ADVANCES IN BUILDING EDUCATION
INNOVACIÓN EDUCATIVA EN EDIFICACIÓN

Canal de Castilla in the 21st Century: Challenges for Sustainable Development

El Canal de Castilla en el siglo XXI: desafíos para el desarrollo sostenible

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Received: 21/07/2025 | Accepted: 08/08/2025 | Publication date: 01/09/2025
DOI: https://doi.org/10.20868/abe.2025.2.5540

HIGHLIGHTS

- The Canal de Castilla is analyzed as a multifunctional asset, balancing heritage preservation, agriculture, water management, and sustainable tourism.
- A methodological framework is proposed, combining engineering approaches, digital tools, thematic mapping, and participatory planning.
- The study identifies both conservation challenges and development opportunities to ensure the canal's sustainable management in the 21st century.

RESUMEN

El Canal de Castilla, una de las obras hidráulicas más singulares del patrimonio español, ha evolucionado desde su función original como infraestructura de transporte hasta convertirse en un recurso multifuncional vinculado a la gestión del agua, la agricultura, la preservación cultural y el turismo sostenible. Este trabajo analiza los desafíos actuales y las oportunidades de desarrollo relacionadas con su conservación e integración territorial, proponiendo un marco metodológico que combina ingeniería, herramientas digitales, cartografía temática y procesos de participación ciudadana. Los resultados de 120 encuestas en el municipio de Alar del Rey muestran un reconocimiento mayoritario del valor cultural del canal, un respaldo significativo a modelos de gobernanza participativa y una clara priorización de la conservación patrimonial y el desarrollo turístico sostenible. Asimismo, la preferencia por el mantenimiento preventivo y la incorporación de energías renovables refleja la creciente conciencia social hacia la sostenibilidad. Más allá de estos aspectos, el estudio destaca también el potencial del canal como recurso educativo, capaz de funcionar como laboratorio vivo para la enseñanza en ingeniería, arquitectura y estudios ambientales. En este sentido, la investigación no solo impulsa la rehabilitación física y la revitalización funcional del Canal de Castilla en el siglo XXI, sino que también contribuye a la innovación docente mediante la aplicación de metodologías activas y el aprendizaje basado en proyectos..

Palabras clave: *Canal de Castilla, Conservación del patrimonio, Mecanismos hidráulicos, Infraestructuras sostenibles.*

ABSTRACT

The Canal de Castilla, one of Spain's most remarkable hydraulic heritage landmarks, has shifted from its original role as a transportation infrastructure to a multifunctional resource linked to water management, agriculture, cultural preservation, and sustainable tourism. This paper addresses the current challenges and development opportunities associated with its conservation and territorial reintegration, presenting a methodological framework that combines engineering approaches, digital tools, thematic mapping, and participatory planning. Survey results from 120 residents in the municipality of Alar del Rey reveal a strong acknowledgment of the canal's cultural significance, broad support for participatory governance, and a clear prioritization of heritage preservation alongside sustainable tourism initiatives. Furthermore, preferences for preventive maintenance and renewable energy integration highlight a growing societal awareness of sustainability. Beyond these aspects, the study emphasizes the educational potential of the canal, positioning it as a living laboratory for teaching in engineering, architecture, and environmental studies. In this way, the research not only supports the physical rehabilitation and functional revitalization of the Canal de Castilla in the 21st century but also contributes to educational innovation by promoting active methodologies and project-based learning in higher education.

Keywords: *Canal de Castilla, Heritage conservation, Hydraulic mechanisms, Sustainable infrastructures.*

1. INTRODUCTION

The Canal de Castilla, constructed during the 18th century, represents one of the most ambitious and emblematic engineering feats of Spain's Enlightenment period. Conceived in 1753 under the reign of Ferdinand VI and directed by engineer Antonio de Ulloa, the canal was designed to overcome the geographical isolation of the central plateau by facilitating

inland navigation and trade. Although its original objective of serving as a transportation network was only partially achieved due to the rapid expansion of the railway system in the 19th century the infrastructure soon revealed an extraordinary adaptive capacity [1]. Over the decades, the canal has been repurposed to serve multiple functions, ranging from agricultural irrigation and hydropower generation to cultural tourism and landscape integration [2,3]. Today, it constitutes not only a hydraulic infrastructure but also a cultural landscape that reflects the historical interplay between technology, society, and territory [4].

From a technical standpoint, the canal spans approximately 207 kilometers across the provinces of Palencia, Valladolid, and Burgos, incorporating an extensive system of locks, aqueducts, docks, and warehouses. Its construction required advanced knowledge in hydraulics, civil engineering, and territorial planning for its time, and it has been recognized as a masterpiece of Spanish hydraulic heritage. The structural elements, such as the locks and bridges, bear witness to the ingenuity and resilience of Enlightenment-era engineering. Today, these elements are under growing pressure due to deterioration, climate change impacts, and changing patterns of land and water use [5-7].

In the 21st century, the multifunctionality of the Canal de Castilla presents both challenges and opportunities. On one hand, conservation challenges involve structural rehabilitation, water quality management, biodiversity protection, and safeguarding its role as a cultural heritage asset [8]. On the other hand, development opportunities arise in areas such as environmental sustainability, rural development, ecotourism, and participatory planning [9-11]. The canal has been integrated into regional strategies as a green corridor and a cultural route, connecting natural ecosystems with human settlements and serving as a catalyst for economic diversification in rural areas. Its potential as a driver of sustainable development is amplified by its capacity to combine traditional irrigation services with new uses such as renewable energy, cycling routes, environmental education, and heritage interpretation centers [12].

The evolving role of the canal requires not only the physical rehabilitation of its infrastructures but also a conceptual redefinition of its value in modern society [13]. Beyond being a hydraulic system, the canal must be understood as a multilayered territorial asset: a living monument that encapsulates history, a provider of ecosystem services, and a platform for community identity [14,15]. To address this complexity, a multidisciplinary perspective is essential, integrating fields such as architectural heritage conservation, graphical engineering, landscape ecology, and social participation. Several studies in Europe have highlighted the reuse of historical waterways as central to landscape regeneration strategies, cultural tourism, and sustainable regional planning [16]. The Canal de Castilla is no exception, yet existing initiatives often lack a coherent methodological framework to harmonize conservation with innovation [17].

This paper proposes a structured methodology grounded in graphical and spatial analysis tools including Geographic Information Systems (GIS), digital modeling, and thematic mapping combined with survey-based diagnostics to capture citizen perceptions and priorities. This integrative approach not only enhances the accuracy of territorial assessments but also fosters community engagement, ensuring that interventions reflect local values and aspirations. By applying participatory planning and digital engineering tools, the proposed framework

seeks to bridge the gap between technical expertise and public involvement, ultimately guiding interventions that reinforce the canal's dual identity as both an infrastructure and a cultural-ecological system.

The opportunities for the Canal de Castilla in the 21st century are vast. As an irrigation system, it remains vital for agriculture in Castilla y León, supporting crop diversification and adaptation to climate change. As a cultural corridor, it offers immense potential for tourism based on history, gastronomy, and local traditions. As an environmental axis, it contributes to biodiversity conservation and the creation of ecological networks. And as an educational platform, it embodies the possibility of transmitting engineering knowledge, heritage values, and sustainability principles to new generations. Harnessing this potential requires moving beyond fragmented actions towards a comprehensive and participatory vision that situates the Canal de Castilla as a strategic resource for sustainable territorial development in Spain and Europe.

Beyond its territorial and cultural significance, the Canal de Castilla represents a valuable educational resource. As a living laboratory, it enables the application of engineering knowledge, heritage management, and sustainability principles in real-world contexts. The methodological framework presented in this paper, combining graphical tools, digital modeling, and participatory planning, can be transferred to higher education programs in civil engineering, architecture, and environmental studies. In this sense, the case study not only addresses the conservation and sustainable development of a historical infrastructure but also contributes to innovation in teaching practices, providing students with opportunities to engage in project-based learning and interdisciplinary analysis.

2. MATERIALS AND METHODS

2.1 Study Area

The municipality of Alar del Rey, located in the province of Palencia, was chosen as the primary site of study. Known as the canal's point of origin, Alar del Rey preserves significant canal-related heritage assets. The selected study area encompasses the historical layout of the canal, nearby urban interfaces, and associated infrastructure such as locks, bridges, and towpaths. Figure 1 shows the location of the study area.

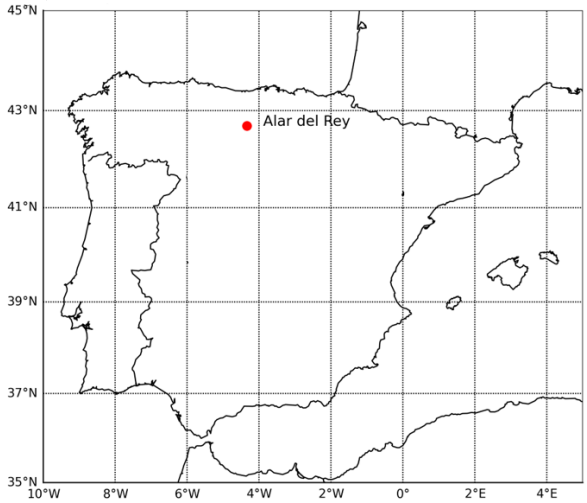

Fig. 1: *Location of the study area.*

2.2 Survey Methodology

A structured survey was designed and distributed among local residents in the municipality of Alar del Rey and surrounding areas (n = 120) with the objective of capturing public perceptions and attitudes regarding the Canal de Castilla. The survey was conceived as a key methodological tool to complement the technical and historical analysis with community-based insights, ensuring that proposals for conservation and development were grounded in local knowledge and values. By integrating both quantitative and qualitative dimensions, the survey allowed for a comprehensive

understanding of how the canal is perceived within its contemporary social and territorial context.

The questionnaire was structured into several thematic sections. First, participants were asked to assess the general relevance of the canal in their daily lives and in the identity of the territory, using a Likert-type scale (1–10). Second, a series of items focused on conservation priorities, including the urgency of structural rehabilitation, water quality management, and preservation of architectural elements such as locks, warehouses, and bridges. A third section addressed the technical and educational interest of the canal, evaluating its potential as an open-air classroom for engineering, architecture, and environmental sciences. Finally, the survey included questions about preferred future strategies, inviting respondents to weigh the importance of irrigation, cultural tourism, sustainable mobility, renewable energy, and landscape integration.

3. RESULTS AND DISCUSSION

The following figures provide a comprehensive summary of the outcomes obtained from the structured public survey conducted in Alar del Rey, offering a visual representation of the collective perceptions, expectations, and priorities associated with the Canal de Castilla. These figures are not merely illustrative but serve as analytical tools to reinforce the interpretation of the data.

The results presented in Figure 2 show that most respondents rated the Canal de Castilla highly in terms of its territorial significance, with the majority of scores concentrated between 7 and 10 points on the evaluation scale. This distribution indicates a predominantly positive perception, suggesting that the canal is strongly recognized as a defining feature of the local landscape and a key element in the structuring of the territory.

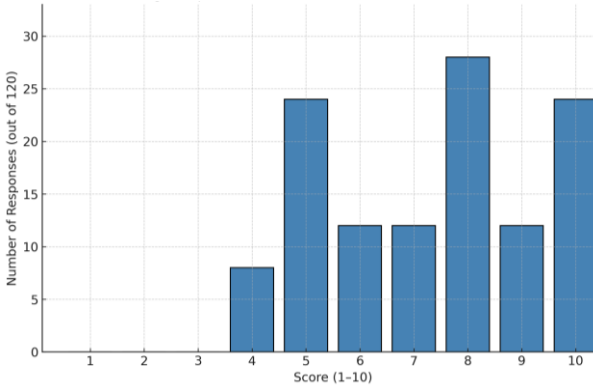

Fig. 2: *Importance of the Canal as a structural territorial element.*

The relatively low number of responses in the range below 5 highlights that only a minor segment of the population perceives the canal as less relevant, reinforcing the notion that its role transcends functional utility to embody a symbolic and identity-driven dimension. This strong valuation of territorial significance provides a solid foundation for future planning strategies, as it demonstrates broad community support for initiatives that prioritize the canal's integration into regional development, heritage preservation, and sustainable tourism.

The results shown in Figure 3 illustrate the evaluations concerning the integration of the Canal de Castilla into urban planning frameworks. Unlike the previous item on territorial significance, the distribution of responses here is more dispersed, spanning the entire 1–10 range and indicating a greater diversity of opinions among residents.

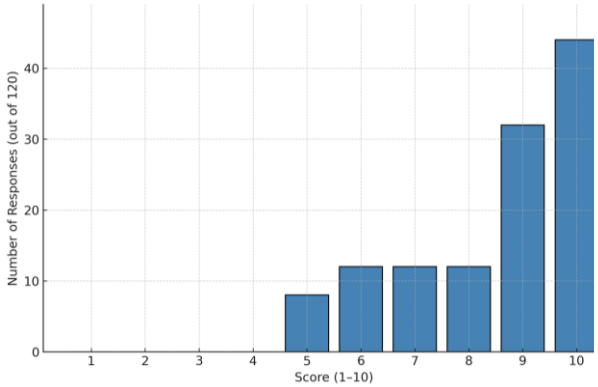

Fig. 4: *Perceived urgency for the rehabilitation of degraded sections.*

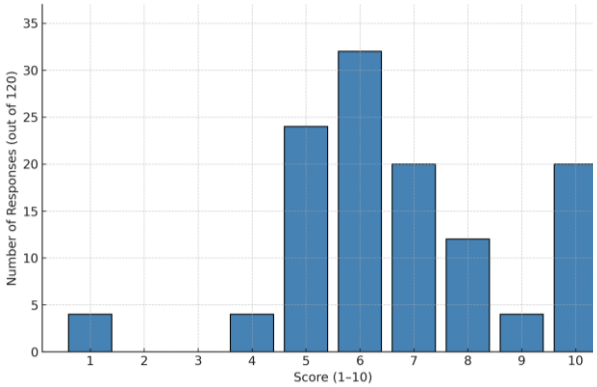

Fig. 3: *Assessment of urban planning incorporating the canal.*

The concentration of responses around the intermediate values (5–7) suggests that many participants perceive a partial or insufficient incorporation of the canal into current urban and regional development strategies. While some respondents (scores 8–10) acknowledged recent initiatives and valued the potential of the canal as an urban and landscape asset, others expressed significant dissatisfaction, with scores at the lower end (1–4) reflecting concerns about neglect, poor integration, or lack of visibility in municipal planning.

The mixed evaluations reinforce the need for a coherent, participatory, and multidisciplinary planning approach that bridges the gap between the symbolic value attributed to the canal and its actual presence in the daily urban fabric. Addressing this divergence will be crucial to ensure that the Canal de Castilla does not remain a marginal or underutilized element, but rather becomes an active driver of urban sustainability, cultural identity, and spatial cohesion.

The results depicted in Figure 4 reveal a clear consensus among respondents regarding the urgent need for action on the canal's physical state. A significant concentration of responses falls within the upper range (8–10 points), with the highest frequency at the maximum score (10), demonstrating that the vast majority of participants view rehabilitation and maintenance as a critical and immediate priority.

The concentration of high ratings has significant implications for planning and policy. It demonstrates a strong social mandate for prioritizing conservation within future strategies and indicates that local residents are likely to support interventions aimed at safeguarding the canal. In this sense, the urgency perceived by the community can be interpreted as both a warning about the risks of inaction and an opportunity to mobilize resources and collective will toward a shared goal of preservation.

By visualizing this near-unanimous demand for urgent rehabilitation, Figure 4 provides robust evidence that conservation measures should be placed at the core of any integrated development strategy for the Canal de Castilla, ensuring that physical preservation becomes the foundation upon which educational, touristic, and environmental initiatives can be sustainably built.

The results presented in Figure 5 highlight the citizens' willingness to be actively involved in decision-making processes regarding the future of the Canal de Castilla. The distribution of responses is clearly skewed toward the upper values of the scale, with a notable concentration at 10 points, indicating strong support for participatory governance models.

This outcome reflects a growing recognition among residents that the challenges facing the canal cannot be addressed solely through top-down interventions. Instead, participants emphasized the importance of dialogue, transparency, and collaborative planning between institutions, technical experts, and the local community. The high scores demonstrate that the population is not only aware of the canal's significance but also motivated to play a proactive role in shaping its conservation and development. In this sense, Figure 5 not only illustrates the willingness of citizens to be involved but also signals a societal demand for new governance models, where the canal is managed not merely as an infrastructure but as a shared cultural and environmental resource.

The evaluations displayed in Figure 6 concern the perceived integration of the Canal de Castilla with nearby urban infrastructure. Unlike other dimensions where responses were heavily skewed toward the upper values of the scale, here the distribution clusters around the intermediate scores (5–7), indicating a moderate overall assessment. This suggests that while residents recognize some degree of connection between the canal and the urban fabric, they also identify significant shortcomings in its functional and spatial articulation.

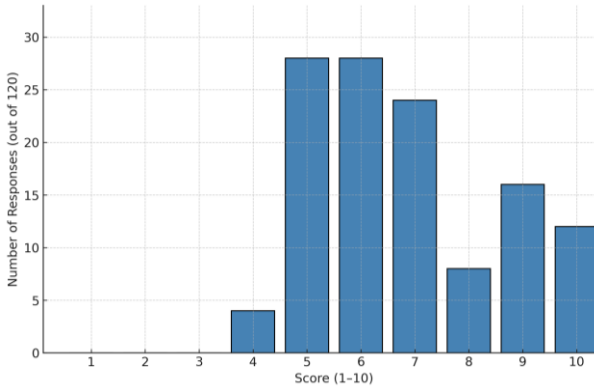

Fig. 6: *Perceived integration with nearby urban infrastructure.*

The relatively balanced presence of responses

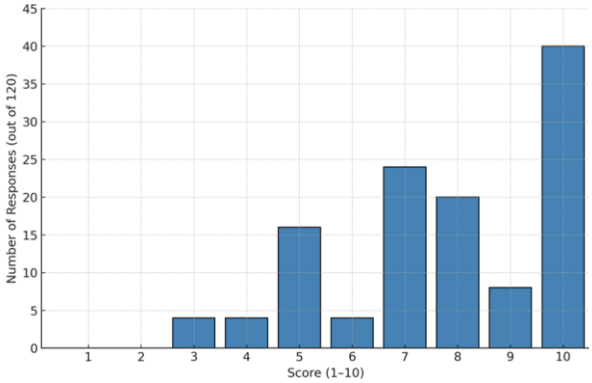

Fig. 5: *Citizen willingness for participatory decision-making.*

across the mid-range categories highlights a perception that existing integration measures—such as pedestrian paths, road crossings, signage, and accessibility—are present but insufficient. Many respondents appear to acknowledge ongoing efforts yet believe that these remain fragmented or limited in scope. The smaller, though notable, proportion of high scores (9–10) reflects satisfaction in certain areas where urban planning initiatives have successfully incorporated the canal into the local landscape, likely in zones where public spaces or recreational routes have been developed. Conversely, the presence of lower scores (4–5) points to dissatisfaction with urban connectivity, particularly in cases where the canal is physically present but underutilized, obscured, or disconnected from everyday urban dynamics. Qualitative responses associated with this question often mentioned barriers to accessibility, lack of continuity in cycling or pedestrian routes, and insufficient visibility of the canal in town centers.Overall, these results emphasize the need to strengthen urban-canal integration strategies, moving beyond isolated interventions to adopt a comprehensive and coherent approach.

The results displayed in Figure 7 concern the technical value attributed to the rehabilitation of canal infrastructures, including key elements

such as sluices, aqueducts, bridges, and associated hydraulic structures. The distribution of responses is strongly skewed toward the upper end of the scale, with a particularly high concentration at 10 points, indicating broad consensus on the relevance of these actions.

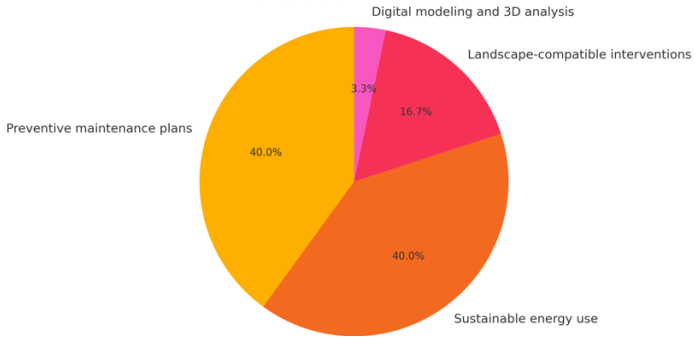

Fig. 8: Preferred strategies for sustainability.

This outcome reflects a widespread recognition among residents that the canal's engineering components are not only functional elements but also technical and cultural landmarks requiring urgent investment. The prominence of scores in the 8–10 range suggests that rehabilitation is viewed as an essential step to ensure the structural integrity and operational potential of the system, while simultaneously preserving its identity as a masterpiece of Enlightenment engineering.

Overall, Figure 7 confirms that the technical interest in restoring the canal's infrastructures is not only high but also socially justified. This finding supports the prioritization of rehabilitation programs within future planning strategies, ensuring that investments address both the conservation of engineering heritage and the promotion of new uses linked to education, culture, and sustainable tourism. In this sense, technical rehabilitation emerges as a strategic action capable of linking heritage preservation with economic and social revitalization in the Canal de Castilla.

The findings illustrated in Figure 8 present the preferred sustainability strategies identified by participants for the future management of the Canal de Castilla. The results show a clear prioritization of preventive maintenance plans and sustainable energy use, each receiving the support of 40% of respondents. This demonstrates a strong awareness of the need to combine traditional conservation practices with innovative approaches to energy efficiency, ensuring both the long-term preservation of the infrastructure and its adaptation to contemporary environmental challenges.

Preventive maintenance emerged as a highly valued strategy because it is perceived as the most practical and cost-effective way to safeguard the canal's integrity. Respondents highlighted the importance of regular inspections, routine repairs, and systematic monitoring to prevent deterioration and avoid costly large-scale interventions. This reflects a recognition that maintenance is not only a technical necessity but also a mechanism for preserving the heritage and identity embedded in the canal's structures. Sustainable energy use, also ranking at the top, reveals the community's forward-looking orientation. Many respondents viewed the canal as an opportunity to incorporate renewable energy solution ssuch as

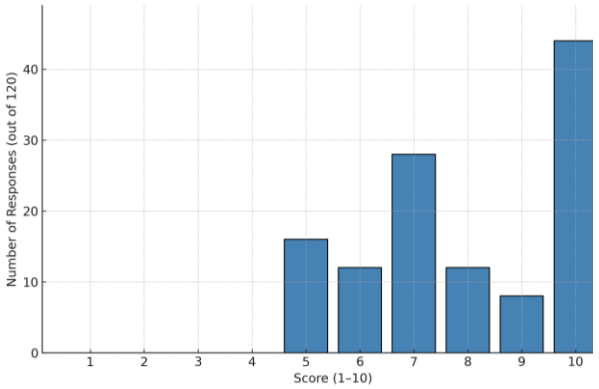

Fig. 7: Technical interest in the rehabilitation of canal structures.

micro-hydropower systems, solar installations on service buildings, and energy-efficient lighting into its management. This preference aligns with broader European policy goals for climate neutrality and suggests that residents see the canal as a platform to demonstrate the compatibility between heritage conservation and ecological innovation. Landscape-compatible interventions were also supported, though at a lower percentage (16.7%). This indicates that while respondents value actions that harmonize rehabilitation with the surrounding environment, they perceive them as complementary to the more urgent priorities of maintenance and energy. Qualitative remarks highlighted concerns about preserving the aesthetic coherence of the canal within its rural and urban contexts, ensuring that new projects do not compromise its historical character. Finally, digital modeling and 3D analysis received the least preference (3.3%), though it still represents a relevant niche interest. This lower percentage likely reflects the technical specificity of the tool, which may be less familiar to the general population. Nonetheless, its inclusion indicates that some respondents acknowledge the role of advanced technologies in supporting documentation, planning, and visualization, particularly for educational or heritage promotion purposes.

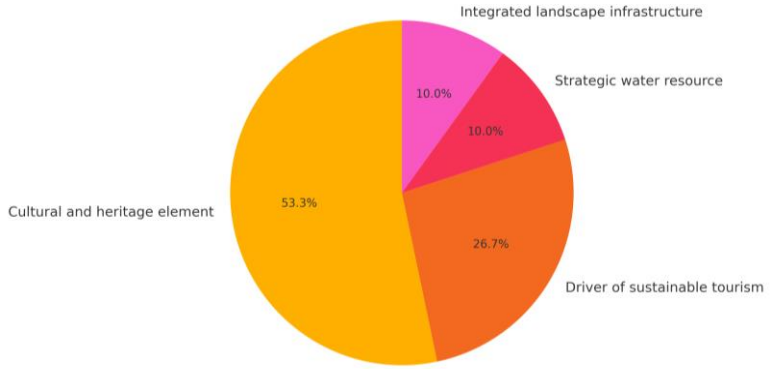

Fig. 9: Perceived main role of the canal today.

The results presented in Figure 9 highlight the perceived main role of the Canal de Castilla today, reflecting the multiplicity of functions attributed to this historical infrastructure. The data reveal a clear prioritization of the canal's cultural and heritage value, which was selected by a majority of respondents (53.3%). This indicates that the population predominantly views the canal not only as a hydraulic infrastructure but as a living monument, embodying historical memory, local identity, and technical ingenuity from Spain's Enlightenment period. Such recognition positions heritage conservation as a cornerstone for future planning and management strategies.

The second most frequently cited role, chosen by 26.7% of participants, is that of the canal as a driver of sustainable tourism. This reflects a strong belief in the canal's potential to act as an engine of local economic revitalization, particularly through cultural itineraries, recreational activities, and eco-tourism initiatives. Respondents stressed that tourism linked to the canal should be developed in ways that respect its historic integrity and environmental setting, thus reinforcing the concept of sustainable and heritage-compatible

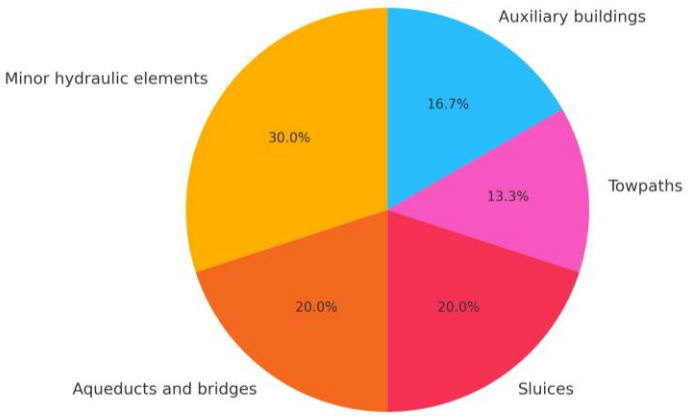

Fig. 10: Architectural or constructive elements to prioritize.

tourism. Other roles were less frequently mentioned but remain significant. Approximately 10% of respondents emphasized the canal's value as a strategic water resource, underlining its continued relevance for irrigation, water distribution, and regional agricultural productivity. Another 10% highlighted its potential as an integrated landscape infrastructure, capable of linking natural ecosystems with urban areas and contributing to green corridor development. Although less dominant in the responses, these roles reinforce the multifunctional character of the canal and point to opportunities for combining environmental, social, and economic dimensions.

The results illustrated in Figure 10 present the elements of the Canal de Castilla that respondents considered to be the highest priorities for conservation efforts. The distribution reveals a nuanced hierarchy of values attributed to different architectural and constructive components of the canal. The minor hydraulic elements (30%) were identified as the most pressing priority. This category includes smaller-scale structures such as spillways, culverts, and drainage channels, which, although less visually prominent than aqueducts or sluices, play a crucial role in the overall hydraulic functionality of the canal. Their degradation can significantly compromise water regulation and the stability of larger infrastructures, making their preservation essential for both technical and environmental reasons.

Sluices (20%) also ranked among the most critical components to conserve. Respondents recognized their dual importance as functional mechanisms for water control and as iconic features of Enlightenment-era hydraulic engineering. Their conservation was frequently associated with both technical rehabilitation and heritage interpretation, as they symbolize the canal's original navigational purpose. Aqueducts and bridges, also at 20%, were valued highly for their architectural and symbolic significance. These elements are often the most visible and monumental structures along the canal, acting as landmarks that connect functionality with aesthetic and cultural heritage. Their deterioration was perceived as particularly detrimental to the canal's historical identity and tourism potential. Other components, while less prioritized, still garnered significant support. Auxiliary buildings (16.7%), such as warehouses, mills, and service houses, were acknowledged as valuable for understanding the canal's operational history, though often in a state of abandonment. Meanwhile, towpaths (13.3%) received the lowest proportion of responses, perhaps reflecting their current underutilization. However, qualitative comments suggested that towpaths could play a renewed role as recreational and mobility corridors, particularly if integrated into cycling and walking routes.

The findings presented in Figure 11 summarize the preferred focal points for future interventions on the Canal de Castilla, revealing how residents envision the long-term orientation of conservation and development strategies. The results show that heritage conservation (40%) and tourism-compatible development (30%) clearly emerged as the dominant priorities, far ahead of other options.

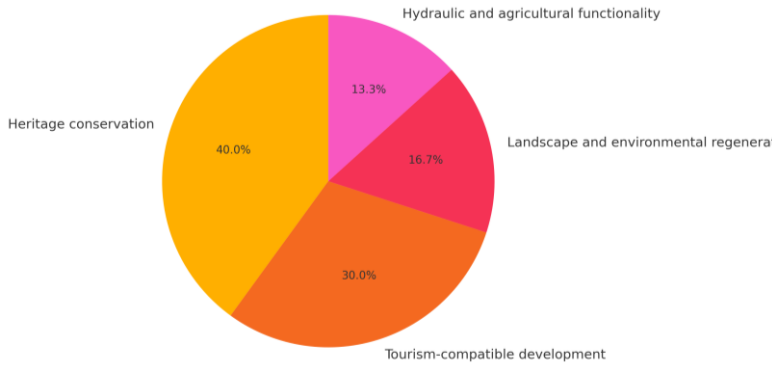

Fig. 11: Main priority for future interventions.

The strong support for heritage conservation underscores the widespread recognition of the canal as a cultural and historical landmark whose architectural and engineering value must be preserved for future generations. Respondents emphasized that interventions should prioritize safeguarding sluices, aqueducts, bridges, and auxiliary buildings, not only to maintain their structural integrity but also to enhance their visibility as heritage assets. This finding aligns with earlier survey results that highlighted the symbolic and identity-driven importance of the canal.

At the same time, the substantial support for tourism-compatible development reflects an understanding that conservation should not be limited to preservation in a static sense, but rather be integrated into dynamic strategies for sustainable regional revitalization. Respondents saw potential in the canal as a backbone for eco-tourism, cultural itineraries, cycling routes, and educational visits, provided that such activities are designed to respect the authenticity of the site and minimize environmental impacts. By contrast, landscape and environmental regeneration (16.7%) and hydraulic and agricultural functionality (13.3%) were ranked lower as immediate priorities. While still valued, these categories were perceived as complementary dimensions rather than central drivers of future interventions. Qualitative remarks suggested that respondents often considered ecological restoration and irrigation improvements as important, but subordinate to the urgent need for heritage safeguarding and the economic opportunities derived from tourism.

Survey results from the 120 participants in Alar del Rey revealed a strong societal appreciation for the canal's current and potential roles:

- Relevance as a structural territorial element: 7.6/10
- Adequacy of urban planning in canal areas: 6.7/10
- Urgency of rehabilitation of degraded areas: 9.1/10
- Importance of citizen participation: 8.0/10
- Urban-canal integration: 6.8/10
- Technical interest in infrastructure rehabilitation: 8.2/10

These indicators demonstrate an engaged public opinion supportive of conservation actions and demand more effective integration in territorial strategies.

When asked about the most important function of the canal today, 53.3% of participants selected "cultural and heritage element," followed by "driver of sustainable tourism" (26.7%).

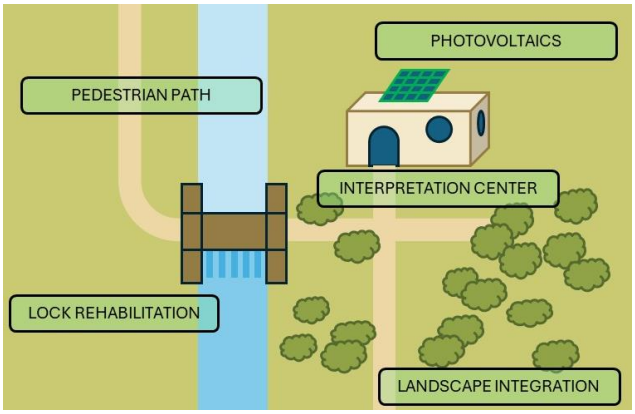

Fig. 12: Conceptual proposal for a multifunctional revitalization node in Alar del Rey, integrating heritage rehabilitation, renewable energy, and interpretive infrastructure.

Regarding conservation focus, minor hydraulic elements (30%) were prioritized, followed by aqueducts and bridges (20%), sluices (20%), auxiliary buildings (16.7%), and towpaths (13.3%).

Preferred strategies included:

- Preventive maintenance plans: 40%
- Sustainable energy use: 40%
- Landscape-compatible interventions: 16.7%
- Digital modeling and 3D analysis: 3.3%

For future interventions, heritage conservation (40%) and tourism-compatible development (30%) emerged as the main priorities, followed by landscape and environmental regeneration (16.7%) and improvements in hydraulic and agricultural functionality (13.3%).

These findings support the application of integrated

planning strategies that merge heritage conservation with digital innovation and participatory governance. The con-vergence of graphical methodologies and community values provides a roadmap for balanced intervention. Our approach enables early detection of critical areas and fosters preventive action rather than reactive restoration, contributing to long-term sustainability.

As a practical synthesis of the data obtained and to exemplify the potential of graphical methodologies, we propose the conceptual design of a multifunctional revitalization node in Alar del Rey. This prototype intervention would consist of the rehabilitation of a historic sluice and adjacent minor hydraulic structures, the implementation of a pedestrian and interpretive route connecting the canal with urban spaces, and the installation of renewable energy elements such as photovoltaic pergolas to power lighting and environmental sensors. Additionally, a modular interpretation center could be deployed using prefabricated or recycled structures to host cultural and educational activities. The proposal is complemented by landscape integration through native vegetation and urban furniture. This model aims to reconcile heritage preservation with tourism development and sustainable innovation, acting as a replicable strategy along other segments of the Canal de Castilla (Fig. 12).

The findings of this research have significant implications not only for the sustainable management of the Canal de Castilla but also for its integration into educational frameworks within engineering, architecture, and environmental studies. Historical infrastructures such as this canal can be effectively utilized as open laboratories where students engage with real-world problems that transcend purely technical dimensions, connecting cultural heritage, community participation, and sustainability.

From a pedagogical perspective, the methodological framework developed (combining GIS analysis, digital modeling, participatory surveys, and graphical interpretation) illustrates how technical tools can be transformed into didactic resources. In higher education, these tools support active learning methodologies, particularly project-based learning, where students are required to work on authentic challenges rather than hypothetical exercises. By analyzing survey results, prioritizing conservation measures, or proposing revitalization strategies, learners develop transversal competencies such as critical thinking, problem-solving, teamwork, and communication skills.

Moreover, the case study fosters interdisciplinary education. The Canal de Castilla is simultaneously a hydraulic infrastructure, a cultural landscape, an ecological corridor, and an urban-rural connector. Its complexity requires contributions from civil engineering, architecture, landscape ecology, tourism management, and

social sciences. This multidimensionality provides a unique educational platform to promote integrative training, enabling students to move beyond disciplinary silos and acquire a holistic understanding of sustainability in built environments.

The use of heritage infrastructures in education also contributes to strengthening the sense of identity and social responsibility among future professionals. Students exposed to real heritage contexts develop a deeper awareness of the ethical dimension of engineering and architecture, learning to balance efficiency and innovation with preservation and community values. This aligns with the principles of Education for Sustainable Development (ESD) promoted by UNESCO, which emphasizes the role of higher education in fostering cultural sensitivity and long-term stewardship of resources.

Another relevant aspect is the transferability of the approach. The methodological framework applied in this study can be adapted to other heritage infrastructures across Europe and beyond, serving as replicable teaching modules. For example, graphical modeling of sluices and aqueducts can be incorporated into structural engineering courses; participatory planning exercises can enrich urban design studios; and sustainability scenarios can be explored within environmental management curricula. In this sense, the Canal de Castilla acts not only as an object of preservation but also as a didactic catalyst for rethinking how we teach and learn about the built environment.

The case study demonstrates how collaboration between academia, local communities, and public institutions generates a fertile ground for educational innovation. By involving students in participatory processes alongside residents and policymakers, universities can promote service-learning initiatives that directly contribute to local development while enhancing student learning outcomes. Such initiatives close the gap between classroom knowledge and societal challenges, reinforcing the social mission of higher education.

Therefore, the educational implications of this study highlight the potential of historical infrastructures to become central elements in innovative pedagogical practices. The Canal de Castilla exemplifies how cultural heritage can be transformed into an educational laboratory where technical excellence, sustainability, and community engagement converge. This perspective not only strengthens the academic value of the research but also situates it within the broader mission of preparing professionals capable of addressing the complex challenges of the 21st century.

4. CONCLUSIONS

The Canal de Castilla presents itself as an exceptional case study where heritage preservation, landscape regeneration and participatory planning can converge within a framework of graphical engineering and sustainable development. The results of this study highlight the relevance of involving citizens in the definition of strategies and the necessity to incorporate technological tools that enhance our capacity to visualize, analyze and plan future interventions. Public opinion strongly supports the canal's cultural and heritage value while also demanding its reintegration into the social and territorial fabric through sustainable and multifunctional uses. The preference for preventive maintenance and renewable energy options points to a clear awareness of long-term sustainability, while support for tourism-compatible initiatives suggests a desire to revitalize the canal without compromising its historical essence.

This work underscores the potential of graphical methodologies as mediating tools between technical analysis and community vision and suggests their integration into regional planning

agendas. Future lines of research will aim to deepen the digital modeling of critical segments of the canal, broaden the application of this participatory and analytical methodology to other sections of the infrastructure, and foster collaborative projects that link heritage conservation with innovation in landscape and infrastructure management.

From an educational perspective, the study highlights the potential of historical infrastructures such as the Canal de Castilla to serve as practical case studies in engineering and architecture curricula. The integration of graphical methodologies, participatory planning, and sustainability strategies provides a rich pedagogical framework that strengthens student competencies in technical analysis, heritage preservation, and interdisciplinary problem-solving. Thus, the project contributes not only to the conservation of cultural heritage but also to the advancement of innovative teaching approaches in higher education.

5. ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the citizens and the municipality of Alar del Rey for their generous participation in the survey and for sharing their valuable opinions, proposals, and local knowledge regarding the Canal de Castilla. Their contributions provided essential insights into the cultural, social, and technical significance of this unique infrastructure, and were fundamental in shaping the outcomes of this research.

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