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Design Orientations for Knowledge, Representation, and Enhancement of Hydrosocial Landscapes

In the contemporary context of the energy transition, the landscape transformation emerges as a “global challenge” in achieving climate-neutral goals and, simultaneously, as a “local opportunity” for enhancing landscapes while preserving their identity. This study aims to explore the concept of “hydrosocial landscapes” in the light of hydropower plants.
Understood as complex systems, these landscapes are characterized by a man-made environment, where human-environment relations are developed around the water element and its management. Large hydropower diversions are emblematic examples of this concept, integrating a natural environment rich in water resources, a built environment characterized by the presence of hydraulic infrastructure, and resulting social dynamics. The interrelationships among these components delineate the complexity of the system, configuring a natural, engineering and cultural heritage to be studied, conserved and enhanced.
The main objective, achieved through a systemic and interdisciplinary approach applied to a real case study, is to provide design guidelines for dealing with complexity in the process of modernising a hydroelectric plant. The research aims to target energy production objectives and investigate existing methodologies to develop operational tools that support creative processes, integrating technical, environmental, and social values for sustainable territorial development. This approach entails a parallel analysis of the most suitable and practical tools for representing such a system.

Keywords:
Water architecture; Cultural Heritage; Complexity; System thinking; Design thinking.

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LANDSCAPES IN TRANSITION

The objectives foreseen by the Paris Agreement1 for the energy transition highlight the need for landscape transformation oriented towards climate change mitigation through the achievement of net-zero emissions by 2050. This poses several challenges, including the complete shift to the use of renewable sources such as solar, wind, and hydroelectric power, in addition to the discussion on how to manage the environmental and social impacts deriving from the construction and management of such facilities. It is imperative to deliberate not solely on landscape integration, aesthetic coherence, and visual integration, but also to meticulously examine the conflicts that emerge when the rationales of the landscape are in opposition to those of innovation, infrastructure development, politics, public interest. Consequently, it is essential to ascertain an equilibrium between the prospect for transformation and conservation strategies, and to incentivise policies, systems, and practices of integrated territorial sustainability (Cresta, 2020).
The European Landscape Convention2 states that "landscape means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (article 1a) and maintains that "the landscape contributes to the formation of local cultures and that it is a basic component of the European natural and cultural heritage, contributing to human well-being and consolidation of the European identity" (preamble), focusing attention on the identity aspect and the rights of the communities involved.
Furthermore, the digital transition and the advent of new technologies highlight potential benefits during the planning and management phases of built heritage through more collaborative digital processes. The methodologies and tools currently available, such as the Geographic Information System (GIS), facilitate the analysis and visualization of geospatial data, which are crucial elements for wide-ranging planning (Bolstad, 2012); moreover, Building Information Modeling (BIM) becomes indispensable, as well as mandatory, in the information management of large-scale projects with benefits identifiable throughout the entire life cycle (Eastman, 2011).
In the domain of communicative field, the London Charter for the Computer-based Virtual Visualisation of Cultural Heritage3 (Londoncharter, 2009) has underscored the necessity for quality standards in visualization methods, promoting principles such as interdisciplinarity, clarity, authenticity, and scientific transparency.

The transformation of the landscape, in accordance with the aforementioned considerations, is configured as a 'necessary' process to achieve technical objectives (Cohen, 2021; Lobosco, 2023), 'interdisciplinary' to ensure coordination and the achievement of heterogeneous objectives (Flaminio, 2022), 'participatory' to guarantee the well-being of the communities involved (De Waal, 2015; Campfens, 2025), and finally 'digital' for efficient representation and communication (Robb, 2021; Chmielewski, 2025) according integrated approaches (Stremke, 2010). In addition to these dimensions, the temporal variant intrinsic in the very concept of transformation is also added, reflecting the rapid evolution of the reference context and the changing rules at play, making the landscape a dynamic system, in continuous reconfiguration.
In the context of these global challenges, opportunities emerge for the valorization of the different specificities of places through local responses, which respect the identity of the reference territories, actively involve the communities involved, and promote innovative solutions in response to concrete needs. In this research, the objectives are pursued by analyzing an exemplary case study in a specific territory of the upper Valle Po in Piedmont. For over a century, this landscape has shown the permanence of a hydraulic infrastructure with significant altimetric and planimetric development, nestled at the foot of Monviso along the Po River axis and its tributaries. Concurrently, there are territorial and social dynamics emblematic of hydroelectric power, which offer a significant cross-section of past and ongoing transformations.

FRAMING COMPLEXITY: UNDERSTANDING HYDROSOCIAL SYSTEM

The strategic importance of large diversions, historically linked to energy supply , has evolved over time within a context of multiple challenges, extending to the current historical period marked by climate change, which further amplifies their relevance. The multiple uses of stored water in reservoirs, the flood moderation effects in downstream territories, drought mitigation, the naturalistic functions that ensure ecological flow levels even during low-water periods, and their landscape and tourism functions are just some of the benefits that extend beyond the primary objective of clean energy production using a renewable source.

Nevertheless, despite the fact that their strategic importance is not always communicated and interpreted correctly, their obsolescence is evident. The majority of these large diversions were constructed at the beginning of the 20th century and have a significant average lifespan, necessitating extraordinary maintenance activities and adaptation measures to updated social and environmental sensitivities.

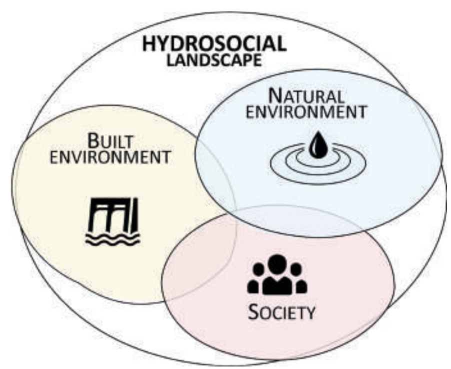

Fig. 1 - Hydrosocial landscape concept.

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From an environmental perspective, the most observed physical and biological impacts in the extant literature include modifications to hydrological regimes and water quality, biodiversity loss, and the management of reservoir sedimentation (Trussart, 2022).
Conversely, their existence and operation are intrinsically linked to a dense network of relationships typical of hydrosocial dynamics. From a political standpoint, the management of large diversions represents an area of significant importance for discussion and debate, involving numerous stakeholders in decision-making processes concerning water resource allocation, energy production, and the distribution of benefits.
Concurrently, the regulatory framework plays a crucial role in the management of concessions, the protection of environmental ecosystems, and the mitigation of the various risks associated with the operation of hydroelectric power plants. In this context, it is also essential to consider the historical and cultural components that have influenced the socioeconomic development of surrounding areas and contributed to shaping the identity of these territories over the years. The social acceptance of new projects or modifications to existing ones can be significantly influenced by the perception and collective memories associated with these infrastructures.
When interpreted in this manner, large diversions can be regarded as socio-technical-environmental systems (Fig. 1) that integrate a natural environment, characterised by the mountains and their watershed, with all its inherent beauty and risks, a built environment, typified by the hydraulic infrastructure and architecturally significant inhabited villages, and a society comprising diverse actors who interact differently with both the natural and built environments. Consequently, a contemporary intervention on a substantial diversion must inherently encompass considerations for the entire landscape system, employing a holistic approach that integrates technical, economic, environmental, ecological, social, and cultural dimensions to ensure the sustainable management of water and energy resources.

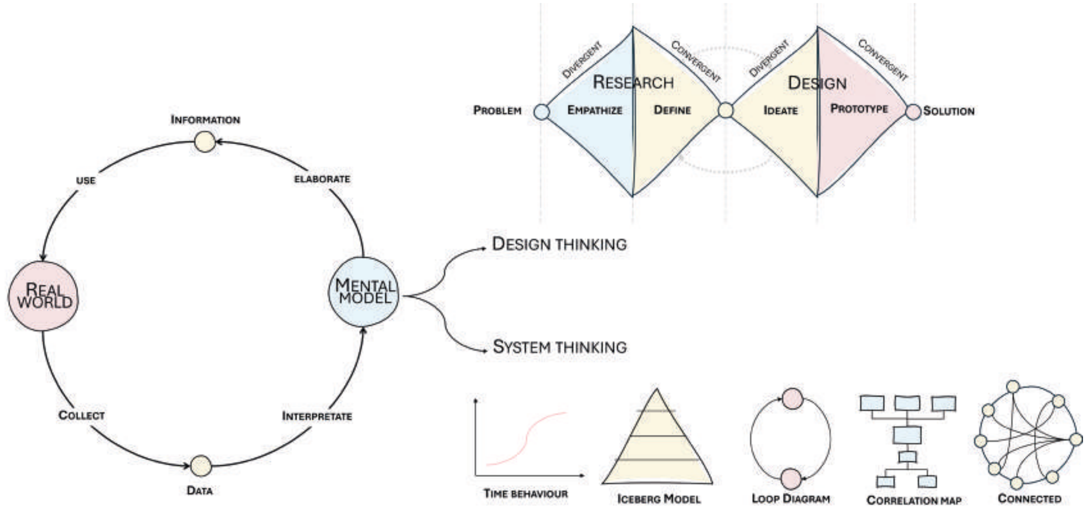

Fig. 2 - Systemic Thinking and Design thinking theories.

TOWARDS AN INTEGRATED METHODOLOGY: BRIDGING SYSTEMS THINKING, DESIGN THINKING, AND REPRESENTATION

The overall objective of this research is to investigate solutions for boosting the role of the hydropower plant on the territory through a creative process experience that embraces a holistic evaluation. Dealing with the complexity of the issues outlined requires a thorough understanding of the system, starting from the framing of the reference context to the specific identification of the problem to be addressed, to the generation of innovative ideas and solutions.
In this study, the application of systemic thinking (Arnold, 2015) and design thinking (Brown, 2008) methodologies for solving complex systems, theories that have triggered significant developments since the 1960s, have been investigated. Systems thinking is based on the hypothesis that the world is understood as a set of increasingly interconnected objects, whose relationships become the focus of analysis to understand their intrinsic characteristics. Such an analytical approach enables breaking down the system into its elementary entities and emphasizing the relationships through zoom-in/zoom-out actions operating at macro, meso, and micro levels, utilizing specific representation tools. In parallel, design thinking is based on the concept of collaboration and the application of collective efforts to abstraction through divergent actions and followed by convergence processes. Referencing techniques allow for the creation of mental models of the surrounding reality through specific visualization tools that enable empathizing with the referenced issue, focusing on the specific problem to be addressed, proposing a range of solutions that can potentially be shared by all stakeholders, and prototyping and testing the final idea within the referenced context (Fig. 2).

In this specific case, these analytical mindsets were combined to pursue the research objectives within a methodological process that can be outlined in three main phases (Fig.3): (i) Context

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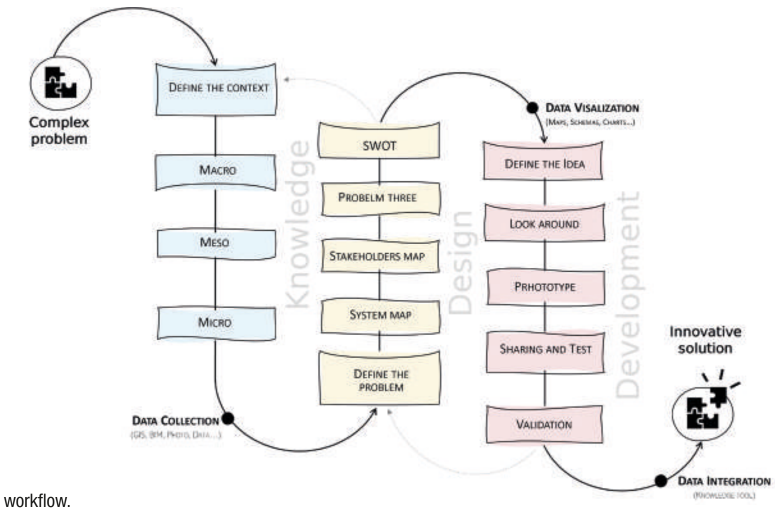
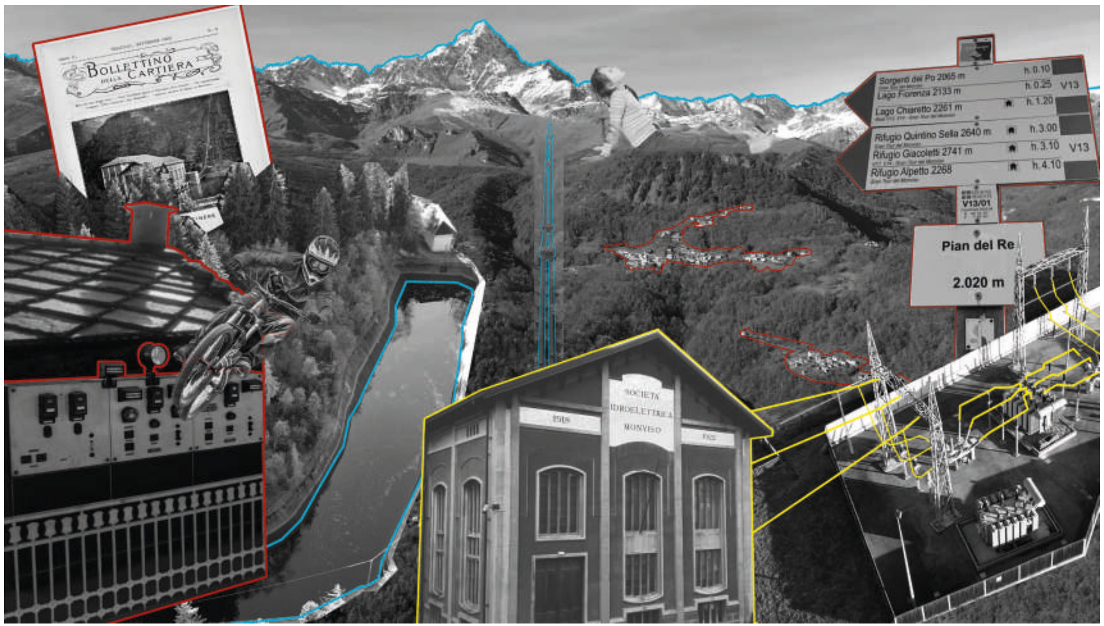


Fig 3 - Methodology workflow.

Fig 4 - Calcinere hydroelectric power plant in the Valle Po.



definition; (ii) Problem definition; (iii) Idea definition. The real model of the phenomenon and the mental model engage in a dynamic, iterative dialogue that gathers and interprets data, progressively transforming it into meaningful and actionable knowledge. In this context, the discipline of Drawing plays a crucial role as a tool for visual reasoning, capable of supporting both systemic and design thinking processes.

Far from being merely illustrative activity, drawing functions as a cognitive instrument that fosters understanding, exploration, and communication. It enables the construction of visual models that help decode the complexity of territorial systems, visualize intangible phenomena, such as territorial impact of the power plant or stakeholder dynamics, and simulate transformations through successive refinements. The graphic representation thus becomes a dynamic interface between analysis and synthesis, capable of making relationships visible, testing hypotheses, and sharing visions across disciplinary boundaries.

The proposed methodology has been applied to a real case study concerning the hydro-social landscape of the Valle Po, a stratified territory in Piedmont, in the southern Cozie Alps, which reveals the century-old presence of the Calcinere hydropower plant (Fig. 4).

CONTEXT DEFINITION

The first crucial step in spatial analysis is a comprehensive survey to exhaustively collect the data necessary for a thorough understanding of the area under consideration. To find and supplement existing information, different types of research can be conducted through appropriate documentary sources and reference datasets, as well as through field inspections geared towards reading landscape features at different scales, from regional (macro) to infrastructural (micro), passing through intermediate scale (meso) with its related social interactions (Fig. 5).

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Macro
The study area is located within the Monviso Biosphere Reserve, an area straddling Italy and France that was recognised as a UNESCO Man and the Biosphere (MaB) heritage site in 2013. Since 1976, this programme has been committed to conserving ecosystems and their biodiversity, while promoting sustainable use of natural resources for the benefit of local communities. Consisting of 88 Italian and 21 French municipalities, the area is highly varied in terms of landscape, yet united by a shared identity rooted in Occitan culture, rural traditions, and an economy based on local resources. The Monviso, at 3,841 m asl, is the symbolic core of the area, where the Monviso and Queyras parks cooperate through regular conferences of various thematic working groups. The candidacy dossier provided a permanent conference, the creation of a transboundary steering committee, interaction between the various working groups and the creation of a shared information system containing operational instructions relating to Conservation, Sustainable Development and Logistical Support.

Meso
The "Valle Po e Monte Bracco", according to the Piano Paesaggistico Regionale (PPR), comprises ten municipalities located in the western part of the province of Cuneo. The area is characterised by a structural axis formed by the Monviso Park and the Po River, which defines the core zone of the Man and Biosphere (MaB) region. Running from west to east with decreasing altitude, three main areas are located along this axis. The first of these is the high-alpine landscape of the Monviso massif, with its glacial rock faces. The Buco del Viso is the only transit area to France, and the Pian della Regina and Pian della Re are the main starting points for alpine tourism due to their proximity to the sources of the Po. At the heart of the area lies the Alpine valley landscape, characterised by medium and low slopes with significant forest and shrub cover. Historically valuable settlements using local building techniques and materials have developed here, including Oncino, home to the Rio Martino cave, and Ostana. Finally, the pseudo-flat landscape centred on Paesana is surrounded by Monte Bracco and consists of agricultural and mining areas.This area is historically associated with events relating to the Partisan Resistance during World War II. The area has a high level of historical and cultural richness, as well as a significant number of winter and summer hiking activities. Despite the widespread abandonment of settlements and pasture grasslands, which are difficult to access, the area has considerable tourism potential.

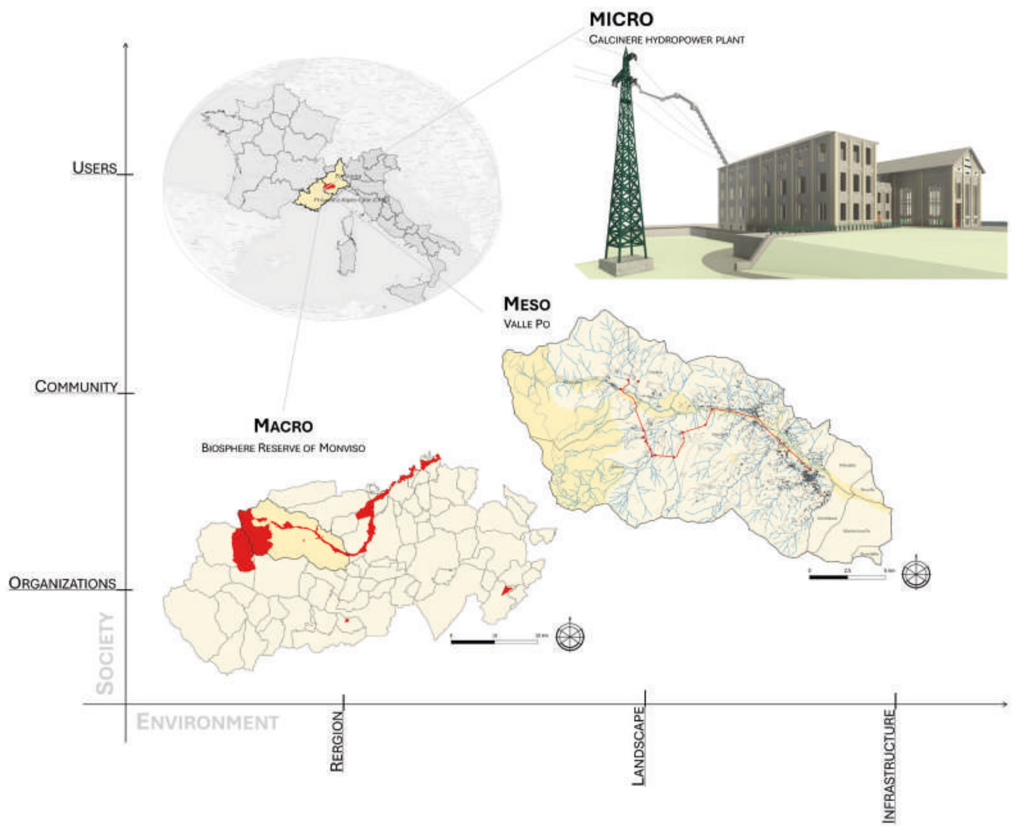

Fig. 5 - The hydrosocial landscape of the Valle Po is represented using GIS and BIM as information systems for collecting and processing data according to different levels of detail.

Micro
The Calcinere hydropower plant was built between 1918 and 1922 at the request of Luigi Burgo, to supply the nearby Verzuolo paper mill with electricity. It was part of a system of 12 plants belonging to the Monviso Hydroelectric Company which supplied electricity to Cartiere Burgo and nearby towns. Today, as in the past, the hydraulic infrastructure extends for around 20 km along the Po River and its tributaries, passing through the mu-

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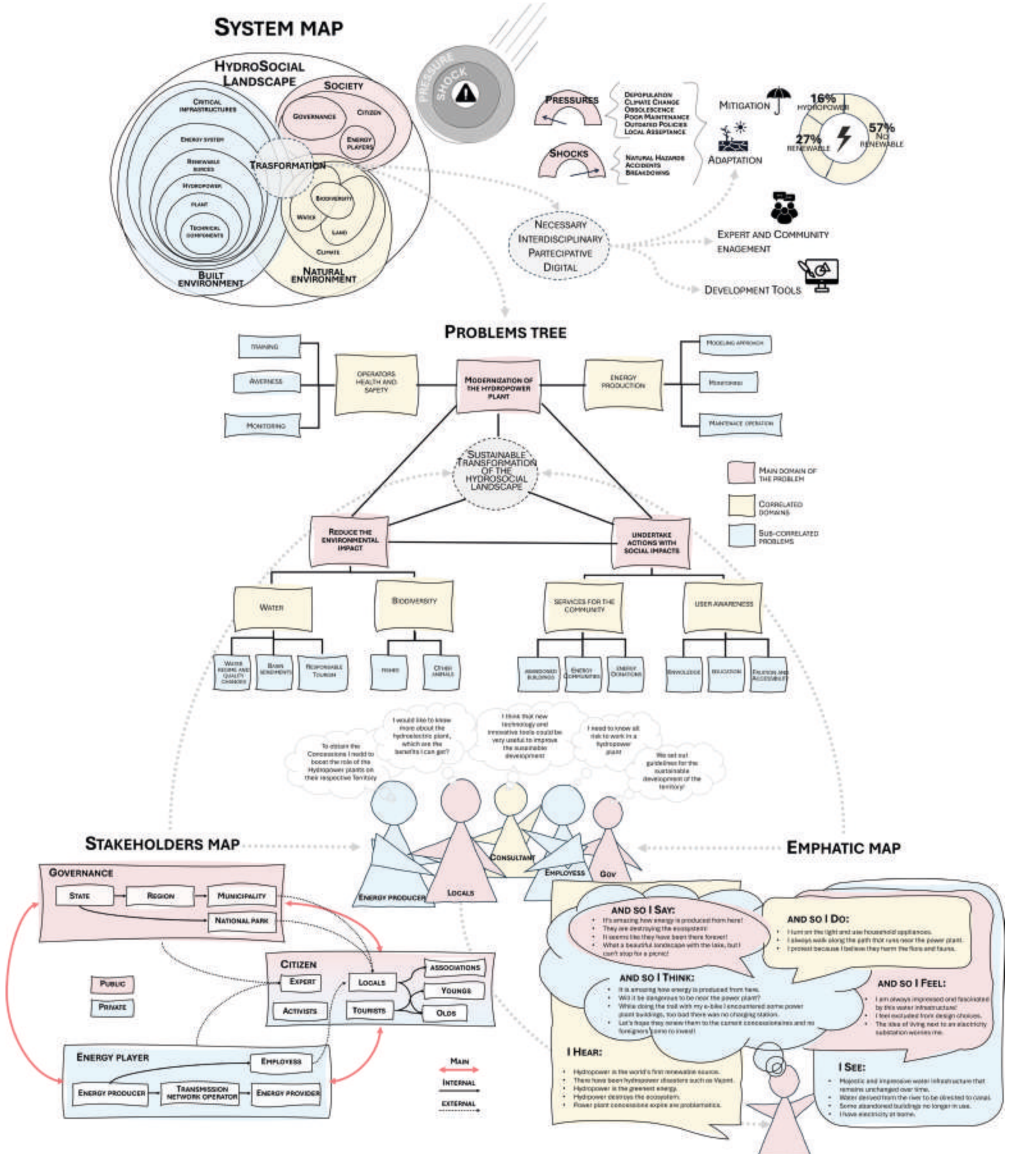

Fig. 6 - Systematic overview of the problems.

nicipalities of Crissolo, Oncino, Ostana, Paesana and Sanfront. The detour channel is approximately 10 km long and has specific intake works located along it that capture a percentage of the water. This ensures the ecological flow of the intercepted watercourse and conveys it within the channel itself. The canal then reaches a loading tank that collects and regulates the flow to the penstocks leading to the power station. Here, the kinetic energy of the water is first converted into mechanical energy by the turbines and then into electrical energy by the alternators. This energy is then transported 8 km to the Sanfront power substation, where it is connected to the national grid. From a design point of view, one of the infrastructure's main characteristics is its planimetric and altimetric development in a mountainous context, which makes travel difficult for operators, visitors, and tourists alike. In fact, travelling between points of interest that are not far apart in a straight line often involves taking long routes, making maintenance activities difficult and discouraging visits. In addition, the canal develops in a horseshoe shape, partly on the hillside and partly in a tunnel.
This integration with the landscape means it is almost never visible, making morphological understanding very difficult. Finally, several disused spaces result from automated work practices, which could be improved.

PROBLEM DEFINITION

The focus of this phase lies in exploring the problem space through empathy and accurate problem definition. What was the initial situation? What was the problem with that situation? What problem do you want to solve? What kind of problem is it? What are its different characteristics? Who were the stakeholders? Achieving a comprehensive understanding of the system allows us to grasp its interconnections and underlying dynamics, highlighting relationships that reveal influences, orientations, flows, and information transfers, often bringing to light emergent properties that would otherwise remain invisible. In this research, both visual thinking and systems thinking techniques have been employed as catalysts to support and give form to mental processes (Fig. 6).

By restating, reframing, and redefining the system through different lenses, a more grounded and nuanced understanding begins to emerge. This iterative, multi-perspective approach allows for a more effective formulation of the design problem. Abstraction plays a strategic role in broadening the range of possible solutions, encouraging us to consider directions that might not be apparent from an initial, more limited viewpoint. One of the key tools used in this stage is the Problem Tree, a diagrammatic technique that structures issues hierarchically from root causes to visible effects, clarifying cause-effect relationships. While this method helps to expand and deconstruct the complexity of the problem, it also sharpens focus on a specific, actionable subset of issues that a design process can realistically address, though always within a wider systemic overview that influences success. In this research, the problem tree did not evolve along a single linear path but rather opened up into multiple branches based on the perspectives of different stakeholders. For instance, revitalizing the public image of the hydropower plant, whether through technical, environmental, or socio-economic strategies, could enhance the energy provider's reputation. Yet, from another perspective, the same issue might be framed in terms of territorial sustainability and long-term resilience, shifting the narrative entirely. In this light, the problem becomes collective, belonging to the entire community.

Although engineers initially leaned toward addressing pragmatic and technical aspects, it quickly became evident that multiple dimensions, such as social, perceptual, and political, were equally critical to the success of any proposal. Graphical schematizations such as Systems Maps are fundamental for organizing and interpreting the situation. These visual models help identify all the entities involved, defining their roles within larger supersystems and smaller sub-systems. In addition, highlighting the relationships between actors within the system plays a decisive role in establishing influences, orientations, information transfers, and bringing out new properties. To this end, the Stakeholder Map proved essential for identifying and categorizing the key actors such as energy operators, public authorities, and local communities, clearly distinguishing between public and private entities, and mapping their interrelations.

This visual breakdown facilitates the immediate identification of potential communication flows and aligns the project with the expectations and influence of those involved. The major initial challenge in framing the problem lies in escaping habitual mental patterns and recognizing the feasibility of developing truly innovative ideas. There is a high

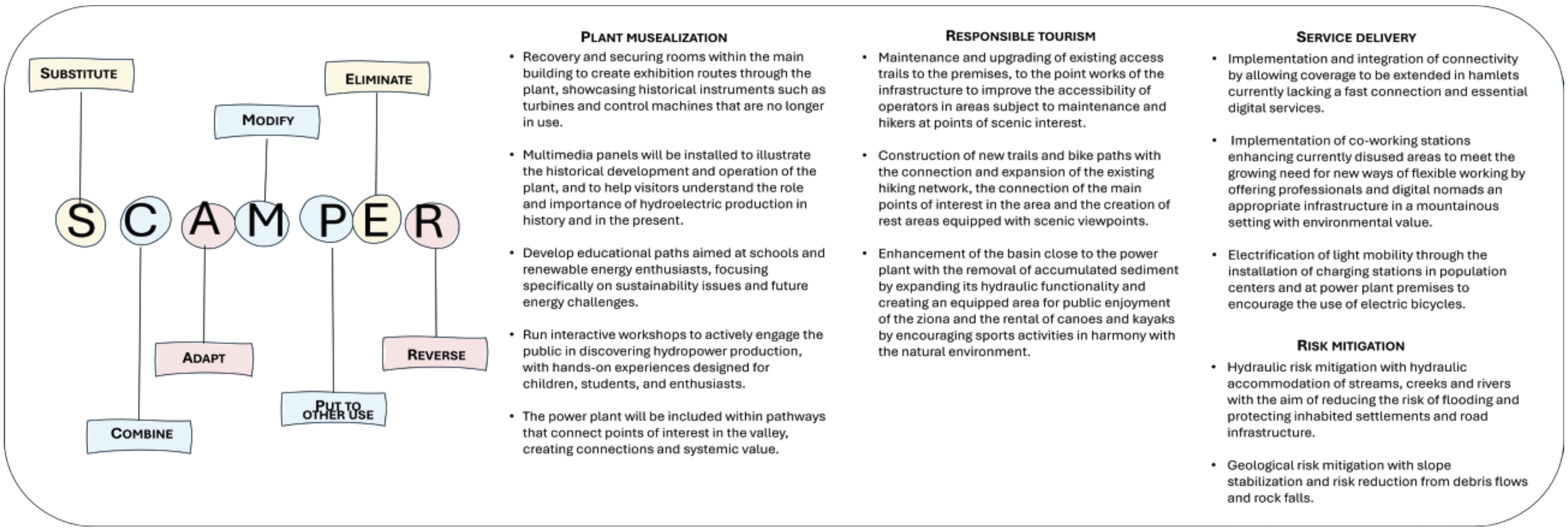

Fig. 7 - SCAMPER analysis.

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risk of falling back on familiar solution/function/process, as is the tendency to note only information that supports pre-existing beliefs, ignoring other information, and to estimate costs based on past investments rather than potential future gains. As the problem involves diverse, often subjective perceptions, Empathy Maps offer an effective tool to highlight the emotions, needs, and perspectives of the various categories involved. The more perspectives are included in the dialogue with stakeholders, the broader the spectrum of possible solutions that can emerge. Within the broader framework of visual thinking, the discipline of Drawing plays a central role as a privileged medium for structuring, communicating, and interpreting thought. Through graphic gestures, spatial relationships, abstraction, and visual synthesis, drawing allows for the exploration of solutions, the mapping of complex ideas, and the visualization of otherwise intangible phenomena. It activates mental processes of interpretation and sharing, turning thoughts into visible, discussable, and transformable knowledge.

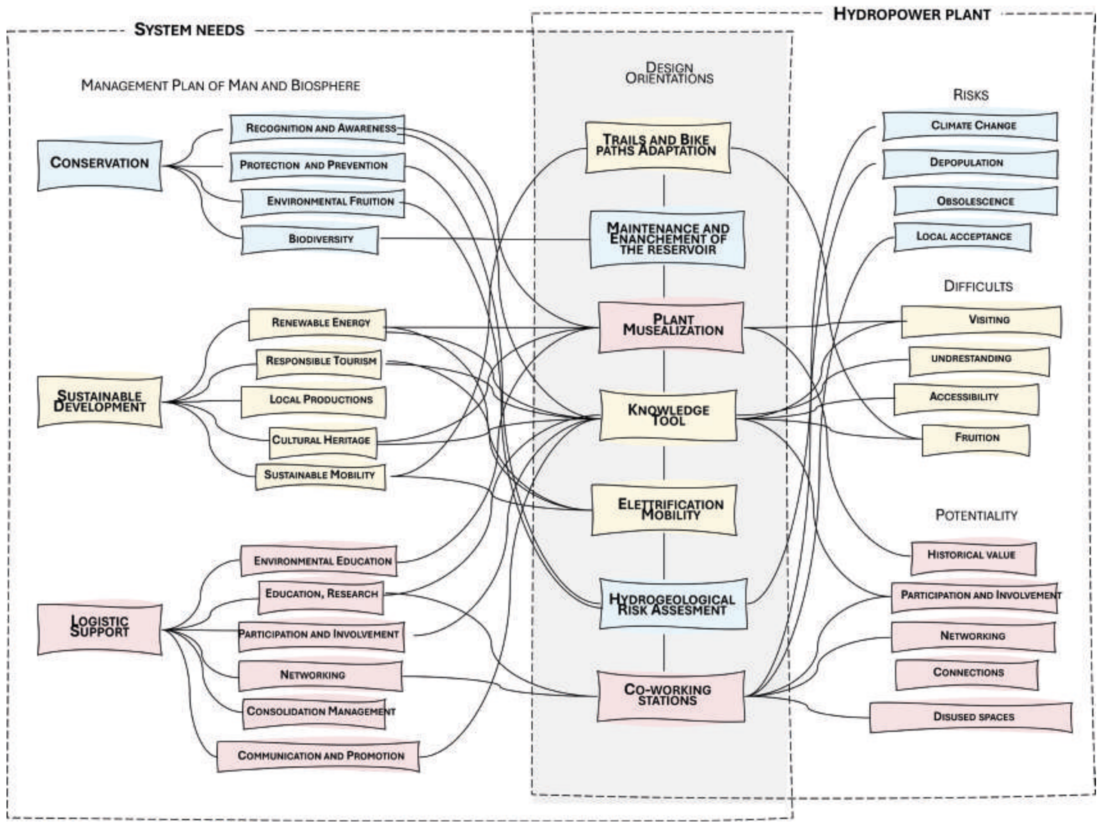

Fig. 8 - Design Orientations.

IDEA DEFINITION

This approach builds on the preceding steps, enabling a more comprehensive examination of the existing solutions to the encountered problems, and subsequently identifying those ideas that are applicable to the target context. While these concepts may manifest as rudimentary nodes or novel components to be integrated into the system, it is imperative that they possess the capacity to exert a favourable influence on the intricate structure, yielding substantial ramifications. The landscape has been studied on a larger scale, which enabled the identification of all the available tools, from the relevant strategic orientations of the UNESCO MaB program to the directions of the PPR.
The documents offer mappings that have facilitated the identification of the most salient aspects of the target area, providing food for thought, significant design directions, and possible synergistic linkages. The study, conducted on a smaller scale, enabled the identification of space and design potentials within the subsystem on which to intervene, with the objective of generating impacts on the larger system. The creative process has been guided by design thinking methods. Analogy Mapping helped us transfer insights and solutions from other domains to reframe our design challenges, while the SCAMPER method supported the exploration of alternative possibilities by prompting us to consider how existing elements could be modified, adapted, or combined in new ways (Fig. 7). The systematization of these aspects led to the identification of several areas for intervention (Fig. 8).

Responsible tourism

Improve the experience of the local community and tourists enjoying the surrounding environment by adapting and expanding footpaths and bike paths, encouraging slow mobility and enhancing water resources for recreational activities. Such interventions would promote slow and responsible tourism, generating new receptive and professional opportunities related to the outdoors, with both environmental and socioeconomic benefits.

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Plant musealization
Enhance the combination of the area's historical and natural value and the power plant's industrial and environmental value through displays, storytelling and enjoyment for a wider and more diverse audience.The musealization of the power plant could significantly contribute to raising awareness of environmental issues and encouraging enjoyment of cultural heritage, while also promoting the plant itself.

Service Delivery
To support local schools and businesses, it is essential to upgrade the infrastructure and provide public services that benefit the community. Such services would reduce the gap between urban and inland areas by offering concrete alternatives to those who wish to live in contact with nature without having to give up essential services. These solutions could contribute to combating mountain depopulation and to the creation of a collaborative network between the power plant, local companies, startups and professionals by promoting innovation, skills exchange and territorial development.

Risk Mitigation
One of the most sensitive issues in the mountain context is related to risk management and the protection of the Po Valley community, workers and visitors. In this perspective, the implementation of interventions aimed at risk mitigation represents an area of intervention that integrates eco-engineering solutions in accordance with municipal civil protection plans and current land use planning.
Hydrogeological risk mitigation and adaptation measures would ensure greater safety for residents and others, as well as increase the resilience of the territory to climate change and extreme weather events.

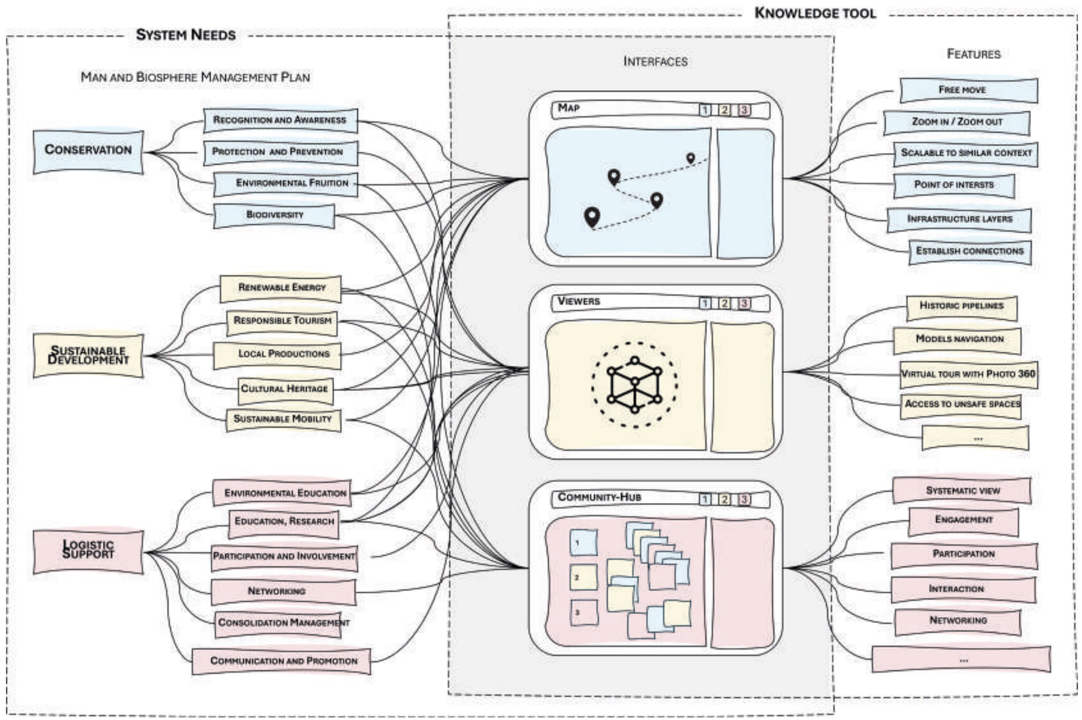

Fig. 9 - Knowledge tool interfaces and features

DRAWING AS KNOWLEDGE INFRASTRUCTURE: FROM REPRESENTATION TO SHARED UNDERSTANDING

Some contemporary conceptual frameworks tend to privilege the achievement of solutions through predefined, iterative procedures, risking the loss of the essential qualities and potential of systemic analysis. Instead, it is crucial to prioritize dynamic processes and flexible design pathways, capable of evolving and adapting to changing challenges over time (Fois, 2022). Based on this perspective and given the duration, complexity, and management challenges of hydropower projects, the design of new spaces in the transformation of the hydrosocial landscape cannot be limited to shaping ideas but rather requires thinking about and providing dynamic interfaces through which different users can connect with the natural and built environment, learn about its peculiarities, and, being part of the system themselves, highlight problems, goals, and solutions that can change and evolve dynamically in resonance with the context of reference. For this purpose, a prototype of a web application has been created, connected to the network and easily accessible with any device, allows for the proper visualization and sharing of data related to the territory and infrastructure and the possibility of collaborative problem-solving approaches, iteratively and dynamically over time. The platform is structured around three main interfaces (Fig. 9):

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An interactive GIS-based map, allowing users to explore the studied territory through layered, two-dimensional representations that highlight its characteristics while also enabling scalability to other similar contexts.
A detailed point-of-interest interface, offering access to historical timelines, navigation through BIM models, and immersive virtual tours using 360-degree images. This component provides a multiscale and multilevel visualization system that enriches understanding.
A Community Hub, designed to foster participation and engagement among a wide range of stakeholders, from infrastructure operators and sector experts to local communities. This interface is essential for meeting the project's broader goals, facilitating knowledge exchange, collective exploration, and co-creation of solutions.

MAKING THE INVISIBLE VISIBLE: DRAWING AS A COGNITIVE, COMMUNICATIVE, AND TRANSFORMATIVE TOOL

The proposed methodology is essential for creating and representing mental models that reflect the complexity of the real world. A systemic view of the territory and the issue to be addressed makes it possible to formulate strategic actions aligned with the overall process. Within an integrated framework that combines systems thinking and design thinking, drawing plays a pivotal role as a transversal tool for observation, interpretation, and transformation. As both a language and a method, drawing supports the entire process, from the exploration of the context to the generation and testing of ideas, by enabling the visual construction of knowledge.
In the context definition phase, drawing facilitates the mapping of spatial, functional, and relational components, helping to decode the complexity of the hydropower system and its interactions with the surrounding territory. During the problem definition phase, it supports analytical reasoning, making visible the cause-effect dynamics, systemic tensions, and design opportunities across different scales. In the idea definition phase, drawing becomes an active design tool: it fuels ideation through visual brainstorming, enables iterative refinement via sketching and diagramming, and fosters communication among stakeholders by translating abstract concepts into shared visual artifacts.
The act of drawing, therefore, is not merely illustrative but generative: it operates as a powerful form of visual thinking, capable of articulating scenarios, simulating interventions, and mediating between different disciplinary languages. By making the invisible visible, the discipline of drawing enhances the capacity to think systemically and design creatively within complex and evolving contexts.
In addition, the integration of digital technologies functions as a medium for both data representation and communication, a shared platform that supports knowledge generation, decision-making processes, and planning practices geared toward the sustainable development of the territory.
This research lays the groundwork for new levels of accessibility to information within hydrosocial landscapes, enabling multidimensional representations and more efficient collaborative procedures. The multiscale representation of the hydrosocial landscape emerges as a cognitive, communicative, and creative strategy, capable of effectively depicting the territory, the infrastructure, and their transformations over time. The proposed methodology aims to manage complexity through systemic and interdisciplinary approaches, supported by connected digital tools that enhance inclusive and participatory processes, shifting the focus from a techno-centric to a more human-centered vision of territorial transformation.

The authors agree on the content, methodological approach, and final considerations presented in this research. Landscapes in Transition, Framing Complexity: Understanding Hydrosocial system, Context definition, Drawing as Knowledge Infrastructure: From Representation to Shared Understanding: G.M.V.; Towards an Integrated Methodology: Bridging Systems Thinking, Design Thinking, and Representation, Problem definition: F.M.U.; Idea definition, Making the Invisible Visible: Drawing as a Cognitive, Communicative, and Transformative Tool: G.M.V., F.M.U.

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NOTE

[1] The Paris Agreement, signed by 194 countries and the EU, aims to limit global warming to below 2°C and to continue efforts to limit it to 1.5°C to avoid the catastrophic consequences of climate change.

[2] Signed in Florence in October 2000 by 40 member states, the European Landscape Convention (ELC) is an international treaty for the protection, management, planning and cooperation in the field of landscape

[3] Conceived in 2006 with "The London Charter for the Use of 3D Visualization in the Research and Communication of Cultural Heritage," which evolved in 2009 under its current title, it reflects the shift from mere 3D visualization to a broader computer visualization that was to include not only academic and cultural contexts but also those related to industry and entertainment involving evocation of cultural heritage.

[4] In the 1950s, hydropower generation contributed significantly to meeting Italy's energy needs. According to data provided by Terna, in 2024, hydropower will account for 40 percent of energy produced from renewable sources, with a share of about 16 percent.

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