offer innovative opportunities for the repurposing and reuse of underutilised or abandoned buildings, contributing to the regeneration of the built environment (Foster, 2020). Extending the lifecycle of buildings is a practice to reduce raw material consumption and minimise environmental impacts (Foster & Kreinin, 2020). Furthermore, the involvement of stakeholders and local communities is essential to ensure that reuse interventions align with socio-economic preferences and needs, while also preserving cultural and architectural identities (De Medici & Pinto, 2012). Multi Criteria Decision Analysis (MCDA) methods play a pivotal role in integrated decision-making processes, enabling the assessment of interactions among economic, environmental, social and cultural factors (Swart, 1994). These methods not only support decision-makers in addressing problems involving conflicting objectives (T. L. Saaty & Alexander, 1989) but also encourage the exploration of alternative scenarios, making the decision-making process more adaptable and dynamic (Fusco Girard & Nijkamp, 1997). An integrated evaluation model facilitates the planning of future activities and measurement of impacts on both local economies and global ecosystems (Weyant, 1994). Adaptive reuse represents a sustainable transformation strategy that, through changes in function, extends building lifespans while meeting new functional needs. This approach preserves the intrinsic values of buildings as expression of a locale's construction culture, historical era, or community (Viola et al., 2021). Therefore, building reuse, supported by multi-criteria methods, serves as a pathway towards achieving a circular economic model with benefits on both local and global scales (Foster, 2020). The reuse process not only prolongs the lifecycle of the built heritage but also enhances its cultural, economic and social meanings, promoting balanced and resilient development (Laefer & Manke, 2008). This research applies MCDA to the case study of Borgo San Leonardo, a rural site, with the aim of identifying a new functional use capable of generating benefits for the broader context in which it is located. This approach seeks to enhance the value of abandoned rural heritage while respecting and preserving its perceptual-cultural values, morphological-dimensional characteristics and material-constructive features. The reuse of rural building heritage requires careful evaluation of choices regarding the conservation and valorisation of its historical, productive and constructive characteristics, within the context of the homogeneous rural area in which it is located (Longo et al., 2006). In this regard, several European projects view rural heritage as a resource to be preserved and developed, outlining a process of actions and guidelines for the management and planning of heritage based on the rural community (De Luca et al., 2021). Therefore, the current research aims to explore a multi-criteria evaluation model for analysing various reuse scenarios, considering contemporary needs and the site's potential, to ensure sustainable regeneration that aligns with the historical identity and the cultural fabric of the area. The paper is structured as follows: Section 2 outlines the research methodology, Section 3 introduces the case study, while Section 4 analyses settlement needs to understand development dynamics. Section 5 discusses potential new use scenarios, examining the constraints on transforming the case study. In the last section, MCDA is applied to the case study to define a shared use scenario through a participatory decision-making process involving the community and local stakeholders.

2. Methodology

The methodology consists of four main steps: (i) acquiring knowledge of the existing heritage, (ii) analysing settlement needs, (iii) evaluating the compatibility of adaptive reuse and (iv) conducting a Multi-Criteria Decision Analysis. (Fig.1) This methodology is applied to a case study described in Section 3. The case study illustrates the decision-making process for defining new uses for rural heritage, through a multi-criteria and participatory approach. The outcomes include an evaluation process for rural heritage reuse, aimed at activating circular development processes. In the first phase, knowledge of the existing heritage is developed through the analysis of the physical, social and economic systems, which allow the identification of buildings performance, relationship with local community, and the area's economic dynamics. From the analysis of local settlement needs, conducted across these three systems, it is possible to deduce the potential and development dynamics of the territory. These insights are fundamental for defining hypothetical reuse

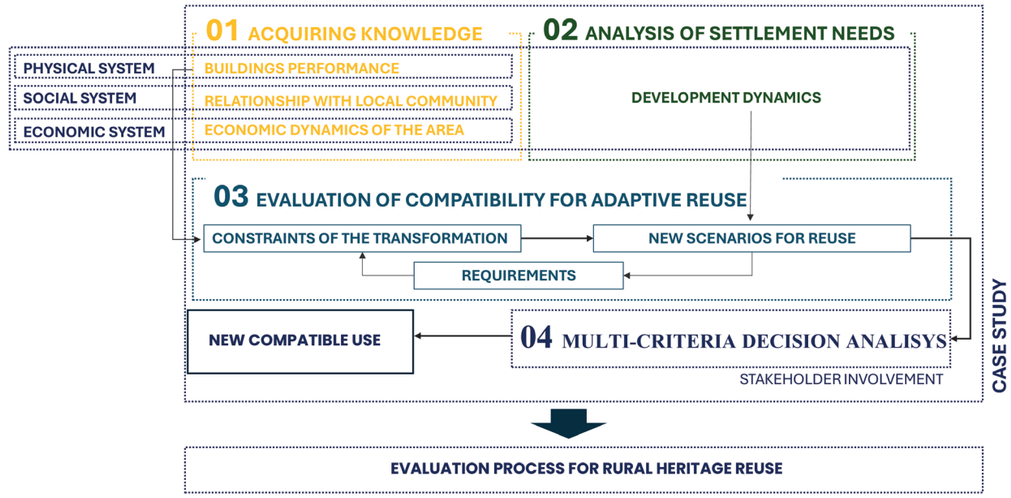

Figure 1: Methodology. *Source: author's elaboration*

scenarios, which must be compatible with the development trajectories of the context in which the architectural asset is situated, as well as with the constraints on transformation identified during the knowledge acquisition phase. Subsequently, by comparing the requirements of potential uses with the constraints on transformation, the evaluation phase identifies compatible reuse scenarios. Finally, the Analytical Hierarchy Process (AHP) is employed to construct a hierarchical structure and facilitate stakeholder involvement, within a participatory and shared decision-making process. This approach identifies the alternative that best aligns with the criteria established for the evaluation.

3. Case study: Borgo San Leonardo

The selected case study is Borgo San Leonardo, an example of disused rural heritage located in Sicily, within the territory of Carlentini. This settlement is situated in an area of high landscape value and development potential. The site has been declared of notable public interest (G.U.R.S., 2005) and still preserves its perceptual-cultural, morphological-dimensional and material-constructive values. Currently, the rural heritage is an under-utilised resource but holds potential to enhance economic processes linked to existing local productive activities and to activate new development processes.

Borgo San Leonardo lies within a vast flat area bordering the San Leonardo River from which it takes its name. It is perched on the rocky walls of a large calcarenite quarry, echoing the typology of Mediterranean spontaneous architecture typical of the Syracuse area. The settlement consists of thirteen architectural units, characterised by either an 'adjacent' or 'mixed' type. The adjacent structures are built within natural caves with constructed elements leaning against the rear walls of these cavities. The mixed structures, on the other hand, combine rock-hewn features with built components extending the caves outwards (Moretti & Bori, 2005). (Fig.2-3)

Originally, these buildings were designed for activities tied to the local economy, such as agriculture and livestock farming. Constructed from the same materials as the surrounding rock walls, they were primarily used as storage spaces. Over time, building types have diversified due to adaptations made to fit the rock face's morphology and to meet evolving functional and productive needs. Although there is no reliable information regarding the origins of Borgo San Leonardo, the configuration of the river suggests that the area adapted over time to human survival needs.

The river's flow and natural erosion processes have altered the landscape, promoting human settlement. The area is also connected to numerous archaeological sites, including the site of San Leonardo Soprano, located a few hundred metres away. Here, a small cluster of pit tombs dating

back to the 3rd-4th centuries a.C. can be found. In addition, other sites along the San Leonardo River bear evidence of artefact from the Greek and Roman-Byzantine periods. This attests to the presence of human settlements in the area since antiquity. The evolutionary process of Borgo San Leonardo is documented in the request for a landscape protection designation published in GURS 42/2005 (G.U.R.S., 2005). In 1810, Borgo San Leonardo was primarily used for grazing, with few buildings, including a shepherd's shelter, an oven and a room for cheese maturation, all carved out of existing natural caves and supplemented only with a façade. By 1835, the acquisition of new land shifted usage from grazing to arable farming, necessitating the construction of five additional buildings to meet new residential and storage needs. In 1900, further spaces for housing and stables were added. The earthquake of 1908 caused significant damage, and some houses were reconstructed on their original foundations. Improvements in water management and the conversion of land to citrus groves led to the construction of retaining walls, surface irrigation methods, and additional storage facilities, stables and the manor house. The last architectural unit was built in 1950, a garage for agricultural vehicles. After a prolonged period of abandonment, the area was repurposed for citrus production in 2015, following the construction of flood protection works.

4. Analysis of settlement needs

The analysis of settlement requirements was conducted by examining the local settlement system which comprises the physical, social and economic subsystems. The aim was to establish a comprehensive understanding of the current state, the area's potential land uses, and the possible development dynamics of both the territory and its population.

4.1 The Physical System

Borgo San Leonardo is situated within the southern part of the Piana di Catania, in the province of Syracuse, specifically in the municipality of Carlentini (Regione Siciliana & Assessorato dei Beni Culturali e dell'Identità Siciliana, 2018). This area is predominantly flat, characterised by agricultural activities, particularly citrus farming, which repre-

Figure 2: Borgo San Leonardo plan. *Source: author's elaboration*

Figure 3: Borgo San Leonardo. *Source: photo of Carla Di Giorgio*

sents one of the main economic sectors. The Borgo is set in a natural environment rich in resources, including the San Leonardo River and the Biviere di Lentini, an artificial lake of significant ecological importance that serves as a refuge for numerous animal species, including migratory ones. Moreover, the river attracts various user groups, and it's also hosts several sporting events and, since 2019, has served as a training site for the Italian Olympic Canoe-Kayak team.

The river, which flows through the area, is a key landscape and geological feature. It lies on the eastern side of Sicily and covers an area of approximately 500 square kilometres. It stretches from the towns of Vizzini and Buccheri to the Ionian Sea, near the San Leonardo Village, on the border between the territories of Augusta and Carlentini (Regione Siciliana et al., 2015). Its river valley is marked by terraces and meanders, indicative of a more dynamic fluvial system in the past. The area also boasts significant geological heritage, including Pleistocene calcarenite formations rich in marine fossils, such as bivalves and molluscs, as well as alluvial sediments attesting to the river's historical evolution.

From an archaeological perspective, the area surrounding Borgo San Leonardo is particularly noteworthy for its numerous historical sites, such as the Orto di Gallo, San Leonardo Soprano, the necropolis of Contrada Piscitello. The strategic location of Borgo San Leonardo, near the urban centres of Carlentini and Lentini, and near critical transport infrastructures such as the Strada Statale Orientale Sicula and the E45 and A18 motorways, makes it an important hub connecting the provinces of Catania and Siracusa.

Furthermore, a new motorway project is underway, aimed at linking Catania to the province of Ragusa, with the works expected to be completed by 2026.

4.2 Social and economic system

The social system of Carlentini has been analysed using data from the ISTAT Censuses of 1991, 2001, 2011 and updated data from 2020-22. The aim is to understand the demographic evolution and social characteristics of the population, comparing them with regional and national averages. According to the latest ISTAT Census (2022), the population of Carlentini currently stands at 17,084 inhabitants. Since 1991, there has been a demographic increase, whit a slight decline starting in 2020. The population growth between 2001 and 2011 can be attributed to a migration from the neighbouring town of Lentini. This demographic expansion has led to urbanisation in the peripheral areas of Carlentini, accompanied by the creation of new utilities and infrastructures, which in turn encouraged the displacement of residents from Lentini to Carlentini. As a result, the boundaries between the two municipalities have become less distinct, both physically and economically. In regard to the population structure, the aging index is more than 7% higher (ISTAT 2020) than the national average, reflecting a growing aging population. The trend of the unemployment rate between 1991 and 2011 shows a progressive reduction, with the rate standing at 9.4% in 2011. This

figure is lower than the regional average for Sicily (21.8%), but higher than the national average (11.4%). A concerning statistic is the youth unemployment rate, which reached 49.2% in 2011, 29.5% higher than the Italian average. The most recent ISTAT 2020 Census data reveal a significant gender gap. In Carlentini, the proportion of women active in the labour market is 35%, about 5%t lower than the national average. This suggests a lower level of inclusion of women in the local labour market compared to the national context. In regard of facilities and work market, the municipality manages only five sports facilities, highlighting an infrastructural shortfall in relation to the populations's needs. (ISTAT 2011) Only 17.8% of the population engages in regular sports activities, a figure significantly lower than the national of 28.9% for municipalities with populations between 10,000 and 50,000. (ISTAT 2021) This discrepancy underscores the urgent need to invest in sports infrastructure and services to promote physical activity and improve citizens' well-being. Regarding employment structure, Carlentini shows a high incidence of employment in the tertiary sector. Following this are hight and medium-skilled professions, which require higher education and specific competencies, and the industrial sector. The labour market follows a pattern like the national average in terms of sector composition and distribution. In recent years, Carlentini has recorded an increase in accommodation facilities, partly due to its proximity to Catania Fontanarossa Airport. According to ISTAT data on tourist movements in the Sicilian Region (2021-2023), the total number of accommodation establishments in Carlentini grew from eight in 2021 (with 241 beds) to eleven in 2023 (with 354 beds). Of these eleven establishments, seven are agritourism businesses, highlighting a strong connection between rural heritage, tourism, and the local economy. However, the area's tourism growth remains largely linked to the larger neighbouring tourist centres, rather than to cultural itineraries within the municipality itself. Therefore, to support tourism development, the Municipality of Carlentini has adopted a regulation for the application of the tourist tax (Comune di Carlentini, 2024) with the aim of funding initiatives for the promotion and enhancement of the local tourist system.

5. Development dynamics and new compatible re-use scenarios

From the analysis of the settlement requirements, it is possible to identify the area's development dynamics, potential and challenges, outlining hypothetical scenarios for the reuse of Borgo San Leonardo. Situated in a context rich in cultural, environmental and economic opportunities, the area present itself as a potential catalyst for new development initiatives. The analysis of the settlement system indicates that new development strategies should aim at four main objectives: (i) stimulating the local labour market by promoting agricultural, artisanal, and agri-food activities that enhance the area's resources; (ii) supporting and encouraging the local tourism by developing new itineraries that highlight the historical, rural and culture heritage; (iii) creating spaces and opportunities for young people by increasing services and prospects to counteract youth depopulation and the progressive aging of the population; (iv) improving the level of education and vocational training by facilitating access to training and specialisation programmes tailored to local market needs.
In addition, the knowledge phase (Sections 3 and 4) also allowed for the identification of existing constraints on transformation (Pinto, 2004). These constraints concern perceptual-cultural, morphological-dimensional and material-constructive aspects. In the case of Borgo San Leonardo, the perceptual-cultural constraints are linked to the deep connection with the local productive culture and the evidence of human settlement over time.
The morphological-dimensional constraints stem from the layout of the individual architectural units, which, although almost all adjacent, feature different floor levels, preventing internal communication between them. As a result, access to the units is from the outside, via steps that allow reaching the internal floor level. The interior spaces are unique and lack internal partitions; the walls that are adjacent to each other and to the rock typically have openings (one window and one door) only on the main front, which becomes the sole source of illumination. As far the material-constructive constraints, these are due to the use of calcarenite blocks sourced from the same quarry, with walls approximately 50 cm thick.
The internal spatiality, typical of rocky spaces, sees the rear walls, mostly made of rock, sculpted and smooth in most cases. Some architectural

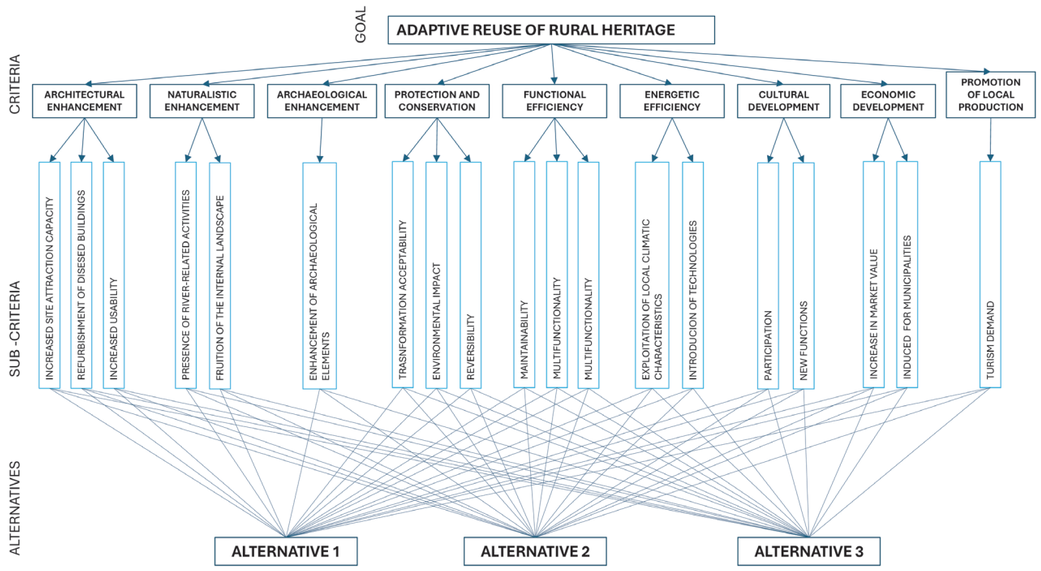

Figure 4: Hierarchical Structure Scheme. *Source: author's elaboration.*

units retain their original wooden roofs, consisting of a wooden structure, reed matting covered with gypsum plaster, and a roof of Sicilian tiles. Based on these considerations and identified development dynamics, three new compatible alternatives of re-use have been proposed in respect of constraints.
The first alternative envisions a Centre for Advanced Education in Archaeology, Natural Sciences and Agrarian Studies (A1). This would be an advanced training centre for graduates, focusing on three distinct areas of expertise. The objective is to converge all area values into a single-use destination capable of accommodating them simultaneously. The site would serve not only as a functional space but as integral part of the project, acting both as an object of study and a hub for ideas and fieldwork. The Centre would become a place of collaboration and a factory of ideas for a territory currently devoid of strategic development plans and facing the risk of depopulation.
The second alternative proposes the establishment of an Athletic Training Centre (A2) for Flat Water Sports. This facility would host, train and prepare athletes and sports technicians, with the added possibly of usage the site for team meeting activities. The goal is to enhance the resources of the San Leonardo River by capitalising on the area's climatic and geographical characteristics. The river is already utilised for athletic training due to its natural attributes and the region's mild winters and low rainfall, which allow for more frequent daily training sessions. Additionally, flat-water sports such as canoeing, kayaking and paddleboarding, are widely practised, and a specialised sports centre could also support smaller local sports associations.
The third alternative explore the potential to transform the Borgo into a destination for Experiential Tourism (A3), distinct from mass tourism. It focuses on creating connections with the unique people and places of the area, fostering activities with strong social and cultural impacts that allow individuals to engage deeply with local history, culture, people and traditions. This new function would offer a novel way of experiencing the site, leveraging its formal and cultural characteristics and linking visitation to a meaningful exploration of cultural heritage and traditions of Carlentini.

6. MCDA decision-making processes

MCDA is used to assess the possible alternatives outlined in the previous section, with the aim of involving stakeholders in the decision-making

process, as choices that are shared by the community facilitate the development of new dynamics and the enhancement of existing values.
The research adopts the Analytic Hierarchy Process (AHP) as a decision support method. Developed by Thomas L. Saaty, AHP is designed to evaluate and select among complex options based on multiple criteria (Saaty, 1987). The method is structured into three main phases: (1) decomposing the decision problem into a hierarchical framework comprising goal, criteria, sub-criteria and alternatives (Fig. 4); (2) conducting pairwise comparisons of elements at each hierarchical level to assess their relative importance using a numerical scale; (3) calculating a score for each alternative by combining the priorities derived from the pairwise comparisons with the weights assigned to the criteria.
Finally, the alternative with the highest score does not necessarily represent the best choice but is the one that most adequately meets the requirements and priorities defined by adopted criteria.
A set of 9 criteria were hypothesised and defined based on the development dynamics analysed in Section 5.
C1 Architectural Enhancement refers to activities aimed at preserving and ensuring the accessibility of heritage through conservation and renovation interventions. In this context, it applies to rural architectural heritage with historical or ethnographic significance, representing traditional rural economies (D.L. 42/2004)
C2 Naturalistic Enhancement involves interventions aimed at creating and preserving integrated landscape values, enhancing natural sites of exceptional universal value, whether scientific, conservational, or aesthetic (L.N. 184/1977).
C3 Archaeological Enhancement refers to functions and activities that facilitate the public access to heritage sites, particularly those with historical significance, irrespective of their aesthetic value (Franceschini, 1967).
C4 Protection and Conservation aims to safeguard the integrity and identity of cultural assets. Conservation refers to activities designed to maintain the integrity, identity, and functional efficiency of a cultural asset in a planned and coordinated manner. Protection ensures the identification and safeguarding of heritage for public access (D.L. 42/2004).
C5 Functional Efficiency focuses on promoting multifunctionality, flexibility of use, and ongoing maintenance. Maintenance involves activities aimed at monitoring and preserving the condition, integrity, and functional efficiency of cultural assets (D.L. 42/2004).

Goal	Criteria	Weighting score	Sub criteria	Weighting Scores of Alternatives		
				A1	A2	A3
Adaptive reuse of rural heritage	Architectural enhancement	0.233	Increased site attraction capacity	0.575	0.366	0.059
			Refurbishment of disused buildings	0.49	0.198	0.312
			Increased usability	0.324	0.321	0.356
	Naturalistic enhancement	0.156	River-related activities	0.646	0.064	0.29
			Fruition of the internal landscape	0.25	0.25	0.5
	Archaeological enhancement	0.146	Enhancement of archaeological elements	0.556	0.09	0.354
	Protection and conservation	0.135	Transformation acceptability	0.49	0.198	0.312
			Environmental impact	0.286	0.571	0.143
			Reversibility	0.539	0.297	0.164
	Functional efficiency	0.079	Maintainability	0.49	0.312	0.198
			Multifunctionality	0.735	0.065	0.199
	Energetic efficiency	0.077	Exploitation of local climatic characteristics	0.198	0.312	0.49
			Introduction of appropriate technologies	0.49	0.198	0.312
	Cultural development	0.064	Participation	0.647	0.098	0.254
			Creating new functions	0.49	0.312	0.198
	Economic development	0.054	Creation of new jobs	0.539	0.164	0.297
			Increase in market value	0.411	0.328	0.261
			Induced for municipalities	0.4	0.2	0.4
	Promotion of local production	0.055	Tourism demand	0.091	0.091	0.818
Consistency Ratio	0,0597					
Priority index				**0.459**	0.22	0.321

Table 1: The weighting score for criteria to an adaptive reuse of rural buildings. *Source: author's elaboration.*

C6 Energy Efficiency refers to the amount of energy required to meet standard building needs. This criterion concerns the potential for adapting local climatic conditions through the introduction of appropriate technologies (D.L. 192/2005).
C7 Cultural Development includes policies aimed at fostering the integrated development of cultural societies, enriching cultural identities, and expanding cultural participation. Broad public participation in cultural creation and its future is essential for genuine cultural development (Nocca, 2017).
C8 Economic Development refers to the long-term growth of key economic variables, including production, consumption, investment, and employment.
C9 Promotion of Local Production focuses on traditional and artisanal products within cultural heritage, contributing to local identity. These products, strongly tied to their place of origin, represent and transmit community values.
Subsequently, each criterion was associated with one or more sub-criteria, resulting in a total of 19 sub-criteria selected from the scientific literature (Nocca, 2017) that define and make the criteria measurable. In the second phase, 50 stakeholders were involved in the decision-making process, expressing their preferences through a pairwise comparison and assigning weights to the evaluation criteria using the Saaty Scale (ranging from 1 to 9).
Stakeholder involvement is pivotal to ensure shared and transparent choices, as it allows the integration of different perspectives, fosters awareness of collective priorities and facilitates broader consensus. The pairwise comparisons enabled the derivation of priority scales, with the reliability of the judgements validated through the Consistency Ratio (CR) (R. W. Saaty, 1987). This parameter, which must remain below 0.10 to ensure consistent and coherent judgements, confirmed the robustness of the decision-making process (Tab. 1).
Finally, the preferred alternative is the Centre for Advanced Education in Archaeology, Natural Sciences and Agrarian Studies (A1) achieving the highest score. This alternative was positively evaluated for its capacity to address territorial regeneration needs, promote social inclusion, and encourage sustainable economic growth through the implementation of high-level educational and training programmes. The AHP method thus facilitated the development of shared scenarios and the identification of optimal alternatives, highlighting the positive impact of adaptive reuse interventions not only in terms of social cohesion, wellbeing and environmental sustainability, but also in promoting participatory decision-making process that better address the needs of the communities involved.

7. Conclusions

The adaptive reuse process proposed for Borgo San Leonardo establishes a new form of use that integrates its various aspects. The choices made create new usage scenarios capable of enhancing development dynamics. This is achieved through a multi-criteria decision analysis (MCDA), which compares alternative adaptive reuse strategies, considering their impacts on environmental, cultural, social, and economic systems, and involving stakeholders in the decision-making process.
A set of 9 criteria has been defined to guide and assess the adaptive reuse process of rural heritage. These criteria are essential for evaluating the long-term viability and effectiveness of different interventions, ensuring that they meet both the preservation and development needs of the site. The characteristics of a rural site are complex, as they relate not only to the local productive culture, but also to territorial and landscape features, and the building traditions that testify to the historical development of the area. Revitalising these sites, both for private and public stakeholders, represents a key point in European research on rural heritage, contributing to the ongoing discourse on how to preserve and revitalise these important areas. However, the research also presents some limitations. One of the main challenges is the often-limited centrality and connectivity of these areas, which makes it difficult to establish strong links with urban centres. This lack of connection can hinder the development of new dynamics that might otherwise bring benefits to the surrounding areas. Overcoming these barriers is crucial for ensuring that adaptive reuse projects can thrive and integrate into broader regional development plans.

Attributions

All the parts of this paper have been discussed and approved by all the authors.
However, the §§ 3 and 4 are by C. Di Giorgio and M.R. Pinto; the §§ 5 and 6 by C. Di Giorgio and P. De Toro; and the §§ 1, 2 and 7 are by all the authors.

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