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Revitalising port heritage via an integrated digital framework

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D.R.S.A.T.E.

POLITECNICO DI BARI

12

Doctor in Risk And Environmental, Territorial And Building Development

2026

Coordinator: Prof. Francesco Fiorito

XXXVIII CYCLE
Curriculum: ICAR/10

DICATECh
Department of Civil, Environmental,
Building Engineering and Chemistry

Cassano Federica

Revitalising Port Heritage via an Integrated Digital Framework

Prof. Fatiguso Fabio
Prof. De Fino Mariella
Department of Civil, Environmental, Building Engineering and Chemistry
Polytechnic University of Bari





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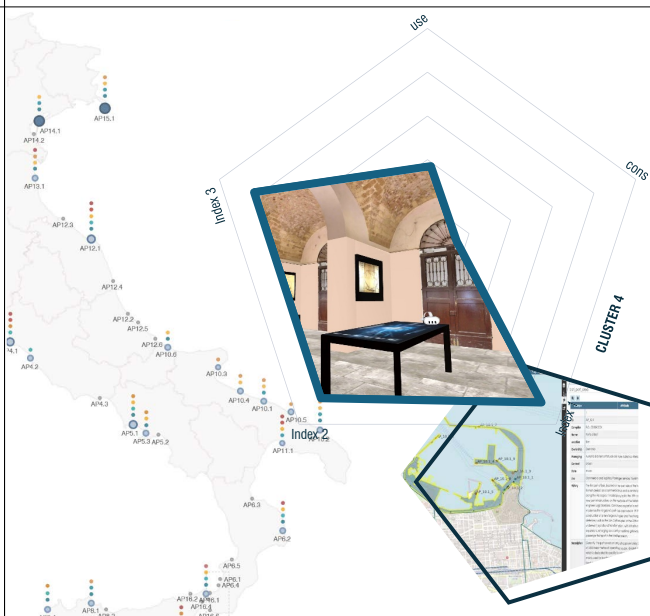
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LIBERATORIA PER L'ARCHIVIAZIONE DELLA TESI DI DOTTORATO

Al Magnifico Rettore
del Politecnico di Bari

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REVITALISING PORT HERITAGE VIA AN INTEGRATED DIGITAL FRAMEWORK

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EXTENDED ABSTRACT (eng)

The evolution of Mediterranean ports is intrinsically related to their geographic context and is the result of complex territorial processes influenced by historical dynamics, as well as economic and technological developments. Ports have always played a strategic role, serving as a point of reference for international economic relations and a crossroads of cultural and social exchange. However, over time, changes in the transportation system and the adoption of innovative technologies have resulted in a progressive loss of centrality of many port areas with respect to the urban context, generating forms of marginalisation and isolation. This evolutionary process occasionally resulted in the phenomenon of the "abandoned threshold," which refers to the abandonment of entire areas that were historically useful for port activities. These areas required spatial and functional redevelopment to coexist synergistically with the port areas still in use.

Transformations over time, combined with a recent interest in regenerating port areas and reconnecting them to the city, have contributed to the evolution of port identity, requiring careful planning to ensure the preservation of the identity and integrity of these places. In this context, port heritage plays a pivotal role, as a tangible sign of the passage of civilisation and a direct expression of needs, as well as the level of technological development. The rapid evolution of production models, particularly containerization, has encouraged the structural and/or functional adaptation of port assets to contemporary needs and ensured their continued use. However, this evolution has also led to the progressive abandonment of heritage assets that are unable to function synergistically with the current context. The preservation of historic port

structures and infrastructure represents a valuable opportunity to enhance these areas, which must be recognised and integrated into broader urban regeneration processes, as well as maintained for ensuring their resilience to change.

The adaptive reuse approach of abandoned or underutilised structures emerges in the literature, with the aim of revitalising heritage and its historical-cultural value, making it functional to contemporary needs and responsive to new requirements.

Based on the above, this research project aims to develop a systematic and integrated methodological approach for the revitalisation of port structures and infrastructures with historical, architectural, and industrial heritage characteristics, preserving their tangible and intangible maritime value and ensuring their reintegration into the port and urban context through compatible strategies.

The methodological approach focuses on the recognition of the port's heritage and the systematic organisation of the cognitive system through the census and cataloguing of the assets within the port context. In this scenario, the identification of its conservation and use conditions is a fundamental milestone in the heritage qualification process. This objective is achieved through the implementation of a data-driven approach, employing the k-means method for the identification of clusters of recurring typologies. The results orient decisional recovery, revitalisation and enhancement strategies of port assets within the contemporary context. Then, starting from the analysis of successful national and international experiences, the meta-design strategies and associated technical solutions identified for the adaptive reuse of port assets are systematised within an atlas of meta-design strategies to support the definition of design solutions according to local specificities. The proposed design strategies are then evaluated according to success factors through a selection of qualitative and quantitative criteria capable of investigating key aspects. The establishment of these criteria is achieved through the involvement of a panel of experts, with the criteria then weighted according to their relevance to reuse processes using the AHP method. The validation of the proposed approach followed the entire methodological workflow and involved the analysis of Italian port areas and their port assets, with a focus on Port of Bari and its Palazzo della Dogana, as a case study for the implementation of the adaptive reuse

strategies. The development of an integrated digital environment has finally been designed to integrate the knowledge and design solution management system by adopting GIS/BIM and VR/AR tools. The approach defined and validated for the port context ensures replicability in different contexts and scalability, supporting more informed decision-making processes and collaborative engagement for both expert and non-expert users.

keywords *port area, port assets, adaptive reuse, digital environments, cultural enhancement*

EXTENDED ABSTRACT (ita)

L'evoluzione dei porti del Mediterraneo, intrinsecamente legata al contesto geografico, è il risultato di processi territoriali complessi influenzati da dinamiche storiche, nonché dallo sviluppo economico e tecnologico. Da sempre i porti hanno svolto un ruolo strategico, rappresentando un punto di riferimento per le relazioni economiche internazionali, ma anche crocevia di scambi culturali e sociali. Nel corso del tempo, i cambiamenti nel sistema di trasporti e l'adozione di tecnologie innovative hanno determinato una progressiva perdita di centralità di molte aree portuali rispetto al contesto urbano, generando forme di marginalizzazione e isolamento. Questo processo evolutivo ha portato, talvolta, al fenomeno "della soglia abbandonata", ovvero all'abbandono di intere aree, storicamente utili per le funzioni portuali, che oggi richiedono interventi di riqualificazione spaziale e funzionale per coesistere in maniera sinergica con le aree portuali tuttora operative. Le trasformazioni avvenute nel tempo, congiuntamente al recente interesse verso la rigenerazione delle aree portuali e la riconnessione delle stesse con la città, hanno contribuito all'evoluzione dell'identità portuale, richiedendo una progettazione attenta, al fine di garantire la tutela dell'identità e l'integrità dei luoghi. In questo contesto, il patrimonio portuale ricopre un ruolo fondamentale, quale segno tangibile del passaggio della civiltà ed espressione diretta delle esigenze, nonché del livello di sviluppo tecnologico. Se da un lato la rapida evoluzione dei modelli produttivi, in particolare la containerizzazione, ha favorito l'adeguamento strutturale e/o funzionale di beni portuali, al fine di soddisfare le esigenze contemporanee e garantirne il mantenimento in uso; dall'altro ha indotto ad un

progressivo abbandono delle stesse, laddove non in grado di essere sinergiche rispetto al contesto attuale. In particolare, la conservazione delle strutture e delle infrastrutture portuali storiche rappresenta una preziosa opportunità per la valorizzazione di queste aree, che richiedono di essere riconosciute ed integrate in processi più ampi di rigenerazione urbana, nonché di continuare ad essere resilienti ai cambiamenti. L'approccio del riuso adattivo di strutture abbandonate o sottoutilizzate, emerge in letteratura, con l'obiettivo di preservare e valorizzare il patrimonio e il suo valore storico-culturale, rendendolo funzionale alle esigenze contemporanee e rispondente alle nuove necessità.

In tale scenario, il presente lavoro di ricerca si propone di sviluppare un approccio metodologico sistematico ed integrato finalizzato al recupero, riuso e valorizzazione di un sistema di strutture e infrastrutture con connotati di patrimonio storico-architettonico-industriale, preservando il loro valore tangibile e intangibile legato alla pratica del mare e garantendo il loro reinserimento nel contesto portuale, nonché urbano, attraverso strategie compatibili. Il flusso metodologico si articola a partire dal riconoscimento del patrimonio portuale e sistematizzazione del sistema di conoscenze attraverso il censimento e catalogazione sistematica dei beni presenti nel contesto portuale. In tale scenario, l'identificazione delle sue condizioni di conservazione e di uso costituisce condizione fondamentale nel processo di qualificazione del patrimonio, attraverso l'individuazione di cluster, mediante metodo k-means, al fine di orientare strategie di recupero, riqualificazione e valorizzazione del patrimonio portuale all'interno del contesto contemporaneo secondo una visione armonizzata e strutturata. Partendo dall'analisi delle esperienze nazionali e internazionali di successo, le strategie di meta-progettazione e le soluzioni tecniche individuate per il riuso adattivo dei beni portuali sono sistematizzate in un atlante di strategie di meta-progettazione a supporto della definizione di soluzioni progettuali in accordo con le specificità locali. Le strategie progettuali proposte sono successivamente valutate rispetto ai fattori di successo, attraverso una selezione di criteri qualitativi e quantitativi capaci di indagare gli aspetti fondamentali, definiti coinvolgendo un panel di esperti e pesati rispetto alla loro rilevanza nei processi di riuso, mediante l'applicazione del metodo AHP.

La validazione dell'approccio proposto ha ripercorso l'intero workflow metodologico, riguardando l'analisi delle aree portuali italiane e del loro patrimonio portuale e concentrando l'attenzione sul Porto di Bari e il suo Palazzo della Dogana, quale caso di studio per l'implementazione delle strategie di riuso adattivo. Lo sviluppo di un ambiente digitale integrato è stato progettato per integrare il sistema di gestione delle conoscenze e delle soluzioni progettuali adottando strumenti GIS/BIM e VR/AR. L'approccio definito validato per il contesto portuale garantisce replicabilità in contesti diversi e scalabilità, supportando processi decisionali più informati condivisi, collaborativi e coinvolgenti sia per gli utenti esperti che per quelli non esperti.

Keywords *area portuale, patrimonio portuale, riuso adattivo, ambienti digitali, valorizzazione culturale*

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INTRODUCTION

The Mediterranean port areas constitute environments of extraordinary significance, as repositories of a rich history and an inestimable architectural heritage related to maritime practices. Connected to specific maritime urban landscapes, “water” built environments are intrinsically characterised by a historical stratification that has contributed to defining their identity. This process of sedimentation finds expression in a complex system of open spaces, structures and infrastructure, with historical, architectural and industrial heritage connotations, reflecting the evolution of production processes and influenced by the passage of civilisations.

The complex and dynamic system of relationships between the built port environment and the surrounding urban context with which it interacts influenced their mutual development, in a dynamic balance between parties, defining patterns of morphological development along with new forms of use and new socio-economic relationship.

Furthermore, the changing nature of the land-sea interface and geo-economic and technological changes expose these contexts to a multiplicity of risks, both natural and man-made. In particular, the historical centres of port contexts were affected, with industrial development, by processes of progressive physical and functional obsolescence, due to the overcoming of the production models for which they were conceived. This process resulted not only in inadequate structures and infrastructure that no longer meet the requirements of the port system, understood according to modern standards, and that nowadays consist of functionally incompatible or disused assets, characterised as industrial archaeological ruins. Moreover, it generated extensive abandoned areas and residual spaces in a state of decay and abandonment. For this reason, it is necessary to adopt design approaches oriented towards sustainability and regeneration of these areas, in order to recover their identity, preserve their historical/cultural value and reconnect the port area with the city, creating new synergies between the physical environment, the built environment and the anthropic environment. At the same time, it is necessary to optimise and improve intrinsic

qualities such as resilience, flexibility, robustness, reflexivity, redundancy and integration, so that these systems are able to respond to critical situations.

In this scenario, adaptive reuse emerges as the privileged strategy. This paradigm, coherent with the principles of sustainability and the circular economy, allows for the preservation and enhancement of architectural and cultural heritage as a strategy to combat the abandonment and demolition of historical assets with intrinsic identity values. Adaptive reuse therefore aims to support the development of recovery and enhancement solutions oriented towards the transformation and conservation of existing heritage, encouraging the integration of the historical dimension into the contemporary context, the functional reintegration within the built environment and the enhancement of resilience, understood its capacity to respond to evolving uses and future transformation scenarios.

CONTEXT AND RELEVANCE OF THE RESEARCH

Since ancient times, Mediterranean ports have been strategic hubs and have played a pivotal role in the development of coastal civilisations, as catalysts for trade, cultural exchange and technical and construction innovations. The trace left by these processes is stratified and visible in the richness of the built heritage, from piers and docks to warehouses, arsenals, customs houses and structures conceived for port activities (Hoyle, 1989).

However, during the 20th and 21st centuries, the profound economic, technological and logistical transformations, particularly containerisation and industrialisation, substantially altered the historical relationship between ports and cities. These transformations, often driven by production-oriented development models and operational requirements related to industrial and infrastructural modernisation, resulted in a physical and functional separation. As a consequence, many historic port areas underwent territorial fragmentation, inaccessibility of port areas and a historical, architectural and industrial heritage that was involved in progressive physical obsolescence and disuse or abandonment (Gastaldi & Baiocco, 2012).

In response to these challenges, integrated strategies for conservation, regeneration and enhancement aim to protect and safeguard the historical, architectural and industrial heritage and reconnect the port system to the urban context by redefining functional, spatial and social dynamics toward a sustainable development (Hein, 2020). This perspective is aligned with the principles of the Blue Economy and the 2030 Agenda, which promote the sustainable use of coastal resources through integrated environmental, economic and social policies (European Commission, 2021; United Nations, 2015). In these important reference systems, port areas are recognised as a privileged context for economic growth, environmental protection and social well-being. In this scenario, port activities, coastal and maritime tourism, maritime transport and other coastal services are identified as central into the European strategy for achieving a competitive, climate-neutral and resilient maritime economy, supported by the European Ocean Pact (European Commission, 2025b). Thus, within this framework, port cities represent strategic interfaces where economic, environmental and cultural dimensions converge. In this context, according to the EU Blue Economy Report 2025 (European Commission, 2025a), Italy is one of the top four contributors to the EU Blue Economy in maritime passenger transport, with 85.4 million passengers, accounting for 22% of the EU's total, and 238 million nights spent in tourist accommodation, out of the 1.4 billion total nights in coastal regions. These principles have been integrated into the national strategy, such as into Piano del Mare (Comitato Interministeriale per le Politiche del Mare, 2023), oriented toward the Ecological and Digital Transition to promote sustainable development and cultural heritage and environmental protection. From this perspective, the concept of sustainability extends beyond environmental performance to encompass the recovery, regeneration and reuse of the port built environment, thought heritage-led regeneration approaches. The coastal built heritage, as historic structure, disused maritime infrastructures, archaeological industrial heritage, is conceived not as a passive remnant of the past, but as an active resource. If properly reactivated, this heritage can contribute to sustainable development and generate economic value, preserving collective memory and strengthening the ecological resilience of coastal systems.

Therefore, achieving this objective requires integrated approaches to recover the identity of the port area, preserve its historical and cultural values and reconnect the port area with the urban context, creating new synergies between the physical environment, the built environment and the anthropic environment.

To this aim, adaptive reuse emerges as a strategic approach for the sustainable regeneration and resilient management of the heritage. The effectiveness of this approach relies on the adoption of interdisciplinary aspects for the functional revitalisation of disused assets, balancing heritage conservation, environmental sustainability, economic feasibility, social inclusion, as well as historical and cultural value preservation (Bullen & Love, 2011; Douglas, 2006). At the same time, the optimisation and enhancement of intrinsic qualities such as resilience, flexibility, robustness, reflexivity, redundancy and integration could increase the long-term capacity of these areas to respond to changes and reduce the risk of disuse or abandonment.

Despite the growing interest, current approaches often remain fragmented, limited “case by case” and without a systemic general overview and structured and replicable assessment framework. These limitation are further hindered by institutional factors such as regulatory systems for heritage and planning, governance systems, human and financial resources and policies on civic engagement and participation (Mérail et al., 2022). To overcome the traditional operative limitations and improve the process to enhance peculiarity and strengths of port heritage, integrated and systemic approaches are required, to support experts, administrations, port authorities and communities in regeneration processes.

RESEARCH QUESTIONS

The present research is structured around a series of pivotal questions aimed at defining a methodological framework oriented to historical, architectural and industrial heritage revitalisation in port areas:

Q1: Is there heritage within port areas and what are its architectural, conservation and functional characteristics?

Q2: What strategies, tools and methodological approaches can be effective in ensuring its conservation and enhancement?

Q3: How can digital solutions contribute to the processes of knowledge, safeguarding and enhancement of heritage assets?

RESEARCH AIM

Port built environments constitute an important resource in the history and identity of Italian and Mediterranean cities, as well as in sustainable development processes promoted with the Blue Economy. However, despite the growing recognition, they are still managed and enhanced through fragmented and case-by-case approaches, highlighting the absence of a comprehensive and systemic framework capable of supporting well-informed decision making.

The objective of this research is to develop a structured, integrated and replicable methodological approach for the conservation, revitalisation and enhancement of architectural, historical and industrial heritage in Mediterranean port contexts. In particular, the research seeks to define strategies and operational guidelines aimed at promoting the sustainable and integrated development of the port context, achievable through adaptive reuse of undervalued, disused or abandoned assets, not adequately functional in the contemporary port environment.

In particular, the research aims to:

A1: Analyse the evolutionary processes of Mediterranean port areas, through a systematic census and cataloguing of port areas and their assets, considering their historical, architectural material- constructive, and assess the current condition of the heritage by investigating its conservative and functional condition;

A2: Identify effective strategies for the conservation, enhancement and adaptive reuse of the heritage with an integrate multidimensional approach, by applying analytical methods and decision-making models;

A3: Development and validation of the proposed methodological framework with digital solutions on emblematic case studies, considered representative of the port context.

A development of an integrated digital system capable to support decision-making processes is considered strategic in dealing with the problem of fragmented data and processes. Digital tools are capable of systematising and making accessible knowledge of the built environment of “water”, ensuring collaborative and shared processes.

STRUCTURE OF THE THESIS

The present thesis is structured in three main parts to outline a systematic approach aimed at achieving the objectives previously outlined.

Part 1 presents the context of the investigation and an overview of the state of the art about approaches, tools and technologies in the field of recovery, reuse and enhancement of built heritage. In particular, the port area evolution and the peculiar characteristics are outlined, as well as the existing heritage cataloguing systems (Section 1); adaptive reuse assessment approaches and best practices for recovery, reuse and enhancement of port heritage are investigated (Section 2); and digital approaches and tools to support the heritage asset management and enhancement are identified (Section 3).

Part 2 outlines the methodological workflow and the tools that could be adopted. The proposed method starting from the definition of a cognitive framework (Section 4.2), including the data collection of port area and port assets (ph.1.1, ph.1.2 and ph.1.3) and the qualification of port assets through the evaluation of state of use and state of conservation (ph.1.4), based on which asset cluster are identified (ph.1.5). Subsequently, the adaptive reuse strategies and the methods for evaluating design solutions are identified, as well as the definition of innovative approaches to orient decision-making processes (Section 4.3). According previously experiences in literature, a system of dimensions, main indicators, and evaluation methods is defined (ph.2.1), the adaptive reuse solutions for an investigating port asset are identified, through the adoption of an atlas of meta-design strategies (ph.2.2); and then the method for the adaptive reuse solutions assessment is defined (ph.2.3). The workflow finally includes the development of an integrated digital ecosystem (Section 4.4), consisting of the knowledge management (ph.3.1) and the design solutions management (ph.3.2), that converge in an integrated digital system, explored in virtual or augmented environment (ph.3.3).

Part 3 provides for the validation of the entire methodological approach, considering representative case studies. In particular, Italian port areas managed by Port Authority Systems and the heritage present within were considered in the cognitive processes (Section 5.1), and, through national and international cases of port heritage, adaptive reuse strategies were identified (Section 5.2.1) and subsequently, the weights were identified through a multi-criteria analysis for the evaluation of design solutions (5.2.2). For the application of adaptive reuse strategies, Palazzo della Dogana in the port of Bari was chosen as a case study. Initially, the context analysis and a deep survey of the asset were conducted and then the workflow was applied to validate the proposed method. To this aim, two adaptive reuse solutions were identified and evaluated. Finally, the digital ecosystem was developed (Section 5.3), systematising the knowledge and validating the approach in an innovative integrated digital environment.

The thesis concludes with considerations of the research and the proposal of possible future research developments.



PART 1. OVERVIEW OF THE RESEARCH

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1. PORT BUILT ENVIRONMENT

Ports represent historical sites of exchange and connection, where cultural, social and political-economic dynamics converge. Over time, port areas have undergone profound transformations that have progressively changed their role in the territorial context and their spatial configuration in relation to the urban system. From spaces originally integrated into the urban system, with a significant social value and a mercantile vocation, ports evolved into complex and strategic infrastructure systems for production and trade, with a heterogeneous distribution of functions.

Their evolution is attested by a historical and technical-constructive stratification of extraordinary value, which today results in a complex and heterogeneous built heritage. In particular, the industrial transformations of the 19th and 20th centuries, with the progressive containerisation of maritime traffic and the introduction of new logistical models, led to processes of marginalisation with respect to the urban context in many port areas, as well as physical and functional obsolescence of structures and infrastructure. This heritage, originally strategic in port dynamics and repository of material and immaterial values connected to maritime culture, is now in a disused or underutilised condition, raising questions about its recognition, recovery, enhancement and reintegration into the contemporary context.

In this scenario, the investigation of the evolutionary processes that affected port systems allows for the recognition of historical stratification and the system of values that characterised their identity, which can be identified in their construction, architectural and functional characteristics. The systematic survey and identification of port areas and their currently recognised and protected heritage is a fundamental preliminary step in recognising the historical, cultural and productive heritage of the port context, identifying its architectural and identity features and the processes

currently underway. Within this process, cataloguing is capable of organising historical and technical information in a structured manner according to consistent and shared criteria, as well as outlining the value system to support the cognitive, management and enhancement processes of the port's built heritage.

1.1. *Port area evolution in the Mediterranean*

“There is history in the Mediterranean, and there is (or can be) history of the Mediterranean” (Horden & Purcell, 2000). This expression highlights the role of the Mediterranean in the history of civilisations, emphasising how it was not a simple scene in the history of peoples, but a moving force in their connections and development.

The port is defined as “a body of water, usually of the sea, next to the coast, more or less large and protected, generally equipped with docking facilities, stopping, repairing ships, boarding and disembarking passengers and goods” (“Porto,” n.d.). From the first episodic and local travels, port facilities were affected by the strategic importance of the geographic area, as well as by winds and waves (Abulafia, 2013). Port systems, strategic nodes in maritime connectivity, encouraged the growth of urban centres on the back of the economic prosperity they generated. Conversely, many ports arose out of city expansion, recognising the land-sea interface as an opportunity for economic development. The synergy between geomorphological conditions and popular culture determined the identity features of each port area: function, form, facilities and infrastructure, as well as adopted techniques and technologies (Kajava, 2021). For this reason, each port constitutes the tangible sign of the passage of civilisations and port structures, intrinsically related to territorial identity, represent a valuable cultural testimony, although some of them show emerging historical/cultural characters and others are mostly industrial/commercial.

In particular, Greek-Roman ports allowed the development of the first interconnected commercial network around the centrality of Rome (Keay, 2020). These were the main hubs within the *Mare Nostrum*, supporting commercial, military and fishing activities. The ancient port systems’ cores were perfectly integrated into the city, both spatially and functionally (Hoyle et al., 1988; Moretti, 2016; Pavia & Di Venosa, 2012), also

performing logistics and storage functions, as well as administrative and fiscal functions. Therefore, in addition to the facilities required for the coast's landings - breakwaters, piers, docks - the structures necessary to the ports' needs were located enclosed within the city walls, such as fortifications, towers for military control and defence and the first offices for the administrative management of maritime traffic, facilities for the storage, sorting and sale of goods (Falco, 2022).

Over time, the original cores were enlarged and/or modified to adapt to the new maritime traffic, which required larger vessels, affecting increasingly distant areas. Therefore, port areas capable of accommodating them and spaces to manage their logistics were necessary. During this period, ports were mainly characterised by commercial activity, such as those on the Silk Road to the East, for trade in silk, spices, perfumes, ivory and other luxury products. Likewise, a pronounced military character associated with an important development of the Italian naval system emerged. Thus, to support the state management of commercial trade from the fiscal, monetary and judicial points of view, it was necessary to equip each port with warehouses, grain, salt warehouses and stores, as well as commercial offices/customs offices. In strategic military areas, such as Venice, Livorno, Taranto, and Naples, arsenals were built for the construction and maintenance of ships and the storage of armaments (Zan, 2019), besides towers and fortifications for sea control.

Since the 19th century, with the industrial revolution, the dynamics related to maritime traffic changed. The opening of the Suez Canal was a key event in international trade in the Mediterranean (Abulafia, 2013). The port with its new technologies became more identified as an autonomous reality, with growing requirements of larger spaces and new connections with the territory. The great potential of the sea in commercial traffic was recognised. Many production facilities were built in port areas to take advantage of water in production, such as paper mills, sawmills and grain mills with manufacturing activities.

However, technology transformed production systems so quickly that it was difficult to adapt to the contest and space. As a result, some migrated inland and port production plants were abandoned. This phenomenon was emphasized until the 20th century with

containerization: on one hand, it allowed the optimization of production processes, maximizing profits and reducing costs, through the adaptation of port facilities, infrastructure and equipment to make the port system efficient (Caroli, 2006), on the other hand, it resulted in the abandonment, especially of historic port areas, with following physical, functional and regulatory obsolescence, towards which a special interest was generated (Dai et al., 2021).

In Italy, delocalisation processes were limited, as in the cases of Genoa and Trieste, and ports often remained adjacent to historic city centres, resulting in a more complex interaction between port cities and regeneration processes (Costituzionale, 2015).

These evolutionary processes were inextricably linked to the social dynamics of dockworkers, as they play a pivotal role in the maritime practice. During this period, progressive industrialisation processes led to the emergence of port workers' organisations (Velardita et al., 1993) aimed at better working conditions and worker protection. In this socio-political context, the construction of port workers' houses served as a reference point for the category.

Currently, we are evolving toward the gateway port model, which requires larger spaces to allow for container handling, as well as larger spaces for the docking of bigger vessels and it is supported by an extensive infrastructure network comprising rails and roads, ensuring efficiency and competitiveness in the international economic system. In this evolutionary scenario, the waterfront always constituted a physical limitation, although broken through the port infrastructures, such as piers, breakwaters, outfalls, artificial platforms, equipped natural islands and so on (Vallenga, 1974).

The absence of a clearly defined boundary shaped the physical conformation of the mainland landscape, leading to a mutable delimitation of the port area, sometimes emphasised by the structural arrangement and sometimes overcome by the infrastructural and transport connections of the entire territory. As a result, there is a continuous relationship of dependence from the service system of the city and, at the same time, of independence for its functions. A clear definition of the functional organisation allowed this area to be almost completely independent from the urban

context, due to city and/or port planning and administrative competencies and to the incompatibility of port activities with urban ones.

This was not a necessary condition for defining a spatial delimitation, which does not yet have a legal definition. This is reflected in the close relationship between the port and the city that is much more complex and depends on the historical development, whose evolutionary layers are difficult to identify, and the relationship with the territory on a larger scale. According to Merk's research (Merk et al., 2011), the growth of urban contexts is strongly related to the economic development of the port area, on which the growth of the urban population has depended: major coastal cities are usually close to significant port areas; if not, connection to the port plays a crucial role in city development. In cases where major urban centres are not near port systems, the reasons for the development of port activities are related to the availability of natural resources, such as coal, oil and minerals.

Nowadays, the development of port facilities in relation to the urban and territorial context influences the management strategies. Where port development is synchronised with urban growth, the focus of planning is on constructing new infrastructure and re-organising the function of port areas in relation to the surrounding urban context. Where the growth of cities is accompanied by a phase of progressive port decline, interventions aim at the redevelopment and refunctionalisation of waterfronts. In contexts where the decline of ports coincides with the cities decline, a comprehensive economic structural transformation is necessary. Conversely, where port growth exceeds urban growth, connections with the hinterland need to be improved to ensure the efficiency of the logistics system and rebalance the relationship with the surrounding area.

Hence, Port Authorities, in order to manage the sustainable development of ports and strategic planning at the local and territorial level, shall promote forms of collaboration with local administrations and citizens to implement strategic and coordinated synergistic actions, in line with the principles of the ESPO - European Sea Ports Organisation (ESPO, 2021).

1.2. *Overview of port built environment heritage*

The historical functional evolution of ports impacted on tangible and intangible heritage. Structures and infrastructures for maritime activities, with historical-architectural-industrial value, are intrinsically associated with the many aspects of intangible heritage, consisting of traditions, practices, and histories of local communities. The richness of this heritage is recognized at the global level by the AIVP's Agenda 2030 (aiVP, n.d.), in which, among the goals for sustainable development for port contexts, goal number six aims to enhance port culture and identity as a starting point for the development of cities.

A fragmented process of cataloguing the tangible and intangible values of port areas unfolds history and evolutionary processes. This was often carried out by different organizations according to their specific requirements and purposes, only partially usable by managing authorities of these areas (Port System Authorities – AdSP).

Among these, UNESCO- United Nations Educational, Scientific and Cultural Organization emerges thanks to joint action with ICOMOS- International Council on Monuments and Sites. Typical structures of port heritage were considered of outstanding universal value and are currently part of UNESCO World Heritage Sites (Dai et al., 2021), such as lighthouses, shipyards, warehouses or entire port areas, including some Italian port cities, such as Venice and its lagoon.

At the national level, some assets are recognised and catalogued by the ICCD -Institute for the Cataloguing of the Built Heritage of the Italian Ministry of Cultural Heritage and Activities, following del DPR n. 805 del 1975 and Tourism (MIBACT) in accordance with the guidelines of the National Catalogue of Cultural Heritage (Art. 17 Legislative Decree 42/2004). For the cataloguing of heritage, the Italian Ministry of Culture (MiC) has defined areas of protection, namely archaeological, architectural and landscape, ethno-anthropological and historical and artistic, each of which includes movable, immovable and intangible assets (Tucci et al., 2018).

Based on the above classification for the General Catalogue of Cultural Heritage, Italian heritage having special cultural interest at the national scale was classified, including that of port areas, such as ancient docks, piers, lighthouses, customs buildings and

warehouses, shipyards, as well as buildings with different uses. Among this architectural heritage, it is possible to distinguish those necessary to make a port area functional and those that can be classified as industrial heritage. The latter consists of the “remains” of industrial culture, having historical, technological, architectural or scientific and social value, related to the working and popular classes, different from the internal heritage and deserving of enhancement and preservation (Astrella, 2021). “These remains consist of buildings and machinery, workshops, mills and factories, mines and processing and refining sites, warehouses, places of energy generation, transmission and use, transportation and all related infrastructure, as well as places used for industry-related social activities such as housing, religious worship or education” (TICCIH, 2003). This recognition is achieved through the synergistic action of international organisations such as TICCHI (The International Committee for the Conservation of Industrial Heritage) and ICOMOS, which aim to recognise, conserve and promote heritage, as well as AIPAI (Italian Association for Industrial Archaeological Heritage), which operates at a national level. Therefore, in this scenario, the role of national and international bodies in recognising the historical, architectural and industrial value of ports is strategic.

1.3. Cataloguing port area and port heritage assets

Many national and international approaches are adopted to catalogue and classify heritage, at different scales and with different degrees of detail (Figure 1).

Cataloguing on a global scale

At the global level, UNESCO is responsible for the cataloguing of Cultural Heritage of Outstanding Universal Value (OUV). World Heritage Online Map Platform (WHOMP), an online Geographic Information System (GIS), was developed to map World Heritage to be preserved (UNESCO, n.d.-c). This platform is linked to the UNESCO database and provides specific information for each georeferenced property, following the Operational Guidelines (UNESCO & World Heritage Centre, 2008). The data support property identification and conservation assessment, facilitating planning activities, supporting management tasks and assisting planners. Although it was not conceived

as a cataloguing system specifically for port heritage, as previously mentioned, some of the assets, such as lighthouses, naval dockyards, fortresses, palaces, are listed, not only for their constructive functional characteristics, but also for their location in port contexts.

A more tailored international experience is the project called The Catalogue of Ancient Coastal Settlements, Ports and Harbours (Arthur de Graauw, n.d.), which identified and located almost 6000 coastal settlements, harbours and ancient ports from Iceland to Sri Lanka. Through an analysis of existing documentation by ancient and modern authors, information related to each port area was collected and catalogued, starting with location, history and ancient structures, with a focus on vessels, with notes also relating to particular earthquake and tsunami events (de Graauw, 2022a). This project aimed to define a methodological framework for an easily implementable system capable of disseminating historical port information.

Cataloguing on a European scale

At the European level, the EU defined specific actions in policies, programs and activities for the conservation and enhancement of Europe's cultural heritage, recognising in maritime and coastal heritage the potential to be valorised (Commission, 2017).

One of the projects funded by the European Union Commission, Horizon 2020, was the PERICLES project (Project Pericle, n.d.), which aimed to catalogue the water cultural heritage. This project involved the development of an interactive online platform, in collaboration with UNESCO and the Council of Europe on Cultural Heritage, in which the tangible and intangible cultural heritage of seascapes and coastal landscapes was mapped. Currently, data on eight European regions (Aegean Sea, Brittany, Denmark, Estonia, Ireland-Scotland, Malta, Portugal and the Wadden Sea) was collected. Through this tool, users can learn about the built heritage of the sea and share their information and media with others. In this way, it is possible to protect these environments and preserve them for future generations (Delaney, 2020)

A further European project is PORT CITY ATLAS, developed by the LDE research group PortCityFutures in cooperation with the Faculty of Architecture of TU Delft, who

conducted an analytical study and developed a comprehensive approach to map 100 port cities. The study aimed to provide support for the analysis and design of the European coastline (Giovinazzi, 2023). In this case, the approach was not focused on historical issues, but rather on a detailed analysis of the port area at the urban and territorial scales, reporting the information through infographic maps (Hein et al., 2023).

Cataloguing on a national scale

In Italy, there is no specific cataloguing system for the sea cultural heritage, although part of it was considered in larger scale cataloguing systems. However, in some contexts, it is possible to trace the presence of cultural heritage of particular interest.

For instance, a platform that allows heritage to be visualised is SID - Sistema Informativo del Demanio Marittimo (Maritime State Property Information System) (Ministero delle Infrastrutture e dei trasporti, n.d.), developed thanks to the collaboration between the Italian Ministry of Infrastructure and Transport (MIMS) and MiBACT. This platform constitutes a useful tool for the identification of port areas and listed cultural assets, as maritime state property, in line with Legislative Decree 201/2016, implementing Directive 2014/89/EU. Interactively, it is possible to view the documented areas as defined by the Port Regulatory Plan (PRP) and the assets catalogued by MiBACT falling within the perimeter of the port area as defined by the AdSP.

Another system is Vincoli in Rete (VIR) (Istituto Superiore per la Conservazione ed il Restauro - ICCD & Ministero dei Beni e delle Attività Culturali e del Turismo -MiBACT, n.d.), thanks to the collaboration between ICCD and MiBACT. This turns out to be an interoperable platform that censuses, catalogues and geolocates immovable cultural assets of territorial value, integrating information from different databases, related to their protection and vulnerability nature. Therefore, it does not only focus on assets related to port areas, but they are included in it, as reported in CartApulia (Regione Puglia, n.d.), referred to the Puglia region experience.

In a study conducted by Martino et al. (Martino et al., 2017), a process of port heritage analysis was initiated, to create a cognitive framework capable of identifying and classifying maritime heritage to support risk analysis. Specifically, the investigation

focused on the morphological configuration of port areas, the architectural heritage and specific construction techniques.

In addition to these, there are cataloguing experiences of industrial heritage with fragmented and heterogeneous systems in response to specific knowledge, protection and management issues. Among these, the 1982 SIAI (Italian Society of Industrial Archaeology) model emerges. Designed for the census of industrial assets in the Lombardy region, it could be used by non-expert users thanks to its simple, compact and fast structure. Inspired by this model, the catalogue card promoted by the Department of Cultural Heritage of the Umbria Region, in collaboration with Renato Covino and Gianni Bovini has been adapted to the specific characteristics of the context. It can be used not only for censuses, but also for in-depth, flexible cataloguing of small and large establishments.

Another relevant example is the Apulian initiative from 1996, which was the outcome of a collaboration between the Italian Association for Industrial Archaeological Heritage (AIPAI) and the Institute for Cultural and Archaeological Heritage (IBAM) of the National Research Council (CNR) in Lecce. This initiative innovatively proposed a georeferenced cataloguing system that incorporates IGM cartography and orthophotos within a digital platform.

Following the above analysis, it emerges how a comprehensive and systematic cataloguing has not been carried out for the port areas particularly for all assets hosted within, whether they are of historical value, functional to the port areas or to industrial production (Marzotta, 2009). Similarly, there is a lack of a standard to catalogue the port areas and their heritage assets.

INTERNATIONAL EXPERIENCES



World Heritage Online Map Platform
- UNESCO

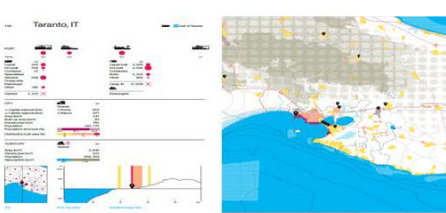


The catalogue of ancient coastal
settlements, ports and harbours - de
Graauw

EUROPEAN EXPERIENCES



PERICLE

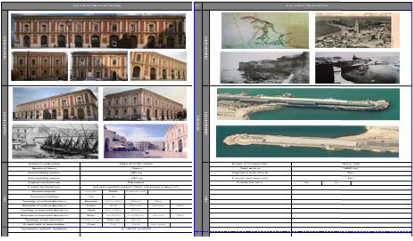


PORT CITY ATLAS
- LDE PortCityFutures e Facoltà di Architettura di TU Delft

ITALIAN EXPERIENCES



ICCD



Martino et al. - Politecnico di Bari



Scheda Umbra - Renato Covino e Gianni Bovini

Figure 1 - National and international cataloguing experiences (Annex 1)

Although these consolidated systems were conceived for different purposes, they reveal common aspects and main port assets related characteristics to attention, thereby identifying both potentiality and critical issues.

An interesting aspect concerns the scale of investigation, which ranges from the urban and territorial dimension, while aside from historical enquiry, as in PORT CITY ATLAS, to the scale of individual asset, where protection-oriented systems record the asset while disregarding its spatial context, as in the ICCD card and UNESCO platform. Only in the work of Martino et al. there is a first attempt to take context into account, for the specific purpose of risk analysis. In a cataloguing system for port heritage, the context is by no means negligible information, as well as in other contexts, it could permit to contextualising the assets. As regards the asset, many recurrent aspects investigated could be identified, such as the historical evolution, technical and constructive systems and information on use.

It further emerges that these databases could be implemented within a georeferenced system and the integration of different databases is feasible, as VIR demonstrates. This is also because, as demonstrated by Italian initiatives such as VIR and CartApulia, these surveys are limited to national or local contexts.

In all systems examined, a systematic census of port assets is lacking, since heritage is catalogued according to its legal protection status. Consequently, a great many unrecognised assets, significant to the historical identity of the port area, fall outside every selection criterion.

2. ADAPTIVE REUSE

The evolution of Mediterranean ports is intrinsically related to the natural environment and strongly influenced by the historical events of the territories, as well as by economic and technological development (Caroli, 2006). Historically, ports have not only had a strategic role in the territories as a reference point of international economic relations, for global trade and commercial activities, but also a place of cultural and social exchange. Over time, due to changes in the transport paradigms and the adoption of new technological innovations, many port areas have lost their centrality within the cities, resulting in their physical and functional detachment from the urban context (De Vito, 1999). In several cases, this evolutionary process culminated in the abandonment of entire areas once useful for port activities. This phenomenon, defined in the literature as “threshold of abandonment” (Hoyle et al., 2022), nowadays requires intervention aimed at spatial and functional reuse and requalification (Pavia & Di Venosa, 2012), so that they may coexist synergically with still operational port areas. The progressive transformations of these areas and the recent growing interest in their regeneration and reconnection with the urban context are contributing to the redefinition of the port identity. This process sometimes might constitute a threat to the authenticity and integrity of these places, highlighting the need for careful and informed planning to ensure the preservation of the sites’ value.

In this context, port heritage constitutes a tangible sign of the passage of civilisation and an expression of the needs and technological level of development. However, although the port areas with their port infrastructures generally constitute resilient environments capable of adapting themselves in response to new needs (De Rosa & Di Palma, 2013; Hein, 2014), the rapid evolution of production systems and modern requirements, particularly following the advent of containerisation, resulted in more vulnerable structures. In fact, in many cases contemporary needs lead to changes their function and to decide whether to continue to use or to abandon structures which are unable to perform in the current context (Adin & Sirel, 2024).

As a witness to maritime culture and a repository of collective memory of the territory, the historical heritage represents the concept of palimpsest in architectural practice, in which each historical and technological evolution left legible traces in the port built environment (Adin & Sirel, 2024).

The recent international debate has redefined the inherent issues. The Historic Urban Landscape approach recognises heritage conservation as the starting point for the historical territories' development (UNESCO, 2011b). Its relevance in this debate regards the extension of the focus of conservation from individual structure to the complex relationship with its context. In this perspective, the preservation of historical port structures and infrastructures is recognised as a valuable opportunity for the enhancement of these areas, which require integration into broader processes of urban regeneration (Grindlay et al., 2018) and to be resilient to the changes (De Rosa & Di Palma, 2013).

The literature widely acknowledges adaptive reuse as a valid strategy for the revitalisation of abandoned or underutilised structures. This approach allows the preservation and enhancement of heritage and its historical-cultural value, making it functionally compatible with contemporary needs and suited to new requirements (Adin & Sirel, 2024; Douglas, 2006; Gravagnuolo et al., 2024). To this end, the decision-making process is complex, in which the definition of strategies depends on a multitude of heterogeneous factors that need to be balanced, including architectural, social, environmental, economic, authenticity and others. This complexity is exacerbated by the specific context of application, characterised by a variety of asset types and by the operational and functional restrictions of the area.

In addition, given the complexity of this approach, it is essential to adopt evaluation methodologies and analytical tools capable of supporting decision-making processes in assessing the compatibility of solutions with the morpho-typological and constructive-materials characteristics of the asset, as well as for comparing different design solutions for an individual asset.

In this context, therefore, adaptive reuse emerges as a strategy for preserving the built heritage and its system of values related to its historical, cultural and productive

significance, whilst at the same time promoting sustainable development. However, interventions in this field are often constrained by fragmented approaches that lack a systematic and scalable methodological framework. Despite the breadth of the debate, it is necessary to investigate approaches adopted through a systematic literature review, recognising the priority necessity to explore the main and recurrent factors to be considered for adaptive reuse projects design; analysing potential and critical issues of existing approaches to assess design solutions; and the investigating successful experiences of recovery, reuse and enhancement of port heritage, considering representative international case studies for each different port asset typology from which good practices could be extracted.

2.1. Adaptive Reuse assessment approach

In the context of approaches to recovery and enhancement of the built environment, adaptive reuse emerges as a design and decision-making strategy aimed at the functional reconfiguration of existing buildings as a response to new use requirements. This approach is not limited to mere spatial transformation, but is a strategy capable of balancing various aspects, ensuring the preservation of material and construction values, as well as historical, cultural and identity values.

The adaptive reuse is by no means a contemporary approach, but it dates back to 19th century dialectic between two opposing schools: on one side Eugène Emmanuel Viollet-le-Duc with his restoration movement, stylistically coherent with the original form and stylistic purity; and on the other side, John Ruskin and William Morris with an anti-restoration movement that valued the material authenticity of existing structures, where modern intervention destroys the memory of the past (Bazazzadeh et al., 2021). So, the concept emerged in the 1970s as a reaction to the “tabula rasa” principle, which privileged reuse of existing structures over the new construction praxis common until that moment, encouraged by a growing awareness of conservation and environmental issues, as well as to deal with rising energy costs (Lanz & Pendlebury, 2022).

Although she never explicitly used adaptive reuse, Jane Jacobs may be considered a pioneer for this approach with her urban ethics and her hypermodern vision of urban planning. The older buildings were recognised as a crucial resource for urban dynamism as low cost incubators for novel concepts, thanks to their high degree of flexibility, allowing adaptation to different uses over time (Jacobs, 1992; Lanz & Pendlebury, 2022). Thus, in early debate, adaptive reuse was conceptualised as a technically and economically sustainable alternative to new construction, capable of synthesising issues related to environmental sustainability and the enhancement of the identity of existing buildings. This approach takes on a paradigmatic value in the transition towards more resilient and circular settlement models, placing itself at the crossroads between functional obsolescence, urban regeneration and technological innovation. In particular, it stands out for its ability to integrate conservative and transformative approaches, activating compatible recovery processes that give disused buildings a new functionality consistent with contemporary needs.

In this sense, adaptive reuse solutions could be a valid solution to keep cultural heritage in a proper conservation state, preserving cultural values exposed to irreversible loss due to abandonment, and ensuring accessibility and enjoyment of heritage assets (Mısırlısoy & Günçe, 2016).

The growing interest in adaptive reuse produced a substantial body of studies aimed at defining decision-making models and evaluation methodologies, often focused on specific performance dimensions.

According to Vardopoulos (Vardopoulos, 2019), adaptive reuse projects affect local sustainable development by the following seven critical factors: quality of life improvement, public environmental awareness and education, environmental management, local memory and cultural identity preservation, community action and involvement empowerment, cultural heritage protection, and land conservation against urban sprawl (Mousavinia, 2024).

A persistent inconsistency nevertheless affects the criteria and indicators used to measure the outcomes of reuse processes, with direct consequences for the construction of systemic and comparable interpretative frameworks. The metrics

currently in use reflect wide variability, not only in terms of scale and scope of application, but also with regard to the underlying theoretical references: they range from economic and financial indicators to environmental and socio-cultural parameters, often used in a disjointed and poorly integrated manner.

Angrisano et al. (Angrisano et al., 2024), dealing with sustainable cultural heritage reuse in urban development, mentioned 16 different methods, highlighting the most popular: the Analytic Hierarchy Process (AHP) (Añibarro et al., 2023), the Step-wise Weight Assessment Ratio Analysis (SWARA) (Annisa & Lukito, 2024), the Best Worst Method (BWM) (Appelgren, 2019) and the FULL Consistency Method (FUCOM) (Arfa, Lubelli, et al., 2022). The choice of the best suited methods depends upon the specific problem (Salerno, 2020).

As a result, scientific maps were created to reveal the knowledge domain of MCDM approaches in heritage buildings' reuse and preservation. Finally, research gaps and future research directions are identified. Results of the analysis highlight that till now MCDM approaches are not widely used in solving heritage buildings reuse and preservation issues. Moreover, there is a lack of complex problem solving approach in the cultural heritage buildings area (Morkūnaite et al., 2019).

Critical issues arise when transitioning from theoretical principles to operational practice. First and foremost, it becomes fundamental to orient the reuse of architectural heritage according to these principles, improving well-being and quality of life and leading interventions on architectural heritage through a virtuous process consistent with the cultural premises of conservation (Abdeen, 2020; Alhojaly et al., 2022). Furthermore, it is strategic to identify evaluation tools capable of supporting and guiding the development of the decision-making process in a more conscious way, translating the guiding criteria into a series of indicators that respond to a more democratic and inclusive logic (Aigwi et al., 2019). The ex ante and ex post phases are necessary to ensure the achievement of objectives and identify consequences unforeseen by the guidelines (Andrade et al., 2024). It is also required that a model that is easily applicable and has some degree of flexibility be identified by promoters

and proponents to facilitate the effective monitoring and evaluation of the interventions carried out (Abdeen, 2020; Dabbene et al., 2024).

This methodological heterogeneity, while expressing the intrinsic complexity of the phenomenon, raises the question about evaluation criteria capable of supporting the replicability, effectiveness and sustainability of reuse strategies in the long term. It therefore seems essential to carry out a critical review of the metrics adopted in the various strands of research, aimed not only at classifying them, but also at highlighting methodological assumptions, convergences and areas that remain unexplored.

With this in mind, the investigation consists of a systematic review about the evaluation of approaches adopted for adaptive reuse, with the aim of providing an overview of the approaches and metrics adopted in the literature, analysing limitations and potential of the different methods, and supported a structured critical reflection on the most common and suitable criteria or indicators for an integrated evaluation of the interventions' effectiveness. The results are intended to contribute to the construction of shared evaluation systems capable of supporting decision-making processes related to the design and management of reuse interventions.

Research method

The aim of the literary review is to investigate the methodologies and respective indicators adopted for adaptive reuse strategy assessment. Particular attention is focused on the typologies of structure to which this evaluation was applied and the scale of investigation. For this purpose, the study is structured as follows: identification of the research questions and the methodological approach adopted; highlighting the main findings; discussion of the results, offering a critical interpretation of the data and identifying the potential of the research.

The scoping review is conducted to investigate the literature concerning the reuse practices, with a particular focus on how these interventions were evaluated. In particular, the review aims to analyse the approaches adopted in previous studies and identify the indicators employed to assess the effectiveness and impact of reuse interventions.

It is structured around four research questions:

Q1: What type of asset was investigated in existing studies on reuse interventions?

Q2: What indicators or criteria were adopted to evaluate the interventions?

Q3: What method of investigation was adopted? What scale of investigation were chosen?

Specifically, the analysis is divided into several steps. Firstly, the literature database is chosen and inquired. The keywords selected allow for obtaining the initial sample of results. Thanks to the addition of further criteria, the search field is further narrowed. Afterwards, all the selected publications are reviewed and the relevant publications are selected, in order to exclude those focusing on questions not relevant to the topic of this study. Finally, the results are categorised and analysed.

Database selection and search criteria

The database consulted to collect relevant publications for this review was Scopus, last access July 2025. To this aim, keywords identified for the research include terms capable to ensure an accurate selection of papers; in particular, each research field refers to the type of intervention, the identification of indicators and the type of heritage analysed.

Through the combination of keywords, the first selection of the publications is carried out on the basis of the titles of the articles, the abstracts and the keywords.

In particular, a literature review is conducted, considering work which identified indicators, through the following string: (TITLE-ABS-KEY (adaptive AND reuse) AND TITLE-ABS-KEY (indicator* OR index OR criter* OR factor*) AND TITLE-ABS-KEY (heritage OR structure* OR infrastructure*) AND TITLE-ABS-KEY (modern OR historic* OR cultural OR architectural OR archeolog* OR industrial))

The results (342 documents) are further limited on the language, as well as publishing year. In particular, the contribute considered are only in English language, in a range between 2015 and 2025, collecting 304 relevant publications.

Screening of the research contributions

The preliminary screening of results was conducted through the examination of titles and abstracts, following the exclusion criteria based on the lack of correlation with the research scope. In detail, the aim of the analysis was to investigate the evaluation carried out *ex ante*, *ex post* or *on-going* to assess one or different possible alternatives for adaptive reuse of a specific asset. Then, they were filtered based on exclusion criteria.

A first exclusion criterion concerned the *scale of the investigation*. Several sources focus on regeneration and adaptive reuse in a broader context, corresponding to the city or entire areas. Examples include the study of Foster and Saleh (Foster & Saleh, 2021) which assessed adaptive reuse opportunities for ARCH (Adaptive Reuse of Cultural Heritage) at the urban and regional scale, supporting decision-making of municipal government and investors within the framework of circular economy, in order to guide sustainable policies, investments and sustainable urban practices; Jawabreh et al. (Jawabreh et al., 2024) explored the challenges and issues associated with the dynamic transformation to achieve sustainable urban development and conservation of historic cities; as well as the works that adopted a territorial scale vision with a transdisciplinary perspective to initiate regeneration processes and protection directions at the historical urban scale (Boeri et al., 2016) or contribution focused on the regeneration of urban industrial heritage quarters (IHQ), highlighting the impact of the urban context on heritage values post-intervention (S. Li & Heath, 2025).

Consequently, macro-scale investigation, despite its integration of heritage conservation into requalification processes, was excluded due to its focus on issues affecting broader contexts. This does not, however, exclude the necessity for a more profound reflection on the relationship between urban structures and their surrounding context. This awareness highlights decisions conceived at the urban scale as providing a frame of reference for those at the building scale. As a result, the analysis encompasses a multi-scale approach, requiring a systematic integration of the building characteristics with the socio-economic, cultural and environmental dynamics of its

surrounding area. This comprehensive framework reveals the diversity of objectives and design dynamics of this analysis.

For the same reason, the publications referring to *intervention priorities* of underutilised historic assets to be requalified through adaptive reuse strategies (Aigwi et al., 2019, 2022; Aigwi, Ingham, et al., 2020; Della Spina et al., 2023; Hong & Chen, 2017) are excluded from the analysis. The focus of these works is not on interventions targeting single asset, but on assets systems with the aim of providing decision support in identifying, comparing and classifying assets with the higher potential for reuse, ensuring that choices are informed, transparent and balance the multiple dimensions (cultural, social functional, regulatory, environmental, and so on) and promoting the effective allocation of resources, thereby contributing to development of sustainable and resilient urban areas.

Moreover, articles in which factors were not intended as indicators were excluded, as articles with purposes *not in line with the research*. These included perceptual and social investigations (Abdeen, 2020; Al Dein & Jawabreh, 2022; Dehghan Pour Farashah et al., 2023; Maulina et al., 2024; Md Ali et al., 2019), market survey (Kee & Chau, 2025; H. Li et al., 2023, 2024; Selim et al., 2023), environmental and energy (Berthold et al., 2025; Hegazi et al., 2021; How & Din, 2022; Huang et al., 2025; Marzouk et al., 2022; Shirzadnia et al., 2023; Slavković, 2020), as well as project and design analyses (Firzan et al., 2022; Ghaderi et al., 2020; Kedyia et al., 2023).

A detailed examination of the results was carried out. A considerable number of contributions did not adopt a specific methodology to assess adaptive reuse intervention: rather, key aspects and criteria were examined in detail, emphasising the complexity and multidimensionality of the approach. In this context, the existing literature provides a comprehensive overview of the fundamental factors for a successful project, exploring the variety of aspects that do not simply focus on the structural and architectural ones.

Bibliometric analysis

The 38 selected contributions were analysed via bibliometric analysis. The distribution of publications over the years reveals a limited number of contributions until 2018. This data probably reflects an embryonic phase of research on the topic. From 2019 onwards, a period of significant and steady growth was observed. This growth may have been stimulated by the international debate on sustainability and the circular economy. The last two years, following the peak reached in 2023, can be regarded as a phase of consolidation of the topic in the literature.

The geographical distribution of contributions suggests the countries in which research on this topic is diffuse. The distribution evidently delineates Italy's predominant position, with a number (four times) significantly higher than the following countries. This occurrence is not unexpected when considering the rich Italian heritage, characterised by historical, architectural, cultural and industrial value. Therefore, this data reflects a significant interest in adaptive reuse within a context characterised by a rich heritage, as an intrinsic necessity to the management of historical and cultural context, rather than merely a design preference.

This is followed by countries with a strong historical and cultural heritage, such as Egypt, Turkey and Spain, where the centrality of heritage necessitates its protection and enhancement. Conversely, within the Chinese context, it may be more related to the issues of sustainability in a context of rapid and massive urbanisation. The heterogeneity of the experiences may be indicative of contexts in which the tradition of new construction is still deeply rooted and in which the concept of reuse is only recently being recognised as a sustainable strategy.

Despite the evident differences in their respective dynamics, these phenomena converge, thereby confirming that the issue is deeply rooted in the territorial, historical and economic specificities of the different contexts.

The type of heritage, the scale of intervention (Bosone et al., 2021), the time of assessment (ex ante or ex post or ongoing) and the method adopted were investigated. Then the criteria and indicators adopted were analysed, from which those

of interest were chosen. The indicators could be classified according to the success factors for adaptive reuse identified in previous studies (Vafaie et al., 2023, 2025). However, not all success factors were considered in accordance with the purposes of this study. So, the following criteria were considered: Architectural (physical), Socio-cultural, Economic, Environmental, Authenticity and Historic, Management and decision-making, and Functional.

Results

The analysis of the results allowed to answer the initial research questions. In particular, the asset typologies investigated (Chapter 2.1.1) were analysed in order to understand the different application contexts. Subsequently, a survey was conducted of the indicators used in the evaluations, with the aim of identifying the key aspects to focus on in the design and subsequent assessment of interventions. In particular, this research was conducted adopting the 10 success factors identified by Vafaie et al. (Vafaie et al., 2023), considered as a comprehensive reference study useful for this research. Finally, the methods used to evaluate adaptive reuse interventions were examined in order to understand the limitations and potential of each approach and to identify the most appropriate methodology for the proposal.

2.1.1. Typology of assets investigated

The analysis of the results revealed a high degree of heterogeneity among the cases studied, which concern different types of heritage, mainly identifiable as historical heritage, modern heritage and industrial heritage, with marginal applications to archaeological heritage. In most of the contributions, these were considered within the broader definition of cultural heritage in the widest sense, making the proposed methodology valid regardless of the specific type of heritage considered.

- **HERITAGE**

The first category comprised contributions that did not explicit the type of asset to which the survey refers. They referred generically to heritage, thus including a range of asset types. In some cases, they adopted the UNESCO definition of cultural heritage

as “the legacy of physical artefacts and intangible attributes of a group or society that are inherited from past generations, maintained in the present, and bestowed to future generations” (Girard, 2025). In all cases, the proposed methodologies were validated through case studies. These included religious buildings, as Seminary in Sant’Agata de’ Goti in Italy for which three cultural and aggregation solutions were proposed responding to the local necessities (Angrisano et al., 2024), civil and residential buildings, as Sille Ak Bath in Turkey (Çelebi Karakök & Ertaş Beşir, 2023), Sabil Mohamed Ali in Egypt (Ismaeel & Mohamed, 2023), Palazzo Ricordi Berchet in Italy transformed into a world-class trade and economic hub (Ismaeel & Mohamed, 2023), Ministerial Building in Egypt, which was expected to be transformed into a research centre, start-up hub, hotel or shopping centre (Metwally et al., 2025).

- **HISTORICAL HERITAGE**

Historical heritage constituted the broadest application, including assets recognised for their architectural, archaeological and monumental value. These were historic structures of value and historical significance at both a regional and local level, such as castles, noble palaces, villas, churches and monasteries, as well as historic railway stations. Conservation aimed to enhance the signs of ageing, compared to the changed social and environmental conditions that led to their abandonment.

Representative cases included the Castello Visconteo in Cusago (Dell’ovo et al., 2021), il Palazzo Stella di Catanzaro, Italy (Della Spina, 2021), Il Sursock Pasha Place, la Villa Capolieto o international abandoned railway, as Museum d’Orsay in Paris, France, Gare Maritime in Bruxelles, Belgium, and Bullona restaurant in Milan, Italy, highlighting how the same structure typology may be reused for different purposes (Bianchi & De Medici, 2023). Several applications had involved multiple buildings within the urban context. Examples include the “Edifici Mondo” in the historic centre of Salerno, Italy (Gravagnuolo et al., 2024). In these cases, the literature emphasised the importance of the HUL (Historic Urban Landscape) approach, which framed historic urban landscapes as dynamic organisms.

- MODERN ASSETS

Modern heritage, often considered a subcategory of historical heritage, concerns 20th-century architecture and infrastructure. These assets are more difficult in recognising and protecting modern heritage stems from its recent historicisation and the weight of ideological interpretation to evaluate given their relative proximity, although they had a great technological and architectural value. The case studies identified concern, for example, public buildings, as the former Governmental building, now known as the National Union Bank in Alexandria, Egypt, for which four alternatives were proposed and evaluated, as hotel, office building, museum or mixed-use building (Dabouh & El Shazly, 2020).

- INDUSTRIAL HERITAGE

Many studies focused on abandoned industrial heritage, encompassing various types of heritage. No longer capable of meeting current operational needs, it draws attention to the need to be reintegrated into the urban system. These included grain silos, such as those in Arezzo, Italy, built in 1930 and used for grain storage, for which various cultural proposals have been put forward, such as data centres and teaching laboratories, archives, museums and cultural centres (Giuliani et al., 2018, 2020).

There are numerous examples of power stations, as the As Pontes power plant in As Pontes de García Rodríguez, Spain (Jato-Espino et al., 2022) or the former ENEL power plant in Bari, Italy, whose reuse project involves the creation of an incubator for films and theatre production (Vizzarri et al., 2021), industrial steel plants as ex Italsider in Bagnoli, Italy (Nocca et al., 2024).

The former Fix Brewery in Athens, converted into the Hellenic National Museum of Contemporary Art-EMST (Vardopoulos, 2019) or the De Hoorn Brewery into an innovation and community hub (Lauro et al., 2025). Kingway Brewery in Shenzhen, China (Ding et al., 2025), mechanical production plant, as Mollificio Bresciano in San Felice, Italy (Dell'ovo et al., 2020).

- ARCHEOLOGICAL ASSETS

Although minor, the contributions also analysed cases of archaeological heritage, such as the Catacombs of San Gennaro in Naples, considered for their ability to generate social value and now constituting archaeological sites (Lauro et al., 2025).

This analysis revealed that several types of assets were considered in adaptive reuse projects. Port infrastructure, by contrast, was not yet fully exploited for this purpose, probably for a limited interest or for a ownership and regulatory frameworks that governing these contexts and complicated or discourages the application.

2.1.2. Main indicators in project assessment

The overview of the studies analysed revealed a common idea of recognising the value of embodied energy in the existing structures (Fuentes, 2017). By giving new life, adaptive reuse aims not only to revitalise the buildings but also to extend the life of heritage through minimal intervention. Furthermore, reuse projects reduce demolition waste, climate emissions and the consumption of new resources. The assets were recognised as a valuable resource for the development of sustainable strategies, balancing the preservation of the past against the needs of the future. The underlying logic was to safeguard the original structure through compatible solutions that improved its performance without distorting its distinctive characteristics. There was a clear need for public policies that promote reuse through careful design strategies capable of extending the useful life of buildings, conserving embodied energy and reducing environmental impact. Adaptive reuse, therefore, was a holistic approach within the circular economy in the built environment, contributing to the pursuit of the Sustainable Development Goals (SDGs), not only in environmental terms, but also in social and economic terms. At the same time, the repurpose of disused spaces enhanced urban quality, strengthened community cohesion and preserved collective identity and memory. The active involvement of citizens in decision-making processes and an increased perception of safety and accessibility were key indicators of social sustainability. Through the implementation of reuse projects, it was possible to activate

dynamics of territorial revitalisation, tourist attraction and new employment, generating both local and systemic added value. Profitability, however, had to be balanced against cultural and social needs, avoiding speculative dynamics.

This practice involved the conscious transformation of a building for new functions or the improvement of its capacity and performance, striking a balance between the preservation of historical and cultural value and contemporary needs (Alavi et al., 2024; Alfari et al., 2024; Munshed & Ashour, 2024; Saifi et al., 2025; Wei et al., 2024). The effectiveness and success of adaptive reuse interventions were determined by a complex interaction of multidimensional factors and criteria that transcend the mere physical-architectural dimension and involve socio-cultural, economic, environmental, energy, historical and authenticity, regulatory-legal, managerial and functional aspects. According to the conceptual framework proposed by Vafaie et al. (Vafaie et al., 2023), the review organised the main indicators into ten dimensions. For each of these, recurrent criteria/indicators were critically discussed.

- *ARCHITECTURAL*

The architectural aspect concerned the ability to accommodate new functions whilst preserving the physical and spatial qualities of the assets. Adaptive reuse is a dynamic process that takes into account, first and foremost, the architectural characteristics related to the building's ability to accommodate its new function and its spatial flexibility in order to respond to changing needs over time, as well as its future adaptability for long-term preservation without invasive interventions. Flexibility referred to the building's ability to sustain functional changes while retaining its essential character, for different physical configurations, which can include various aspects such as adaptability (Metwally et al., 2025). In order to preserve the identity of the structure over time and adapt it to new requirements, minimal and reversible interventions were preferred, using prefabricated components, modular systems or multifunctional spaces, preventing premature obsolescence (Martínez et al., 2020). This decision was intended to ensure that spatial adaptability serves as a key factor influencing the long-term sustainability and resilience of adaptive reuse projects.

At the same time, the minimum intervention criterion was widely recognized as a fundamental requirement for heritage conservation. The aim was to preserve the authenticity, physical integrity, and architectural character of the building, minimising irreversible alterations and preserving as high a percentage as possible of the original elements (Djebbour & Biara, 2019).

Meanwhile, the principle of minimal intervention was widely recognised, highlighting that an excessive alteration can compromise both the historical and cultural value and the long-term sustainability of the property. Such interventions should be in harmony with the identity of the property, while standing out when necessary, in order to preserve its character and identity and ensure the continued use (Alavi et al., 2024; Bianchi & De Medici, 2023; Djebbour & Biara, 2019; Metwally et al., 2025).

Particular attention was focused on the compatibility of materials and construction techniques, the visual harmony between historic and modern components, the preservation of architectural proportions, and the conservation of the original architectural elements and spatial layouts; In other cases, the preservation of the architectural identity and the recognisability of the cultural heritage site were considered to be ensured through distinguishable interventions (Metwally et al., 2025).

- *STRUCTURAL*

Considering the interventions on existing heritage, the structural aspects had sometimes been related to the architectural aspect; the measures to enhance and adapt the structural performance of historic buildings must simultaneously ensure their long-term functionality and safety. In this context, it was conceived as a balance between the conservation of the original construction systems and the need to assess the condition of the building and preserve its structural integrity when introducing a new function, in accordance with regulatory requirements (earthquake resistance, fire safety, accessibility), which, if not satisfied, necessarily require interventions and reinforcements (Giuliani et al., 2018; B. Mohamed & Marzouk, 2025; Morandotti et al., 2019). Once again, the term ‘flexibility’ refers to the ability of structural and construction components to adapt to future modifications without requiring extensive demolition or

irreversible interventions, by adopting solutions characterised by ease of installation and dismantling and the modularity of construction components. Where it is necessary, new structural elements must be in harmony with the original structure, without compromising its historical and cultural value. Structural integration therefore involves achieving technical compatibility, whilst preserving the legibility and authenticity of the structure (B. Mohamed & Marzouk, 2025).

- *SOCIO CULTURAL*

Preserving the identity of heritage also involves communities, re-establishing connections with history and reviving collective memory. This helps to strengthen the sense of place. Social acceptance also becomes a measure of the project's success. In this way, it is possible to genuinely improve the living conditions of the community and promote social interaction, with a knock-on effect on security and social issues. From this perspective, interventions should aim to create inclusive contexts encouraging public participation, preserving local identity and reinforcing the social significance of heritage assets for both present and future generations (Dell'ovo et al., 2020). Rather than merely pursuing conservation objectives, studies have shown that adaptive reuse initiatives intend to use heritage sites as catalysts for social regeneration, capable of strengthening the relationship with the built environment through measures designed to ensure accessibility and social attractiveness, by hosting activities that benefit diverse user groups and encouraging interaction amongst local communities (Bianchi & De Medici, 2023; Djebbour & Biara, 2019; Nocca et al., 2024) improving the quality of urban life (Bianchi & De Medici, 2023; Metwally et al., 2025) revitalising neighbourhoods and fostering community development.

Although the terminology varies in the literature, ranging from 'sense of place' and 'place identity' to 'intrinsic value' and 'collective memory', studies agree on the importance of the cultural meanings and emotional connections that bind communities to these places (Cerreta & Savino, 2020; Djebbour & Biara, 2019; Nocca et al., 2024). The enhancement of heritage value, which reflects the relationships that individuals and communities establish with historic buildings through memory, identity and shared

cultural experiences, through the introduction of new functions enables heritage assets to continue to hold significance in contemporary society (W. Li et al., 2025).

- *ECONOMICAL*

The economic aspect is fundamental to success, including the assessment of added value following redevelopment. It also includes jobs linked to the new activities planned. This aspect is linked not only to increasing the value of the asset and contributing to the economic development of the area, aiming for the so-called spillover effect (Giuliani et al., 2020; Lauro et al., 2025), but also to the project's ability to generate economic inflows linked to new activities, aiming for financial self-sufficiency (Djebbour & Biara, 2019; Lauro et al., 2025). This is reflected in the social dimension and the well-being of the community. For example, with an impact on employment determined by the new intended use (Cucco et al., 2023; Lauro et al., 2025) on the improvement of citizens' mental and physical well-being through the creation of vibrant, safe and accessible spaces (Lauro et al., 2025). This objective can be achieved by ensuring a diversity of functions, attracting a wide range of user groups, enabling year-round use, ensuring that activities complement one another economically, and ensuring that the new functions guarantee the long-term operational sustainability of the historic property (Yu et al., 2025). In this process, the role of tourism emerged as a key factor. Consideration is given to the potential to attract visitors, the promotion of cultural tourism, the diversification of tourism services, the contribution to the local economy, and the capacity of the repurposed heritage site to become a cultural landmark within wider tourism networks. If managed appropriately, adaptive reuse can enhance the cultural appeal of historic sites, stimulate local economies and contribute to urban regeneration through increased visitor numbers (Djebbour & Biara, 2019). Mixed-use solutions were also recognised as factors that enhance the continuous use of heritage assets, thereby contributing to their conservation whilst responding to changing social and market needs (Metwally et al., 2025; Vizzarri et al., 2021). The diversity of proposed functions, the compatibility between different uses, the ability to attract a wide

range of user groups, and year-round use all aim to ensure the long-term operational sustainability of the heritage asset (Vehbi et al., 2021).

In literature, collaboration between public institutions, private investors and local communities (Bianchi & De Medici, 2023; Giuliani et al., 2018) is recognised as an essential condition for successful implementation. Some studies also emphasised that effective partnerships should balance economic objectives with the public interest, ensuring that commercial investments contribute to heritage conservation and bring benefits to the community, rather than aiming solely at financial returns (Djebbour & Biara, 2019; Nocca et al., 2024). There was broad consensus that collaborative investment models enhance both the financial viability and the long-term sustainability of adaptive reuse initiatives (Metwally et al., 2025).

- ENVIRONMENTAL

Existing buildings were considered as components of wider urban systems, the successful regeneration of which depends on their integration into the surrounding environmental and spatial context (Bianchi & De Medici, 2023; Djebbour & Biara, 2019), through the integration of heritage sites into the urban fabric, the reconnection of previously inaccessible or abandoned areas, the strengthening of links between heritage and the uses of the surrounding area, as well as the contribution of adaptive reuse to broader urban regeneration processes (Cerreta & Savino, 2020; Djebbour & Biara, 2019; W. Li et al., 2025; Vizzarri et al., 2021).

Furthermore, it is necessary to ensure that architectural barriers are overcome and access is guaranteed for all users (Giuliani et al., 2020; Gravagnuolo et al., 2024; Morandotti et al., 2019). Accessibility was therefore understood not only as ensuring physical accessibility, but also the efficient connection with the surrounding transport infrastructure and urban connections (Bianchi & De Medici, 2023; Kutlu et al., 2025).

The environmental performance of heritage regeneration extends beyond the building itself to include the quality of the surrounding open spaces and their contribution to urban quality of life. Several studies also emphasised that well-designed public spaces strengthen the relationship between heritage assets and local communities,

encouraging their frequent use and enhancing the overall appeal of regenerated areas (Bianchi & De Medici, 2023; Nocca et al., 2024; Yu et al., 2025). Whilst some authors focused primarily on the ecological benefits of green infrastructure, others highlighted its complementary social and cultural functions, recognising open public spaces as essential components of successful adaptive reuse and sustainable urban regeneration (Vizzarri et al., 2021).

- *ENERGETICAL*

In all the studies examined, energy efficiency was consistently interpreted as a balance between heritage conservation and environmental sustainability, recognising that historic buildings require customised solutions capable of reducing energy demand without compromising their authenticity or architectural character.

In line with the circular economy paradigm, particular attention was paid to reducing environmental impact. Energy efficiency and decarbonisation are emerging, through the use of renewable energy sources and improved building envelope performance, as well as the recovery and reduction of demolition materials. The literature consistently recognises that historic buildings often possess passive environmental qualities that should be preserved and enhanced rather than replaced with highly invasive interventions. Adaptive reuse projects should therefore capitalise on existing climatic responses, whilst introducing compatible improvements that minimise operational energy consumption (Kutlu et al., 2025; Metwally et al., 2025). Several studies also highlighted that passive solutions should be designed improving the quality of the indoor environment and user comfort, whilst preserving the architectural identity of assets (Metwally et al., 2025) and ensuring, in all cases, that building services systems were compatible with the architectural and heritage features of the building. Added to this is the reduction in land consumption and the integration of nature-based solutions.

- *AUTHENTICITY AND HISTORICAL*

The dimension most closely linked to cultural value and conservation is the most cross-cutting dimension linked to safeguarding the identity of the building when a new function is proposed. Respect for the architectural characteristics of the building and historical features is significant, requiring that transformations that obscure its original meaning be avoided. This translates into authenticity and integrity (Djebbour & Biara, 2019), as well as intrinsic value and memory, which highlights the need to preserve the “Genius Loci” and the intangible values perceived by the local community as part of its history (Angrisano et al., 2024). Furthermore, each intervention has its own degree to which the function respects the spatial layout and historical character of the property. Intrinsic values represent the fundamental reason for preserving heritage assets regardless of their economic performance or functional transformation (Angrisano et al., 2024). The meaning of heritage was considered a multidimensional concept that should guide design decisions and the selection of new compatible uses (N. Mohamed & Alauddin, 2023). While some authors distinguish between tangible and intangible values, others adopt a more integrated perspective of values associated with the heritage asset (Dell’ovo et al., 2021; Nocca et al., 2024).

- *MANAGERIAL/ DECISION-MAKING*

The management and decision-making dimension concerns the governance processes through which adaptive reuse projects are planned, evaluated, and implemented. In the studies reviewed, effective decision-making was always interpreted as a collaborative and multidisciplinary process that integrates the knowledge and perspectives of multiple stakeholders throughout the entire project lifecycle. ensuring that the proposed transformations meet local needs, values, and expectations. Rather than being viewed as passive beneficiaries, local communities are increasingly seen as active contributors, whose knowledge and experiences can improve the quality of decisions regarding adaptive reuse and strengthen social acceptance of the projects.

Rather than relying exclusively on technical or conservation expertise, adaptive reuse was increasingly understood as a participatory process in which management practices foster consensus-building, transparency, and informed decision-making, while balancing heritage conservation with social, economic, and environmental objectives. In this process, the participation of local residents and stakeholders in decision-making, planning and design is essential in order to align the project with the real needs of the population (Dell'ovo et al., 2021; Yu et al., 2025), ensuring that the proposed transformations meet local needs, values, and expectations. Rather than being viewed as passive beneficiaries, local communities are increasingly seen as active contributors, whose knowledge and experiences can improve the quality of decisions regarding adaptive reuse and strengthen social acceptance of the projects (Nocca et al., 2024; Yu et al., 2025).

- *LEGAL*

A fundamental legal aspect concerned compliance with the legislative and regulatory frameworks governing heritage preservation and the renovation of buildings. This includes compliance with heritage protection regulations, consistency with urban planning and zoning provisions, adherence to conservation principles, compliance with building codes, compatibility with official zoning plans, and respect for legal restrictions associated with protected heritage sites (Metwally et al., 2025). Several studies also emphasize that regulatory compliance should be integrated from the earliest stages of project development in order to reduce implementation risks and ensure that conservation objectives remain compatible with new functional requirements (Vardopoulos et al., 2021).

All this must comply with urban planning, as well as the regulatory framework and building regulations, and heritage conservation policies. Compliance with plans must be valid not only with local regulations, but also with regional development strategies. Although regulatory contexts differ from country to country, the literature highlighted a broad consensus that compliance with regulations constitutes the institutional foundation upon which sustainable adaptive reuse can be successfully achieved. In this

processes Furthermore, it is essential to create partnerships between administrations, investors and the third sector to manage the asset as a “common good” (Angrisano et al., 2024; Dell’ovo et al., 2020), with stakeholder participation, coordination among government institutions, collaboration across different administrative levels, transparency in decision-making processes, the effectiveness of institutional cooperation, public engagement, and the inclusion of local communities throughout all stages of planning and implementation (Angrisano et al., 2024; Dell’ovo et al., 2020, 2021; Giuliani et al., 2018; Jato-Espino et al., 2022; Metwally et al., 2025; Yu et al., 2025).

- *FUNCTIONAL*

The functional dimension is the key aspect of this function, and its objective is to identify uses that ensure the continued use and long-term sustainability of historic buildings, while respecting their cultural significance and physical constraints. Rather than merely selecting economically viable uses, the literature emphasizes the importance of achieving compatibility between the new functions, the existing building, and the surrounding urban environment, thereby balancing conservation objectives with contemporary social and economic needs (Metwally et al., 2025).

Several studies also emphasize that effective uses contribute to broader regeneration processes, reconnecting heritage assets to everyday urban life and enhancing their relevance within contemporary cities (Vizzarri et al., 2021; Yu et al., 2025). Functional compatibility is thus interpreted as maintaining conceptual or operational continuity between past and present uses, while avoiding transformations that contradict the property’s historical value (Djebbour & Biara, 2019; N. Mohamed & Alauddin, 2023). However, other studies acknowledge that complete functional continuity is not always feasible and argue that new uses may legitimately deviate from the original ones, provided they remain respectful of the heritage values embodied by the building (Djebbour & Biara, 2019; Metwally et al., 2025). Functional compatibility is therefore interpreted as the selection of uses that adapt to the building’s intrinsic characteristics,

rather than forcing the building to conform to incompatible requirements (N. Mohamed & Alauddin, 2023; Nocca et al., 2024).

The overview of indicators outlined the main issues of interest in the practice of adaptive reuse for each dimension of success (Vafaie et al., 2023), as previously defined. These were considered independently of the asset type in order to support the development of an approach effective for a diverse system of assets.

2.1.3. Methodologies of analysis

Decision-making in the field of adaptive reuse is a cognitively complex and multidimensional process, requiring a suitable approach to choose appropriate solution among multiple alternatives while balancing multiple aspects, criteria and indicators, as previously emerged. The complexity of these decisions depends on the different criteria, as well as on the different judgements and heterogeneous nature of the available information. Sometimes, the absence of a structured methodology hindered the ability to determine the most appropriate reuse solution (Jasim & Ismaeel, 2023).

Analysis of the selected literature revealed the adoption of various analytical tools, including multi-criteria approaches, often hybrid and participatory, intended to support decision-making processes and address the complexity of heritage adaptive reuse.

Among these methodologies, multi-criteria approaches clearly predominate as a means of addressing the complexity of adaptive reuse of heritage. These methods constituted structured and multidimensional approaches suitable for decision-making problems across different areas in order to identify sustainable solutions (Giuliani et al., 2020; Jasim & Ismaeel, 2023; Maselli et al., 2024). They were preferred for their ability to manage complex decision-making problems characterised by divergent objectives and heterogeneous data, both quantitative and qualitative. No single taxonomy existed, and they were distinguished in relation to the nature of the decision-making problem, the objectives, the modelling of preferences and other similar aspects (Belton & Stewart, 2022; Figueira et al., 2005).

Among these, the *Analytic Hierarchy Process* (AHP) was adopted in numerous applications to identify the most effective new use (Bianchi & De Medici, 2023; Cucco et al., 2023; Dabouh & El Shazly, 2020; Metwally et al., 2025; Vehbi et al., 2021; Vizzarri et al., 2021). This method enabled the selection of the best solution among different proposals by weighting criteria through pairwise comparisons and ranking the alternatives hierarchically (Saaty, 1980; Saaty & Vargas, 2012). The original rating scale (1-9) proposed by Saaty remained the main reference, although in some applications it was reduced to simplify the decision-making process (Salerno, 2020). The consistency of the experts' judgements was validated through the consistency ratio (CR). It was appreciated for its flexibility and ability to integrate qualitative and quantitative parameters. AHP was often integrated with one or more techniques (B. Mohamed & Marzouk, 2025), such as Discounted Cash Flow Analysis (DCFA) (Della Spina, 2021), fuzzy analysis (Ding et al., 2025; Zhang & Zhang, 2023), TOPSIS (Jato-Espino et al., 2022) or combined previously with PESTLE analysis and SWOT analysis (Vardopoulos et al., 2021), in order to strengthen its discriminating capacity.

There were also cases in which the *Simple Additive Weighting method* (SAW) was applied, widely used for its simplicity in multiple attributes decision analysis (MADA), weighting each criterion and allowing comparative evaluations to be made (Giuliani et al., 2018, 2020; Kutlu et al., 2025).

Specifically, *TOPSIS* (Technique for Order Preference by Similarity to Ideal Solution) was another MCDA method that allowed the identification of the best alternative by ranking the alternatives according to their proximity to a positive ideal solution and their distance from a negative ideal solution, using a proximity coefficient between 0 and 1 (Gravagnuolo et al., 2024; B. Mohamed & Marzouk, 2025; Nocca et al., 2024). This approach offered the advantage of clear logic and computational simplicity, which facilitates and streamlines its application through both quantitative and qualitative criteria and indicators, although it did not include any consistency checks.

Consequently, AHP and TOPSIS, being supplementary, are often applied together rather than as alternative methods.

Fuzzy logic was used to manage uncertainty and the inherent subjectivity of judgments. This approach was not employed as a stand-alone method, but served to refine the results of deterministic multi-criteria techniques. From the preliminary stages in combination with the Delphi method, for the selection and definition of criteria, thereby reducing the number of cycles required to reach consensus (W. Li et al., 2025), to the integration of processes, such as AHP, TOPSIS or *DEMATEL* (W. Li et al., 2025; B. Mohamed & Marzouk, 2025; Vardopoulos, 2019), in order to reduce the uncertainty of more qualitative data assessments, in cases where the estimation of criteria needs to be evaluated through a confidence interval.

A single case involved the application of *H-MCDM* (Heritage Multi Criteria Decision Method) specifically conceived for the adaptive reuse of historic buildings, integrating evaluation indicators adopted from Sustainable Development Goals, UNESCO principles and ICOMOS quality standards (Maselli et al., 2024).

A different methodology was *PROMETHEE* (Preference Ranking Organisation Method for Enrichment of Evaluation), which was based on outranking procedures, allowing the aggregation of information, evaluation and classification of a set of alternatives based on partial preferences. When *PROMETHEE* was applied, it was possible to define a partial or complete ranking according to the degree to which one alternative prevailed over the others (Cerreto & Savino, 2020; Dell'ovo et al., 2020).

Another method was *NAIADE* (Novel Approach to Imprecise Assessment and Decision Environments), which stood out for its ability to deal with uncertainty and to integrate stakeholder opinions (Dell'ovo et al., 2021). It allows alternatives to be evaluated by means of a performance matrix, through which alternatives could be ranked via direct pairwise comparison.

A distinctive approach was *SOCRATES* (Social multi CRiteria Assessment of European policieS), developed by the European Commission's Joint Research Centre, designed for impact assessments, with the possibility of including quantitative, ordinal and/or linguistic data) and qualitative data, including stochastic and/or fuzzy data (Angrisano et al., 2024).

In addition to multi-criteria approaches, statistical and computational methodologies were also applied in the literature. These include *Structural Equation Modelling* (SEM), an integrated hierarchical model used to investigate causal relationships between variables and multi-path links between latent variables (complex concepts that cannot be measured directly) and observable variables (Lauro et al., 2025). This method can be combined with others to demonstrate reliability and significance (Ismaeel & Mohamed, 2023).

Simpler methods were the *Weighted Sum Model* (WSM) and *SMARTER* (Simple Multi-Attribute Rating Technique Extended), which allowed the aggregate value of multiple criteria to be calculated in a single score for each alternative, but with different levels of complexity. In particular, SMARTER was a simplified version of the SMART method (Dell'ovo et al., 2021) that allowed criteria to be weighted and alternatives to be classified with little effort on the part of the decision-maker, for example, by adopting Rank Order Distribution (ROD), reducing cognitive effort compared to direct weighting methods (Dell'ovo et al., 2021) and less realistic for very complex decisions.

Among the methodologies, *AdaptSTAR* also stood out. It was a multi-criteria tool for estimating adaptive reuse potential and long-term sustainability, combining methods such as the STAR method, from which its rating was adopted, in order to compare different scenarios (Sharifi & Farahinia, 2020).

More recently, models based on artificial intelligence, such as *neural networks* (GA-BP), were introduced. These were capable of dealing with complex scenarios and

producing predictive assessments of the assets' adaptability. They were used to quantify the subjective assessments of experts and their reliability, addressing the uncertainty caused by a lack of complete information or the inherently ambiguous nature of assessment processes (Yu et al., 2025).

Among the approaches, *SWOT* (Strengths, Weaknesses, Opportunities, Threats) analysis was used to identify strategic factors in reuse interventions. Often, defined frameworks were used to select the factors to be considered in the analysis, such as the PESTLE framework (Porkar et al., 2025; Vardopoulos et al., 2021), or for defining strategies, adopting, for example, the TOWS matrix (Ragheb, 2021). As a tool for defining a knowledge and structural basis to support complex multi-criteria decision-making processes, it was almost never used as a stand-alone tool, but often integrated into hybrid approaches to manage the complexity of adaptive reuse projects and assess the impact of criteria (Çelebi Karakök & Ertaş Beşir, 2023). In some cases, it is combined with AHP, in the so called hybrid A'WOT models, to make the qualitative factors that emerged in the previous analysis measurable and prioritised (Ragheb, 2021).

Another strand comprised *participatory approaches*, which integrated assessment processes with the direct involvement of stakeholders. This made it possible to accommodate the needs of local communities, administrations, experts and investors, thereby reducing the risk of social conflict and broadening the legitimacy of the choices.

Closely related to these approaches was *sensitivity analysis*, which was used to verify the robustness of decisions and identify the most influential criteria through variations in weights or in the assessment matrix. In this overview, some contributions did not provide specific methodologies for diagnosing and evaluating design solutions (Djebbour & Biara, 2019; Mazzetto & Vanini, 2023; N. Mohamed & Alauddin, 2023), in which different assessments were conducted, such as residual performance (PAV-

Performance Adequacy and Vulnerability or RTE- Resilience Threshold Evaluation) (Morandotti et al., 2019).

The existence of different methodologies reflected the growing awareness of adaptive reuse as a complex multidimensional decision process that could not be interpreted merely as a technical problem. Moreover, adaptive reuse projects require an evaluation approach capable of considering both quantitative and qualitative value. The analysis highlighted that the AHP was frequently applied and was often used within broader hybrid analyses, where it was combined with optimisation procedures, sustainability assessment or uncertainty modelling, since it was an approach capable of improving robustness and reducing subjectivity.

2.2. *Best practices of Adaptive Reuse of port heritage*

According to the main factors previously identified in the literature as successful in adaptive reuse processes (Chapter 2.1), examples of the reuse, regeneration and enhancement of port heritage are analysed to identify effective strategies adopted and how meta design strategies result in design solutions. To this end, the most successful experiences on Italian and European territory were critically examined systematically for each previously defined dimension (Chapte 2.1.2). Due to the typological heterogeneity of port heritage, representative asset types emerged in the analysis of evolutionary processes of port area (Chapter 1.1), such as maritime stations, recreative buildings, fortresses, customs houses, factories, warehouses, shipyards, silos and lighthouses, are selected to provide a comprehensive overview of the transformation processes and intervention approaches. For each heritage asset type, one Italian case study, one from the Mediterranean area and one located within a northern European port are selected; these projects were implemented from the late 1990s onwards, as part of the regeneration of port areas, including recent initiatives funded by regional and European grants. In this way, for each dimension, it is possible to identify how each strategy was translated into a specific design solution with the potential to support

decision-making processes relating to adaptive reuse. Thus, for the purpose, 27 projects were considered, three for each type identified, each of which is identified by a consecutive number (Pn), as follows (Figure 2):

- maritime stations:
 - MARITIME STATION in Napoli (P1) (FAI, n.d.-b)
 - LA CITÈ DE LA MER in Cherbourg (P2) (La Cité de la Mer, n.d.)
 - GARE MARITIME in Bruxelles (P3) (Awards, n.d.)
- recreative buildings:
 - CASA DEL LAVORATORE PORTUALE in Trieste (P4) (Monumenti Aperti, n.d.)
 - MAISON DU DOCKER in Marseille (P5) (Métropole AMP - PLUi de Marseille-Provence, 2025)
 - VOORUIT in Gand (P6) (Visit Gent, n.d.)
- fortresses:
 - FORTEZZA VECCHIA in Livorno (P7) (Autorità di Sistema Portuale del Mar Tirreno Settentrionale, n.d.)
 - FORT SAINT JEAN in Marseille (P8) (Office de Tourisme, n.d.)
 - FORTRESS DI AKERSHUS in Oslo (P9) (Visit Norway, n.d.-a)
- customs houses:
 - DOGANA D'AQUA in Livorno (P10) (FAI, n.d.-a)
 - CONSIGNÈ A IMAGES in Marseille (P11) (Tourisme Marseille, n.d.)
 - TOLLBODEN in Stavanger (P12) (Visit Norway, n.d.-b)
- factories:
 - HYDRODYNAMIC POWER STATION in Trieste (P13) (Trieste, n.d.)
 - SUGAR REFINERY PLACE in Rijeka (P14) (Rijeka, n.d.)
 - VAN NELLE FABRIEK in Rotterdam (P15) (UNESCO, n.d.-b)
- warehouses:
 - FORMER WINE WAREHOUSE in Trieste (P16) (Associati, n.d.)
 - LES DOCKS in Marseille (P17) (AF517, n.d.)
 - NDSM LOODS warehouse in Amsterdam (P18) (NDSM, n.d.)

- shipyards:
 - GALATA MUSEO DEL MARE in Genoa (P19) (*Galata Museo Del Mare | Genova*, n.d.)
 - DRASSANES REIALS in Barcelona (P20) (mmb Museu Marítim de Barcelona, n.d.)
 - ROTTERDAMSCHE DROOGDOK MAATSCHAPPIJ in Rotterdam (P21) (Rotterdam, n.d.)
- silos:
 - the SILOS in Bari (P22) (MDF, 2024)
 - SILO D'ARENC in Marseille (P23) (Denante, 1998)
 - SILO in Copenhagen (P24) (Malighetti, 2023)
- lighthouses:
 - LA LANTERNA in Genova (P25) (Ministero della Cultura, n.d.)
 - TORRE DEL RELLOTGE in Barcellona (P26) (Barcelona Turisme, n.d.)
 - FARO DI HOEK VAN HOULAND in Rotterdam (P27) (Rotterdam Tourist Information, n.d.)

The analysis of the selected cases provides an overview of the application of each strategy dimension in adaptive reuse processes.

MARITIME STATIONS	 P1: STAZIONE MARITTIMA in Napoli	 P2: LA CITÉ DE LA MER in Cherbourg	 P3: GARE MARITIME in Bruxelles
RECREATIVE BUILDINGS	 P4: CASA DEL LAVORATORE PORTUALE in Trieste	 P5: MAISON DU DOCKER in Marseille	 P6: VOORUIT in Gand
FORTRESSES	 P7: FORTEZZA in Livorno	 P8: FORT SAINT JEAN in Marseille	 P9: FORTRESS DI AKERSHUS in Oslo
CUSTOMS HOUSES	 P10: DOGANA D'AQUA in Livorno	 P11: CONSIGNÉ A IMAGES in Marseille	 P12: TOLLBODEN in Stavanger
FACTORIES	 P13: HYDRODYNAMIC POWER STATION in Trieste	 P14: SUGAR REFINERY PLACE in Rijeka	 P15: VAN NELLE FABRIEK in Rotterdam
WAREHOUSES	 P16: FORMER WINE WAREHOUSE in Trieste	 P17: LES DOCKS in Marseille	 P18: NDSM LOODS WAREHOUSE in Amsterdam
SHIPYARDS	 P19: GALATA MUSEO DEL MARE in Genoa	 P20: DRASSANES REIALS in Barcelona	 P21: RDM in Rotterdam
SILOS	 P22: Silos in Bari	 P23: SILO D'ARENC in Marseille	 P24: SILO in Copenhagen
LIGHTHOUSES	 P25: LA LANTERNA in Genoa	 P26: TORRE DEL RELLOTGE in Barcellona	 P27: FARO DI HOEK VAN HOLLAND in Rotterdam

Figure 2 - Best practices of Italian and European port heritage assets

Architectural dimension: The minimum intervention strategy recurs in all the projects, although it is declined with different degrees of severity. The exception concerns the silos (P23 and P24), whose functional adaptation required more substantial intervention for adaptation to the new function, while preserving the monumental perception of the original volume. Where the intervention involved the reconstruction of parts (P3, P10, P16) or the addition of volumes (P17 and P19), architectural harmony and visual compatibility are pursued through the use of compatible materials, such as glass surfaces or lightweight metal structures, without hiding the original structure. Internally, the adoption of lightweight and reversible structures (as P18) allows a reorganisation of the spatial layout. These solutions ensure spatial flexibility and adaptability to future uses, responding to current needs while preserving the potential for future transformations.

Structural dimension: As the assets examined have historical or industrial archaeology value, each intervention is subordinated to prior structural consolidation. Considering the recurring typological characteristic of large internal spaces, two strategies emerge: the space is either preserved in its integrity (P2, P15, P19 and P20) or occupied by adding internal structures to reorganise the space, often with independent and self-supporting structures without compromising the original structure (P3, P16, P18, P23 and P24). The latter solution does not modify the original volume, but occupies it by constructing an additional independent structure inside, demonstrating the capacity for reversibility and dismantling, ensuring long-term sustainability of the asset.

Socio-cultural dimension: The social aspect plays a crucial role in the design proposals for the community. The interventions pursue social integration through the creation of public spaces (P17), sometimes conceived for cultural and educational purposes (P11, P19, P20 and P21). Appropriately targeted, the refunctionalisation turns these assets into catalysts for identity and a sense of belonging (P18, P21, P23, P25, P26, P27). This aspect is particularly relevant in the case of fortifications (P7, P8 and P9): these are military structures that had lost their military function, but retain their historical

identity and symbolic value within urban contexts. Conceived to reinforce the centrality of communities, intrinsic tangible and intangible values of identity could be preserved and transmitted not only through their typological construction systems, but also through the narration of the culture of work (P4, P5, P6, P13, P14, P15) and of the maritime tradition (P19, P20, P25, P26, P27).

Economic dimension: The design choices inevitably impact the local and territorial economic system, closely related to the new function introduced. The choice of a functional mix, with a strong relation to the context, guarantees the attractiveness of a diversified target and activates local economies and private partnerships, contributing to the regeneration of the wider area. Examples include residential complexes with services (P24), educational, event and business centres realised with public-private partnership (P21), multifunctional creative and cultural spaces (P18) and museums coexisting with office and events area (P15). Moreover, the functional choices influence touristic attractiveness, particularly in cases of recognised value of the asset, such as those protected by UNESCO (P15), of artistic and cultural interest (P22) or for the value of preserved heritage (P19 and P20). Public-private partnerships emerge as a fundamental condition of feasibility, pooling resources and expertise to achieve effective results.

Environmental dimension: In a port context, the reconnection between the port area with the city is central priority issue, that can be pursued not only through new economies (P18 and P21), but also through the relocation of functions (P16, P23 and P24) and the musealisation of productive and maritime history (P13, P14, P19 and P20), supported by appropriately designed spaces (P17). This is possible by multimodal accessibility, ensuring access to these often-closed port systems, by land as well as by sea (P21) or by providing preferential routes and spaces (P17). In addition, the project of public spaces could improve environmental quality with green spaces (P15) and prove strategic for hosting events (P18).

Energy dimension: Historical and industrial buildings are intrinsically predisposed to sustainability, characterised by massive structures with extended spaces and large windows that favour direct daylight gain (P2 and P3). Therefore, their spatial configuration (P15) and technical-material characteristics are maximised in the implementation of passive design strategies, sometimes even through the design of external spaces (P3). At the same time, the recovery process offers an opportunity to activate sustainable energy and environmental regeneration processes, using renewable resources, also ensuring energy neutrality and fossil fuel freedom (P15, P16 and P24).

Authenticity and historical: The intrinsic value of these architectures lies in their capacity to transmit both tangible and intangible heritage values. This value is not limited to their typological features, such as steel and glassed structures (P10, P15, P16, P19 and P20), but extends to a function that evokes history and transmits the values of maritime practice (P19, P20 and P22) and the heritage preserved within them, which embodies layer of historical and cultural significance (P1, P2, P15, P19 and P20). At the same time, the preservation of the authenticity and integrity of the site is achieved through the legibility of its original construction systems, despite the interventions (P16, P20, P22, P23, P24). Furthermore, the recognition and valorisation of the heritage asset significance is connected to industrialisation (P2), maritime tradition (P1, P19) and innovative production processes (P13).

Legal dimension: Projects are required to be consistent with territorial planning instruments and different regulations, as well as regulatory systems for heritage protection, because they are part of complex, multi-value and multi-functional systems. It is therefore essential to involve the various stakeholders to carry out coherent planning at different levels. The reuse and regeneration purposes were possible by the adoption of special legislative and planning instruments, which allowed for the coordination of a number of public and private entities, such as the Municipality, the

Region, the State Property Office and the Port Authority, simplifying procedures and ensuring compliance with constraints and urban planning (P14, P16, P18, P21).

Managerial dimension: The implementation of these interventions requires well-defined decision-making processes, sometimes requiring continuous use during the implementation of new functions (P1). A bottom-up approach capable of redefining relational systems is strategic in ensuring that projects are able to respond adequately to the needs of the population. Community involvement through participatory processes in the definition of design proposals (as in the case of P14) and the sharing of the projects (P22) with stakeholders, such as public bodies, educational institutions and businesses (as in the case of P19 and P21), support the complex decision-making processes while maintaining a unified direction and promoting the effectiveness of intervention.

Functional dimension: In the reuse processes, function constitutes a priority. Its choice is fundamental to ensuring the adequacy, continuity and compatibility of the port heritage use with respect to the function of the area, the original use and the identitarian characteristics of the building. The function of the assets could be maintained (P1, P21, P22, P25) e integrated or changed (P2, P4, P8, P12, P14, P17, P19, P24, P27), predominantly toward cultural purpose. This will ensure integration with the contemporary functions and dynamics of the area, encouraging, with reuse processes, the cultural and economic recognition of port assets and regeneration o and regeneration of the port context, without erasing the traces of its past.

The outcome of this investigation provides a useful cognitive resource to enhance decision-making processes related to the development of adaptive reuse interventions on the port heritage asset. If systematised, the common strategies that emerged could support and orient the project development in line with successful approaches, allowing for the identification of the most effective solutions in accordance with the specific characteristics of the asset and the local context.

3. DIGITAL ASSETS MANAGEMENT

The development and adoption of digital approaches within the construction sector are of particular interest, especially as regards the preservation and valorisation of cultural heritage, in line with the strategy promoted by the European Union (European Union, 2021). The Architecture, Engineering, and Construction (AEC) sector is characterised by fragmentation of data and a lack of interoperability between tools that are, in some cases, still traditional. This condition negatively affects the decision-making processes between different, public and/or private, stakeholders, involving difficult coordination and communication and causing loss of resources (Parsamehr et al., 2023; Zhao et al., 2021).

The decision-making process is particularly complex when the objective is the preservation of historical architectural heritage due to the necessity of ensuring the integration of technical conservation requirements and functional needs, as well as guaranteeing aesthetic standards. Contemporary approaches aimed at the restoration, conservation, management and enhancement of existing built heritage involve the adoption of multidisciplinary approaches, using digital tools in cognitive processes, as well as in integrated multidimensional decision-making.

The fragmentation of historical and technical-diagnostic data has encouraged the adoption of interoperable systems capable of systematising data according to an integrated, intelligible and updatable logic. In this context, digital technologies and platforms play a pivotal role in supporting the entire life cycle of the asset, from preliminary planning to operational management (Luo et al., 2022), as recovery, regeneration and valorisation interventions, particularly by enhancing knowledge management, stakeholders' engagement and informed decision-making processes.

In the scientific context, several approaches exist for acquiring the real environment, including reality-based methods, computer-based approaches for digital modelling and simulation, and virtual reality (VR) and augmented reality (AR) environments for visualisation. The technologies currently adopted are largely established in support of

cognitive, diagnostic and decision-making processes based on principles of semantic interoperability and standardisation of information flows.

The present chapter aims to examine these technologies, illustrating their logic and operational potential with a view to digital heritage management. Recent literature highlights how these tools, if adopted in a coordinated manner, are capable of supporting the transition in the field of conservation and enhancement of built heritage towards predictive, participatory and sustainable management models.

3.1. *Reality based approaches*

In the field of digital management of built heritage, reality-based approaches represent the first level of knowledge within the digitisation process. These approaches allow the acquisition of two-dimensional and three-dimensional data directly from physical reality through non-invasive digital surveying techniques. These methodologies enable the reconstruction of artefacts with a high degree of accuracy, including their geometry, material characteristics and, in many cases, their state of conservation. This is achieved without direct contact with the object under investigation, thereby preserving its material integrity. In this sense, they constitute the information base on which subsequent modelling, analysis and management processes developed in computer-based environments are integrated, particularly in Scan-to-BIM workflows and HBIM models, as well as virtual and augmented reality environments.

Reality-based approaches, which mainly include photogrammetry (terrestrial and UAV-based) and laser scanning (LiDAR), have brought about a significant change in the documentation practices of built heritage, contributing to the transition from traditional surveying systems to complex digital systems capable of supporting representation, diagnosis and decision-making processes. The existing literature generally distinguishes between two main families of techniques: range-based techniques, based on the use of active sensors such as laser scanning, and image-based techniques, based on passive sensors, including close-range photogrammetry. The main difference between these approaches concerns the principle used to determine the three-

dimensional position of points (Luhmann et al., 2007). Laser scanning is a process which reconstructs geometry by measuring distance based on the return time of laser pulses or electromagnetic signals. This process generates extremely dense and metrically reliable point clouds. Photogrammetry, conversely, derives the shape, size and spatial position of objects by analysing photographic images acquired from different viewpoints (Alonso et al., 2012).

Among these methodologies, photogrammetry has assumed a particularly significant role, due to its versatility, relatively low costs and ability to provide both metric information and high-resolution colourimetric data, which is useful for analysing materials and surface degradation. The process is based on the principle of central projection, according to which each point in the object space is projected onto the image plane through a ray that passes through the centre of capture. Spatial reconstruction is achieved through the intersection of the projecting rays of the acquisitions made, thereby enabling the position of the point to be defined according to the principle of photogrammetric triangulation. This process is formalised through collinearity equations, which describe the geometric relationship between the object point, the centre of capture and the image point, integrating internal and external orientation parameters of the camera (Stylianidis et al., 2022). Data processing is currently carried out using Structure from Motion (SfM) and Dense Multi-View Reconstruction (DMVR) algorithms. The employment of artificial vision techniques, such as the SIFT (Scale-Invariant Feature Transform) algorithm, facilitates the identification and comparison of homologous points between disparate images. This process enables the reconstruction of geometric relationships between photographs and the generation of an initial sparse point cloud. Subsequently, densification algorithms are employed to generate dense point clouds, composed of millions of three-dimensional points with spatial coordinates and radiometric values (Danesh & Rajabi, 2022). Consequently, it is possible to produce various digital outputs, including polygonal meshes, high-resolution textures and orthomosaics, which constitute an accurate and photorealistic three-dimensional representation of the asset.

Terrestrial laser scanning, in addition to photogrammetry, is distinguished by its ability to rapidly generate dense and precise point clouds, which are especially advantageous in the documentation of complex geometries and detection of deformations or geometric discontinuities. For these reasons, the integration of range-based and image-based techniques is one of the most effective strategies for the digital documentation of heritage, as it combines the high metric accuracy of laser scanning with the radiometric richness of photogrammetry (Alshawabkeh & Baik, 2023; Fawzy, 2019). In addition to geometric documentation, three-dimensional models and high-resolution orthoimages generated by these techniques provide a fundamental basis for mapping degradation and analysing surface pathologies. Compared to traditional visual inspections, which are often time-consuming, expensive and constrained by the physical accessibility of the asset, digital models allow detailed analyses to be carried out remotely (De Fino et al., 2023; El Masri & Rakha, 2020). The latest research is exploring the use of image processing techniques and machine learning algorithms for the automatic identification of degradation phenomena, such as cracking patterns or physical-mechanical and surface alterations, reducing dependence on the subjective interpretation of the operator (Caciora et al., 2024; Teruggi et al., 2020).

Another field of application concerns the structural assessment and monitoring of historic buildings. The availability of high-precision three-dimensional data allows for the comparison of point clouds acquired at different times, thereby enabling multi-temporal analysis of structural deformations and movements. By comparing successive models or the surveyed model with ideal geometric shapes, it is possible to identify out-of-plumb conditions, progressive deformations and variations in crack patterns that are not easily detectable (Casula et al., 2023; Kong & Hucks, 2023). Furthermore, reality-based data can be utilised as a geometric basis for the construction of structural simulation models, such as finite element (FEM) models or discrete element (DEM) models (Guarnieri et al., 2013). These models are advantageous for analysing the structural behaviour of buildings and assessing seismic vulnerability, particularly in post-disaster contexts where the use of drones facilitates rapid surveys, thereby reducing risks for operators (Xing et al., 2025).

The integration of reality-based data and non-destructive testing (NDT) is also of particular importance, as it allows the development of data fusion approaches capable of combining information from different sensors, such as thermographic images (TIR), ground-penetrating radar (GPR) data or ultrasonic velocity maps, facilitating the correlation of visible alterations with degradation phenomena (De Fino et al., 2023; El Masri & Rakha, 2020).

Reality-based data also provides the starting point for the construction of advanced information systems dedicated to asset management. The transformation of point clouds and three-dimensional models into intelligent parametric objects allows for their integration into HBIM, GIS or virtual tour platforms, thereby enabling remote data consultation and analysis (Saricaoglu & Saygi, 2022).

Reality-based approaches offer numerous advantages for decision-making processes related to heritage conservation. The flexibility and scalability of these techniques allow for adaptation to different levels of analysis, ranging from architectural details to entire monumental complexes (Caciora et al., 2024). The utilisation of drones and remote sensors contributes to a reduction in costs and risks associated with preliminary inspections, thereby minimising the exposure of operators in hazardous environments. Concurrently, photorealistic three-dimensional models emerge as effective instruments for communicating diagnostic outcomes to non-expert stakeholders, thereby facilitating comprehension of conservation issues and intervention strategies.

3.2. *Computer based approaches*

In the process of digitising the management of historic built heritage, Building Information Modelling (BIM) assumes a fundamental role, from the design and implementation of interventions to the monitoring of built heritage. BIM is an approach that transcends the mere representation of three-dimensional objects to become an integrated information system (Becerik-Gerber et al., 2012; Sacks et al., 2018). The elements that constitute the model are not merely geometric entities, but rather parametric objects that integrate heterogeneous information, including material and construction, thermo-hygrometric, economic, and maintenance data. This wealth of information represents a significant advantage for the construction process, overcoming the limitations of traditional methodologies characterised by fragmentation and loss of information, and promoting a collaborative, interdisciplinary and interoperable approach between different stakeholders and operating software through the adoption of an open, standardised system (Bruno et al., 2018; Penjor et al., 2024). In this scenario, the Historic Building Information Modelling (HBIM) approach is widely adopted, representing the transposition of parametric, three-dimensional information models to existing historical built heritage. HBIM is not limited to the geometric reproduction of assets but also enables the structuring of an information model capable of integrating historical and documentary data, morphological and typological characteristics, material and construction information, diagnostic data, pathological phenomena, and content relating to the conservation and maintenance of structures. This multi-level nature of the model allows each element to be associated with updatable, queryable information according to an interoperable logic based on open standards.

An important role in creating HBIM models is provided by the Scan-to-BIM methodology, where the acquisition of accurate geometric and dimensional data is a preliminary step for the creation of BIM models relating to existing heritage. In this context, terrestrial laser scanning (TLS) and digital photogrammetry technologies have reached a high level of maturity, enabling rapid, systematic and highly accurate surveys. These techniques provide point clouds representing an essential knowledge

base in traditional documentation processes and Scan-to-BIM workflows. They support the digital representation of assets (Ferreyra et al., 2024; Redweik et al., 2020), improving knowledge of their geometric and material characteristics and facilitating investigations into the current state of conservation (Jalón et al., 2021; Taileb et al., 2023), maintenance interventions (Ermenyi et al., 2020) and cultural heritage performance analysis (Yuliana et al., 2024). However, the transition from point cloud to semantically enriched BIM model remains a complex process requiring specialist skills and established workflows. The process of transforming the collected data into parametric objects involves segmentation, interpretation, modelling, and semantic attribute operations, which are particularly challenging in the context of historical heritage due to the geometric irregularity, material stratification and typological variability of the elements.

In this context, Artificial Intelligence (AI) is emerging as a promising area of research for the automation of certain stages of the process. In particular, machine learning and deep learning algorithms are employed for the automatic semantic segmentation of point clouds, recognition of architectural elements (Croce et al., 2021; Franzini et al., 2023), comparison of acquisitions made at different times (Gawronek & Noszczyk, 2023; J. Liu et al., 2023), and supporting HBIM parametric modelling (Kyriakaki-Grammatikaki et al., 2022; Yang et al., 2023). Furthermore, some studies highlight the potential of deep learning for semi-automatic or automatic generation of BIM components from 3D point clouds (Tang et al., 2022). These approaches help to reduce manual effort and increase process efficiency, although they are still being developed, especially in the complex contexts of historical and industrial heritage.

The application of AI-based algorithms to point clouds can also support the analysis of the state of conservation of cultural heritage. Machine learning techniques can recognise pathologies and degradation phenomena automatically (Raimundo et al., 2024; Rodrigues et al., 2022), thus facilitating data interpretation and making information accessible to both experts and non-specialist users (Pan et al., 2024).

In this perspective, the BIM model functions not only as a data container, but also as a cognitive environment capable of organising, visualising and returning information that

is useful for decision-making processes. The structured storage of information within a BIM model facilitates not only the digital documentation of the asset, but also the conservation (Basu et al., 2023; Giuliani et al., 2024), maintenance (Ciuffreda et al., 2024) and operational management of cultural heritage (Godinho et al., 2020).

The integration of historical documentation, archival and technical data, material characteristics and construction techniques, as well as diagnostic, energy and monitoring information (Galiano-Garrigós et al., 2024) into the model makes it possible to improve the quality of inspections (Piaia et al., 2021), accelerate the identification of critical issues, support the estimation of intervention costs (Tahoon et al., 2024) and guide more informed conservation scenarios (Khan et al., 2022; Martinelli et al., 2025). In particular, the increasing accuracy of semantic models facilitates enhanced effectiveness of analyses and interventions through optimised integration of data collected during the pre-diagnosis, diagnosis and monitoring phases, thereby promoting multidisciplinary and collaborative approaches (Penjor et al., 2024).

From this perspective, HBIM is increasingly being adopted as a tool to support assessment and decision-making systems in conservation contexts. A wide range of experiences demonstrates its use as a knowledge and management platform capable of integrating digital surveys, textured meshes, thermographic data, material stratigraphy and diagnostic information, up to the simulation of intervention scenarios. In some cases, the integration of laser scanner data, automatic classification algorithms and FEM models allows the information model to be connected with structural analyses and vulnerability assessments (Chen, 2025). Concurrently, the existing literature highlights critical issues in the coding of information attributes and the shared definition of historical libraries, emphasising the necessity to formalise metadata and ontologies specific to heritage (Lovell et al., 2023).

At an operational level, HBIM contributes to decision-making processes by enabling the integration of multidisciplinary data within a dynamic digital ecosystem. This is useful for assessing the state of conservation, defining priorities for intervention and comparing design alternatives. The integration of quantitative tools serves to further strengthen BIM's capacity as a decision support system. The existing literature

highlights approaches based on synthetic indicators of the state of conservation and data fusion methods, which are useful for combining information from inspections, sensors and historical sources and reducing interpretative uncertainty (Y. Liu & Zhang, 2025). In order to achieve this objective, the model has the capacity to incorporate multi-criteria analysis methodologies, such as AHP and TOPSIS, semantic modules and logical inference algorithms, supporting the definition of conservation priorities and the comparative evaluation of intervention scenarios (Vizzarri et al., 2021). These tools enable the establishment of urgency levels, thereby distinguishing between elements that necessitate immediate intervention or continuous monitoring. To this end, the possibility of visually representing the level of criticality through colour-coding systems makes it easy to identify vulnerabilities and facilitates the construction of risk maps to support heritage managers (Y. Liu & Zhang, 2025).

In addition to the evaluation of the condition of assets, BIM approach can also support performance assessments in the field of energy retrofitting. In this context, the integration of accurate data on material degradation, residual performance and the thermo-physical characteristics of building elements allows for the development of more reliable energy simulations, improving the assessment of redevelopment interventions. From this perspective, BIM can be regarded as a tool for integrating sustainability and energy efficiency into decision-making processes, allowing different design alternatives to be compared on the basis of performance parameters, life cycle analysis and cost-benefit assessments (Liedes et al., 2025; Souza et al., 2025). Furthermore, during the management phase, integration with IoT sensors and real-time monitoring systems supports predictive maintenance strategies and allows for the evaluation of the cost-effectiveness of routine maintenance, redevelopment, and energy retrofitting (Mazzoli et al., 2021; Wu & Maalek, 2023).

Another area of application concerns dynamic simulation and emergency management. The integration of BIM models and specialised software facilitates the quantitative analysis of risk scenarios, including fires and evacuations, thereby enabling a comprehensive assessment of safety conditions and the efficacy of implemented strategies. In this context, the combined use of Building Information Modelling and

Artificial Intelligence has the potential to contribute to the prediction of evacuation times and the stratification of risk levels, thereby offering advanced support for real-time decision-making (Liao et al., 2026; F. Wang et al., 2025). In this manner, BIM can be regarded as a supportive element within the decision-making system, offering a collaborative and predictive platform capable of facilitating the integrated management of historical heritage in both ordinary and extraordinary conditions.

Computer-based approaches, and BIM/HBIM in particular, show significant potential in the field of built heritage conservation, thanks to their ability to integrate heterogeneous data, support multidisciplinary analysis and guide decision-making processes. However, several critical issues persist, mainly related to the complexity of the transition from survey to information model, the limited standardisation of attributes for historical heritage, and the need to consolidate interoperable and replicable workflows. It is precisely these critical issues that offer the most promising prospects for development, especially in relation to the integration of HBIM, evaluative analysis, and complementary digital tools.

3.3. *Virtual and augmented environments*

The integration of advanced digital technologies into heritage documentation, management and communication practices represents a significant advancement over traditional consolidated approaches. The progressive evolution from devices primarily conceived for simple visualisation to comprehensive operational platforms has progressively extended their capabilities, enabling effective knowledge management and encouraging their use in the decision-making and enhancement of heritage assets throughout their entire life cycle.

In this sense, Virtual Reality (VR) and Augmented Reality (AR) serve as advanced interfaces between the geometric modelling enriched with semantic data and its utilisation by users with different levels of expertise. These environments allow users to explore high-resolution BIM models, consult historical documentation, query informative hotspots, simulate intervention scenarios and display multimedia content in an immersive and interactive form. This results in an improved ability to access, understand and share cognitive system, particularly relevant in the context of cultural heritage, where the complexity of the asset requires tools capable of connecting geometric, semantic, historical and management data. Despite their recognised potential, the transition from specific applications to interoperable systems remains a challenging issue.

One of the main areas of application concerns support for decision-making processes and asset management. In this context, VR and AR tools empower decision-makers to make more informed decisions through Digital Twins, a dynamic digital replica of the asset. In particular, the integration of HBIM models and immersive environments facilitates the consultation of technical data, information from monitoring campaigns and previous maintenance interventions, thereby supporting long-term sustainable decision-making processes (Kong et al., 2025; Savini et al., 2025). As a paradigmatic application for heritage conservation, the VERBUM platform exemplifies the potential of immersive environments. An integrated Digital Twin environment centred on Virtual Technical Tours was created from georeferenced spherical images and integrated with multidisciplinary content accessible via web services for collaborative use in

synchronous or asynchronous immersive mode. The platform's modular structure comprises three distinct levels: on-site editing (surveying), desk editing (content organisation), and multimodal fruition (via web browser or VR headsets) (De Fino et al., 2020).

The contribution of immersive environments realised with high-resolution three-dimensional models also concerns the planning of conservation interventions. In this case, the applications aim to overcome the interoperability limitations between HBIM and GIS in multiscale data management. The experience of Ramos Sánchez et al. (2022) (Ramos Sánchez et al., 2022), for example, demonstrates the potential of the virtual environment to facilitate the monitoring of structures over time and the planning of interventions, thereby assisting stakeholders in making more informed decisions.

The analysis of flows and safety management constitutes a related dimension of this field. Indoor maps based on OpenStreetMap could be integrated into VR environments to support resource planning, emergency management and safety within cultural buildings (Gaspari et al., 2025), thus guiding operational decisions. Furthermore, the use of AR to visualise BIM models can facilitate the comprehension of emergency evacuation routes (Kuo et al., 2023). These applications exemplify the potential of augmented reality to address specific operational requirements, particularly for dissemination and training, with direct implications for user safety and awareness.

A second established field of research concerns structural inspection and the assessment of conservation status in a virtual environment. For the inspection of civil infrastructure, VR platforms provide a safer, more accessible and economical alternative to on-site surveys. Three-dimensional models derived from UAV photogrammetry enable the identification, quantification and monitoring of deterioration phenomena, such as cracks, corrosion or deformations, within a controlled virtual environment (Kong et al., 2025). Critically, however, in these applications, the reliability of such assessments mainly depends on the visual fidelity of the model: maintenance decisions derived from virtual inspection are only as valid as the accuracy with which the model reflects the actual real conditions of the asset. Consequently, this dependency has prompted the development of frameworks for the quantitative

assessment of visual fidelity, thereby ensuring the integrity of the decision-making process (Kong et al., 2025). The emerging integration of Artificial Intelligence further extends its capacity, enabling the automatic identification and classification of damage directly within the immersive environment (Mishra & Lourenço, 2024).

Immersive technologies are also particularly relevant to the management of vulnerable or physically inaccessible sites. Web-based VR platforms allow, for example, the exploration of monumental environments or interior spaces that are not accessible to the public for reasons of safety, conservation or logistics, thus expanding the physical and cultural accessibility of heritage (Paradkar et al., 2025; Savini et al., 2025). Similarly, in hypogeal or poorly illuminated heritage sites, real-time image processing technologies integrated into VR headsets compensate for unfavourable environmental conditions and reveal chromatic and structural details that would otherwise be imperceptible (Olbrycht et al., 2025). The literature highlights the potential of digital technologies for enabling the visualisation of inaccessible areas, while also revealing their evolution over time (Ramos Sánchez et al., 2022; Scianna et al., 2020). VR and AR applications could extend the temporal dimension, allowing not only the current state of the asset to be represented, but also its historical evolution. Through space-time navigation in a virtual environment, it is possible to segment the construction history of a building into discrete phases, allowing the observation of structural additions, transformations or removals (Fiorillo & Bolognesi, 2023; Roggio et al., 2025). In this way, immersive representation serves not only an informative function, but also becomes a dynamic data repository for the critical reading of permanence and transformation, useful for planning future conservation interventions (Klapa et al., 2025; G. Lin et al., 2024). The combination of advanced surveying techniques, information modelling and virtual and immersive tools has progressively extended the role of digital models, transforming them into environments capable of recreating the complexity of such contexts (Barrile & Genovese, 2024; Ramos Sánchez et al., 2022). Therefore, VR and AR digital environments are no longer conceived solely for dissemination, but rather as integrated informative environments capable of supporting complex decision-making processes. In particular, the literature reveals that virtual tours were designed

for diagnostics, monitoring and safety training purposes, as well as for digitalisation and dissemination projects aimed at recovering and preserving heritage (De Fino et al., 2022; Giuffrida et al., 2021).

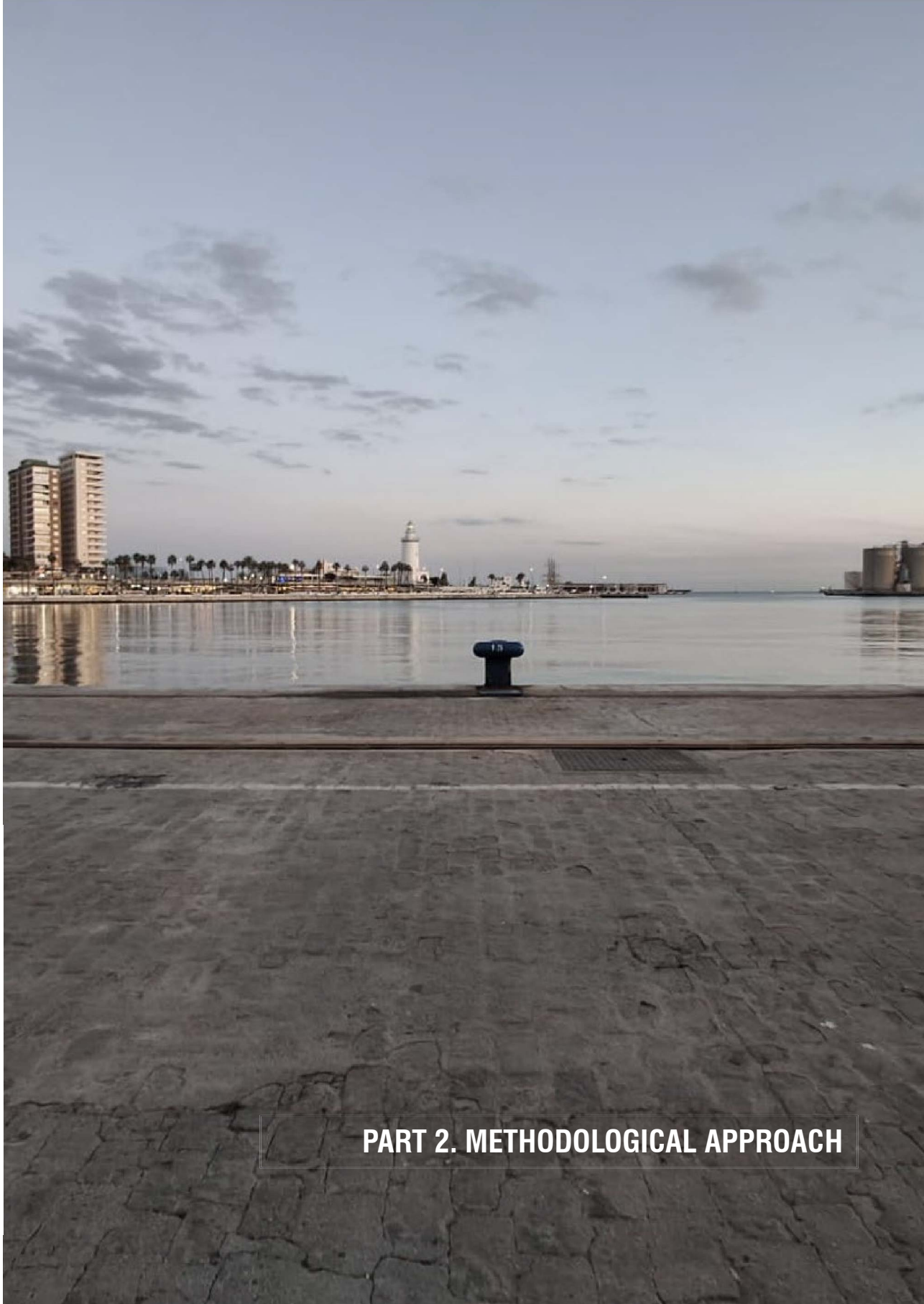
Another field of application concerns the use of AR in the construction site monitoring and quality control phases. In such cases, most experiences do not involve direct visualisation of the point cloud in an AR environment. Instead, a scan-to-BIM approach is adopted, whereby the point cloud is utilised to support modelling, and subsequently, the BIM model is visualised and superimposed on the real context.

This approach facilitates the real-time comparison of the "as-designed" model with the "as-built" status, thereby enabling site managers to monitor the progress of the work directly in the field (Z. Lin et al., 2019). Other studies have proposed innovative on-site visualisation methods, utilising scans of the site and feedback systems that enable workers to verify the observations of the inspector responsible for control (Ali et al., 2020). In the context of the operational management of built environment, a further area of investigation concern relates to the monitoring of safety measures. The use of UAVs to facilitate continuous inspection of the construction site enables the as-built BIM model to be updated with the planned safety measures. In the AR environment, workers can thus access information on the location of protective equipment during the various construction phases (Johansen et al., 2021).

In addition to technical and managerial applications, the literature highlights the effectiveness of VR in improving historical understanding and user satisfaction, contributing to the enhancement and protection of sites (Zhang et al. 2025), including through the involvement of non-expert users for educational purposes. The integration of cultural content into applications created for technical purposes demonstrates the potential for these tools to be utilised by different audiences, thereby promoting wider accessibility to heritage knowledge (Barrile & Genovese, 2024; Ramos Sánchez et al., 2022; Scianna et al., 2020). Several applications have been developed to enhance engagement and collaboration between relevant parties. With respect to tourism and cultural applications, an interactive application based on a 3D model derived from point clouds has been proposed, allowing user interaction and the uploading of photographs,

historical documents and information on previous restorations (Baik, 2021). Another AR application aimed at promoting knowledge and enhancing the territory offers a participatory environment in which users can add new contributions or access to point clouds and meshes via external links (Luigini et al., 2019). The implementation of such systems on portable devices, including smartphones and tablets, ensures accessibility for both professionals involved in heritage documentation and conservation, as well as the general public interested in cultural tourism (Barazzetti et al., 2015). Furthermore, the use of VR and AR in educational contexts can improve understanding of practical aspects in disciplines such as architecture, construction and engineering (Min, 2018). It is evident that VR and AR act as a bridge between technical data derived from BIM/HBIM, surveying, monitoring and historical documentation and the dimension of human interaction, transforming static data into dynamic, immersive and collaborative decision-making environments. As demonstrated in literature, these tools now play a cross-cutting role, extending from conservation to asset management, from inspection to cultural enhancement, from security to participation. In this sense, virtual and augmented environments are not only visualisation support technologies, but increasingly central components of integrated built heritage management processes. Nevertheless, a recurring limitation emerges, concerning the development of application frequently addressed a specific objective without a systemic view of the broader decision-making process, as well as the limited integration of data, interoperability between digital environments and scalable infrastructure.

When associated with external databases and information systems, these tools can contribute to a more detailed reconstruction of the built environment and its historical, architectural and functional complexity.



PART 2. METHODOLOGICAL APPROACH

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4. METHOD AND TOOLS

The process of knowledge, management and enhancement of port areas and their heritage is intrinsically complex. It involves different disciplines and unfolds across multiple scales of investigation, from the territorial scale down to the individual asset level, requiring the coordinated involvement of different stakeholders. Currently, critical issues emerge as a consequence of the fragmented character of both the operational processes and the knowledge system related to this context. To achieve an integrated view of the intrinsic and extrinsic aspects of a complex and dynamic context, such as the port environment, a structured, organic and shared methodological approach is required in order to support the definition of strategies for recovery, reuse and regeneration.

In this scenario, the definition of a cognitive framework constitutes an essential preliminary phase aimed at identifying the investigative context and collecting and systematising data related to port areas and their heritage assets. To this end, the structuring and adoption of a cataloguing system enables the census and cataloguing of port sites with their heritage, as well as an in-depth cataloguing of port assets, conducted through the survey of its historical, material, constructional, conservation and functional characteristics. Starting from this cognitive foundation, the investigation of the state of use, disuse and reuse of assets, in conjunction with the systematic assessment of their state of conservation, allows for clustering aimed at qualifying port heritage and defining recurring typologies so as to orient recovery and redevelopment strategies.

Based on previous experiences of reuse and enhancement of international port heritage, a multidimensional atlas of meta-design strategies is developed, structured around 10

success factors in Adaptive Reuse and related specific indicators, to orient the definition of design solutions. The Adaptive Reuse design solutions identified cluster-oriented are evaluated adopting a multi-criteria decision-making methodology, such as the Analytic Hierarchy Process (AHP).

The entire process is synthesised through the development of an innovative integrated digital ecosystem, within which the cognitive system is organised as a structured, dynamic and shared database and made consultable in a virtual environment via a reality-based and BIM models. Moreover, the adoption of virtual and augmented reality tools allow for the management of information complexity and support multidimensional, multiscale and multilevel decision-making processes. These tools thereby facilitate the sustainable management and enhancement of heritage assets through collaborative operational processes.

4.1. *General methodological workflow*

In line with the approaches and emerging potential identified in the literature, the methodological approach outlined (Figure 3) addresses the aforementioned issues for the recovery, reuse and enhancement of port built heritage. To this end, the proposed workflow encompasses the development of methods and the adoption of tools capable of improving and systematising the knowledge system relating to port heritage. This includes the rapid assessment of its state of conservation and use for defining strategies for the conservation, reuse and enhancement of the heritage in an integrated way through multi-criteria logics and supporting collaborative decision-making processes by means of digital tools.

Specifically, the proposed methodology (Annex 2) is articulated into the following macro-phases:

- Ph. 1. cognitive framework for systematising knowledge of port areas and their heritage, through the adoption of a cataloguing card for rapid census and cataloguing, structured on the consolidate experiences in literature (chapter 1) and aimed at assessing their condition and subsequently defining port heritage clusters representative of the state of conservation and use;

- Ph. 2 analysis and definition of design strategies for adaptive reuse of port heritage, through the adoption of an atlas of meta-design strategies and a multi-criteria approach to evaluate their effectiveness, identified from approaches and tools for adaptive reuse emerging in the literature, as well as best practices of port heritage (chapter 2);
- Ph. 3 digital ecosystem for knowledge and design solutions management, conceived as an integrated digital environment to raise the awareness of the port environment complexity and support decision-making processes for the management and design of interventions, by means of virtual environment within which heterogeneous data and digital models converge in a virtual and augmented environment, by exploiting the potential of the approaches for asset management highlighted in previous studies in the literature (chapter 3).

The proposed methodological approach is subsequently validated through its application to Italian port contexts managed by the Port System Authority and to one port asset case study.

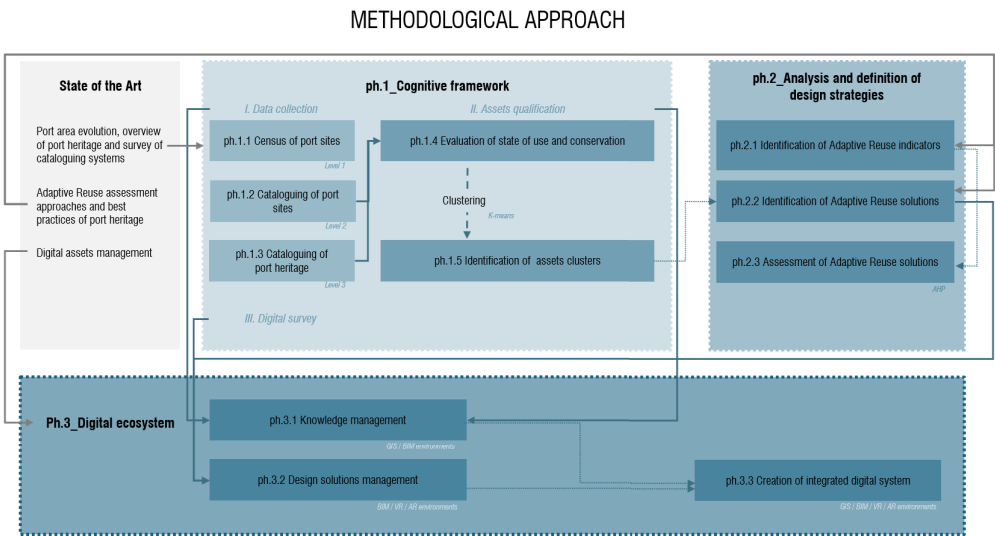


Figure 3 - Methodological approach

4.2. *Ph. 1 Cognitive framework of the port area*

The first phase of the proposed methodological approach involves the definition of an integrated framework to understand and characterise port built environments.

To this end, the cognitive process is structured into two macro-subphases (Figure 4): the first concerns data collection (I) and the second the assets qualification (II).

Regarding the first subphase (I), the data collection process is articulated into three levels for the cataloguing and census of port areas and their heritage, characterised by a scalar progression of investigation. The proposed methodology is supported by a cataloguing card structured for the rapid, homogeneous and systematic census of the port built environment, in line with consolidated experience in the literature and specifically conceived to achieve the research objectives.

The investigation begins with a preliminary survey of the port built environment and progresses toward a detailed characterisation of the assets. Specifically:

- Level I: expeditive census of the port site, collecting general information such as name, location, ownership and management, current use and state of use;
- Level II: expeditive cataloguing of the port site, describing its historical, architectural and conservation aspects, including a census of assets present in the area;
- Level III: in-depth cataloguing of the port assets, including historical and construction information, as well as detailed information concerning their state of use and conservation.

Multiple sources can be consulted for data collection, including urban and territorial plans, regional geoportals, GIS maps with both open and proprietary data management (regional and national), web mapping platforms (Google Maps and Google Earth) and cultural heritage cataloguing databases (ICCD cards, Vincoli in Rete).

The heterogeneous condition of port assets further requires the development of a methodology capable of providing an asset qualification (II) with a systematic and structured overview of their current state and the assessment of functional compatibility level expressed through three specific qualitative indicators, evaluated with respect to the contemporary context and the original functional and architectural characteristics.

Data-driven interpretative models may be used to analyse the physical, functional and contextual characteristics of the built environment. In this regard, the adoption of unsupervised learning techniques, particularly the k-means clustering algorithm, responds to this methodological requirement, enabling the identification of recurrent patterns within complex and multivariate datasets. The theoretical assumption is based on typological characteristics, as well as state of conservation, use condition and functional compatibility, in order to delineate homogeneous groups through an inductive classification approach. This method holds potential to be applied in vulnerability assessment of heritage, coherently with the requirement recovery, conservation and enhancement, and in the broader planning, management and regeneration of the built environment, as port areas. Therefore, the proposed methodology aims to provide a semantic mapping of the built environment, useful not only to comprehend its current conditions, but also as a basis for defining differentiated and targeted operational strategies, in line with the principles of sustainability, adaptability and resilience of the context with its current peculiarities.

In this framework, the outputs addressing the research questions consist firstly of a systematic cataloguing card, suitably structured for rapid census and cataloguing. Unlike the existing cataloguing systems, it provides a comprehensive multi-level overview from the port area to the detailed level for each asset. Furthermore, a clustering of port assets, applying the consolidated unsupervised k-means method, is conducted considering, in this case, conservative and functional characteristics of the port asset, in order to subsequently orient adaptive reuse interventions. Moreover, these outputs constitute the cognitive framework underlying the unified structured methodological approach.

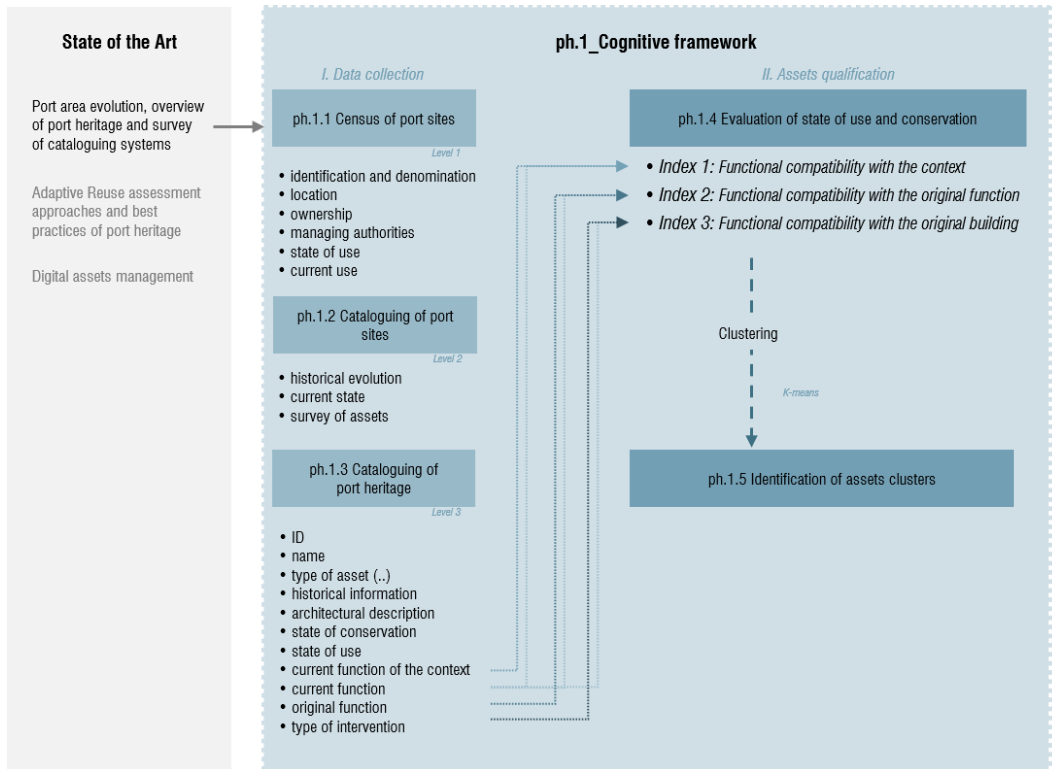


Figure 4 - Cognitive framework workflow

4.2.1. Ph. 1.1 Census of port sites

The initial phase of the cognitive process begins with the identification and qualification of the investigation context. To carry out a comprehensive analysis of the port built environment, the first part of the cataloguing card is structured on the basis of previous experiences in literature. Specifically, Level I allows an expeditious general overview of the port areas, defining their relationship with the territory and identifying the functions hosted within. It includes general information, such as:

- identification code, defined for the purpose to ensure the unequivocal identification of the port area, as in any cataloguing system (de Graauw, 2022b; Delaney, 2020; Hein et al., 2023; Martino et al., 2017; Ministero delle Infrastrutture e dei trasporti, n.d.; UNESCO & World Heritage Centre, 2008). The code is formatted as APX.y: two letters (AP) refer to the port area, followed by a number assigned to the

reference AdSP (X) and a second number associated with the specific port (y) (Cassano et al., 2024; Russo et al., 2026);

- name of the compiler and reviewer, including date of compiling (Russo et al., 2026);
- denomination, as commonly identified (Cassano et al., 2024; Russo et al., 2026);
- location, namely locality and geolocation, via spatial coordinates (Cassano et al., 2024; Russo et al., 2026);
- ownership and managing authorities;
- urban position (urban/ periurban/ suburban) (Cassano et al., 2024; Russo et al., 2026);
- state of use (in use/ partially in use/ not in use) (Cassano et al., 2024; Russo et al., 2026);
- current use in accordance with specific port documents (Cassano et al., 2024; Russo et al., 2026). Following Article 4 of Legislative Decree 84/1994 for port areas managed by the AdSP, the following functions are considered: commercial and logistics/ industrial and oil-handling/ passenger service/ fishing and/or tourism and leisure. In addition to these, other types of functions, such as shipbuilding functions, could be freely specified.

4.2.2. Ph.1.2 Cataloguing of port sites

For a more detailed survey, Level II of the cataloguing card allows for the collection of detailed historical and current information about the port area, as well as a census of assets present within it, supported by documentary, archival and photographic sources. It comprises:

- historical information, outlining the evolutionary process, with a specific focus on the original historical core of the port, including the main chronological references that characterised the evolutionary process (as first attestation, expansion, modification and so on) and a brief historical description, accompanied by historical technical iconography, images and other main documents (Cassano et al., 2024; Russo et al., 2026);

- available cartographic resources, necessary for the spatial framing and identification of the port area boundaries defined by each PRP, i.e. the port masterplan (Cassano et al., 2024; Russo et al., 2026);
- list of assets present on the site, each coded through a progressive number, accompanied by a map of the site indicating the location of each one (Cassano et al., 2024; Russo et al., 2026).

4.2.3. Ph.1.3 Cataloguing of port heritage

Level III of the cataloguing card is structured to provide an in-depth description and documentation of the port heritage assets. The survey focuses on the systematic collection of detailed information for each previously identified port asset, allowing for the most exhaustive documentation possible of the historical, architectural and industrial assets present in the areas. Historical investigation and architectural and conservation description are supported by documentary, archival and photographic sources. In particular, the cataloguing of port heritage involves the collection of the following data:

- asset identification code (ID), previously assigned (Cassano et al., 2024; Russo et al., 2026);
- name, for a unique identification of the asset (Cassano et al., 2024; Russo et al., 2026);
- ownership and managing entities (Russo et al., 2026);
- type of assets, classified according to six distinct types, in line with classifications defined by MiC, as follow (Cassano et al., 2024):
 - TYPE I Architecture - modern buildings (public/private buildings, houses of worship, mansions built after the '900);
 - TYPE II Architecture - historic buildings (public/private buildings, houses of worship, mansions built before '900);
 - TYPE III Architecture - industrial heritage (such as industrial plants, warehouses, sheds, mills, silos, arsenals);

- TYPE IV Architecture - port infrastructure (lighthouses, towers, piers, docks, dams);
- TYPE V Archaeological assets (assets having archaeological value);
- TYPE VI Works/objects of art (such as fountains and monuments).
- current state of use (in use/partially in use/not in use)
- current function of the context, according to the definition of the functional areas previously identified (commercial and logistics/ industrial and oil-handling / passenger service/ fishing and/or tourism and leisure)
- current function of the asset (Cassano et al., 2025);
- original function of the asset (Cassano et al., 2025);
- brief survey of historical information, specifying the main stages of intervention (design, construction, extensions, renovations/recovery intervention), citing the designer, the owner and, where relevant, the construction company, accompanied by historical iconography, photographs and technical documents (Russo et al., 2026);
- brief description of architectural information, identifying morphological, typological and material-constructive characteristics (Russo et al., 2026);
- brief description of the state of conservation, accompanied by current iconography (Russo et al., 2026).

The aforementioned information about heritage could be collected through the rapid consultation of available documentary sources, thereby reducing the need for site surveys. The sources include the cultural heritage database (ICCD's General Catalogue of Cultural Heritage and VIR- Vincoli in Rete), archival documents, as well as historical and technical ones. For a spatial recognition of the assets in the territorial context, online mapping services (Google Maps/Earth) might be consulted. Instead, the function of the surrounding area in which the assets are located could be investigated through the Port Authority System planning documents.

4.2.4. Ph.1.4 Evaluation of state of use and conservation

Preliminary data previously collected for each asset, as state of conservation, current state of use, current function of the context, current function, original function, type of intervention, constitute the cognitive basis for port assets qualification.

Based on this data, the degree of integration of the assets in the specific port context and the capacity of the current function to enhance the historical and cultural value of the asset are investigated. The functional compatibility assessment is carried out considering assets located within port areas chosen as representative of different territorial conditions. In this analysis, port spaces, such as docks and piers, and assets of type VI are excluded, since they are not affected by reuse interventions.

For this purpose, three specific qualitative indicators are adopted (Cassano et al., 2025). The evaluation ranges for each indicator are defined and validated through a panel of experts using the Delphi method.

- *Index 1: Compatibility between the function and the context*

The first index allows for the assessment of the degree of compatibility between the current function of the asset and that of its surrounding area. Evaluation is based on a 5 point Likert scale, as described below: (5) very compatible, when the asset is well integrated in the area and its function is functional to the context activity; (4) compatible, when the asset is well integrated in the area and its function provides support the context activity; (3) partially compatible, when the function of the asset does not have a direct implication with the function of the area; (2) poorly compatible, when the function appears isolated, poorly contextualised and does not contribute to the functional dynamics of the area; (1) incompatible, when the function of the asset is not integrated with the function of the area and creates operational conflict.

- *Index 2: Compatibility between the current function and the original function*

The second index concerns the evaluation of the degree of compatibility between the current function and the original function of each asset, in the case where the asset has undergone a transformation, and is evaluated using five point Likert scale: (5) very compatible, when the original function is retained; (4) compatible, when the

current function recalls the original purpose, maintaining a similar operational logic; (3) partially compatible, when the function is different and there is no direct recall to the original function, but they require the similar space dimensions and have same people flows, operational processes, and so on; (2) poorly compatible, when the current function does not have continuity of use with the original function and there is a lack of congruence with the functional and operational characteristics; (1) incompatible, when the function is completely unrelated in logic and purpose to the original function.

- Index 3: Compatibility between the current function and the original building

The third index is used to assess the compatibility between the current function and the property's historical-cultural identity features, i.e. how the new function has preserved the spatial configurations and original features. This indicator is also assessed using a 5 point Likert scale, as follows: (5) very compatible, when there is a functional continuity and the original layout remains unchanged, with only routine maintenance interventions; (4) compatible, when the function is well integrated, but limited functional adaptation and internal spatial reorganisation interventions were necessary, respecting the identity features; (3) partially compatible, when the function is coherent and the identity characters are maintained, but with reconstruction of parts using modern techniques and technologies; (2) poorly compatible, when the function is coherent, but the identity characters are not maintained; (1) incompatible, when the function is not compatible, so that restructuring interventions are necessary, leading to a functionally and constructively new organism.

In order to ensure the internal consistency and replicability of the evaluation process, clearly defined values have been assigned to the most common combinations for each indicator, as outlined in Table 1. This reduces the possibility of interpretative ambiguity linked to case-by-case evaluation and makes the evaluation of indicators unambiguous. For assets not in use, however, the value of each index is zero, given the absence of the fundamental condition, i.e. a function relative to which the asset is assessed.

Table 1 - Functional compatibility values for Index 1 and Index 2

	INDEX 1								INDEX 2												
	commercial	industrial/oil-hadling	port-city	fishing	services	passenger services	touristic and leisure	military	residential	touristic-receptive	military	logistic/storage	infrastructural	industrial	directional	cultural	commercial	religious	health services	recreative	multifunctional
residential		●	●						●												
touristic-receptive			●			●	●			●		●									
military			●		●	●	●				●	●		●				●			
logistic/storage	●	●	●		●	●	●					●		●							
infrastructural					●	●	●						●								
industrial	●	●			●	●								●							
directional	●	●	●		●	●	●	●	●	●	●	●	●	●	●		●		●		
cultural	●	●	●	●	●	●	●		●		●	●	●	●		●	●	●	●		
commercial	●		●		●	●			●			●					●				
recreative	●	●	●				●				●						●			●	
multifunctional	●	●	●		●	●	●		●	●	●	●		●					●	●	●
religious	●																	●			

● very compatible (5), ● compatible (4), ● partially compatible (3), ● poorly compatible (2), ● incompatible (1)

4.2.5. Ph.1.5 Identification of assets clusters

The heterogeneity of heritage types and current conditions highlights the need to identify homogeneous asset typologies for which adaptive reuse strategies can be defined. To this end, clustering represents a strategic methodology for identifying intrinsic and latent typologies, organising data into distinct groupings on the basis of similarities or common patterns. Unlike supervised learning approaches, it requires no predefined class labels, thereby allowing relational systems to be revealed within large datasets (Chander & Vijaya, 2021; Jain et al., 1999).

The literature encompasses several clustering algorithms, including k-means, Hierarchical Clustering (HCA), DBSCAN (Density-Based Spatial Clustering of Applications with Noise) and HDBSCAN, among others. These approaches differ according to specific criteria, such as: the ability to impose a hierarchical or partitional structure on the data; the choice between distance or dissimilarity measures depending on the quantitative or qualitative nature of the dataset, the shape, density of the clusters and the scalability; and the computational complexity of the algorithm, related to the size of the dataset and robustness towards noise and outliers (D. Xu & Tian, 2015; R. Xu & Wunsch, 2005).

Among the most widely adopted algorithms is the k-means method, formally introduced by MacQueen (MacQueen, 1967), to identify k clusters in the distribution in relation to their centroid. This method is adopted in the present research to identify clusters based on their state of use, state of conservation and functional compatibility. The rationale underlying these parameters lies in the overarching objectives of developing adaptive reuse solutions. The aim is to identify new functional proposals for disused or underused buildings that may not be in an optimal state of conservation, in order to extend their useful life in accordance with the principles of sustainability, or for which interventions are required to accommodate the new function, with a view to conservative enhancement (Amato et al., 2021; Bragança et al., n.d.; Douglas, 2006). This preliminary assessment is essential for understanding the complexity of the interventions required and highlighting the main critical issues that may affect the existing heritage assets. In this way, the heterogeneity of the condition of the heritage could be attributed to recurring situations, synthesising multidimensional datasets into internally coherent groups defined with respect to specific parameters. This process enables the qualification of assets, thus contributing to the definition of a cognitive framework that provides the basis for orienting recovery strategies, rather than reuse strategies, or both. According to the resulting classification, it will be possible to evaluate specific strategies in line with adaptive reuse approaches, capable of increasing the resilience of the built heritage in response to the evolutionary dynamics of the port context.

The methodological approach consists of the following phases, as illustrated in figure 5:

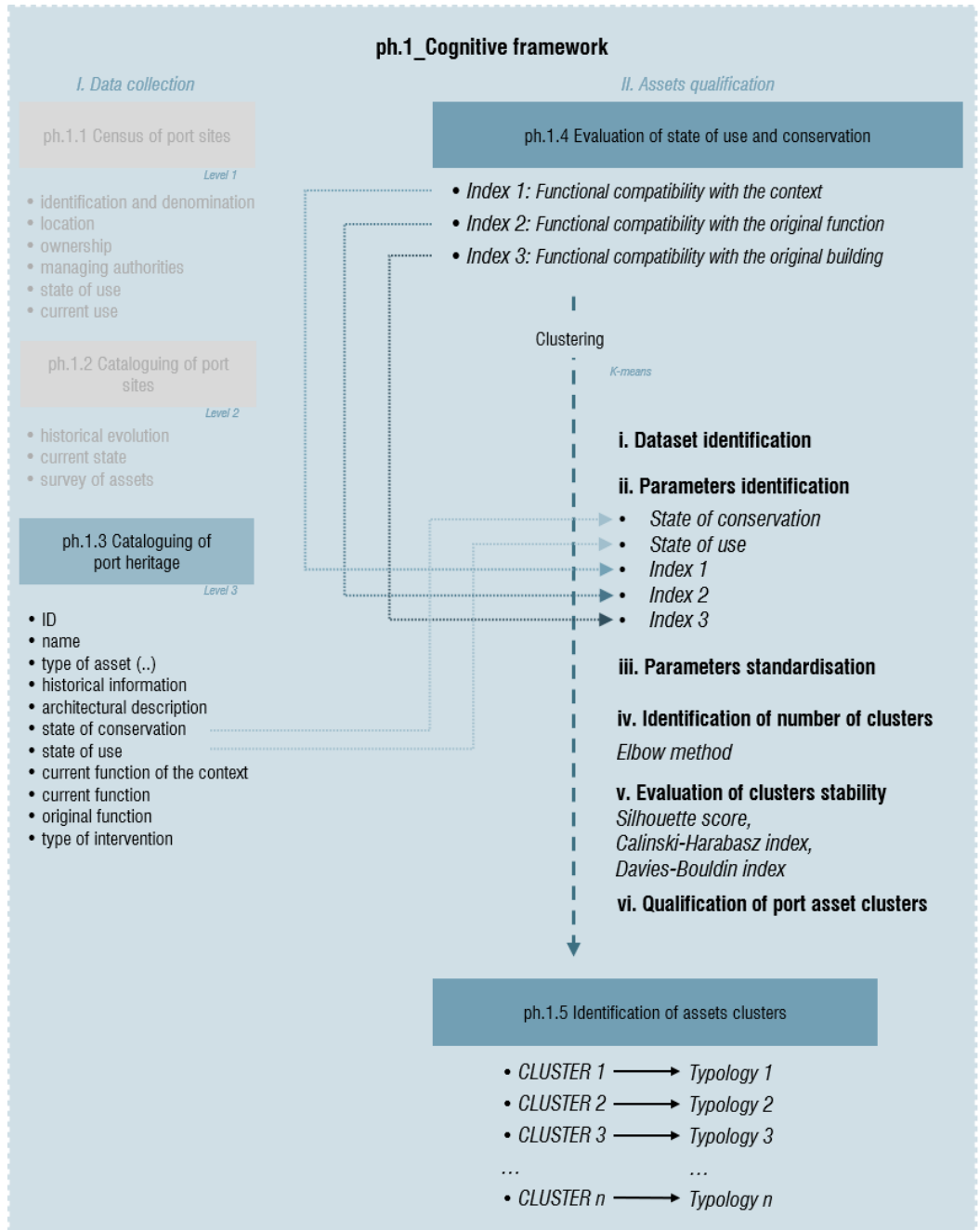


Figure 5 - Cluster analysis workflow

i. Dataset identification

The process begins with the identification of all assets to which adaptive reuse strategies are intended to be applied, in accordance with the previous phase 1.4. Therefore, the analysis excludes port area and assets of type VI, as well as assets for which complete information is unavailable.

ii. Parameters identification

For this purpose, five main parameters deemed representative of the heritage state, previously defined and assessed, are considered, according to the research aim:

p1: State of conservation

p2: State of use

p3: Level of compatibility between the current function and the function of the context (Index 1)

p4: Level of compatibility between the current function and the original function of the asset (Index 2)

p5: Level of compatibility between the current function and the original architectural characteristics of the asset (Index 3)

iii. Parameters standardisation

The process of standardisation (Everitt et al., 2011) is necessary to ensure comparability among parameters evaluated with different scales, thereby preventing the dominance of criteria characterised by greater numerical amplitude.

iv. Identification of number of clusters

The following step consists of the identification of the number of clusters k . The iterative process is initialised, in which, as in an optimisation problem, the k centroids are identified and each point is assigned to the nearest centroid, until compact and well-separated clusters are obtained.

Several methods allow for assessing cluster compactness, including the Elbow method with elbow curve analysis, which relates inertia and number of clusters, allowing for visual identification of the point that optimises the function.

v. Evaluation of clusters stability

Once the number of clusters is identified, the evaluation of cluster stability is performed, that could be evaluated through the value of the average Silhouette score, the Calinski-Harabasz index and the Davies-Bouldin index, choosing the value of k that balances statistical robustness, with typological interpretability.

vi. Qualification of port asset clusters

Finally, the output of the cluster analysis identifies groups of assets characterised by different condition profiles. In this way, each asset is assigned to a specific cluster. The diversity of the resulting clusters will therefore facilitate the definition of differentiated intervention strategies, both in terms of priorities and applicable strategies.

4.3. Ph. 2 Analysis and definition of design strategies

In a scenario where heritage is in a state of decay, disuse or underuse, the recovery and requalification of heritage assume a strategic importance (Preite, Massimo, 2013), stemming from the recognition of heritage values and reconstruction of memory and territorial identity (Covino, 2011) and the adoption of integrated approaches for territorial reconnection (Tanis & Erkok, 2016), environmental resilience and multi-level governance (International Association of Port and Cities - AIVP, 2015). For this purpose, adaptive reuse emerges as an approach capable of supporting the definition of appropriate design solutions for existing heritage, preserving the built environment (Cleempoel & Plevoets, 2013) and promoting sustainable development (Plevoets & Lanz, 2023). This approach is based on evaluative processes concerning the assets and their context (Douglas, 2006; Plevoets & Lanz, 2023), involving historical-cultural, technological-constructional, functional, environmental and

managerial aspects. According to the literature, the success of adaptive reuse interventions depends on the ability to balance the preservation of original values with the introduction of new compatible uses, often achieved through flexible and reversible design solutions (International Association of Port and Cities - AIVP, 2015; Plevoets & Lanz, 2023). These solutions are frequently conditioned by local legislation on the architectural heritage protection and urban regeneration policies. Furthermore, they are characterised by case-by-case approaches (Dell'ovo et al., 2021) without a systematic, replicable and scalable methodological framework, from preliminary knowledge acquisition to the definition and subsequent implementation of design solutions. However, the meta-design dimension has the potential to improve recovery and requalification processes of existing built heritage by defining a structured set of criteria and strategies that guide decision-making processes in complex contexts (Giaccardi, 2017) and avoid fragmented solutions. A systematic and multidimensional approach to heritage assets, characterised by recurring spatial, technological and material construction characteristics, as well as environmental and logistical issues, provides valuable support for reflecting and interpreting the intrinsic complexity of reuse processes. Therefore, the adoption of an atlas of meta design strategies could support the design process, orienting choices towards integrated and sustainable solutions to enhance the heritage in the port built environment.

In this context, the workflow is structured as follows (Figure 6). Starting from a comprehensive literature review of the success factor in Adaptive Reuse of architectural heritage, the methodological approach involves the identification of ten principal dimensions (D) that influence adaptive reuse processes, i.e. architectural, structural, socio-cultural, economic, environmental, energy, historical, legal, managerial, functional dimension (Vafaie et al., 2023). For each of them, the main specific indicators (I) are defined and then translated into meta-design strategies for port heritage at the meso-scale, i.e. considering the assets and their territorial context (S). Based on the system of dimensions and indicators/strategies, the adaptive reuse design solutions for an investigated asset are defined. To this end, meta design strategies are declined into technical design solutions (s), identified by critically investigating the

previous experiences of recovery and requalification of port heritage at the international scale. The outcome, in which dimensions, meta-design strategies and technical solutions converge, lays the groundwork for developing an Atlas of compatible solutions to support the decision-making processes for the adaptive reuse of port heritage. As a result, the applicable meta design strategies and related technical solutions orient the projects, according to the clusters obtained in the cognitive framework (ph. 1.5) and related to specific asset typology.

The effectiveness of the design solutions defined for the asset is then verified through the adoption of previously defined indicators and their associated assessment method, applying a multi-criteria decision support methodology, such as the Analytic Hierarchy Process (AHP).

Within this framework, the structuring of an open and multidimensional atlas of meta-design strategies and technical solutions constitutes a useful tool for orienting the development of complex adaptive reuse solutions consistent with international best practices. Furthermore, the weights obtained from the AHP method, appropriately calibrated according to the multidimensional structure of the approach, are effective for the evaluation of further applications, without case-specific recalibration, overcoming the usual case-dependency as a transferable and coherent evaluation.

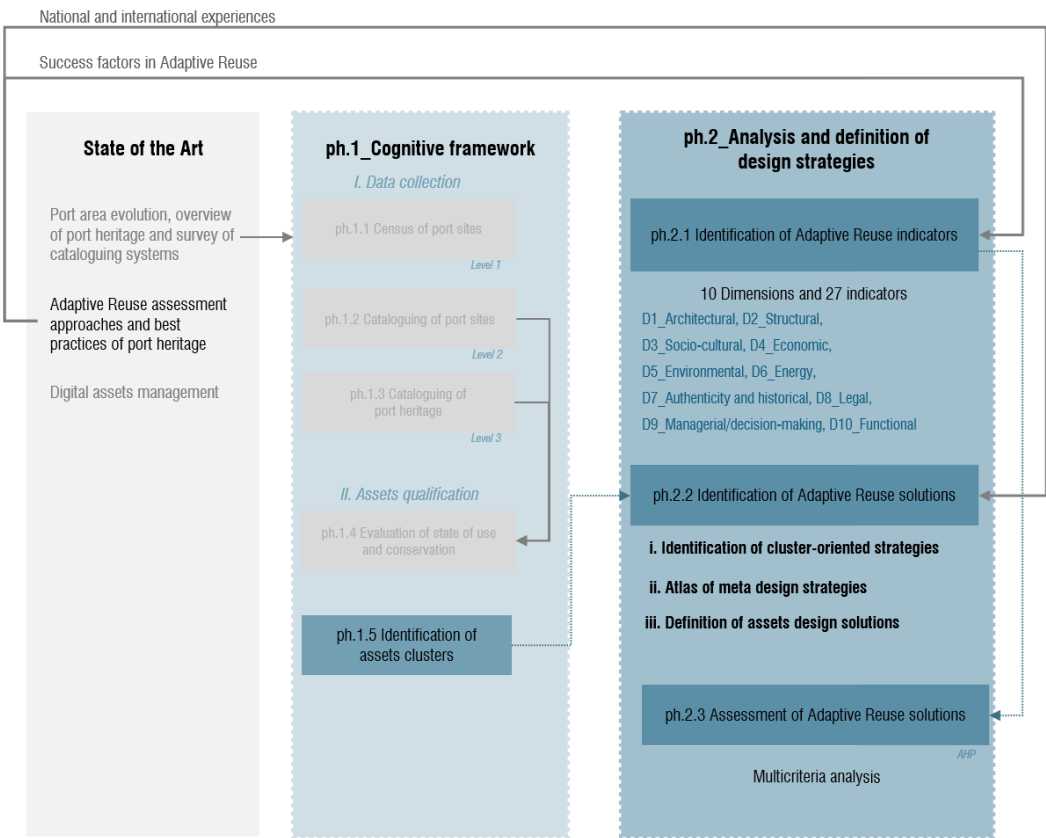


Figure 6 - Definition of design strategies workflow

4.3.1. Ph.2.1 Identification of Adaptive Reuse indicators

In defining a structured and coherent methodological framework capable of supporting the definition of adaptive reuse strategies for the recovery and enhancement of port heritage, it is essential to identify the main factors to be considered in adaptive reuse interventions, given the multidimensional complexity inherent to this approach. In accordance with the approaches defined and consolidated in the literature, the most significant indicators are identified for each dimension, each of which is evaluated in a specific way. These indicators support the design of solutions and the evaluation of the effectiveness of the proposed design solutions not only with respect to the ex ante

condition, but also in relation to design alternatives, thereby allowing the definition of structured processes to support decision-making.

According to the literature, ten dimensions (D) affect the success of adaptive reuse as a strategy to regenerate heritage (Vafaie et al., 2023), described by 27 specific indicators (I) that best represent the main aspects (Cassano, De Fino, et al., 2026). Each indicator may be understood as a design guideline, capable of guiding operational choices, to which a meta-design strategy (S) is associated (Bullen & Love, 2011) corresponds. For the proposal, the dimensions, indicators and strategies are appropriately identified as follows:

- dimensions are coded with the letter D, followed by a consecutive number;
- indicators are coded with a letter I, followed by the number of the dimension to which they are related and a consecutive number;
- meta-design strategies, which express the applicability of the specific indicator, are identified by the same code as the corresponding indicator, with the letter S in place of the letter I.

Specifically, the dimensions and associated indicators emerging from the literature review are defined below.

D1. *Architectural dimension* concerns the preservation of the original identity, including architectural, material, morphological, typological and spatial characteristics related to their capacity to accommodate a new function in coherence with original identity value. The meta-design strategies related to this dimension focus mainly on:

I1.1. minimum intervention, preservation of the identity of the structure and reduction of invasive interventions, such as the demolition of parts (S1.1) (Bullen & Love, 2011; Cucco et al., 2023; Dabbene et al., 2024; Della Spina, 2021; Djebbour & Biara, 2019; Icomos, 1983; Z. Lin et al., 2024; Vafaie et al., 2023);

I1.2. architectural harmony and visual compatibility, conservation of original architectural elements, preserving their formal, material and chromatic consistency between new and existing elements, making alterations explicit (S1.2) (Cucco et al., 2023; Dell'ovo et al., 2021; Pinto et al., 2017; Vafaie et al., 2023);

11.3. adaptability and spatial flexibility, capacity of the space to be adapted to different functions over time without compromising legibility, using lightweight and reversible components (S1.3) (Angrisano et al., 2024; Cucco et al., 2023; Dell'ovo et al., 2020, 2021; Ding et al., 2025; Djebbour & Biara, 2019; Jato-Espino et al., 2022; Kutlu et al., 2025; Mohd Abdullah et al., 2020; Nguyen Duc Vinh, 2021; Nocca et al., 2024; Pinto et al., 2017; Ragheb, 2021; Salerno, 2020; Vafaie et al., 2023; Vizzarri et al., 2021).

D2. *Structural dimension*, interconnected with the architectural one, concerns the structure's ability to ensure stability, durability and adaptability, as well as resilience, to extend its useful life. The most common meta-design strategies in this area include:

12.1. retrofitting of existing structure, selective conservation and structural consolidation intervention, maintaining the main structures and extending their useful life (S2.1) (Bullen & Love, 2011; Giuliani et al., 2018, 2020; B. Mohamed & Marzouk, 2025; Nasr & Khalil, 2022; Sefa Adin & Sirel, n.d.; Vafaie et al., 2023);

12.2. structural integration, addition of structural elements, with the construction of new structures and volumes (S2.2) (Añibarro et al., 2023; Cucco et al., 2023; Dabbene et al., 2024; Sefa Adin & Sirel, n.d.; Vizzarri et al., 2021);

12.3. dismantlability/flexibility of components, integration of flexible and removable systems, to easily disassemble unused parts (S2.3) (Bianchi & De Medici, 2023; Cucco et al., 2023; Sharifi & Farahinia, 2020; Vizzarri et al., 2021).

D3. *Socio-cultural dimension* explores the role of adaptive reuse in creating and enhancing collective identity, strengthening the sense of belonging and shared memory of places, through its tangible and intangible identity value of heritage. The main meta-project strategies identified for this dimension include:

13.1. social integration and inclusion, design spaces and activities that strengthen cohesion between different groups and contrast processes of exclusion or gentrification, considering gender, class, race, ethnicity, culture (S3.1) (Bullen & Love, 2011; Dabbene et al., 2024; De Vita et al., 2022; Giaccardi, 2017; W. Li et al., 2025;

Mazzetto & Vanini, 2023; Rohini & Shefali, 2023; Vafaie et al., 2023; Vizzarri et al., 2021);

I3.2. attachment and sense to place, enhancing identity characteristics that are meaningful to the local community (S3.2) (Bullen & Love, 2011; Dabbene et al., 2024; Ding et al., 2025; Giaccardi, 2017; Rohini & Shefali, 2023; Sharifi & Farahinia, 2020; Vafaie et al., 2023).

D4. *Economic dimension* analyses the capacity to generate sustainable economic value at both local and regional levels, focusing on the economic effects related to the recovery and refurbishment project. The main meta-project strategies identified for this dimension include:

I4.1. functional mixes, promoting mixed uses that stimulate broad-based economic development, real estate, new job positions and attraction of diverse users (S4.1) (Arfa, Quist, et al., 2022; Dabbene et al., 2024; Della Spina, 2021; Gravagnuolo et al., 2024; Metwally et al., 2025);

I4.2. public-private partnerships, as a financial and governance model for heritage conservation, to encourage investments and reduce the economic burden on the institution (S4.2) (De Vita et al., 2022; Lauro et al., 2025; Metwally et al., 2025);

I4.3. tourist attractiveness, increase the number of visitors, enhancing heritage as a resource for increasing attractiveness and consequently the sustainable tourism economy (S4.3) (Angrisano et al., 2024; Arfa, Lubelli, et al., 2022; Arjomand Kermani et al., 2020; Dabbene et al., 2022, 2024; Giaccardi, 2017).

D5. *Environmental dimension* considers the relationship between industrial assets and the urban and territorial environment, assessing the project's impact on the environment and pursuing sustainable development goals, towards integrated and resilient urban regeneration and often in line with the circular economy. The main meta-design strategies for this dimension include:

I5.1. port city interaction, through measures aimed at reconnecting the urban contexts to the sea (S5.1) (Nocca et al., 2024);

15.2. mobility and accessibility, ensuring accessibility with vehicular, pedestrian infrastructures, as well as slow mobility, and public transport systems (S5.2) (Bullen & Love, 2011; Cleempoel & Plevoets, 2013; Cucco et al., 2023; Dabbene et al., 2024; Dabouh & El Shazly, 2020; Dell'ovo et al., 2020, 2021; Metwally et al., 2025; B. Mohamed & Marzouk, 2025; Morandotti et al., 2019; Nocca et al., 2024; Ragheb, 2021; Salerno, 2020; Sharifi & Farahinia, 2020; Vafaie et al., 2023; Vizzarri et al., 2021);

15.3 public open and green spaces, promoting environmental and social regeneration, through open spaces and green areas, contributing to climate mitigation (S5.3) (Angrisano et al., 2024; Añibarro et al., 2023; Cucco et al., 2023; Ding et al., 2025; Gravagnuolo et al., 2024; W. Li et al., 2025; Metwally et al., 2025; Mohd Abdullah et al., 2020; Nguyen Duc Vinh, 2021; Nocca et al., 2024; Sharifi & Farahinia, 2020; Vafaie et al., 2023; Vizzarri et al., 2021).

D6. *Energy dimension* focuses on the energy performance of the structures and on reducing energy consumption in buildings, preserving their material and constructive integrity. The main meta-design strategies in this area include:

16.1. passive design strategies, ensuring thermal, visual, acoustic comfort and indoor air quality through passive solutions (S6.1) (Dell'ovo et al., 2020, 2021; W. Li et al., 2025; Nasr & Khalil, 2022; US Green Building Council, 2023);

16.2. efficient energy systems, adopting efficient energy systems, including renewable energy resources as a renewable energy system, upgrading/implementation of systems for efficient HVAC (Heating, Ventilation and Air Conditioning), domestic hot water and Smart Controls and Energy Management Systems (S6.2) (Añibarro et al., 2023; Bullen & Love, 2011; Cinquepalmi et al., 2023; Dabbene et al., 2024; Ding et al., 2025; Giaccardi, 2017; Ismaeel & Mohamed, 2023; B. Mohamed & Marzouk, 2025; US Green Building Council, 2023; Vafaie et al., 2023).

D7. *Authenticity and historical dimension* concerns the protection, enhancement and transmission of the tangible and intangible identity values of assets, recognising consolidated and stratified historical and cultural identity values. The main meta-design strategies relating to this dimension include:

I7.1. intrinsic values, recognition, safeguarding traditional technical expertise, production practices and sea culture (S7.1) (Andrade et al., 2024; Angrisano et al., 2024; Arfa, Quist, et al., 2022; Arjomand Kermani et al., 2020; Dabbene et al., 2024; Giaccardi, 2017; Nocca et al., 2024; Vehbi et al., 2021; Yu et al., 2025);

I7.2. authenticity and integrity, conserving of its tangible and intangible aspects that defined through its formal, spatial and functional configuration (S7.2) (Abdul Aziz, 2021; Adin & Sirel, 2024; Andrade et al., 2024; Angrisano et al., 2024; Arfa, Lubelli, et al., 2022; Bullen & Love, 2011; Dabbene et al., 2024; Dell'ovo et al., 2020; Ding et al., 2025; Djebbour & Biara, 2019; Ismaeel & Mohamed, 2023; Lauro et al., 2025; W. Li et al., 2025; Mohd Abdullah et al., 2020; Nasr & Khalil, 2022; Vafaie et al., 2023; Vehbi et al., 2021);

I7.3. significance of the heritage, preserving architectural and technical values that reflect the construction respect to productive history and the local culture (S7.3) (Angrisano et al., 2024; Arfa, Lubelli, et al., 2022; Arjomand Kermani et al., 2020; Dabouh & El Shazly, 2020; Mazzetto & Vanini, 2023; Metwally et al., 2025; Nasr & Khalil, 2022; Vehbi et al., 2021; Zhang & Zhang, 2023).

D8. *Legal dimension* concerns the normative and regulatory provisions at international, national and local levels that constrain and drive adaptive reuse processes, as well as define the legitimacy and feasibility of interventions. The main meta-design strategies for this dimension include:

I8.1. respect of regulatory, ensuring consistency with territorial planning and regulatory frameworks, as building code requirements, health and safety regulations, preservation rules and provisions, zoning and planning requirements (S8.1) (Aigwi, Phipps, et al., 2020; Bullen & Love, 2011; Mohd Abdullah et al., 2020; Ragheb, 2021; Vafaie et al., 2023; Vardopoulos et al., 2021; H. J. Wang & Zeng, 2010);

18.2. multi-level and participatory governance, activation of forms of multi-level and participatory governance, involving institutional actors, local communities and private stakeholders (S8.2) (Bullen & Love, 2011; Djebbour & Biara, 2019; Giuliani et al., 2018; Paavola, 2016; Vafaie et al., 2023).

D9. *Managerial/decision-making dimension* concerns the complexity of the processes and actors and governance involved in the assessment, design, implementation and management phases of adaptive reuse interventions to ensure their success and long-term sustainability. The main meta-design strategies related to this dimension include:

19.1. involvement of community, recognition of territorial and local needs, with a proactive engagement of local communities and various stakeholders, to ensure the functional and social sustainability of interventions over time (S9.1) (Abastante et al., 2022; Añibarro et al., 2023; Bianchi & De Medici, 2023; Dabbene et al., 2024; Ding et al., 2025; Djebbour & Biara, 2019; International Association for Public Participation, 2018; Martínez et al., 2020; Metwally et al., 2025; Treseder et al., 1997; Vafaie et al., 2023);

19.2. involvement of different stakeholders, supporting integrated and multidisciplinary decision-making, involving different stakeholders (as “investors”, “producers”, “regulators”, and “users” and academics) (S9.2) (Aigwi, Phipps, et al., 2020; Arfa, Quist, et al., 2022; Bullen & Love, 2011; Dabbene et al., 2022; Gravagnuolo et al., 2024; Ragheb & Naguib, 2021; Sharifi & Farahinia, 2020; Vafaie et al., 2023; Yu et al., 2025);

19.3. use of digital tools (Bosone et al., 2021; Della Spina, 2020; H. J. Wang & Zeng, 2010).

D10. *Functional dimension* concerns the ability to introduce new functions responding to contemporary needs, ensuring flexibility of use and integration over time. The design approach is oriented towards functional compatibility, with a focus on maintaining coherence with the context and respect for the historical and architectural identity of the asset. The main meta-design strategies for this dimension include:

I10.1. compatibility with the context, introduction of functions integrated with current local function (S10.1) (Baqrasham & Al-Khafaji, 2025; Cucco et al., 2023; Vizzarri et al., 2021);

I10.2. compatibility with the original use, promotion of a dialogue with the original vocation (S10.2) (Bullen & Love, 2011; Dell’ovo et al., 2020; Haroun et al., 2019; W. Li et al., 2025; Mohd Abdullah et al., 2020; Nocca et al., 2024; Vafaie et al., 2023; Vehbi et al., 2021);

I10.3. compatibility with the architectural characteristics, ensure function that define its identity, exploiting the original spatial-functional logic (S10.3) (Angrisano et al., 2024; Bullen & Love, 2011; Cucco et al., 2023; Dabbene et al., 2024; Dell’ovo et al., 2021; Giaccardi, 2017; Giuliani et al., 2018; Gravagnuolo et al., 2024; Haroun et al., 2019; Nocca et al., 2024; Vafaie et al., 2023).

Annex 3 provides an overview of each dimension and its associated indicators, including their definitions and the assessment method useful to evaluate the project alternatives (ph.2.3).

The indicators marked with an asterisk (*) are adopted from the extant literature; however, the evaluation ranges for each indicator are appropriately defined and validated through a panel of experts by means of the Delphi method in order to reduce the level of subjectivity inherent in the evaluation procedure.

In this regard, the assessment methods are based on criteria of validity, reliability, and reproducibility, so as to ensure that they effectively measure the dimension they purport to express and yield consistent, comparable results, regardless of the subjects involved in the assessment process.

4.3.2. *Ph.2.2 Identification of Adaptive Reuse solutions*

The structured systems outlined provides the basis for the definition of Adaptive Reuse solution for investigated assets. The clustering results, obtained in ph.1.5, provide the basis for associating specific adaptive reuse strategies with each identified cluster. For instance, when a cluster is associated with a poor state of conservation, interventions should primarily focus on structural restoration. When functional compatibility with the surrounding context is low, the actions should instead address the relationship between the asset and the area, in order to ensure safe and effective use within the context or, if necessary, to evaluate a change of use. If the current function is poorly compatible with the original vocation, strategies should include measures aimed at safeguarding and enhancing its identity value. Finally, when functional compatibility with the existing structure is low, the intervention should seek a more effective integration of the intended use while preserving the asset's defining identity features.

Subsequently, in the context of designing solutions for the recovery, reuse and redevelopment of heritage, it is crucial to examine previous experiences to identify best practices capable of guiding the design process. In the heritage recovery processes, the international references outlined by ICOMOS, such as the Venice Charter (ICOMOS, 1964), the Burra Charter (The Australia ICOMOS Charter, 2013) and the recommendations provided by UNESCO (UNESCO, 2011a) are fundamental. The literature also highlights the interest in case-based approaches for the identification of adaptive reuse strategies. The analysis of real cases allows for the identification of success factors, as well as of compatible and sustainable design approaches and strategies (Buglione et al., 2024; Mısırlısoy & Günçe, 2016; Vafaie et al., 2023).

However, the approaches based solely on the transposition of best practices tend to fail when designing solutions are transferred to a new context; for this reason, design is more oriented towards the adoption of meta-design approaches (Gustafsson & Ripp, 2022; Morandotti et al., 2019). This methodological approach ensures a higher level of abstraction than traditional design approaches (Ripp, 2022), in the phase before the definite project, reducing the possibility of choosing inadequate solutions that could

have negative impacts on heritage, recognising heritage not only as a physical system but also as a complex system of values that needs to be resilient over time (Mocerino et al., 2024; Morandotti et al., 2019). Moreover, the systemic perspective requires more collaborative approaches, integrating specialists' expertise with the necessities of the communities who are the end users of the space (Fischer & Giaccardi, 2006; Morandotti et al., 2019).

In this scenario, the definition of a meta-design strategy atlas is a strategic endeavour aimed at systematising meta-design strategies for the identification of design solutions for the recovery, reuse and regeneration of heritage assets. Its usefulness is not limited to the mere collection of best practices, but constitutes a structured operational instrument capable of translating the complexity of previous experiences into operational strategies and technical solutions (s) within each dimension (D) to meet the objectives highlighted by each success indicator/strategies (I) (ph.2.1). This tool is not intended to be prescriptive, rather it is conceived as an operational tool to support decision-making processes (Cassano, De Fino, et al., 2026).

To this end, the critical and comparative analysis of the reuse and redevelopment experiences previously examined (section 2.2) allows the association of specific design solutions with each strategy.

Methodologically, the workflow is articulated into three main phases: (i) identification of of cluster-oriented strategies, (ii) development of Atlas of meta design strategies, and (iii) definition of assets design solutions.

- i. In the first phase, main dimensions and their corresponding meta-design strategies are identified for each cluster, according to the specific condition. This association makes it possible to identify the priority dimension of attention in the project aimed at enhancing heritage conditions, since each cluster has specific critical issues. The dimensions don't carry the same importance across contexts and this approach permits a hierarchisation of priorities dimension to attention according to the specific condition of the case.

- ii. The analysis of reuse, recovery and enhancement interventions related to national and international real cases enables the identification of relevant practices

and strategies. This is carried out based on the most successful indicators in the adaptive reuse of existing buildings previously identified (ph.2.1), which are subsequently interpreted as strategies.

The dimensions, strategies and design solutions enable the construction of the atlas of meta-design strategies. In order to ensure recognition as best practices and transferability, the identified strategies are referred to real case studies. Organised by dimension, each international case of port heritage is analysed (chapter 2.2) to identify how the strategies have been translated into specific intervention solutions, identifying recurrences across the various projects. The atlas, designed as an open and continuously evolving tool, systematises the different intervention solutions for each strategy, serving as a device to support decision-making processes. In this way, it is possible to identify strategic guidelines before translating them into specific technical solutions that take into account local specificities, through shared, scalable and replicable decision-making processes, adopting practices considered best practice in similar scenarios.

iii. Following this, the design solutions for the specific case investigated are defined. The methodological workflow is further articulated, for each proposed solution, into the following sub-phases (Figure 7):

- a. definition of the design concept based on previous experience, ensuring improved levels of functional compatibility, according to ph.1.4;
- b. definition of the preliminary project proposal through the definition of the distributive-functional layout of the spaces and its organisation;
- c. definition of asset design solutions, consulting the atlas of meta design strategies to refine the project and enhance the design solution consistent with the local specificities.

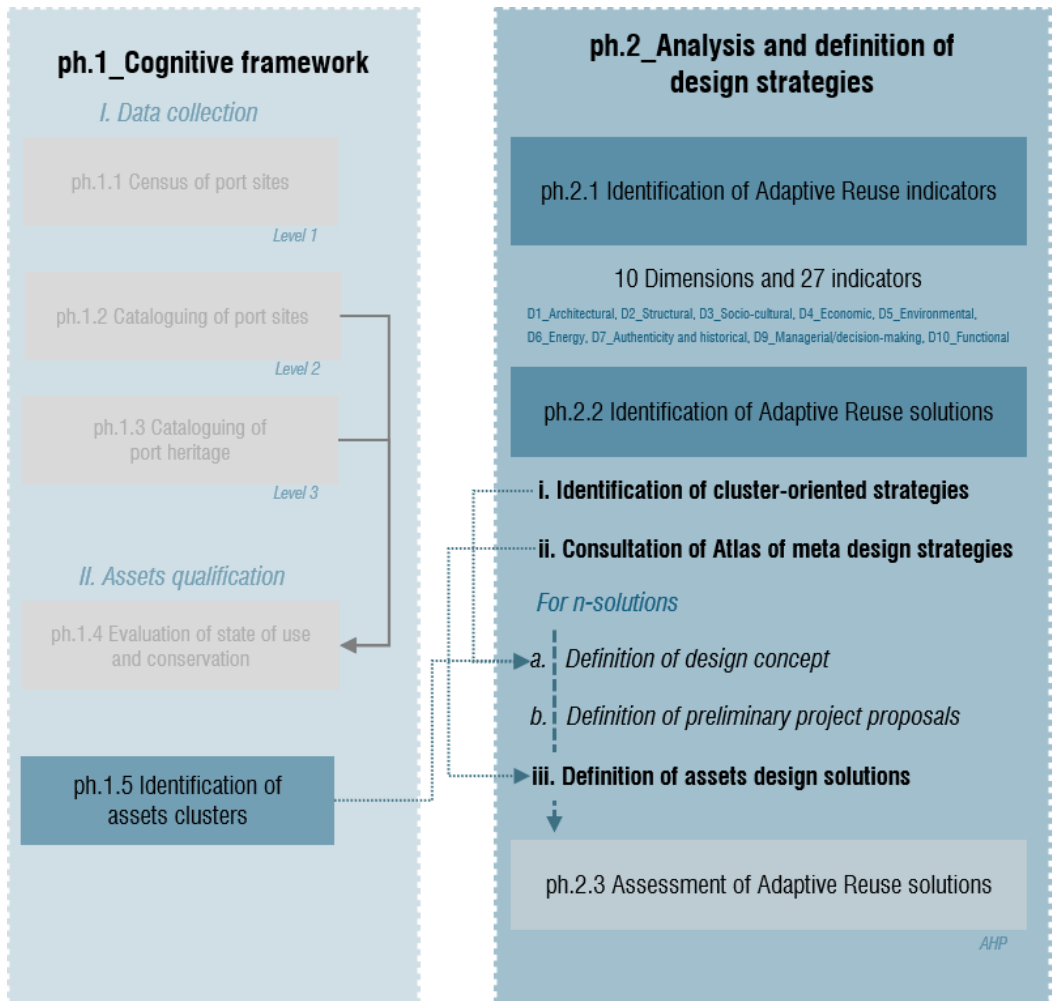


Figure 7 - Identification of Adaptive Reuse solutions workflow

4.3.3. *Ph.2.3 Assessment of Adaptive Reuse solutions via AHP*

In line with existing literature on multiple criteria decision analysis (MCA) methods for evaluating alternatives using different quantitative and qualitative criteria, AHP analysis emerges as the most appropriate method for determining the weighting of each indicator in the comprehensive evaluation.

This method, developed by Thomas L. Saaty (Saaty, 1980; Saaty & Vargas, 2012) provides support in the formulation of complex decisions, without exonerating decision-makers from making judgments, but helping them to understand the complexities and priorities, as the outcome of shared processes between different stakeholders, converging towards simplicity and transparency (Belton & Stewart, 2022; Brunelli, 2015; Geneletti & Ferretti, 2015).

The MCDA evaluation framework is structured according to six well-defined steps, as follow described in figure 8, to compare different design solutions proposed for an individual asset. The efficacy of the design solutions proposed is verified by adopting the system of indicators defined in ph.2.1 and in accordance with the evaluation methods outlined for each indicator in Appendix 3. By combining the weights obtained through a multi-criteria analysis, such as the Analytic Hierarchy Process (AHP), with the specific scores assigned to each indicator for each design solution of the examined asset, it is possible to obtain the final score allowing for a comparison of the different solutions.

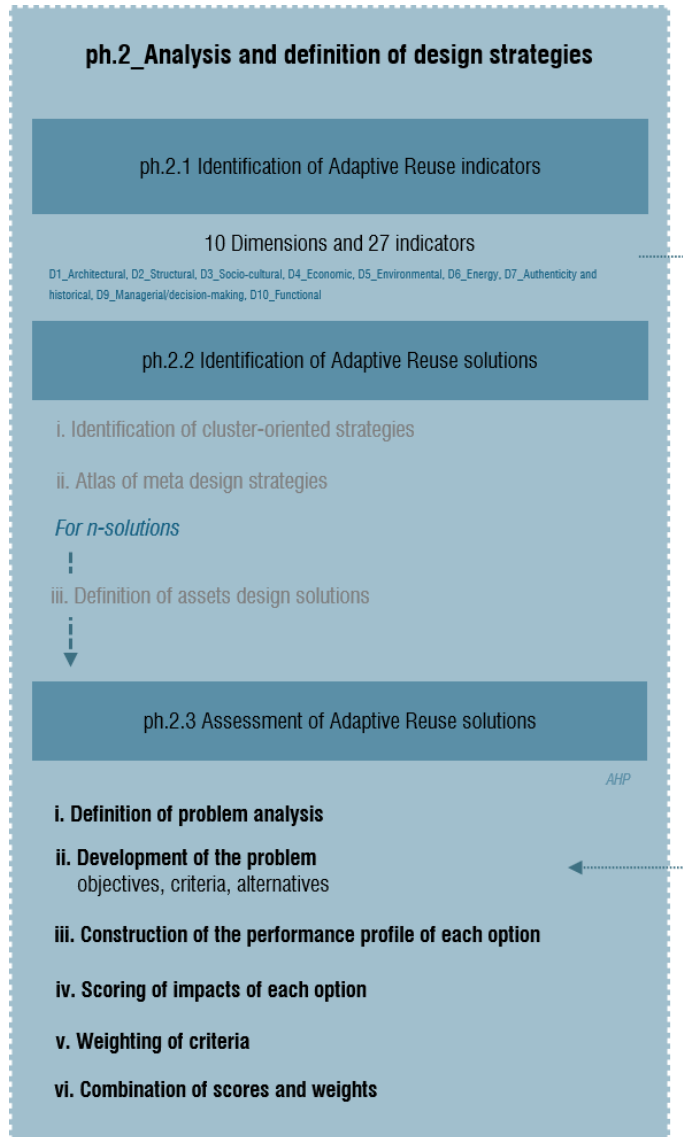


Figure 8 – MCDA evaluation framework

i. This analysis aims to assess the adaptive reuse strategies for the recovery and enhancement of port heritage. In particular, the focus is not only on the asset, but also on its relationship with the context in which it is located. Accordingly, the scope of the investigation may be defined as meso-scale, i.e., it is not limited to the asset solely, since such a perspective would offer a limited understanding of a problem

that is strongly related to the context in which it is situated and does not consider broader dynamics that could reduce the accuracy of the analysis with respect to the established objective.

In this framework, it is fundamental to consider the moment of evaluation during the process, from the planning of the intervention to its implementation and, finally, to its management. For each of these moments, it is possible to associate a type of evaluation (Dean, 2022). The *ex ante* evaluation, conducted in the planning phase, supports the decision-making process by enabling the validity and effectiveness of the proposed solutions to be assessed. The *mid res* (or *interim*) evaluation aims to monitor the progress of the intervention and, where necessary, to implement efficiency improvements. The *ex post* evaluation, by contrast, aims to assess the actual effects of the intervention against the expected outcomes. Therefore, it is necessary to establish at which stage of the intervention the evaluation is being carried out, since the objectives of the evaluation change and as a result, it is effective, adequately supporting the decision-making process and contributing to the optimisation of the effectiveness of the intervention and the resources used.

According to the aim of the research, the purpose is to conduct an *ex ante* analysis, while also allowing for *ex post* assessments.

ii. The decision support framework provides for the definition of key elements as options, objectives and criteria, to each of which a performance score and a criterion weight will be assigned (Dean, 2022). These are organised according to a hierarchical structure with the general objective, followed by macro-criteria and their respective sub-criteria.

In this case, the objective is the evaluation of Adaptive Reuse interventions for heritage assets, whilst the macro-criteria and sub-criteria correspond respectively to the dimensions and indicators previously identified in ph.2.1 (architectural, economic, social, environmental, and others) (Figure 9). The criteria must be considered relevant in the decision-making process (Saaty, 2006), ensuring that they are not redundant and sufficiently comprehensive with respect to the principal aspects, without imposing an

excessive analytical or cognitive burden (Belton & Stewart, 2022). Furthermore, they should be clearly defined and readily intelligible to decision-makers.

In this specific instance, all indicators were considered except for those related to regulatory aspects, as compliance with regulatory requirements and compatibility with higher-level planning instruments are assumed as preconditions.

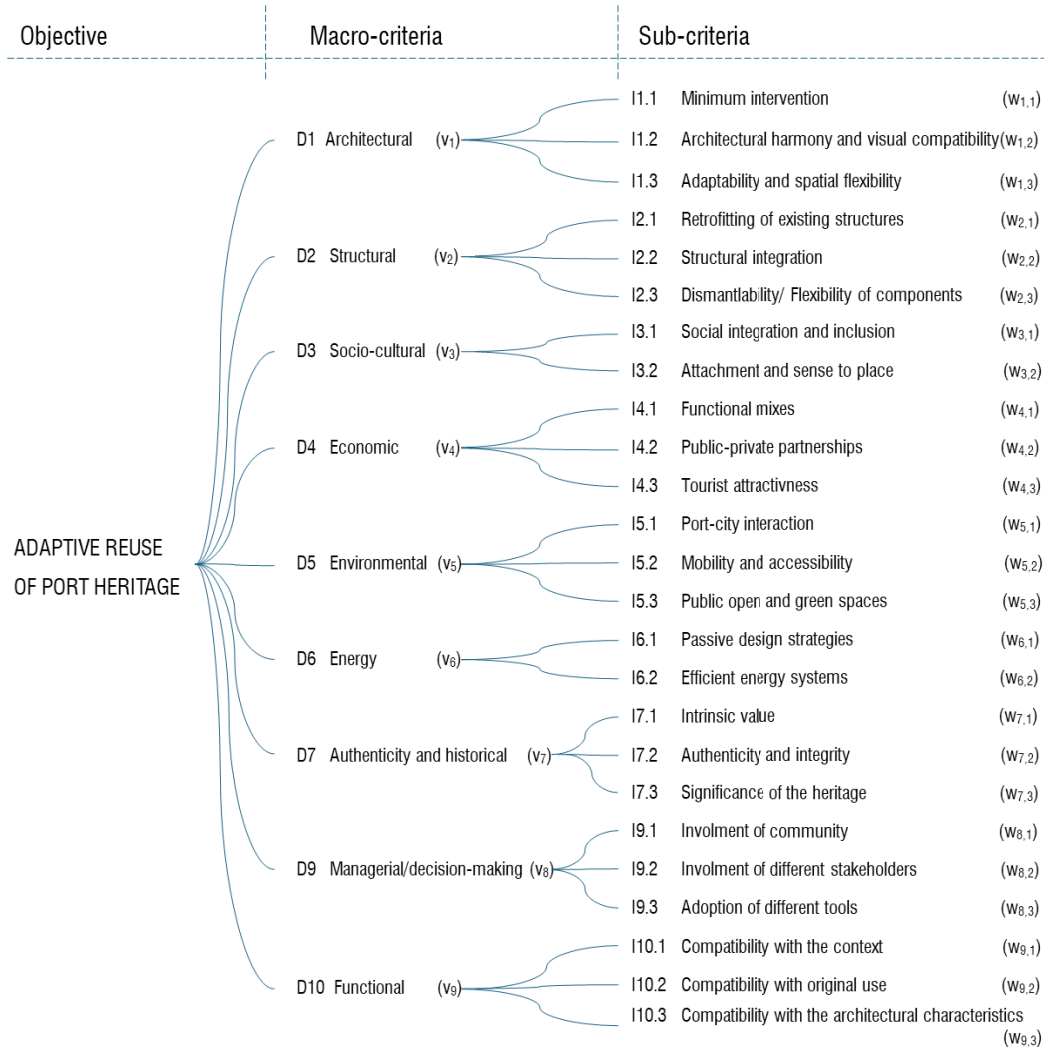


Figure 9 – Structure of macro-criteria and sub-criteria

iii. Each criterion is associated with a sub-criterion, e.i. a measurable indicator of performance in relation to the established objective, in quantitative or qualitative terms, as explain in Annex 3. Each indicator may be evaluated using different units of measurement, without requiring homogeneity across criteria.

iv. To evaluate the scoring of each solution proposed for an asset investigated, pairwise comparisons are made between elements of the same hierarchical level with respect to the element at the higher level. To this end, Saaty's 9-point fundamental scale (Saaty, 1990), is adopted, assigning values from 1 (equal importance) to 9 (extreme importance). In this way, it is possible to formulate structured and semantically interpretable judgements. This structured analysis takes the form of a square and reciprocal matrix, a comparison or judgement matrix, from which the normalised principal eigenvector is obtained to determine the score for each element.

v. The effective priority or weight of each criterion is therefore calculated using the normalised principal vector (Saaty, 1980). To ensure that the judgements expressed by decision-makers are not contradictory, a check is performed to assess the internal consistency of the judgements by calculating the Consistency Index (CI) and the Consistency Ratio (CR) (Saaty & Vargas, 2012), defined as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)}$$

where λ_{max} is the largest or principal eigenvalue of the matrix A' of pairwise comparisons, with n elements to weight:

$$CR = \frac{CI}{RI}$$

where RI is the average random consistency index.

An acceptable level of consistency is achieved for CR values below 0.10 ($CR \leq 0.10$); otherwise, the judgments must be reviewed to reduce inconsistency. This check is methodologically essential to ensure the reliability of the results.

vi. Finally, the combination of scores and weights is obtained by multiplying the weights of the criteria by those of the alternatives in order to obtain a final score by means of a weighted sum. In this way, it is possible to establish a ranking of the alternatives evaluated.

Given the wide variability of design solutions, the method does not include a weighted evaluation of specific alternatives of an individual asset investigated. This means that the weights obtained for each criterion and sub-criterion are therefore not calibrated to any specific design solution, but instead remain valid for other applications.

4.4. Ph. 3 Digital ecosystem

The processes of enhancement and management of these assets require multidimensional and multi-level approaches (Sliwinska, 2025). The complexity of port contexts necessitates the integration of different types of information, such as documentary sources related to historical, architectural and industrial significance, as well as technical information, regulations and plans of the site for the definition of recovery, reuse and redevelopment projects. At the same time, it is strategic to involve different actors, from port authorities to public-private stakeholders, including local communities as direct users of the spaces, in order to develop shared visions and integrated, long-term sustainable intervention programmes (Daldanise & Clemente, 2022).

The growing use of digital tools for the documentation, analysis and communication of the built environment has profoundly redefined the role of virtual models in cognitive and decision-making processes. The combination of advanced surveying techniques, information modelling and virtual and immersive technologies has progressively extended the role of digital models, transforming them into environments capable of recreating the complexity of such contexts (Barrile & Genovese, 2024; Ramos Sánchez et al., 2022). The VR and AR digital environments are no longer conceived only for dissemination, but as integrated informative environments capable of supporting

complex decision-making processes. In particular, the literature reveals that the virtual experiences were designed for diagnostic, monitoring and safety training, as well as for digitalisation and dissemination aimed at recovering and preserving heritage (De Fino et al., 2022; Giuffrida et al., 2021).

When associated with external databases and information systems, these tools can contribute to a more detailed reconstruction of the built environment and its historical, architectural and functional complexity.

In light of this evidence, a virtual environment allows for the systematisation and accessibility of the information density of built environments, particularly in port contexts that are characterised by a fragmented knowledge system and an undervalued heritage. This enables the association of a rich array of historical, documentary, technical and managerial content with the reality-based digital model, effectively resulting in a dynamic repository easily navigable by different categories of users. In this scenario, an innovative methodological approach is proposed, involving the structuring of a dynamic and shared informative digital ecosystem related to the port context.

The proposed methodological approach (Figure 10) involves, firstly, the process of digitisation of the knowledge management system and design solutions. To this end, Geographic Information System (GIS) and Building Information Modelling (BIM) models are coherently structured for knowledge management purposes, constituting the basis for analyses aimed at describing the built environment and evaluating design solutions. These evaluations are conducted through machine learning and visual programming language algorithms, further supported by the adoption of virtual and augmented reality technologies.

The comprehensive process culminates in the development of an integrated digital environment, wherein Geographic Information System (GIS) and Building Information Modelling (BIM) models, as well as virtual reality (VR) and augmented reality (AR) tools, allow for the management of a complex information system, thereby ensuring interoperability and encouraging collaboration among the involved stakeholders. It is configured as a multi-level cognitive and management tool with high communicative

capacity and ease of use, providing operational support for planning, long-term design and management activities, as well as the development of shared strategies for the enhancement and sustainable development of port areas adequate to the specificities of local contexts. In addition, the virtual experience enhances engagement and awareness of port heritage as a strategy for preserving heritage, aligning with the UNESCO Thematic Indicators for Culture in the 2030 Agenda (UNESCO, n.d.-a). This collaborative environment supports the processes of port heritage asset recovery, reuse and enhancement within a broader and more complex dynamic context.

To overcome the fragmentation of data and approaches, the cognitive information system is also structured to support rapid automated assessment with Python algorithm in a GIS environment and automated weighted assessment of design alternatives through parametric BIM models with Visual Programming Languages, such as Dynamo. In addition, the proposal also provides for the integration of information into a comprehensive database aimed at developing a webGIS and an integrated digital environment. Finally, all the digital systems converge in an innovative integrated digital ecosystem, structured as a shared, collaborative and multimodal environment, with an original approach integrating BIM models and point clouds into a VR and AR environment to explore design solutions, supporting participatory processes.

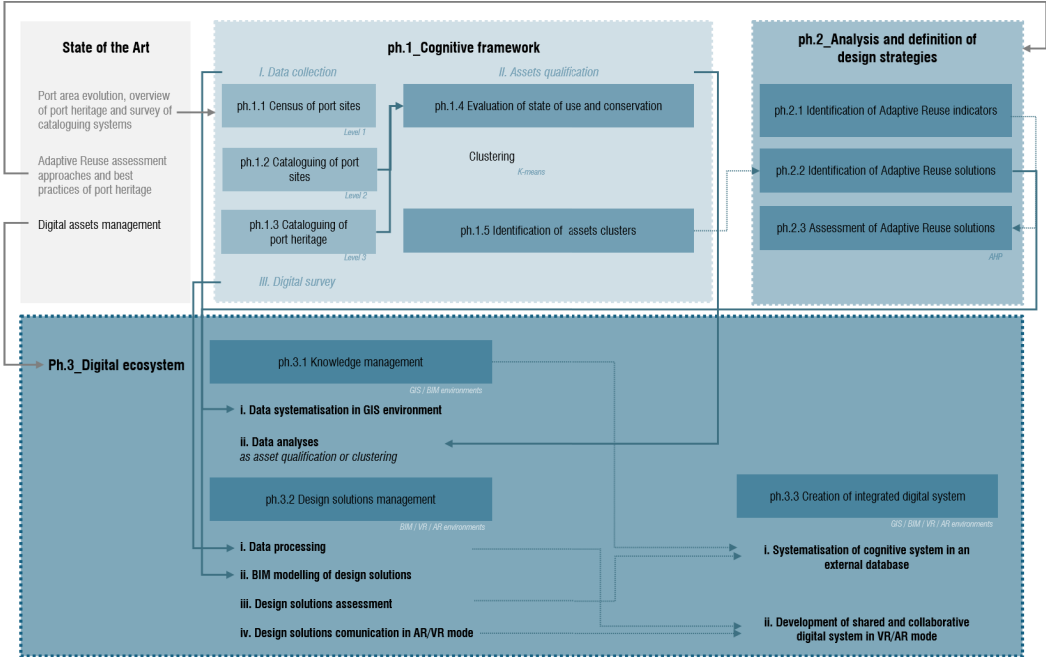


Figure 10 - Digital ecosystem structure

4.4.1. Ph. 3.1 Knowledge management

The management of built environments at a territorial scale requires the integration of heterogeneous and multi-level data resulting from continuous processes involving a plurality of actors. Currently, this process is affected by issues related to fragmentation, inaccessibility of information and a lack of interoperability, which is reflected in the efficiency of decision-making approaches. In this scenario, an integrated cognitive database with a machine learning algorithm outputs related to the heritage qualification could enable the construction of an integrated knowledge management system. To this end, the adoption of Geographic Information System (GIS) tools has the potential to facilitate the systematic organisation of information at a territorial scale, integrating local specificities within their broader territorial context and providing effective support for large-scale decision-making processes. This would facilitate the understanding of critical issues in an organic and systemic way, supporting complex multi-scale decisions within governance processes.

i. Data systematisation in GIS environment

The knowledge could be collected and systematised in a GIS environment so as to create a unified system, ensuring a comprehensive and integrated overview of the port area comprising all assets located therein. Therefore, the data collected (ph.1, I), in the cognitive framework, could be associated with each port system and each system of assets. Specifically, the data contained in Level 1 (ph. 1.1) and Level 2 (ph.1.2) of the cataloguing card could be associated with port areas, represented as polygons to best describe the boundaries of these specific functional areas; instead, the data included in Level 3 (ph. 1.3) are assigned to port assets, identifiable as point elements. The information can be assigned directly, appropriately coded and integrated with other information systems or geodatabases.

ii. Data analyses

Based on this integrated knowledge system, evaluation for the analysis and management of the built environment, as the asset qualification (ph.1, II), becomes feasible. By way, it is possible to conduct an automatic and rapid evaluation of aforementioned indicators related to the functional compatibility levels (ph. 1.4), for instance, using an algorithm developed in Python or other specifically developed applications. In this way, it is possible to directly associate with each asset the relative score for each indicator, based on the previously defined criteria (Index 1, Index 2, Index 3). In the same way, no-hierarchical cluster analysis, using a machine learning algorithm, could be conducted by directly considering data that is adequately structured in a database or implemented in a GIS environment.

The potential of this system may be maximised when a local data management system becomes a shared information system through the creation of an external database, enabling continuous data exchange among stakeholders. This further opens the possibility of importing data from BIM-based information models as well.

The result is the definition of a more structured, integrated, updated and shared workflow that promotes multi-level and multi-scalar collaborative processes.

4.4.2. Ph.3.2 Design solutions management

The digitisation process at asset scale begins with the modelling of design solutions in a BIM environment, where the three-dimensional information model involves the construction of solutions accompanied by an informative system relating not only to geometric and material-construction characteristics, but also to parameters adopted in the evaluation of adaptive reuse design solutions. In this sense, the informative model may constitute a reliable cognitive basis for conducting simulations, with rapid and automated assessments, for example, through the adoption of Visual Programming Language (VPL). Furthermore, based on previous experiences in literature, virtual and augmented reality emerge as a strategic support tool in decision-making processes. During the decision-making phase, the visualisation of design solutions may prove strategic to effectively support decision-making processes. In this scenario, the proposed methodology approach for the design solution management comprises the following sub-phases, as shown in figure 10.

i. Data processing

The preliminary step includes the data collection (ph.1, I) of available documentation, both historical and technical, as a planimetry, as well as direct in situ digital surveys to define the current state of the asset investigated.

In particular, the direct survey for the reconstruction of a digital 3D models, traditionally, is carried out through meticulous, expensive and sometimes inaccurate methods, due to the complexity of the site and the operator's expertise. To overcome this issue, it is possible to carry out a laser scanner or photogrammetry (terrestrial or aerial) technology to acquire topographic, environmental and heritage 3D data. These measurement systems are a non-contact, faster, precise, and high-resolution technology returning a complete geometric reconstruction of an environment. This can be conducted with more or less advanced tools.

The data acquired are subsequently processed to generate a point cloud adequate for the reconstruction of building/environmental geometrical properties. Where direct point

cloud acquisition is not feasible, it is generated from the photogrammetric data using specific software, such as Agisoft PhotoScan or Metashape.

ii. BIM modelling of design solutions

Once the point cloud generated is imported into modelling software, the proposed methodological approach adopts a non-traditional approach (Cassano, Giannuzzi, et al., 2026). In particular, design solutions are modelled according to Scan-to-BIM similar approach, where the point cloud is used as a reference to model only the technological solutions as a BIM object. In this way, only the elements of interest will be modelled or, if necessary, only specific parts will be reconstructed, not the entire built environment. This approach ensures that the geometrically modelled solutions will be perfectly aligned and scaled with respect to the point cloud model. The element could be BIM-based, using software like Revit®. This choice is based on the necessity to have parametric objects comprehensive of related information. According to the project phase, the Level of Development (LOD) of building components, as defined by UNI 11337:2017, can be low, such as LOD C to ensure a defined object.

In order to obtain parametric model as a database useful for supporting subsequent investigations or analyses, it can be enriched with a structured system of parameters. To this aim, shared or project parameters required to conduct the analysis may be associated with each modelled element. In line with the objectives of this research, these include the previously defined system of indicators (ph.2.1) to a rapid evaluation of design solutions.

iii. Design solutions assessment

The parametric configuration of the model enables the subsequent integration of an assessment workflow. For this purpose, specific algorithms enable the automatic assessment of the intervention solutions (ph. 2.3). It is possible adopting, for example, Visual Programming Language - VPL environments, such as Dynamo or Grasshopper, connected to the BIM model. This analysis allows for evaluating changes introduced by

design solutions compared to the initial condition or different proposed design solutions.

The algorithm, structured to query the informative model, reads the values of the associated parameters and, in accordance with the algorithm, returns the evaluation results in real time based on the changes introduced with the design solutions. In this way, the evaluation process is completely integrated into the operational flow, transforming the BIM model into a dynamic decision support system, capable of effectively assisting designers in verifying design choices. The evaluation outputs promote an immediate understanding of the impact of the proposed solutions and supports the systematic comparison between alternative scenarios.

iv. Design solutions communication in AR/VR mode

In the current scenario, the communication of design solutions is increasingly oriented towards experiences, enhancing realism and user engagement through the adoption of virtual reality (VR) and augmented reality (AR) technologies, which have a high communicative potential. For this purpose, the framework proposes an innovative approach, consisting not only of the visualisation of three-dimensional design solutions, but the combined visualisation of point clouds, BIM models and VR/AR environments, particularly in case where the in situ visualisation of design solutions in AR is not feasible. The choice between virtual and augmented reality is, moreover, strongly related to the level of technology available.

For virtual reality visualisation, dedicated software offers the possibility to structure the experience in accordance with the project's aim, as 3D Vista. For AR visualisation of design solutions, the development of an application is required, starting from the development of a graphical interface, integration of the 3D models in an AR development environment and generation of an application which allows contextual visualisation of point clouds and three-dimensional design solution modelled within the context of AR visualisation.

The development of the application that combines the physical and digital environment could be initiated in a software platform for AR application development, such as Unity® 3D which allows the development of games and interactive content.

In AR applications, the central issue is spatial registration, which allows the digital model, such as BIM, point cloud or mesh, to be positioned in the real environment. The process involves two main aspects: tracking (i) and registration (ii). The first is device-related and allows real-time estimation of the position and orientation of the device (camera, headset, smartphone), allowing the model to remain anchored despite the movement of the device. The second is essential for the digital model to be aligned with the real world, ensuring a correspondence between the reference system of the digital model and that of the real environment. For localisation and tracking, in the case of non-in situ visualisation, marker-based technologies can be used, which involve the use of physical markers, such as QR codes, ArUco, AprilTag, high-contrast images or customised targets. The marker is identified by a device equipped with a camera, the position of the marker relative to the device is evaluated, and the digital model anchors itself to that reference system.

Based on these premises, the application can be developed using appropriate development software.

Initially, the user interface is designed to allow interaction with. In particular, specific buttons are implemented to enable users to display or hide various solutions, providing an intuitive way to visualize the available options. In addition, more content may be provided, for instance, containers with technical information about the solution, such as cost, material detail and maintenance information, and an upper container with detailed information about the project, as name and localization.

Subsequently, parametric models created previously and point cloud are imported into AR software development. In this way, it is possible to simultaneously visualize in AR the point cloud with the BIM models' solutions which reconstructs the rest of the building or built environment. Finally, the application is exported thanks to a technology that permits to overlap of the AR content in the physical context. The 3D model is scalable and visualisable in AR mode from multiple viewpoints, with a real aspect

thanks to BIM objects modelled textured overlap to 3D model point cloud based, through specific device or a low cost and mobile devices, as smartphone, tablet and so on. In this way, the aspects of technological and environmental compatibility, as well as technical-economic feasibility can be assessed.

4.4.3. Ph.3.3 Creation of integrated digital system

In order to systematise the knowledge system, make it accessible to both experts and non-experts involved in decision-making processes and to offer support in identifying the most appropriate solutions, an integrated digital reality-based environment could be developed.

The proposed methodological approach is based on the assumption that a cognitive system can be consulted by all actors involved in decisional processes. The structured and continuously updatable knowledge system may be queried in a virtual environment offering an adequate level of realism, high communicative capacity and ease of use, in accordance with the research purpose. In particular, the digital system is conceived with a multilevel structure, so as to collect multidisciplinary data and recreate the complexity of the built environment; it is articulated across three hierarchical levels, each calibrated to specific competencies and operational needs, adopting different tools with varying degrees of immersivity. To this end, the contents are calibrated to specific expertise and operational necessities, adopting different tools with different degrees of immersion.

The resulting system has the potential to provide operational support for planning, long-term design and management activities. In particular, it has the capacity to promote a comprehensive informed understanding of the built environment and facilitate the development of shared recovery and reuse strategies aimed at the enhancement and sustainable development adequate to local specificities. To achieve the aforementioned objective, the methodological workflow is structured in two main sub-phases: i. systematisation of cognitive system in an external database; ii. development of shared and collaborative digital system.

i. Systematisation of cognitive systems in an external database

The informative content obtained from the aforementioned cognitive processes systematised in a GIS/BIM environment (ph.3.1 and ph.3.2) is heterogeneous by nature and concerns different scales of investigation from the territorial/urban scale to the building one. The data to be collected include planning instruments and regulations, as well as information on the evolutionary processes at the area level and historical, material-constructive, conservative and functional information relating to the building. The data systematisation within a GIS platform has the potential to support territorial analysis. To ensure that these contents constitute a useful and easily accessible resource for management processes, they need to be systematised into an easily consultable and updatable system. In this perspective, the creation of an external database is a valid solution not only for operational purposes, but also for archiving, reducing fragmentation, increasing accessibility and ensuring reliability. This database, adequately structured in a semantically coherent and hierarchically consistent way with the levels of investigation previously outlined, may be implemented directly by experts or connected to online open-source repositories.

Ensuring the bidirectional communication between the different local databases and a central database is necessary to maintain a dynamic system that could be continuously updated and kept up to date. Within this process, the creation and configuration of a server allow a local storage to be transformed into a central infrastructure, guaranteeing continuous data availability, more or less controlled accessibility and continuous collaboration among the actors involved.

ii. Development of shared and collaborative digital system

Based on the previously structured information system, organised in a database, and the data acquired through the survey, the integrated digital system is conceived not merely as a tool for three-dimensional visualisation, but as a digital environment capable of organising the knowledge system, in which cognitive system and design solutions could be explored in an intuitively way.

Users' profiles orient the implementation of specific contents, as well as the communication strategies of the systems, which target two main user clusters to optimise accessibility and usability of the tool:

- *expert users*, including managers, technicians and designers involved in the planning and design phase of interventions. They require highly technical data and tools aimed at understanding the functional spatial layout and technical construction characteristics of the heritage in order to define appropriate design solutions;
- *non-expert users*, as citizens, require simplified tools aimed at raising awareness of the built environment through real world references. Therefore, the interface requires no technical skills or expertise in the advanced technological tools, thereby promoting inclusive use.

The digital system is conceived as an integrated and multilevel structure articulated across the three hierarchical levels, with increasingly detailed levels of information, from the port areas system to the design solutions for an individual asset. In particular, the first informative level contains information relating to each port area, ph.1.1 and ph.1.2; in the second informative level, information relating to each asset can be consulted for each port area, ph.1.3; the third informative level concerns the design solutions developed for each individual asset, defined according to ph.2.

Each of these informative levels could be accessible through different tools, calibrated to specific competencies and characterised by an increasing degree of immersion.

In particular, the first is technical-oriented, adopting technical tools for access to GIS and BIM projects.

The following are also accessible to non-expert users, in a non-immersive or immersive mode, and could be reached directly from technical environments.

In particular, a non-immersive environment with technical contents could be accessible via webGIS platform or structure as a virtual tour for a desktop mode. For the creation of the virtual digital environment, spherical photos or meshes permit a digital reconstruction of port environment for virtual space development, ensuring accuracy and greater realism than traditional documentation and technical tools, such as planimetry or GIS systems. In this way, it is possible to achieve a virtual reconstruction

of the urban context and the asset of interest with design solutions. The virtual experience involves the reality-based digital model enriching with different types of content, according to the previously defined informative structure. The information implemented in a database are organised according to a multilevel structure and made accessible through specific access points (hotspots) located in the virtual environment. In this way, it is possible to consult data in the specific reference context.

Finally, to achieve a greater degree of immersion, the virtual tour can be enjoyed in PC mode, as well as using immersive headsets, ensuring more realistic exploration of the built environment, as well as viewing 3D models of the assets with associated design solutions.

Structured in this way, the virtual environment constitutes a technical tool for expert users due to the technical content useful for assessments and analyses, as well as for identifying appropriate solutions. At the same time, non-expert could be involved in the decision-making process, with the possibility of exploring and comprehending the context of the investigation, with different levels of details and immersion, encouraging collaborative processes.



PART 3. CASE STUDY APPLICATION

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5. CASE STUDY

The methodological approach outlined in Chapter 4 was subsequently validated, demonstrating its operational applicability in port contexts.

MIMS identified more than 350 major Italian ports (Ministero delle Infrastrutture e dei Trasporti, n.d.). Given the considerable size of this potential dataset, the sample was limited to ports managed by the Port Authority System - AdSP, focusing the survey on the area delimited by official planning.

In this context, Legislative Decree No. 84 of 28 January 1994, 'Reorganisation of port legislation', represents a fundamental legislative instrument for the regulation of port activities in Italy. The decree is structured mainly along two lines: the reorganisation of the governance of Italian ports and the definition of the roles and responsibilities of port authorities. In particular, it establishes the creation of Port Authorities, bodies with public legal status and financial, administrative and accounting autonomy, responsible for the management, planning, promotion and coordination of port operations, as well as infrastructure development and environmental preservation. In addition, it specifically identifies port areas of national and international interest, outlining a planning system integrated with national transport policies. Specifically, Article 4 defines the dimensional, typological and functional characteristics of ports, classifying them into specific categories and classes. The subdivision is divided into two categories and three classes:

- a) Category I: ports, or specific port areas, aimed at military defence and state security;

- b) Category II, Class I: ports, or specific port areas, of international economic importance;
- c) Category II, Class II: ports, or specific port areas, of national economic importance;
- d) Category II, class III: ports, or specific port areas, of regional and interregional economic importance.

In accordance with the February 2023 update, the legislative decree provides for 16 authorities responsible for the management and organisation of assets and facilities in more than 60 Italian port areas.

Furthermore, the law specifies that the ports or specific port areas referred to in category II, classes I, II and III, have the following functions: a) commercial and logistics; b) industrial and oil-handling; c) passenger services, including cruise passengers; d) fishing; e) touristic and leisure.

- a) The commercial and logistics function consists of the transport of goods and the integrated management of intermodal operations, including the loading and unloading of containers, transshipment between sea, rail and road carriers, and the management of warehouses and terminals, thereby configuring these infrastructures as key nodes in the global supply chain.
- b) The industrial and oil-handling function is characterised by the presence of activities involving the processing of raw materials, industrial production and hydrocarbon refining, supported by specialised infrastructure such as storage facilities for oil and derivatives, shipbuilding and repair yards and facilities for the treatment of industrial materials.
- c) The passenger service function is related to maritime transport of persons, from ferry connections to tourist navigation, to the reception and management of cruise flows, requiring infrastructure suitable for ensuring embarking and disembarking operations, adequate accommodation facilities and complementary commercial and catering services.

- d) The fishing function relates to all activities connected with commercial fishing, providing fishing fleets with a dedicated infrastructure system consisting of quay berths, fish markets and facilities for processing, packaging and storing the product.
- e) The tourism and leisure function includes all activities connected with recreational boating and maritime tourism, through dedicated infrastructure for the docking of recreational boats and luxury vessels and other services, supplemented by recreational and commercial facilities.

Therefore, the investigation focused on the main Italian port areas, with particular reference to the 63 port areas managed by the Port System Authority, distributed along the coast of the peninsula (Figure 11).

The ports of the AdSP, distributed along the entire coastline of the Italian territory, are those of international (category II, class I) or national (category II, class II) economic importance. Consequently, ports of regional and interregional economic importance (category II, class III) and those aimed at military defence and state security (category I), as well as minor ports, were excluded.

In the variety of their configurations, related to the territorial context in which they are placed, as well as the conditions of their development and the needs to which they responded, the identified ports are considered representative of the peculiar characteristics of Italian ports and, therefore, of different scenarios. It was further noted that economic significance did not exclude the presence of smaller ports among those considered.

The validation concerned the entire process applied to ports managed by Port Authorities and their heritage assets. These contexts were considered as more representative due to their economic importance in the national or international context, which is reflected in contexts that are sometimes not only more extensive but also more heterogeneous from a functional point of view and therefore in terms of the heterogeneity of the built heritage used for port activities.



Figure 11 - AdSP ports distribution on Italian territory

5.1. *Cognitive framework of the port areas*

Once the context of the investigation had been identified, the cognitive process began with the data collection (I) and then with the port asset qualification (II). The data collection (I) comprises three phases for the expeditious census and cataloguing of the 63 port sites managed by the Port System Authority, as previously identified, and the heritage located within each port site. This was carried out through the adoption of a cataloguing card adequately structured for the purpose, as defined in the cognitive framework of the methodological approach (ph.1, I).

Specifically, the cognitive process involved the identification of port areas and the expeditious census of the port site identified (ph.1.1), collecting the general information; the expeditious cataloguing of port site (ph.1.2), with a more deep survey descriptive of their evolutionary processes and current state, including a census of the assets present; finally the cataloguing of port heritage (ph.1.3) present in each port, for a more detailed survey about its historical, architectural, functional and conservative aspects. Subsequently, the port asset qualification (ph.1, II) allowed the identification of typological classes of heritage based on their state of conservation and use. To this end, the assessment of the state of use and conservation (ph.1.4) constitutes the fundamental and necessary phase for the identification of port asset clusters (ph.1.5), via k-means method.

5.1.1. *Ph. 1.1 Census of port sites*

In accordance with the methodological approach defined in ph.1.1, the cataloguing cards were filled out. Level I provided an overview of port areas through an expeditious census, collecting general information on the port area.

For this purpose, initially, to each port area was associated an identification code to uniquely identify the port, formatted as APX.y, as two letters (AP) refer to the port area, followed by a number assigned to the reference AdSP (X) and a second number associated with the specific port (y) (Table 2), as define in chapter 4.2.1.

Table 2 - Identification code of AdSP ports

	Port System Authorities	AP X .1	AP X .2	AP X .3	AP X .4	AP X .5	AP X .6	AP X .7	AP X .8
AP1.y	Mar Ligure Occidentale	Genova	Prà	Savona	Vado Ligure				
AP2.y	Mar Ligure Orientale	La Spezia	Marina di Carrara						
AP3.y	Mar Tirreno Settentrionale	Livorno	Capraia	Piombino	Portoferraio	Rio Marina	Cavo		
AP4.y	Mar Tirreno Centro-Settentrionale	Civitavecchia	Fiumicino	Gaeta					
AP5.y	Mar Tirreno Centrale	Napoli	Salerno	Castellamare di Stabia					
AP6.y	Mar Tirreno Meridionale e Ionio	Gioia Tauro	Crotone	Corigliano Calabro	Palmi	Vibo Valentia			
AP7.y	Mare di Sardegna	Cagliari	Olbia	Porto Torres	Golfo Aranci	Oristano	Portovesme	Arbatax	Santa Teresa di Gallura
AP8.y	Mare di Sicilia Occidentale	Palermo	Termini Imerese	Porto Empedocle	Trapani	Gela	Licata		
AP9.y	Mare di Sicilia Orientale	Augusta	Catania	Pozzallo					
AP10.y	Mar Adriatico Meridionale	Bari	Brindisi	Manfredonia	Barletta	Monopoli	Termoli		
AP11.y	Mar Ionio	Taranto							
AP12.y	Mar Adriatico Centrale	Ancona	Pescara	Pesaro	San Benedetto del Tronto	Ortona	Vasto		
AP13.y	Mar Adriatico Centro-Settentrionale	Ravenna							
AP14.y	Mar Adriatico Settentrionale	Venezia	Chioggia						
AP15.y	Mar Adriatico Orientale	Trieste							
AP16.y	Stretto	Messina	Milazzo	Villa San Giovanni	Tremestieri	Reggio Calabria	Saline		

Afterwards, for each one the following information was collected the general information of the Level I (Table 3) concerning:

- identification code;
- name of the compiler and reviewer, including date of compiling;
- denomination, as commonly identified;
- location, namely locality and geolocation, via spatial coordinates;
- ownership and managing authorities;

- urban position (urban/ periurban/ suburban);
- state of use (in use/ partially in use/ not in use);
- current use in accordance with specific port documents.

Table 3 - Overview of main general information of AdSP ports

ID	Port area	Context/location	<i>Current use</i>	State of use
AP_1.1	Port of Genova	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_1.2	Port of Prà	urban	Industrial and oil-handling, touristic and leisure, commercial and logistics	in use
AP_1.3	Port of Savona	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_1.4	Port of Vado Ligure	urban	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_2.1	Port of La Spezia	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_2.2	Port of Marina di Carrara	urban	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_3.1	Port of Livorno	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_3.2	Port of Capraia	suburban	Touristic and leisure	in use
AP_3.3	Port of Piombino	periurban	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_3.4	Port of Portoferraio	urban (historical)	Passenger services, touristic and leisure, fishing	in use
AP_3.5	Port of Rio Marina	urban	Passenger services, touristic and leisure, fishing	in use
AP_3.6	Port of Cavo	urban	Passenger services, touristic and leisure, commercial and logistics	in use

AP_4.1	Port of Civitavecchia	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_4.2	Port of Fiumicino	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_4.3	Port of Gaeta	urban (urban)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_5.1	Port of Napoli	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_5.2	Port of Salerno	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_5.3	Port of Castellamare di Stabia	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_6.1	Port of Gioia Tauro	periurban	Industrial and oil-handling, commercial and logistics, fishing	in use
AP_6.2	Port of Crotone	urban (historical)	Industrial and oil-handling, touristic and leisure, commercial and logistics, fishing	in use
AP_6.3	Port of Corigliano Calabro	periurban	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_6.4	Port of Taureana di Palmi	urban	Touristic and leisure, fishing	in use
AP_6.5	Port of Vibo Valentia	urban	Passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_7.1	Port of Cagliari	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_7.2	Port of Olbia	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_7.3	Port of Porto Torres	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use

AP_7.4	Port of Golfo Aranci	periurban	Passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_7.5	Port of Oristano	suburban	Industrial and oil-handling, passenger services, commercial and logistics	in use
AP_7.6	Port of Portovesme	suburban	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_7.7	Port of Arbatax	urban	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_7.8	Port of Santa Teresa Gallura	periurban	Touristic and leisure, commercial and logistics	in use
AP_8.1	Port of Palermo	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_8.2	Port of Termini Imerese	urban	Passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_8.3	Port of Porto Empedocle	urban (historical)	Passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_8.4	Port of Trapani	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_8.5	Port of Gela	periurban	Industrial and oil-handling, touristic and leisure, commercial and logistics, fishing	in use
AP_8.6	Port of Licata	urban (historical)	Industrial and oil-handling, touristic and leisure, commercial and logistics, fishing	in use
AP_9.1	Port of Augusta	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_9.2	Port of Catania	urban (historical)	Industrial and oil-handling, , passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_9.2	Port of Pozzallo	suburban	Touristic and leisure, commercial and logistics, fishing	in use

AP_10.1	Port of Bari	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_10.2	Port of Brindisi	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_10.3	Port of Manfredonia	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_10.4	Port of Barletta	urban (historical)	Touristic and leisure, commercial and logistics, fishing	in use
AP_10.5	Port of Monopoli	urban (historical)	Industrial and oil-handling, touristic and leisure, commercial and logistics, fishing	in use
AP_10.6	Port of Termoli	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, fishing	in use
AP_11.1	Port of Taranto	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_12.1	Port of Ancona	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
A_PE_12.2	Port of Pescara	urban	Touristic and leisure, commercial and logistics, fishing	in use
AP_12.3	Port of Pesaro	urban	Passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_12.4	Port of San Benedetto del Tronto	urban	Passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_12.5	Port of Ortona	suburban	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_12.6	Port of Vasto	suburban	Touristic and leisure, commercial and logistics, fishing	in use
AP_13.1	Port of Ravenna	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_14.1	Port of Venezia	urban (historical)	Industrial and oil-handling, passenger services, commercial and logistics	in use

AP_14.2	Port of Chioggia	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_15.1	Port of Trieste	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_16.1	Port of Messina	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics	in use
AP_16.2	Port of Milazzo	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_16.3	Port of Villa San Giovanni	urban	Passenger services, touristic and leisure, commercial and logistics	in use
AP_16.4	Port of Tremestieri	periurban	Passenger services, commercial and logistics	in use
AP_16.5	Port of Reggio Calabria	urban (historical)	Industrial and oil-handling, passenger services, touristic and leisure, commercial and logistics, fishing	in use
AP_16.6	Port of Saline	suburban	-	not in use

As a result of the card validation for 63 Italian ports, all managed by AdSP, at the port area level, the main features of the Italian port areas were outlined through the analysis of the most recurrent characters.

At Level I, the investigation highlights that the ports considered, uniformly distributed on the national territory, are all currently in use, with the exception of the port of Saline. To define the current use, the port area planning documentation was examined, such as the Port Master Plans drawn up by the Port System Authority.

The analysis of the functions (Figure12) shows that ports serve different functions ranging from commercial and logistics to passenger services, both touristic and leisure, as well as industrial, comprising shipbuilding and fishing. The commercial function appears to be the most prevalent, as well as the touristic function, for passenger and leisure boating traffic, consistent with the historical function of ports for the transport of goods and people. Conversely, the industrial/oil-handling function and the fishing

function are marginal. While the latter can be carried out outside the port area as delimited by AdSP, the former appears to be less diffuse because it is the consequence of a particular local and territorial economic condition, associated with the resources of the territory.

Only a few ports present all functions, such as the ports of Brindisi, Cagliari, Civitavecchia, Genoa, La Spezia, Livorno, Ortona, and Trieste.

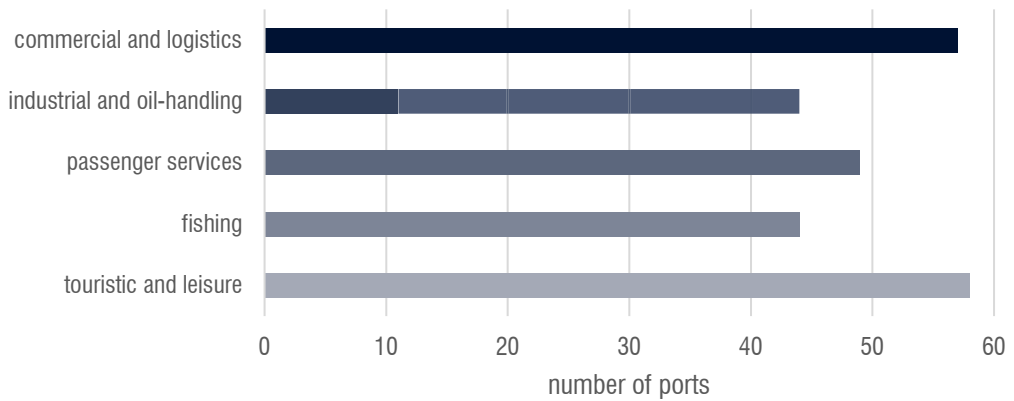


Figure 12 - Distribution of AdSP port areas functions

The historical condition of the system still influences its role in the territorial context and its function. Ports, as they currently are, often result from the extension of ancient port cores, except for a few cases in which they constitute new establishments; they turn out to be relocated due to changed regulatory requirements and they provide modern facilities. This is the case of the port of Bari, Piombino, Taranto or the case of Ravenna, whose ancient port, Porto di Classe, is nowadays an archaeological area. Analysing the territorial setting shows that most of the ports are urban/periurban, about 78%, particularly very close to historic urban centres. The remaining 22% is more delocalized, as in the case of the port of Ravenna or Portovesme located in industrial areas. The latter condition is closely associated with the "production" function and the "modern" setting in which they were first born because they required large spaces for production facilities.

5.1.2. Ph.1.2 Cataloguing of port sites

Level II consisted of a more detailed investigation of the port areas. Specifically, information about the development processes were collected, as well as a description of the current state with a census of the assets present within.

Ports of different foundation periods, from the oldest Roman layout to the newest ones with technological facilities, exemplify through the many different transformation processes that can be traced in the historical, cultural, material and structural stratification of the built heritage. Within the management perimeter of these ports, different types of assets are identified and allowed to validate the defined typological classification in 4.2.3 section.

The census of these assets was divided into three main steps. Initially, assets of interest or value were identified at the local and national levels and included in cataloguing systems. In this phase, platforms such as SID and VIR were consulted.

The survey revealed that the assets surveyed do not constitute the entire port heritage of the Italian territory. Decay and abandonment made invisible and/or uninteresting a great number of structures that are not essential for the functioning of the system, although crucial in narrating a history to which they constitute valuable testimony. Emblematic are the ports of AdSP Southern Tyrrhenian and Ionian Seas, such as Crotona, whose assets could not be surveyed through SID and VIR platforms.

Therefore, the survey was further deepened by identifying assets that were not listed but were of recognised interest within the port area planning tools or by local entities or identified within historical sources. Moreover, with careful investigation of the port areas, it can be seen that not all assets were identified. Concerning the case of Livorno, this condition is evident. From the analysis through the SID and VIR platforms, only 10 assets were surveyed; besides, the analysis of the cultural heritage in the port carried out in a study for the Livorno Port Master Plan in 2013 by AdSP, additional assets were identified, for a total of 18. However, following the identification of these on a cartographic basis (Figure 13) it is evident that, despite further in-depth analysis, there are assets not considered in either line of investigation (such as silos, warehouses and other structures) whose presence and historical cultural value cannot be neglected.



Figure 13 - Assets in port of Livorno

The asset dataset was further enriched by identifying assets whose historical, architectural and industrial value had been recognised in scientific studies or local touristic mapping systems.

At the end, heritage assets (over 400 ones) were identified, distributed over the entire Italian coast for all the AdSPs, except for the AdSP of the Southern Tyrrhenian and Ionian Seas (AP6), where no port has any historic cultural heritage within.

As figure 14 shows, the density of identified heritage is higher in the ports of central and northern Italy, including Sardinia, than in southern Italy, where the density per port is generally lower, including fewer than 10 assets, except for port of Napoli.

Out of the entire sample of the identified heritage of cultural interest, about 5% is found in the General Information System of the Catalogue of Catalogued Assets by ICCD. Slightly higher is the percentage of heritage protected by the General Directorate of Fine Arts and Landscape, nearly 10%.

5.1.3. *Ph.1.3 Cataloguing of port heritage*

Once the port heritage was identified, the detailed cataloguing of each asset was carried out. In this phase, in-depth historical research was conducted for each asset, collecting relevant data on its construction, including information on the designer, client and construction company, as well as any extensions, functional modifications and recovery interventions. This historical research was accompanied by a collection of historical iconography, including photographs, technical drawings and plans that attest to the evolution of the asset. Subsequently, each asset was described through a technical and architectural description, including details on its geometric, material-construction and typological characteristics. The survey of their current state also included an assessment of their state of conservation, classifying each asset according to its condition (poor, discrete or good), again accompanied by pictures documenting the current state. After the cataloguing of these assets, it was possible to identify recurring types in each identified category (Figure 15).

Except for port infrastructure, these types of assets are identified by Mic Classification, therefore they are representative of the port heritage, as well as the heritage in the urban context. In particular, the archaeological and historical heritage attests the ancient port area integration into the urban context; as for the industrial heritage, which is not exclusively related to port activities, such as the shipyards, it highlights the industrial and productive vocation of several port areas.

- Type I, i.e., modern heritage includes stations, military barracks, sports clubs, customs buildings, and others.
- Type II, i.e. historic buildings comprise churches, customs buildings, forts and others.
- Type III, i.e. industrial heritage includes all structures for production/manufacturing activities, such as warehouses, depots, sheds, mills and silos in addition to arsenals.
- Type IV, i.e. port infrastructures comprise lighthouses and towers, as well as spaces such as piers, docks, and dams.

- Type V, i.e. archaeological assets, such as piers and arches of Greek-Roman settlements. Finally, artworks, categorised as from type VI, are represented, for example, by the monument to Giovanni Pacini in Catania and the monument to the Fallen of the Masotto Battery in Messina.

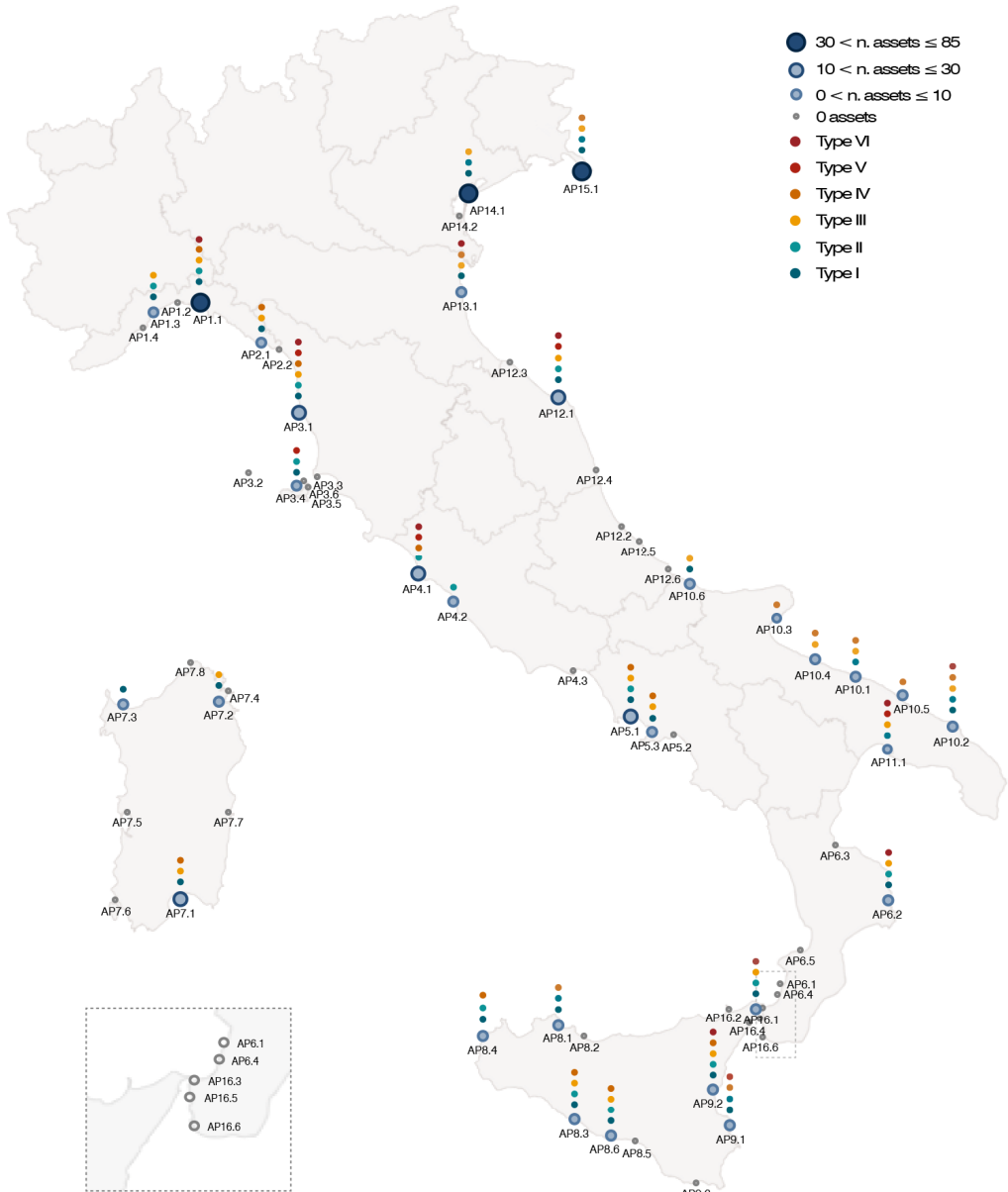


Figure 14 – Density and typological distribution of assets for each AdSP port

Type I - modern buildings	 Stazione marittima Andrea Doria - Genova	 Palazzo Coppoldi - Portofino	 Capitaneria di Porto - Bari	 Circolo Casertani "La Pensata" - Portofino
Type II - historic buildings	 Chiesa di Santa Maria - Venezia	 Porta Vecchia - Livorno	 Castello Doria 119 - Trieste	 Palazzo Doria "Alla Marina" - Genova
Type III - industrial heritage	 ex Centrale Elettrica Cantiere San Marco - Genova	 Silos granario - Genova	 Ex magazzino Montecatini - Biadene	 Arsenale - Palermo
Type IV - port infrastructure	 Torre del Macerone - Livorno	 Diga Curvilinea - Livorno	 Bacino di Careggi - Genova	 Molo Audace - Trieste
Type V - archeological asset	 Porto di Civitavecchia	 Molo romano o del lazaretto - Civitavecchia	 Arco Traiano - Ancona	 Fornace - Porto Tolle
Type VI - work/object of art	 Caduti della Battaglia di Mauthausen - Messina	 Monumento a Giovanni Pecini - Catania		

Figure 15 - Types of surveyed assets

Due to previous port heritage cataloguing, industrial heritage is the type of asset that received the most attention (Figure 16a). Nevertheless, it is important to consider that the percentages concerning architectural assets, whether historical or modern, are not very significant. This is due to a considerable number of assets surveyed but not

catalogued according to the defined typologies, because there was no information on the VIR platform about the construction period of those specific assets. On the other hand, the number of port infrastructures surveyed is smaller (type IV), followed by archaeological assets (type V). As for works of art (type VI), these constitute a very small percentage. Moreover, it is possible to recognise trends when the types of assets are analysed by a single port (Figure 16b).

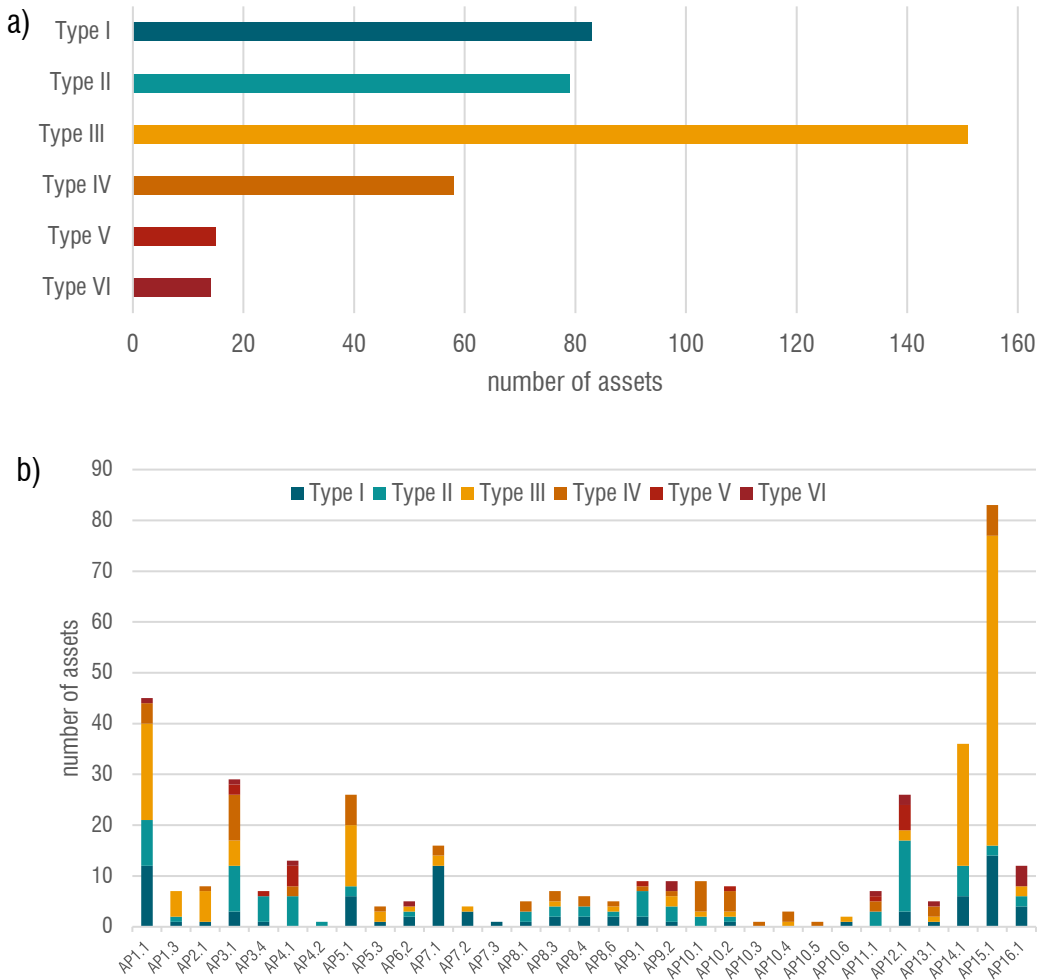


Figure 16- Distribution of assets a) by type and b) by type and location

Furthermore, information was collected on the condition, state of conservation, original function and current function of all the assets surveyed, consulting national and local cultural heritage databases, integrated with the use of digital mapping tools such as Google Maps/Earth.

As regards the functional analysis of the context in which the assets are located, the planning documentation for the port area was examined. Specifically, through the Port Master Plans drafted by the Port System Authority, it was possible to identify the functional areas in which the port assets are located, such as commercial, leisure, military, touristic, services and urban port areas.

5.1.4. Ph.1.4 Evaluation of state of use and conservation

Based on preliminary census and cataloguing of port area and heritage located within, a systematic asset qualification was conducted through the assessment of state of conservation and use of each asset, in accordance with the indicators and assessment methods outlined above in the methodological approach defined in ph.1.4. In particular, the functional compatibility levels were evaluated through qualitative indicators by assigning a Likert scale score.

This detailed analysis, aimed at the subsequent identification of clusters (ph.1.5), was conducted on a limited sample of assets. To this end, the main Italian ports managed by AdSP were considered, one for each AdSP, preferring those with more assets, chosen as representative of different territorial conditions. Specifically, the following port areas were considered: Genova, La Spezia, Civitavecchia, Livorno, Napoli, Crotone, Cagliari, Palermo, Catania, Bari, Taranto, Ancona, Ravenna, Venezia, Trieste e Messina. This methodological choice was considered functional to provide a comprehensive and synthetic overview of the most relevant dynamics, considering all assets located within the port area. The dataset included 260 assets, excluding those for which there were an incomplete information.

Initially, a comprehensive investigation was carried out on the state of use and disuse of the port heritage. The analysis revealed a significant percentage, equal to 28%, of the assets surveyed that are currently not in use (Figure 17). This percentage, consisting mainly of industrial heritage (type III), was determined by the significant

number of disused warehouses in the port area of Trieste. There were also cases of modern buildings (type I) currently in disuse, including the former Locanda 116, Refettorio 107, Edificio 133 and Edificio 118 of the former administration in Trieste, as well as isolated cases in other ports, such as the former fishing fair in Ancona.

Regarding the state of conservation of the identified assets, the analysis highlighted a strong correlation with the state of use/disuse (Figure 18). Most of the disused structure are in a very poor state of conservation, as shown by some examples in figure 19; on the other hand, the assets in use are generally in a good state of conservation.

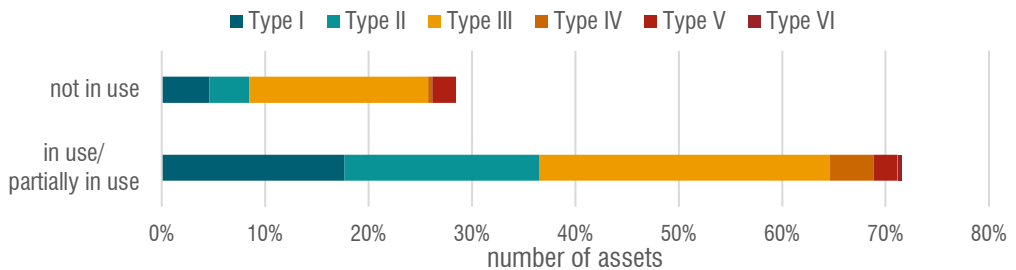


Figure 17 - State of use

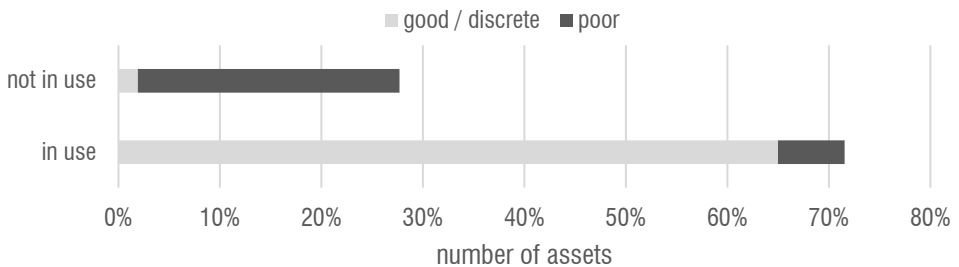


Figure 18 - State of conservation



Figure 19 - Assets currently not in use and in a very poor state of conservation: a. Former inn 116, b. Former administration building 118, c. Warehouse 2. Source (Il Porto Vecchio Di Trieste, n.d.)

The analysis of functions, referring specifically to heritage currently in use, revealed a percentage of approximately 47% of surveyed assets that have retained their original function (Figure 20). The heritage involved includes different types, with a prevalence of modern assets, followed by industrial, historical and port infrastructure ones. An emblematic case is the port of Bari, where all the assets have maintained the function for which they were conceived. In contrast, for example, in the port of Ancona, few assets have maintained their original function; these include the 18th-century buildings and the Enel coal bunker, originally used as a coal depot and currently as a warehouse, thus continuing to perform a function similar to its original one. There are intermediate scenarios, such as the ports of Trieste and Catania, characterised by the partial preservation of their original function, as in the case of historic warehouses.

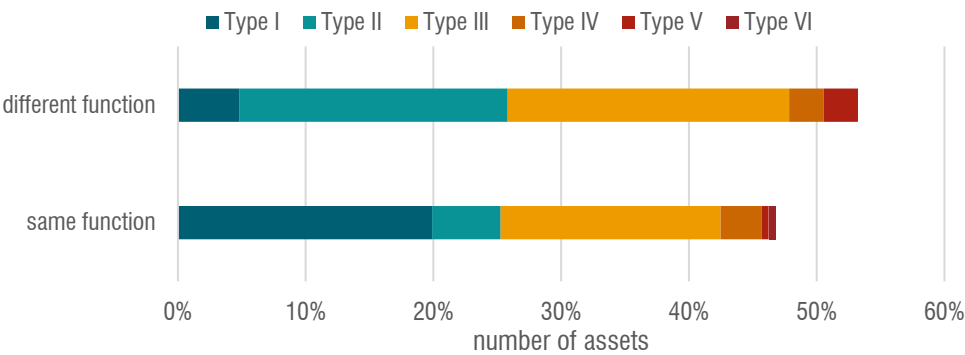


Figure 20 - Function analysis for assets in use

By analysing the heritage in use affected by requalification projects, although it includes different types of assets with different functions, it is possible to identify recurring aspects. For example, historical assets, such as those found in the port of Ancona, have tended to lose their original function over time and are now cultural attractions. Industrial assets and port infrastructure, on the other hand, are frequently reused as offices and cultural centres, particularly museums and conference centres.

Indicator 1, defined as functional compatibility with the surrounding context, allowed to assess the degree of functional integration of each asset in relation to the function of the specific area in which it is located. The results were analysed by considering

categories of functions capable of expressing the functional use of the asset as Commercial, Cultural, Directional, Industrial, Infrastructural, Logistic/storage, Military, Multifunctional, Touristic-receptive, Recreative, Religious, Residential (Figure 21), in order to outline an overview. Almost all of the assets with high compatibility (5) are industrial heritage assets. Some of these, such as warehouses, silos and customs buildings, continue to perform their original logistics and storage functions, remaining integrated and coherent with the commercial vocation of the area in which they are located. However, other structures have been reused and redeveloped, maintaining a good level of compatibility with the function of the area. Representative examples include modern heritage such as the Sanità building in Catania, currently used as the headquarters of the Port Authority (Capitaneria di Porto), the former civil seaplane station and the Lanterna di Trieste. Although these were repurposed for administrative use, they continue to support the activities of the specific area in which they are located coherently. A similar scenario occurs in tourist areas, given the presence of maritime stations and passenger terminals that continue to operate as tourist facilities.

A similar scenario was observed in tourist areas, given the presence of maritime stations and passenger terminals that continue to operate as touristic-receipt facilities, highlighting a high level of compatibility with the context. A good level of compatibility (4) recurs in the case of historical assets, particularly in the port of Ancona, such as the Arco Clementino, the Arco di Traiano and the archaeological area of the Trajan port, which are cultural attractions and can be considered in line with the tourist function of the area in which they are located. The remaining part of the industrial heritage of the port of Trieste was re-functionalised mainly for cultural purposes, such as museums, cultural spaces and conference centres, and has partial compatibility (3) with the service function of the port area in which it is located. There are isolated cases where the property has retained its original function despite the evolution of the context, thus presenting a condition of minor or total incompatibility (2-1) with the current function of the port area; a case in point is Power Station 129, located in the service area of the port of Trieste.

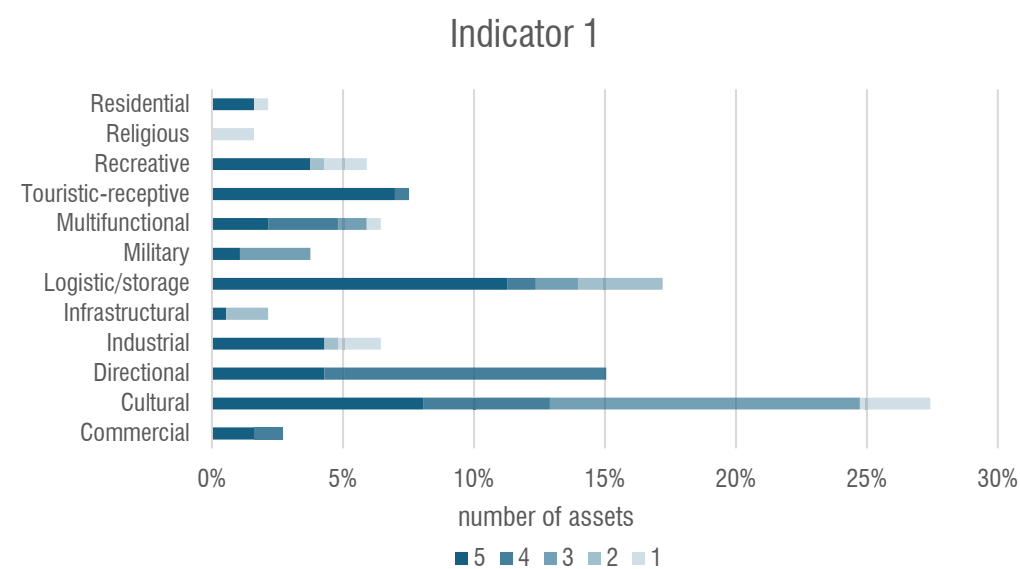


Figure 21 - Indicator 1 values relating to functional compatibility with the context

Through the Indicator 2, the compatibility between the current function and the original function was assessed, analysing the continuity of use over time. The results revealed that approximately 50% of assets with high compatibility (5) consist of different type of assets that retained the function for which they were originally conceived. At the same times, numerous assets present partial (3) or low (2) functional compatibility (Figure 22). The latter mainly consists of industrial heritage that was converted to cultural functions, such as museums, cultural centres and conference centres. They also include historical or archaeological heritage originally used for military-defensive purposes and now constitutes a cultural attraction. Although they are in use, in line with the formulation of the indicator, their current function does not evoke the original function or have a different operational logic.

Indicator 2

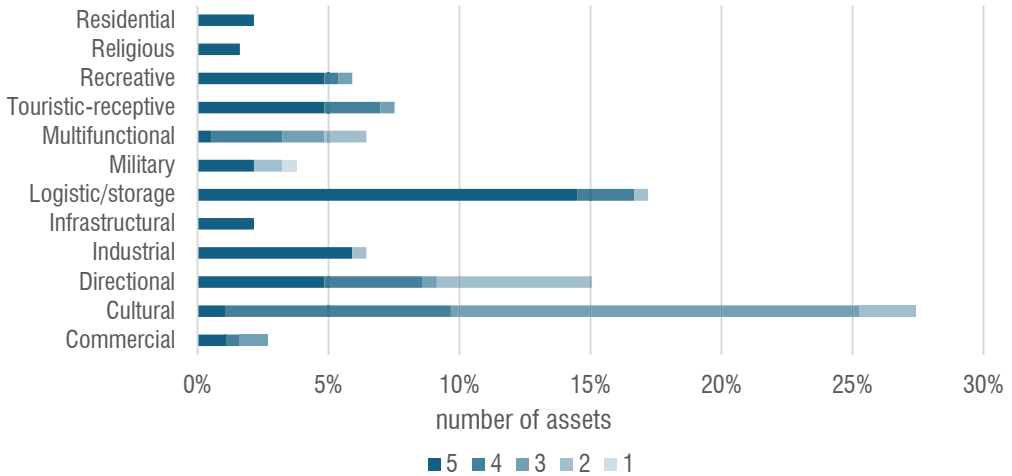


Figure 22 - Indicator 2 values relating to functional compatibility with the original function

Indicator 3, concerning compatibility between the current function and the original architectural characteristics of the asset, allows for the assessment in relation to the type of intervention carried out to maintain the asset in efficiency or to adapt it to accommodate a new function responding to contemporary needs. The analysis highlights a high percentage, approximately 40%, of properties which, in maintaining their original function, have preserved the identifying characteristics of the original property. In addition to these, there was a high percentage of different types of assets that were highly compatible with the original building (5) despite no longer being used for the same purpose (Figure 23). These included the historical heritage of the port of Ancona, which has preserved the historical characteristics of the assets, making them usable as cultural heritage. A similar case concerns part of the industrial heritage, such as the former Central Fish Market in Trieste, currently accommodating an exhibition space, the Salone degli Incanti, where not only the exterior was preserved, but also the configuration of the interior spaces adapted well to the new function. These are followed by cases with good compatibility (4), where there has been an attempt to reconstruct the original features of the building or to adapt the interior spaces to accommodate the new functions. One example is the former Wine Depot in Trieste, which now

accommodates a EatItaly food chain store, where the reuse project involved the reconstruction of parts of the original building that had been destroyed and the construction of an additional, independent internal structure using glass surfaces capable of maintaining visual continuity with the original structure. Another example is the Mole Vanvitelliana or Lazzaretto in Ancona, where only the external spaces were reorganised. There were isolated cases of low compatibility (2) or total incompatibility (1). This is the case of the basement of the Trieste lighthouse, on which an additional building has been constructed, and of Warehouses 27 and 28, which have almost completely lost the identifying features of the original structure.

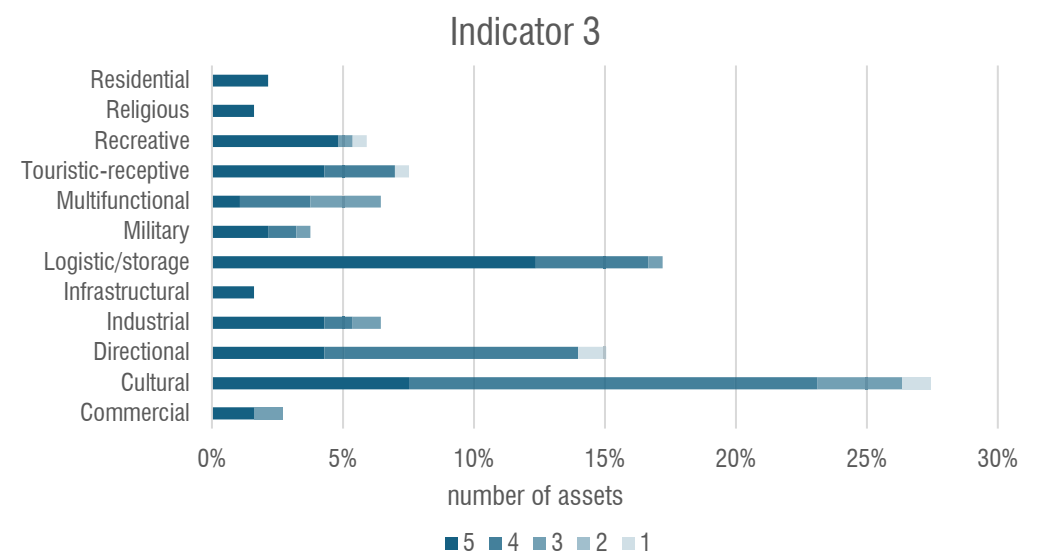


Figure 23 - Indicator 2 values relating to functional compatibility with the original asset

According to the aims of this research, the investigation allowed to outline an overview of the port heritage, through sixteen port contexts of different origins and evolutionary dynamics, considered representative of the Italian territory. The heterogeneity of the built heritage reflects territorial dynamics and socio-economic developments, significantly influencing the type of heritage present, as well as its state of use, state of conservation and current function.

The analysis revealed that approximately 28% of the assets surveyed were in disuse and in a poor state of conservation. These are industrial assets, mainly warehouses,

generally located in commercial or service areas. From a historical point of view, this phenomenon could be traced back to the transformations of the 20th century and the overcoming of the economic-productive models for which they were conceived, as well as continuous technological progress, which has emphasised their inadequacy compared to contemporary production models. Consequently, as they gradually lost their usefulness, they were not reintegrated into the logistics chain. This situation is not unique to some cities such as Trieste, but can be considered representative of a broader phenomenon affecting other contexts characterised by similar evolutionary processes. As regards the heritage currently in use, functional continuity emerged in the 19th-century constructions, suggesting a context still capable of meeting contemporary needs, thereby ensuring continuity of use. Where, on the other hand, reuse interventions were carried out, this does not appear to be associated with specific functional dynamics of the context over time, but rather as a result of consolidated historical and evolutionary processes that have characterised the development of the port area over time. In this scenario, functional transformation played a crucial role not only in preventing abandonment and degradation, but also in contributing to cultural and economic revitalisation.

The port heritage, with specific focus on assets in use, was analysed by evaluating indicators related to function and compatibility with the function of the context (indicator 1), with the original function of the asset (indicator 2) and with the construction characteristics that define the identity of the asset (indicator 3). With the exception of cases where the assets have maintained continuity of use over time, as well as conserving their structural characteristics, the survey highlighted some interesting dynamics. The first indicator, characterised by greater variability, highlighted two opposing situations: on the one hand, the re-functionalisation projects exemplify the capacity of reuse not only to preserve the built heritage, both historical and industrial, but also to effectively reintegrate it into the port and urban context in line with contemporary needs and without incompatibility with the function of the area and the operational activities carried out; on the other hand, the evolution of the functions of the areas, in relation to the changed port activities and related production processes, has

led to a reduction in the functional compatibility of a series of structures which, although still operational, are now less compatible with the context in which they are located. The second and third indicators highlighted similar outcomes. The analysis revealed that the reuse of port assets, as well as the intent to maintain operational structures or infrastructure, demonstrates an awareness of the necessity to reintegrate abandoned or underutilised structures and the importance of maintaining a connection with one's historical identity. In particular, the interventions are not only functionally compatible with the original function, but often increase its tangible and intangible value. This is evident in cases where new uses, such as museums, remain thematically aligned with maritime culture and traditions. By hosting exhibitions related to the history and maritime practices of the port, a meaningful and contemporary use is attributed to it, while reinforcing its symbolic significance. Such interventions not only ensure the functional recovery of the heritage, but also enhance its historical and cultural value as a port.

5.1.5. Ph.1.5 Identification of assets clusters

In order to orient strategies for the recovery and adaptive reuse of port assets, the research aimed to identify representative conditions relating to port assets. Specifically, the research involved the application of an unsupervised clustering technique in order to highlight recurring conditions.

i. Dataset identification

According to the methodological approach defined in ph.1.5, the dataset considered consists of the 260 assets previously analysed, for which data was collected on their state of conservation, state of use and levels of compatibility. Based on these variables, appropriately defined and normalised, an algorithm was performed to conduct clustering. The algorithm chosen was the k-means method, considered the most effective for this purpose. Therefore, the optimal number of clusters was determined through an integrated assessment of the elbow method with cluster stability tests. Finally, the groups obtained were profiled by analysing the values of the variables involved in the assessment.

ii. Parameters identification

To conduct the cluster analysis, specific parameters associate to each asset were considered, as defined in the phase1.5 (Table 4). These parameters were collected during the cataloguing of port heritage, state of conservation and state of use, (ph.1.3) and obtained with the functional assessment, Index 1-2-3, (ph.1.4). Since two parameters were expressed in an ordinal scale, a preliminary data processing was conducted to simplify the analysis, converting them into a cardinal value. Subsequently, in order to preserve robustness and reliability, the dataset was controlled, to any incomplete rows to avoid data that could influence the final output. Once the dataset consisting of values for each asset, the cluster analysis was initiated.

Table 4 - Parameters identification for clustering

Parameter	Evaluation range	Metric
State of conservation	good/discrete/bad	[1-3]
State of use	in use/ partially in use/ not in use	[1-3]
Index 1	[1-5]	[1-5]
Index 2	[1-5]	[1-5]
Index 3	[1-5]	[1-5]

iii. Parameters standardisation

The data were initially standardised using z-score transformation. This normalisation was necessary given the presence of heterogeneous parameters, i.e. the difference in range between state of conservation and use and levels of functional compatibility.

In the expression, μ is the mean and σ the standard deviation of the variable x_i considered.

$$x_{normal} = \frac{x_i - \mu}{\sigma}$$

iv. Identification of number of clusters

The optimal value of k was determined in order to establish the optimal number of clusters. This assessment was conducted using the Elbow method, in which the SSE (Sum of Squared Errors) value indicates the compactness of the clusters: lower SSE values indicate more compact clusters, while higher SSE values suggest greater internal dispersion.

$$SSE = \sum_{i=1}^k \sum_{x \in C_i} ||x - \mu_i||^2$$

Specifically, inertia was calculated for k values between 2 and 10. The ‘elbow’ of the curve indicates the optimal k value in relation to the SSE value (Figure 24). Therefore, a k value equal to 6 was chosen.

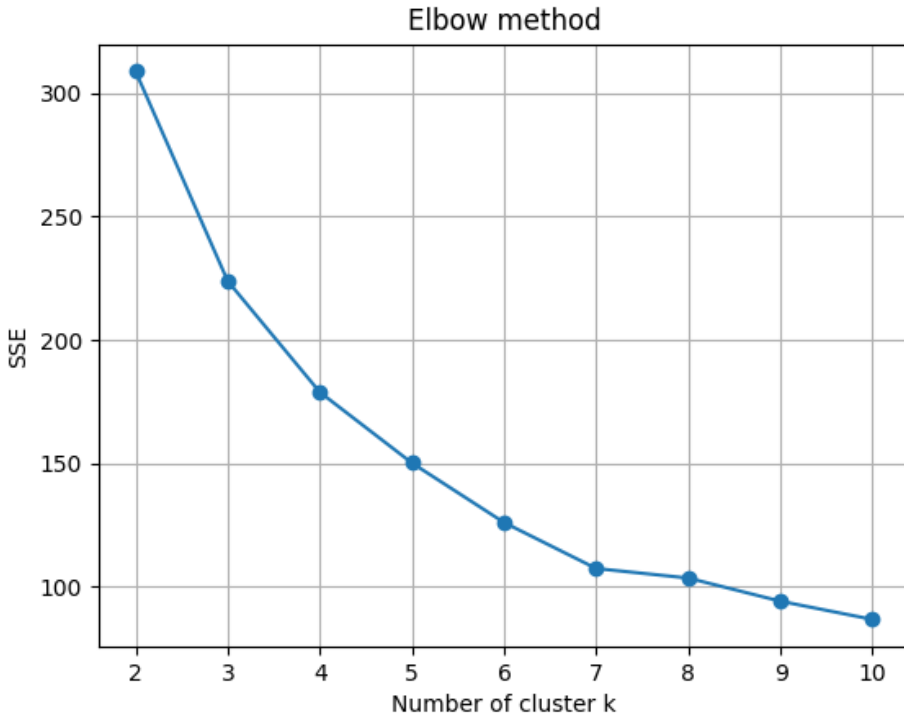


Figure 24 - Result of Elbow method application

v. Evaluation of clusters stability

Afterwards, test were carried out to verify the stability of the clusters. The chosen k value had to be able to balance statistical robustness and typological interpretability. Therefore, the analyses were carried out to determine:

- the average Silhouette score, for cohesion/separation within the clusters
- the Calinski-Harabasz index
- the Davies-Bouldin index

The Silhouette score equal to 0.54 indicated good separation between clusters and greater cohesion than cases with lower k values. This assessment was accompanied by analysis of the Calinski-Harabasz index and the Davies-Bouldin index for the evaluation of internal consistency, supporting the identification of the optimal k. Specifically, when k was increased (to 7), the Silhouette score increased marginally,

while the Calinski-Harabasz index decreased and the Davies-Bouldin index increased, highlighting how, as the number of clusters increases, the quality of segmentation worsens, despite a slight improvement in the Silhouette score, risking over-partitioning of a homogeneous group.

Furthermore, the analysis of the distances between the centroids revealed a clear separation in some cases and a smaller separation in others, attributable to the significant variation observed for specific conditions (Figure 25).

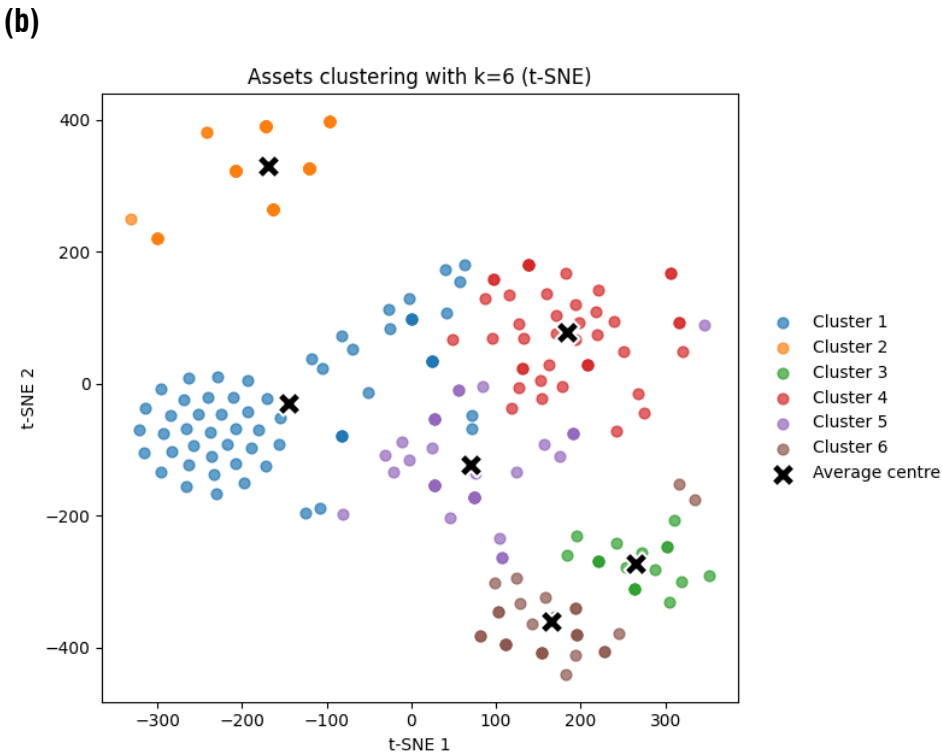
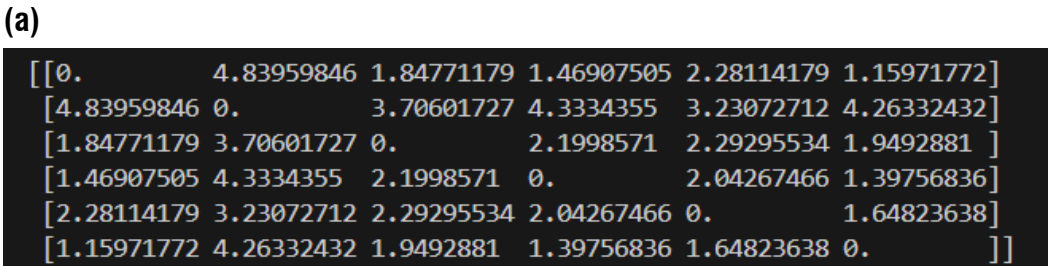


Figure 25 – Distance between centroids (a) and visual distribution of clusters through t- SNE (b)

vi. Qualification of port asset clusters

Based on the output, it was possible to interpret the different conditions based not on individual indicators but on configurations that combine different aspects capable of representing the complexity of the state of the port heritage. The output of the cluster analysis identified six average cluster profiles. The results highlighted the specific identifiable conditions, as illustrated below (Figure 26).

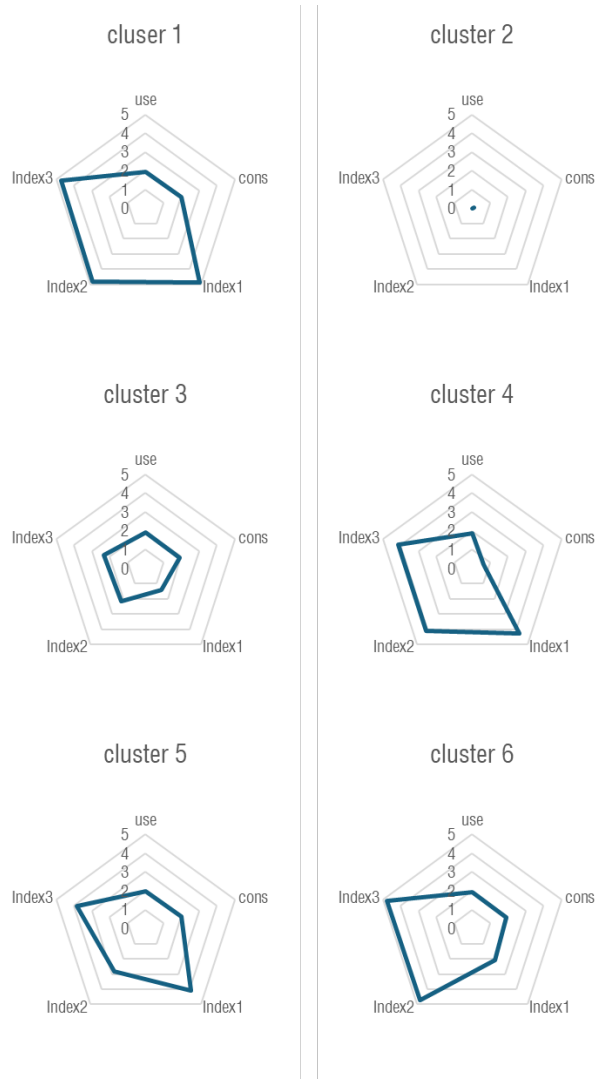


Figure 26 - Characteristics distribution in each cluster

Specifically, the clusters identified were defined, as follows:

- **Cluster 1:** assets in use (≈ 2), in good state of conservation (≈ 2) and with high levels of functional compatibility (≈ 5);
- **Cluster 2:** assets not in use ($= 0$), in poor state of conservation (≈ 0) and therefore with null compatibility levels, given the absence of a current function in relation to which to conduct the analysis;
- **Cluster 3:** assets in use (≈ 2), in good state of conservation (≈ 2) and with low functional compatibility levels (≈ 2);
- **Cluster 4:** assets in use or partially in use (≈ 1.5), with a generally poor or mediocre state of conservation (≈ 1), good compatibility with the context, the original function and the original building (≈ 4);
- **Cluster 5:** assets in use (≈ 2), in good state of conservation (≈ 2), average compatibility with the context and the original building (≈ 4) and lower compatibility with the original function (≈ 3);
- **Cluster 6:** assets in use (≈ 2), good state of conservation (≈ 2), lower compatibility with the context (≈ 2) and high compatibility with the original function and original building (≈ 5).

Although clusters 3, 4, 5 and 6 were characterised by high levels of use and conservation overall, they included cases with lower values, which constitute cases of comparatively lower incidence in the respective cluster. Based on profiling results, each asset was assigned to a cluster according to the algorithm output, with variable distributions (Figure 27). Moreover, analysis of the distribution of each asset type within each cluster revealed that all clusters included almost all types of assets.

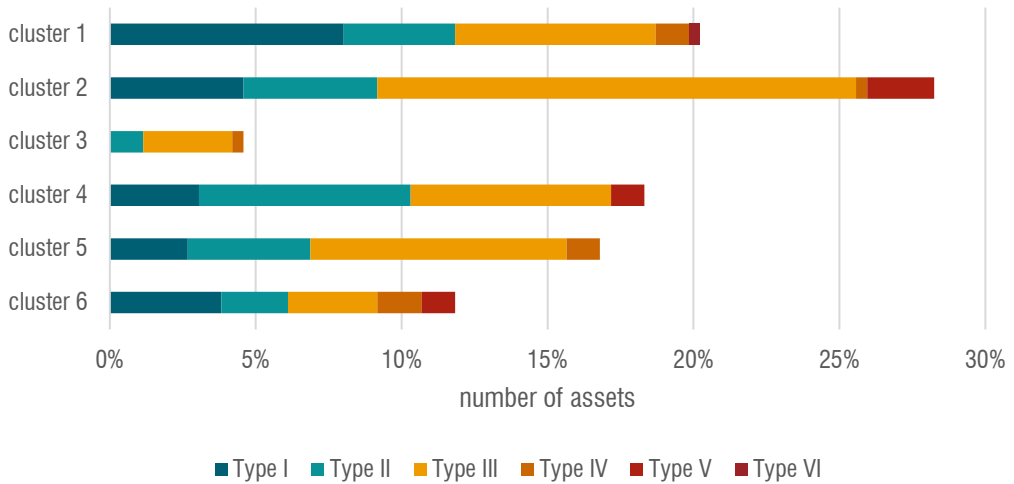


Figure 27 - Profiling of each cluster

Through a cross-cutting perspective, the analysis highlighted that the largest cluster was composed of assets that are not in use and in poor state of use (cluster 2), confirming the assumption that port areas contain a rich port heritage in a state of decay and abandonment, which needs to be recognised and reintegrated into the port and territorial context. This was followed by assets that continue to perform their function in continuity with the past (cluster 1), attesting to the functional continuity of the port area itself. The remaining assets constituted a significant percentage of the port heritage and presented different conditions, requiring attention and reintegration into larger regeneration projects. Among these, the cluster consisting of assets in use or partial use that was in a state of disuse and decay (cluster 4) was particularly significant.

5.2. *Ph.2 Analysis and definition of design strategies of Adaptive Reuse*

In the proposed methodological framework, the definition of design strategies was part of a data-driven decision-making process, starting with the cognitive framework. In this scenario, the results of clustering (ph.1.5) were pivotal in identifying strategic approaches coherent with the intrinsic characteristics of the heritage. These strategies required adaptation to local specificities. Therefore, the efficacy and feasibility of the design strategies (ph.2.1) were validated through the analysis of design solutions in main real cases, considered as best practice, where paradigmatic interventions were carried out. The aim was to investigate how the most recurring meta design strategies, in the practice of adaptive reuse and enhancement of port heritage, were applied and declined in design solutions, providing insights into effective heritage transformation practices (ph.2.2). For the purpose, the analysis of 27 recovery, reuse and requalification projects of national and international port assets cases allowed for the definition of an atlas of meta-design strategies, conceived as an open multidimensional tool of strategies and intervention solutions for adaptive reuse.

These were subsequently evaluated through a multi-criteria decision analysis (MCDA), using the Analytic Hierarchy Process (AHP) method (ph.2.3) to compare different design solutions for the adaptive reuse of port heritage.

The process was then validated through its application to a real case (section 4.6.3), to highlight the potential and applicative issues of the method. The case study was Palazzo della Dogana in the port of Bari. Belonging to the largest cluster of assets in use (cluster 4), it was chosen to analyse the most recurrent condition. According to profiling, as well as the local specificities, the design solutions were identified, demonstrating the capacity to respond to real conditions. Finally, the proposed solutions were then evaluated to suggest the more suitable solution for the local context.

5.2.1. Ph.2.2 Identification of Adaptive Reuse solutions

Based on the conservative and functional aspects that characterise each cluster's profile, the research aimed to outline possible strategic directions that requiring priority attention in design solutions. For each case, the necessity for conservative intervention was assessed, in relation to the state of conservation, and the main aspects to be considered were identified, according to the dimensions previously identified as fundamental to the adaptive reuse of heritage. In detail:

- **Cluster 1:** these assets are in good condition and well maintained, with high levels of compatibility, showing continuity of use over time and permanent good integration into the port system, for which minimal ordinary maintenance is required;
- **Cluster 2:** the assets of this cluster are in a state of decay and abandonment, requiring recovery and reuse interventions, in which all dimensions will be carefully considered;
- **Cluster 3:** in this case, the assets have significantly low levels of compatibility, highlighting a situation similar to the previous one (cluster 2), without presenting conditions of decay and abandonment, requiring a redesign of their function for greater enhancement;
- **Cluster 4:** these assets are characterised by heterogeneous conditions of use and a mediocre/poor state of conservation, with good levels of compatibility, requiring recovery and reuse interventions aimed at conservation and enhancement of the asset. In this case, it may be necessary to focus on authenticity and historicity, as well as social and environmental aspects, in order to better respond to the community's needs and improve integration into the contemporary context;
- **Cluster 5:** this cluster includes assets in use and in good condition, but with low level of compatibility with their original function, highlighting situations in which the function has been changed to meet contemporary necessities and for which interventions aimed at preserving their identity may be necessary, focusing on the aspects of authenticity and historicity, as well as social

aspects, in order to increase recognition of their historical and architectural value;

- **Cluster 6:** the assets of this cluster are characterised by low compatibility with their context. These are assets that continue to perform the same function in a context that has evolved over time. Therefore, it may be necessary to adapt them by defining reuse strategies to ensure adequate functionality and enhancement within the contemporary context, or strategies that allow for greater integration and use within the area, with attention to the environmental dimension.

The above indications should be considered as priority guidelines, rather than prescriptive rules. Each dimension is interconnected with the others and mutually inclusive, since any proposed intervention may simultaneously respond to different design perspectives.

Moreover, to overcome the limitations of “case-by-case” approaches, the proposed approach allowed to interpret the complexity of adaptive reuse port heritage, offering a methodological basis. In line with the multidimensional approach, the analysis of international recovery, reuse and requalification projects related to port heritage resulted in the definition of an atlas of meta-design strategies for adaptive reuse, structured around the main dimensions. The 22 meta-design strategies (S), analysed in terms of design solutions (s) for the 27 port assets in chapter 2.2, were not conceived as prescriptive, but rather as guidelines intended to support complex decision-making processes in different contexts, enhancing the peculiarities of the considered heritage and according to local specificities. The analysis of real cases highlighted that, despite the heterogeneous port contexts and distinct types of port assets, the same meta-design strategies could be identified. The atlas, structured in this way, constitutes an open methodological tool that could be enriched and validated through further real cases and project applications.

In this analysis the functional dimension was excluded, for which the consultation was demanded in a preliminary stage for the assessment of functional compatibility,

according to the ph.1.4, as well as the legal one, as necessary condition to ensure compliance with local and territorial requirements and for the heritage conservative. The system of meta-design strategies (S) and technical solutions (s) identified for each dimension are illustrated below, with reference to the best practices (P) analysed in chapter 2.2, from which they were derived, and presented in the Atlas of meta design strategies (Annex 4).

D1 ARCHITECTURAL DIMENSION

S1.1 MINIMUM INTERVENTION

CONSERVATIVE RESTORATION

- *s.1.1.1 Restoration of original external finishing (P4, P11, P13, P14, P16, P17, P25)*
- *s.1.1.2 Restoration of original internal finishing (P4, P6, P14)*
- *s.1.1.3 Conservation of decorative elements (P1, P4, P6, P13, P14)*
- *s.1.1.4 Conservation of non-structural elements, such as roof finishing (P11), furniture (windows, shutters) (P4, P6, P11), roof windows (P18)*
- *s.1.1.5 Repair of building components (P14, P16, P18)*

MAINTENANCE

- *s.1.1.6 Replacement of non-structural elements, such as cladding, pavement (P13)*
- *s.1.1.7 Renovation of building systems/ facilities repair (P6, P13, P14, P15, P16, P19)*

S1.2 ARCHITECTURAL HARMONY AND VISUAL COMPATIBILITY

ELEMENTS CONSERVATION

- *s.1.2.1 Preservation of architectural composition (P4, P12, P13, P14, P15, P18, P20, P21, P22)*
- *s.1.2.2 Use of compatible materials, as stone, bricks, steel, glass and concrete (P4, P6, P13, P14, P15, P18, P21)*
- *s.1.2.3 Use of the same materials (P2)*
- *s.1.2.4 Conservation of constructive technology (P15, P18)*
- *s.1.2.5 No finiture for internal spaces (P24)*
- *s.1.2.6 Aesthetic integration of systems (P11)*

NEW ELEMENTS INTEGRATION

- *s.1.2.7 Use of glass surface for internal/ external elements (P15, P16, P17, P19, P20, P24)*
- *s.1.2.8 Use of glass surface and steel elements for internal partition (P16)*
- *s.1.2.9 Addition of external cladding in steel and glass (P10, P17, P19, P24)*
- *s.1.2.10 Addition of ceramic cladding on steel structure (P17)*
- *s.1.2.11 Dry systems for external/internal wall and suspended ceiling (P10)*

S1.3 SPACE FLEXIBILITY

SPACE RECONFIGURATION

- *s.1.3.1 Adoption of lightweight elements (P14, P15, P16, P17, P18, P19, P20, P21, P23, P24)*
- *s.1.3.2 Adoption of modular prefabricate elements, as painted cladding panels (P13, P18, P21)*
- *s.1.3.3 Construction in mezzanine floors using lightweight steel components (P16)*
- *s.1.3.4 Use of flexible furniture to organise the space and accommodate new function (P23)*

D2: STRUCTURAL DIMENSION

S2.1 RETROFITTING OF EXISTING STRUCTURE

STATIC CONSOLIDATION

- *s.2.1.1 Structural consolidation (P11)*
- *s.2.1.2 Structural strength improvement (P1, P14, P23)*
- *s.2.1.3 Roof reinforcement (P3)*

STRUCTURAL CONSERVATION

- *s.2.1.4 Conservation of constructive element and technologies, as concrete or steel element (P11, P15, P18, P23)*
- *s.2.1.5 Conservation and consolidation of foundation (P10)*

REGULATORY COMPLIANCE

- *s.2.1.6 Structural adequacy (P14)*
- *s.2.1.7 Fire adequacy (P6, P11)*

S2.2 STRUCTURAL INTEGRATION

- *s.2.2.1 Inclusion of internal/external structural steel element (P13, P16, P17)*
- *s.2.2.2 Addition of vertical connections in steel and glass (P10, P16, P19)*

INTEGRATION OF NEW INDEPENDENT STRUCTURE

- *s.2.2.3 Addition of external structures structural steel and glass element (P6, P17, P18)*
- *s.2.2.4 Integration of internal structures prefabricate, modular (P16, P20)*
- *s.2.2.5 Integration of internal structures prefabricated and dry-built, in wood (P3)*

INTEGRATION OF NEW COLLABORATIVE STRUCTURE

- *s.2.2.6 Addition of internal structures (P23), as walkways (P17)*
- *s.2.2.7 Addition of structure in steel at different level using existing industrial structures (P21)*
- *s.2.2.8 Addition of elevation structure with the same materials (P24)*

S2.3 DISMANTABILITY/FLEXIBILITY OF COMPONENT

- *s.2.3.1 Addition of modular prefabricated elements, in cross-laminated timber (P3, P18)*
- *s.2.3.2 Addition of new floors in steel and glass (P16, P19) or in steel and concrete (P24)*

D3: SOCIO-CULTURAL DIMENSION

S3.1 SOCIAL INTEGRATION AND INCLUSION

- *s.3.1.1 Organisation of public and private events (P6, P7, P12, P13, P18, P21, P23, P24, P25)*

- *s.3.1.2 Organisation of collaborative activities for educational purpose (P6, P14, P18, P19, P21), workshops for artistic purpose (P11)*
- *s.3.1.3 Organisation of cultural activities, as theatrical and musical (P4, P6, P8, P18, P20, P23, P25) or artistic activities (P11, P23) or social activities (P7)*

S3.2 ATTACHMENT AND SENSE TO PLACE

CONSERVATION OF INDENTITY CHARACTERISTICS

- *s.3.2.1 Spatial conservation (P13, P14, P20)*
- *s.3.2.2 Conservation of furnishing (P14), as chandeliers (P6)*

CONSERVATION OF IDENTITY SIGNIFICANCE

- *s.3.2.3 Maintenance of symbolic role in the area (P7, P12, P18, P22, P25, P26, P27)*
- *s.3.2.4 Design of transversal passage (P17)*
- *s.3.2.5 Narration of local identity with artistic implementation, as literary façade (P17), murals (P22)*

D4: ECONOMIC DIMENSION

S4.1 FUNCTIONAL MIXES

ECONOMIC DEVELOPMENT

- *s.4.1.1 Addition of new commercial activities, as bar, restaurants (P6, P12, P17), shopping centre (P1)*
- *s.4.1.2 Addition of new services (P17)*

CREATION OF NEW JOB POSITIONS

- *s.4.1.3 Addition of new activities (P6, P9, P11, P18, P23, P25)*
- *s.4.1.4 Increase activities related to the same function or operational structure (P1)*

ATTRACTION DIVERSE USERS

- *s.4.1.5 Forecast activities for different categories of users (P1, P2, P3, P4, P6, P7, P8, P11, P12, P13, P17, P18, P18, P20, P21, P22, P23, P25)*

S4.2 PUBLIC-PRIVATE PARTNERSHIP

OWNERSHIP AND MANAGEMENT

- *s.4.2.1 Multilevel governance (P14)*
- *s.4.2.2 Multi stakeholders management (P18, P21)*
- *s.4.2.3 Public ownership with private management (P9, P23)*

FINANCING

- *s.4.2.4 Use of European funds (P14)*
- *s.4.2.5 Use of different public funds (P6)*
- *s.4.2.6 Use of public and private funds (P18, P21)*

S4.3 TOURIST ATTRACTIVENESS

- *s.4.3.1 Use for cultural thematic purpose, as museum of the sea (P2, P13, P18, P19, P20, P25) storytelling about identity/history (P2, P8, P9, P13, P22)*
- *s.4.3.2 Use for commercial purpose, as bar, restaurant (P2, P6, P12)*
- *s.4.3.3 Integration into tourist circuits (P18, P25)*
- *s.4.3.4 Promotion of events (P6, P8, P11, P12, P13, P14, P18, P21, P23, P25) as festivals (P18)*

D5: ENVIRONMENTAL DIMENSION

S5.1 PORT-CITY INTERACTION

ACCESSIBILITY

- *s.5.1.1 Direct access to the building (P1, P2, P4, P7, P9, P12, P18, P19, P21, P24)*
- *s.5.1.2 Direct access to the port area by internal walkway, passageways (P3, P17)*
- *s.5.1.3 Direct access to the port area by external overpasses (P8, P25)*
- *s.5.1.4 Free access to the building (P1, P8, P9, P12, P24)*
- *s.5.1.5 Free access to the port area (P4, P2, P7, P9, P18, P19, P21, P24)*

INFRASTRUCTURE

- *s.5.1.6 Systematisation of connection through direct pathways at different levels, as creation of gallery or overpasses (P1)*

S5.2 MOBILITY AND ACCESSIBILITY

IMPLEMENTATION OR IMPROVEMENT OF INFRASTRUCTURE

- *s.5.2.1 Implementation or improvement of infrastructure for pedestrian mobility (P1, P8, P18, P21)*
- *s.5.2.2 Implementation or improvement of infrastructure for vehicular mobility (P18)*
- *s.5.2.3 Implementation or improvement of infrastructure for bicycle mobility (P18, P21)*
- *s.5.2.4 Implementation or improvement of integration with public transport (P18)*
- *s.5.2.5 Integration transport via sea (P18, P21)*

IMPROVEMENT LEVELS OF ACCESSIBILITY

- *s.5.2.6 Remotion of architectural barriers, with ramps, elevators and escalators (P1, P2, P11, P21)*

S5.3 PUBLIC OPEN AND GREEN SPACES

OPEN AND PUBLIC SPACES

- *s.5.3.1 Systematisation of public spaces, with the installation of benches (P1, P18)*
- *s.5.3.2 Transformation of open spaces, as courtyards, into public spaces (P17)*
- *s.5.3.3 Forecast of public access to the panoramic viewpoint on the roof (P24)*
- *s.5.3.4 Forecast of public functions on the lower levels (P24)*
- *s.5.3.5 Creation space for sportive activities (P18)*
- *s.5.3.6 Creation of internal public space (P3)*

GREEN SPACES

- *s.5.3.7 Integration of internal green spaces, planting trees (P8, P17)*
- *s.5.3.8 Addition of external green spaces, with regreening of the area (P2, P8, P18, P24)*

D6: ENERGY DIMENSION

S6.1 PASSIVE DESIGN STRATEGIES

THERMAL COMFORT

- *s.6.1.1 Installation of shading devices (P2)*

- *s.6.1.2 Integration of green walls (P17), trees (P3, P8), gardens (P8)*
- *s.6.1.3 Adoption of perforated steel elements (P24)*
- *s.6.1.4 Adoption of direct adiabatic cooling system (P3)*
- *s.6.1.5 Insulation for building envelopes (P11)*

VISUAL COMFORT

- *s.6.1.6 Design full-height windows and balconies (P24)*
- *s.6.1.7 Ensuring direct lighting, not artificial (P20), delocalising activities (P2)*

QUALITY OF THE AREA

- *s.6.1.8 Ensuring natural ventilation (P3, P6)*
- *s.6.1.9 Integration of greenery (P3, P8, P17)*

S6.2 EFFICIENT ENERGY SYSTEMS

RENEWABLE ENERGY

- *s.6.2.1 Installation of solar panels on the glass of windows (P3)*
- *s.6.2.2 Installation of geothermal systems (P3)*
- *s.6.2.3 Reuse of rainwater (P3)*

AIR CONDITIONING

- *s.6.2.4 Installation of a system with heat recovery (P6)*

D7: AUTHENTICITY AND HISTORICAL DIMENSION

S7.1 INTRINSIC VALUES

PRESERVATION OF WORK CULTURE

- *s.7.1.1 Preservation of skills related to maritime practice (P18, P19, P20, P25)*
- *s.7.1.2 Preservation of industrial machinery (P13)*
- *s.7.1.3 Conservation of industrial machinery (P13, P18, P21)*
- *s.7.1.4 Exhibition and valorisation of working memory original machinery (P13, P14, P25)*

TRANSMISSION OF LOCAL CULTURE

- *s.7.1.5 Valorisation of the history, for example with historical path (P2, P8, P7)*

- *s.7.1.6 Narration of history and working memory through museum function and artefact expositions (P2, P13, P14, P18, P19)*
- *s.7.1.7 Narration of history of the place (P8, P14, P18, P19)*
- *s.7.1.8 Organisation visit to full-scale reconstruction or artefact (P2, P18, P19, P20)*

S7.2 AUTHENTICITY AND INTEGRITY

- *s.7.2.1 Conservation of formal integrity (P4, P6, P7, P8, P11, P20, P23, P24)*
- *s.7.2.2 Conservation of spatial integrity (P11, P20, P19)*
- *s.7.2.3 Conservation of frescoes (P14), stone inscriptions (P4)*
- *s.7.2.4 Sharing virtual experience to visit the place, as virtual tour (P2, P13, P23)*
- *s.7.2.5 Visual and perceptual continuity conservation through the same colours (P6, P11, P24), compatible materials (P6, P11, P24)*

S7.3 SIGNIFICANCE OF THE HERITAGE

- *s.7.3.1 Realisation of reversible interventions (P16)*
- *s.7.3.2 Demolition of modern non-structural element, as wall (P6, P20)*
- *s.7.3.3 Material conservation (P2, P6, P11, P13, P14, P17, P18, P20, P23)*

D9: MANAGERIAL/DECISION MAKING DIMENSION

S9.1 INVOLVEMENT OF COMMUNITY

- *s.9.1.1 Adoption of bottom-up approach (P18)*
- *s.9.1.2 Development of guide with citizen (P18)*

S9.2 INVOLVEMENT OF DIFFERENT STAKEHOLDERS

- *s.9.2.1 Collaboration between public and cultural centre (P11)*
- *s.9.2.2 Collaboration between administration and stakeholders (P18)*
- *s.9.2.3 Involvement of multi-level public stakeholders (P7, P22)*
- *s.9.2.4 Collaboration between directors and development team (P21)*

S9.3 USE OF DIFFERENT TOOLS

-

5.2.2. *Ph.2.3 Assessment of Adaptive Reuse solutions via AHP*

In order to evaluate adaptive reuse design solutions, in accordance with ph.2.2, each indicator was assessed using the AHP method to assign each dimension and each factor, according to the previously defined hierarchical structure (Figure 9), a weight that expresses the importance of each aspect in adaptive reuse projects.

For this purpose, a form was provided to collect information. The first part consisted of participant profiling, while the second part included a reference to the evaluation form accompanied by useful information about the procedure and the description of criteria and sub-criteria, as defined in ph.2.2, to enable informed judgements.

The assessments were collected from a panel of 15 academics and professionals, recognised as experts in the field of Architectural and Engineering. In particular, all participants reported having experience in the recovery and reuse of built heritage, with only four also including expertise in port heritage.

To this end, an online tool, AHP-OS (Goepel, 2018), was adopted to collect judgments. Each participant independently had to conduct the assessment, indicating the intensity of the importance of each criterion i in comparison with indicator j on a numerical scale from 1 to 9, each of which is associated with a verbal scale, in accordance with the scale defined by Saaty (Saaty, 2008), as explained in Table 5.

Table 5 - The fundamental scale defined by Saaty (Saaty, 2008). Reworked by the author

Importance of priorities	Intensity of importance	Definition	Explanation
$a_{ij} = 1$	1	Equal importance	Two activities contribute equally to the objective
$a_{ij} = 3$	3	Moderate importance	Experience and judgment slightly favour one activity over another
$a_{ij} = 5$	5	Strong importance	Experience and judgment strongly favour one activity over another
$a_{ij} = 7$	7	Very strong or demonstrated importance	An activity is favoured very strongly over another
$a_{ij} = 9$	9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

2,4,6,8 are values in-between

The values collected were then input into a square, positive, reciprocal matrix A, where the element a_{ij} represents the judgement attributed to criterion i with respect to criterion j, through which the weights were estimated, in accordance with the methodology proposed by Saaty (Saaty & Vargas, 2012).

In this methodological workflow, consistency assessment is a crucial phase for verifying the coherence of the judgements. To this end, the Consistency Index (CI) and subsequently the consistency ratio (CR) was evaluated for each matrix. For each matrix a CR value less than 0,1 was obtained, meaning that the consistency was considered acceptable. This value was ensuring by the adoption of the AHP-OS tools, which allows preliminary assessment of the CR value before confirming the judgments assigned.

Once the weights of the macro-criteria (v_i) and sub-criteria (w_{ij}), were obtained, the overall weight of each sub-criterion was calculated, as shown in figure 28. In this way, collected evaluations of adaptive reuse design solutions for each indicator, they are

subsequently weighted. In detail, the following formula could be applied, whereby the overall weighting of each sub-criterion w'_{ij} is multiplied by the score assigned to it in the project p_{ij} .

$$AR_{value_{solution}} = \sum (w'_{ij} * p_{ij})$$

Objective	Macro-criteria		Sub-criteria		Global weight
ADAPTIVE REUSE OF PORT HERITAGE	D1 Architectural	0,110	I1.1 Minimum intervention	0,247	0,027
			I1.2 Architectural harmony and visual compatibility	0,269	0,030
			I1.3 Adaptability and spatial flexibility	0,485	0,053
	D2 Structural	0,163	I2.1 Retrofitting of existing structures	0,268	0,044
			I2.2 Structural integration	0,293	0,048
			I2.3 Dismantlability/ Flexibility of components	0,439	0,072
	D3 Socio-cultural	0,088	I3.1 Social integration and inclusion	0,599	0,053
			I3.2 Attachment and sense to place	0,401	0,035
	D4 Economic	0,072	I4.1 Functional mixes	0,387	0,028
			I4.2 Public-private partnerships	0,332	0,024
			I4.3 Tourist attractiveness	0,283	0,020
	D5 Environmental	0,133	I5.1 Port-city interaction	0,34	0,045
			I5.2 Mobility and accessibility	0,348	0,046
			I5.3 Public open and green spaces	0,313	0,041
	D6 Energy	0,116	I6.1 Passive design strategies	0,428	0,050
			I6.2 Efficient energy systems	0,572	0,067
	D7 Authenticity and historical	0,119	I7.1 Intrinsic value	0,24	0,029
			I7.2 Authenticity and integrity	0,317	0,038
			I7.3 Significance of the heritage	0,443	0,053
	D9 Managerial/ decision-making	0,076	I9.1 Involment of community	0,402	0,031
			I9.2 Involment of different stakeholders	0,447	0,034
			I9.3 Adoption of different tools	0,151	0,012
	D10 Functional	0,122	I10.1 Compatibility with the context	0,322	0,039
			I10.2 Compatibility with original use	0,214	0,026
			I10.3 Compatibility with the architectural characteristics	0,464	0,057

Figure 28 - Decision hierarchy and weights

5.2.3. *Palazzo della Dogana in port of Bari*

The case study identified for the validation of the methodological workflow for the definition and evaluation of adaptive reuse strategies is the Palazzo della Dogana, located in the port of Bari (Figure 29).

An overview on port of Bari

According to the Burra Charter Process (The Australia ICOMOS Charter, 2013), understanding the significance of the place is the fundamental first step in the design and management process, because there is a reciprocal relationship in which the asset and the context mutually attribute cultural significance. Each new intervention may be integrated harmoniously and enhance the cultural significance of the place (*Design Guide for Heritage. Implementing the Better Placed Policy for Heritage Buildings, Sites, and Precincts*, 2018).



Figure 29 – Port of Bari in MAM AdSP

This first port of Bari (Figure 30), located on the east side of the old town, dates back to the Roman period when it was already a commercial hub and a central point for land connections, serving as a crucial crossroads for sea routes and the Via Appia. A prosperous period during the Byzantine and Norman periods was followed by periods of instability due to invasions and revolts, maintaining a strategic role, especially in trade, as evidenced by commercial traffic and the reconstruction and expansion of port infrastructure. Furthermore, in the 9th century, the port of Bari served as a strategic base for Saracen forces. The inadequacy of the ancient port led in the 19th century to the design and construction of a new port infrastructure. The construction of the new port infrastructures on the west side of the historic centre began in 1852, thanks to engineer Luigi Giordano.

An important transformation was achieved with the Gran Porto project, which was conceived around 1904, as part of a more ambitious national project to modernise the Kingdom's port, representing an ambitious response to the growing commercial needs of the city. Approved in 1919, the project involved the construction of a new large outer pier and the strengthening of the port's defences, such as the San Cataldo pier.

The 20th century was a further period of significant transformation for the port of Bari with the construction of the Gran Porto in 1922 and various improvements and expansions to the port infrastructure. During this century, the Port of Bari continued to grow in importance, becoming a crucial hub for freight and passenger transport in the Mediterranean (I.T.C. – Linguistico Moderno “G. Cesare,” 2005).

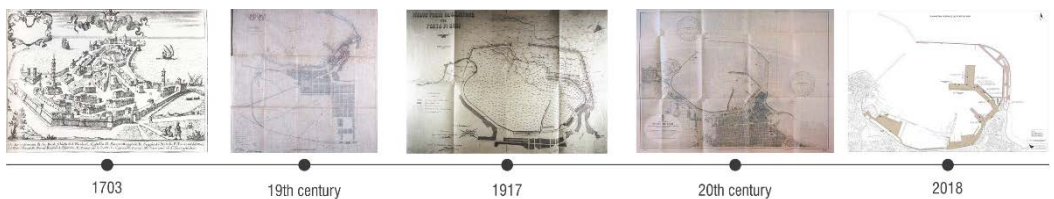


Figure 30 - Evolutionary process of port of Bari

Currently, only the new Gran Porto constitutes the port area of Bari managed by the Port Authority, maintaining an urban-historical location, well connected by road, less so by rail, as the railway does not directly reach the port area (Figure 31).



Figure 31 - Identification of port area of Bari, port access, main vehicular roads and railway lines

The infrastructure of the port of Bari is the result of a continuous development process in response to the growing needs of maritime transport. Currently, the port covers an area of approximately 285 hectares, with a total of 3800 linear metres of operational quays, divided into several docks (Figure 32), each of which is dedicated to specific functions. In particular, the Ponente Dock is mainly used for docking Schengen ferries and cruise ships, while the Levante Dock is used for cargo traffic. The Internal Dock houses the San Vito pier, used for extra-Schengen ferries, and the old external pier,

used for nautical vessels such as tugboats and boats used by the Guardia di Finanza. The Old Dock is reserved for public support services.



Figure 32 - Porto di Bari. Pianta del porto. Source: AdSP MAM

The port of Bari is therefore a complex, multi-purpose infrastructure that integrates commercial, tourist and public service activities, contributing significantly to the economic development of the area and positioning itself as a reference point for traffic in the Mediterranean. Specifically, the following current uses have been identified: commercial and logistics, industrial (related to shipbuilding), passenger services, and tourism and leisure.

The main assets identified in the port of Bari are those shown in figure 33. Most of the port assets are infrastructure, such as piers, except for the grain silos, the Harbour Master's Office building and the Customs House. These are not listed in cataloguing systems, but their historical, architectural and cultural value is recognised, except for the Bourbon pier and lighthouse.

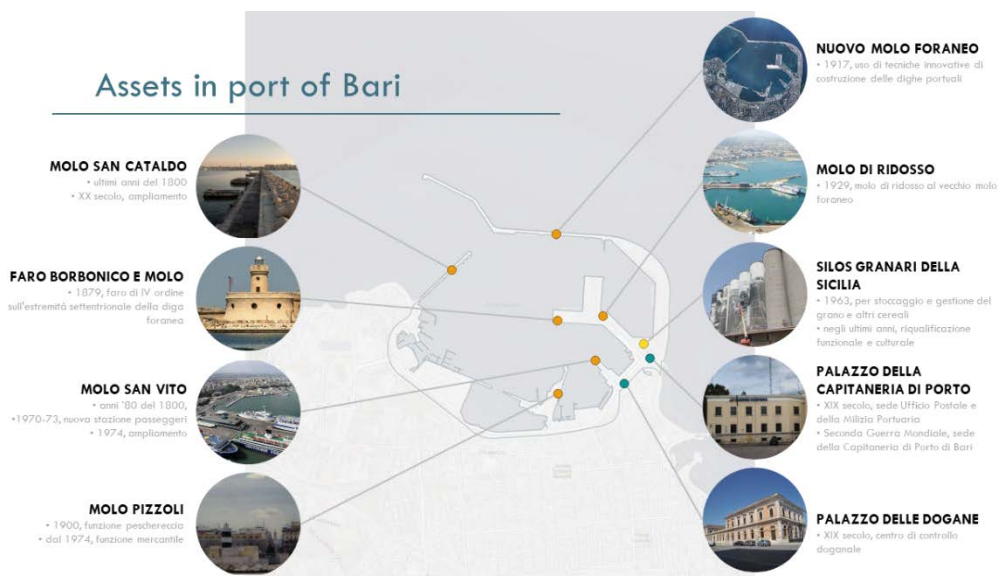


Figure 33 - Assets in port of Bari

Of these, the Customs House was chosen as representative of the most numerous cluster of assets in use, as shown in ph.1.5, paragraph 5.1.5.

In the context of ports, the customs house is a central institution, situated at the crossroads between economic, logistical, political and symbolic functions. It is a control point and a connection between the maritime and urban environments, regulating the flow of goods and people crossing the physical and fiscal frontiers of the state. In addition to its fiscal and logistical function, the customs house in ports also plays an institutional and symbolic role. The customs building is a manifest expression of the state's presence in the port area. For this reason, in many 19th-century European port cities, customs architecture took on monumental characteristics, often inspired by neoclassical or eclectic models, which emphasised its importance (Nicali & Favale, 2004).

In the city of Bari during the second Bourbon period, the Harbour Master's office was initially located in Piazza Mercantile, in the building now occupied by the offices of Guardia di Finanza (Finance Police), where the Royal Customs Office was also located. Subsequently, with the unification of Italy and the completion of the construction of the new Port of Bari, which was completed in the second half of the 19th century, the Royal

Harbour Master's Office was allocated to a wing of the new large building of the Royal Customs House in Corso Antonio De Tullio.

The new Regia Dogana building represents the material concretisation of the relationship between the state and the sea, as well as direct evidence of the development of the port of Bari between the 19th and 20th centuries.

To this end, the knowledge acquired in phases ph.1.1, ph.1.2 and ph. 1.3 was further explored with detailed investigations to better understand the specific characteristics of the asset and the dynamics of the context in which it is located. On this basis and in accordance with the subsequent phases ph.2.2 and ph.2.3, two project proposals were defined with the support of the atlas of meta-project strategies, one cultural and one commercial, and subsequently evaluated using the AHP method.

Evolutionary processes of Palazzo della Dogana

The Customs House in Bari, designed by architect Enrico Alvino and commissioned by the Ministry of Finance, is a 19th-century building with a long history of service as a customs control centre, playing a crucial role in facilitating maritime trade and protecting Italy's economic borders (Figures 34-35-36-37). The Customs headquarters building was constructed between 1883 and 1887, together with the old Harbour Master's Office, at the same time as the “Molo della Sanità” pier, now known as the Molo S. Vito. (Tomasicchio, 2014).

The construction of the building was commissioned to Vincenzo Storelli, who on 20 October 1895 received the final payment for the work carried out on the construction of the building for use as a customs house and harbour master's office in the Port of Bari (*Gazzetta Ufficiale Del Regno d'Italia Del 4 Giugno 1896*, n.d.).



Figure 34 - Custom House in Port of Bari, view from plaza Saint Chiara, 1901. Anonymous author



Figure 35 - Royal Custom House in the background, Port of Bari, 1901. Anonymous author



Figure 36 - Custom House in Port of Bari, second decade of the twentieth century. Anonymous author



Figure 37 - Custom House in Port of Bari, 1915-1916. Anonymous author

Over time, the building has undergone substantial changes, such as the replacement of the roof, which was originally pitched (Figure 38), and the closure or conversion of some entrances on the south-west façade.



Figure 38 - Postcard depicting the Royal Custom House, 1922 – Private collection

On 27 September 1932, the Honourable Superintendent of Public Works for Puglia requested an expert assessment of the roof structure (Genio Civile, n.d.-a), which revealed advanced deterioration of the roofing membrane and an inadequate guttering system that was causing water infiltration into the attic space.

This was followed by a notice dated 15 November 1932, no. 20115, which highlighted the widespread fire hazard associated with the presence of chimney flues in close proximity to the timber structures.

For this reason, the intervention involved the demolition of the existing pitched roof and the construction of a flat roof with an impermeable covering consisting of three layers of asphalt felt, a technique that became widespread in Italy in the 1930s (Reichlin & Pedretti, 2011). The new roof was to be constructed using perforated tiles maintaining

15 centimetres in thickness, laid to falls so as to ensure the adequate rainwater drainage, replacing the sloping rock with an air cavity of 40 centimetres in depth. Adjacent to the main building, there was another smaller structure that hosted the Cabotage Section operational unit. Cabotage activities played a crucial role in the economic and infrastructural development of the port of Bari, especially between the late 19th and mid-20th centuries. This section managed and supervised the transport of goods between Italian ports, which, although exempt from international customs duties, nevertheless required registration and inspection (Trizio, 2021) (Figure 39).



Figure 39 - The Cabotage Section building, in Il grande porto di Bari, P. B. Trizio

On 9 April 1945, during the Second World War, the explosion of the American merchant ship SS Charles Henderson (Figure 40) caused one of the most severe wartime tragedies in Italy, causing over 300 deaths and more than 1,700 injuries. The majority of the victims were civil, dock workers and crew members.



Figure 40 - 9 April 1945: Explosion of the SS Charles Henderson in Port of Bari. Photo of WOJG Hubert Platt Henderson, di stanza a Bari come Direttore della 773^a Banda

The explosion completely destroyed the ship and part of the old Molo Foraneo pier, causing severe damage to buildings within the historic centre of Bari. Restoration work following the explosion was entrusted by Francesco Ficarelli's company. The intervention included the repair of masonry, flooring, window frames as well as plumbing and heating systems damaged by the explosion. The repair of the load-bearing tuff masonry was executed by means using solid brick or tuff block and cement-based mortar.

The building services renovation entailed the complete replacement of the water and sewage systems and the installation of new lead and cast iron supply and drainage pipes. The heating system was converted to a centralised systems, with cast iron radiators powered by a coal or oil-fired boiler. The installation also included a flue for the evacuation of flue gases (Genio Civile, n.d.-b). The restoration of the Customs Coastal Shipping Section building in the port of Bari attests to the desire to rapidly rebuild the strategic port infrastructure damaged during the conflict, thereby contributing to the port's recovery intervention.

Architectural- constructive analysis of Palazzo della Dogana

The building that currently accommodates the Customs Office and the Chemical Laboratory is located at the historic gateway of the port of Bari, between the port and the old town (Figure 41-42).



Figure 41 - View from the city of Palazzo della Dogana



Figure 42 - View from the port area of Palazzo della Dogana

It is an example of eclectic architecture with neoclassical influences, typical characteristic of Italian public buildings of the late 19th century. The façades are rigorously symmetrical, articulated by decorative elements such as cornices, pilasters and string courses. The complex is tripartite and symmetrical in plan, consisting of two side sections and a central block that connects them, and is organised on three levels, one below ground and two above. The complex faces north-west onto the Sant'Antonio pier and south-west on Corso Antonio De Tullio. The two main entrances are located on the lateral sides, with the entrance to the chemical laboratory offices to the west and the customs and monopoly agency offices to the east.

Over time, the building has undergone substantial changes, such as the replacement of the original pitched roof and the closure or conversion of some entrances on the south-west façade. At present, the entrance to the Customs and Monopolies Agency offices gives onto a hall. On the left there is the first staircase, serving the offices on the upper floors, while on the right, within the services zone, a trapdoor gives access to the

basement. According to unofficial sources, the basement formerly was reserved to “English cells”. Nowadays the basement accommodate plumbing and heating plant serving the building. The central area at ground floor is configured as an internal quadrangular courtyard, where are located administrative offices and service counters for citizens. This space originally served as a source of natural light and ventilation, essential in buildings with a deep floor plan to ensure lighting and ventilation in interior rooms not facing the street (Figure 43- 44).

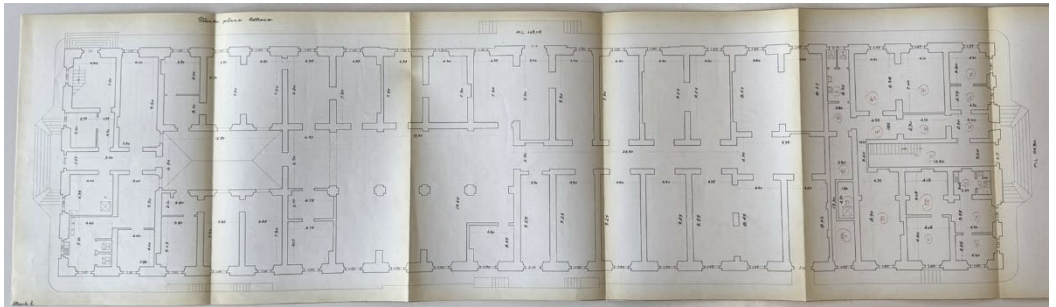


Figure 43 - Ground-floor plan (source Archivio di Stato)

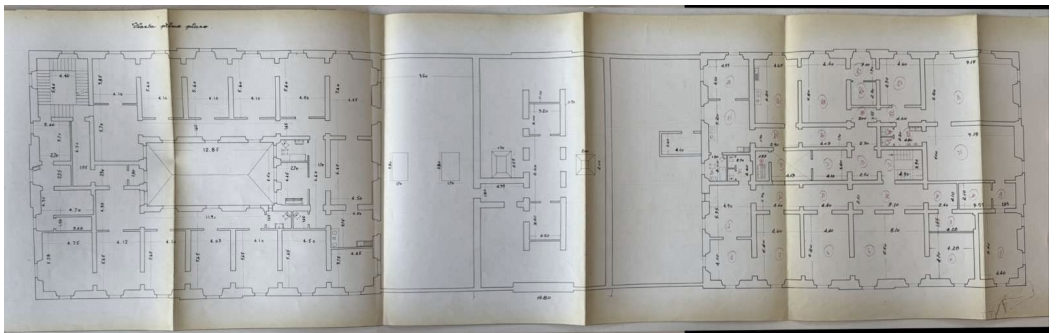


Figure 44 - First- floor plan (source Archivio di Stato)

In order to protect the interior surfaces, the courtyard was roofed over with a glass pavilion roof supported by a lightweight metal structure. This type of roof was a widely used technical solution in renovation projects of the first half of the 20th century, aimed at transforming internal courtyards into spaces usable throughout the year. The adoption of a transparent roof preserved the original lighting function of the courtyard, while ensuring effective protection against rainwater infiltration. Beyond the inner

courtyard, there is a wide corridor or internal distributive space, articulated by a succession of four large arches in local stone, partly plastered and partly left exposed. The roof is built with iron beams and vaults composed of brick bubbles, with a concrete slab. Of particular interest is the system of linear rooflights integrated into the ceiling, made of riveted metal structures and glazed infill panels. These elements allow natural light from above, ensuring visual comfort and spatial legibility of the environment. The protective metal mesh visible in the rooflights attests to a later phase of technical adaptation, probably associated to safety measures. As Figure 45 shows, localised deterioration is evident near the rooflight, affecting both the plastered surfaces and the metal structural support elements.



Figure 45 - Rooflights in internal distribution space

Plaster detachment is visible in the areas immediately adjacent to the metal frame of the rooflight. There are also damp patches and widespread discoloration, indicating

rainwater infiltration from the roof above or throughout inadequately sealed joints. In addition, it shows signs of oxidation at the metal joints, with possible transfer of corrosion products onto the surrounding plaster.

Both in the internal courtyard and in the gallery, the flooring is made of local limestone slabs, probably attributable to the types of stone from Trani or Chianca type, materials widely used in historical buildings in Apulia for their durability and mechanical resistance (Figure 46). From a conservation point of view, the stone surface shows signs of varying degrees of deterioration, mainly attributable to mechanical, hygrometric and material factors.



Figure 46 - Paving in local limestone slabs (chianche)

In the section dedicated to the Customs and Monopolies Agency's Chemical Laboratories, there is a long barrel-vaulted corridor, which has recently been modernised and brought into line with fire safety regulations (Figures 47). The corridor, linear in plan and slender in proportions, is characterised by plastered walls and a continuous barrel vault, set on a wall structure of considerable thickness.



Figure 47 - Barrel-vaulted corridor in the Chemical Laboratory section of the Agency

Along the sides, several symmetrical openings are located, fitted with large wooden doorways, now hidden by drywall partition (Figure 48). The latter were built to fit homologated REI doors and ensure the fire compartmentalisation required by current regulations; however, unfortunately, they altered the material and spatial perception of the original architecture, concealing the valuable historical elements.



Figure 48 – Drywall partition with opening for access to the space and wooden doorway

The archive rooms, accessible from the corridor, preserve the original pavilion vaults with terracotta cylinder, called *bubbole* (Figure 49), a traditional construction type in the Apulia region, documented in particular in rural architecture in the 18th and 19th centuries.



Figure 49 - pavilion vaults with bubbole in rooms destined for storage

The flooring in both the rooms and the corridor is made of local limestone slabs, laid in a herringbone or irregular pattern, showing signs of wear consistent with the age of the building.

Overall, the recent intervention allowed for the functional and regulatory adaptation of the spaces without substantially altering the original construction characteristics, despite sacrificing the visibility of some historical elements.

On the upper floor, in one of the main rooms of the Chemical Laboratory wing, there is a coffered ceiling (Figure 50).



Figure 50 - Coffered ceiling in one of the reception rooms in the wing dedicated to the Chemical Laboratory of the Customs and Monopolies Agency

The intrados is structured in a regular grid of square panels, each of which has a floral motif in relief in the centre, created using mouldings or applied plaster elements. The whole system is punctuated by modular frames that separate the different panels, giving the ceiling a plastic rhythm and a strong ornamental connotation.

Along the perimeter, there is a string course decorated with dentils and small projecting modules, which acts as a transition between the wall and the ceiling.

From a structural point of view, the visible system does not appear to be a load-bearing part of the building, but rather a decorative false ceiling that masks the structural framework of the original floor. Near the wall-ceiling junction, there are some slight cracks. Finally, the structure underwent static consolidation using FRP. The building is currently affected by deterioration. Specifically, there is widespread depigmentation of the façade, which compromises the aesthetic appearance and surface protection of the walls. In addition, there are washout stains caused by rainwater and surface deposits of atmospheric particulate matter and dust. In addition, there are areas where the plaster has detached, leaving the underlying substrates exposed to further damage caused by atmospheric agents. At the base of the building, there is a significant presence of spontaneous vegetation and biological patina on the surfaces. A further problem concerns the root of the wooden entrance door, which has suffered significant deterioration due to humidity and exposure to atmospheric agents. These phenomena alter the state of conservation of the building, failing to preserve its historical and architectural value.

Regeneration projects in the area

In order to define design solutions for the Palazzo della Dogana compatible with the context in which it is located, the regeneration projects currently underway in the surrounding area were analysed and presented below.

- The first project, developed by the Municipality of Bari in collaboration with the MAM Port System Authority and eligible for funding under the Action and Cohesion Plan (PAC), complementary to the Ministry of Infrastructure and Transport's 2014-2020 National Operational Programme (NOP) "Infrastructure and Networks", is divided into four areas of intervention aimed at sustainable urban and port development (Comune e Autorità di Sistema Portuale MAM, n.d.) (Figure 51).

The first axis (A), dedicated to the digitisation of logistics, involves upgrading the PCS GAIA port communication platform, developing the Single Administrative Desk, upgrading port gates for the logistical tracking of goods and cooperation with the AIDA

customs system, the extension of public and operational WiFi networks, and the upgrading and extension of the video surveillance system.

The second axis (B) concerns the redevelopment of the waterfront, rebuilding port-city interaction by removing the infrastructural barriers that currently interrupt the connection with the sea. Among the interventions, developed in agreement with the Port System Authority, is the undergrounding of the urban coastal road (part of Corso de Tullio), from the Isabella D'Aragona garden area to the customs buildings, allowing a pedestrian connection between the Swabian Castle, the old town and the sea.

It also provides for the landscape and environmental redevelopment of the areas between the old town and the Swabian Castle with the creation of a new urban park and the enhancement of sustainable and intermodal mobility.

The third axis is aimed at improving tourist accessibility to the Swabian Castle, a monument that currently lacks adequate connections with the surrounding urban fabric, with a view to recreating the identity of the Bari area, characterised by its castle, historic centre and sea. The project also aims to integrate the castle into the existing cycle and pedestrian network, restoring functional coherence to the system.

The fourth and final axis, under the responsibility of the Port System Authority, is aimed at the environmental sustainability of the port through the creation of quay electrification systems and the installation of photovoltaic systems, with the aim of increasing energy production from renewable sources and reducing the environmental impact of port activities.

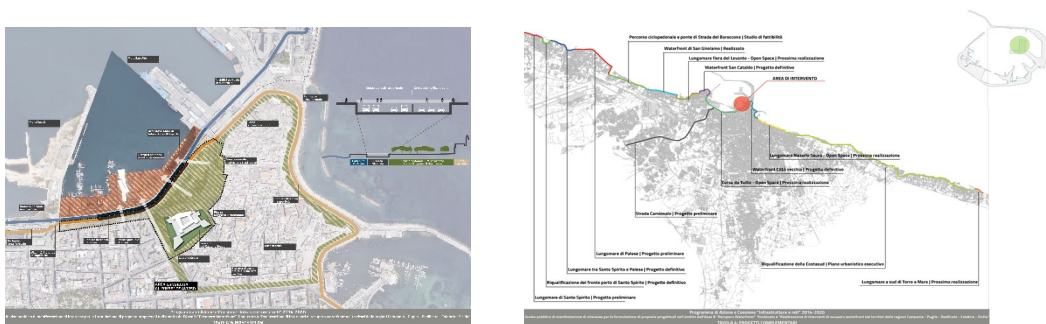


Figure 51 – Requalification project developed by the Municipality of Bari in collaboration with the MAM Port System Authority

•A second project nearing its completion involves the construction of the new Passenger Terminal on Quay 10, a work that fits into a context of particular historical and environmental significance (Autorità di Sistema Portuale MAM, n.d.-b) (Figure 52). To this end, plans have been made to extend the “Bourbon pier” or “old outer pier”, a nineteenth-century structure which, due to its unique historical and architectural characteristics, is now protected by the Ministry of Cultural Heritage (decree of 07/12/2001) of the Regional Superintendency for Cultural Heritage and Activities pursuant to Legislative Decree 490/1999 (repealed by Article 184, paragraph 1, tenth indent of Legislative Decree 42/2004)".

However, the project does not fall within the restricted area, but is an extension.

One of the most significant design challenges was the inclusion of the terminal near the area of cultural interest, with particular attention to the study of flows and accessibility within the pier.

Safety requirements were a priority and influenced the definition of the spaces, in which the building acts as a filter between the boarding finger and the area used for the loading and unloading of passengers and luggage, as well as the spaces for access by the terminal's service vehicles.

The structure is designed to accommodate both cruise and ferry traffic, with flows that are not simultaneous but differentiated thanks to careful design of the accesses and distribution.



Figure 52 – Passenger Terminal on Quay 10

- A third project concerns the upgrading of the San Cataldo pier, a strategic project promoted by the Port System Authority with the support of the Municipality of Bari and the Puglia Region and co-financed by the Ministry of Infrastructure and Transport (Autorità di Sistema Portuale MAM, n.d.-a). The project involves the construction of new quay works, covering a total area of approximately 33,000 square metres, to extend the existing San Cataldo pier, already home to the Coast Guard, together with seabed deepening works to improve the landing of naval vessels.

The work will provide moorings for both the Coast Guard and tourist vessels in the Darsena di Ponente, making it a strategic infrastructure in relations with neighbouring countries and for the protection of the southern Adriatic basin. The project also includes the construction of a pier equipped to moor two RO-PAX ships, helping to expand the capacity and functional versatility of the port of Bari (Figure 53).



Figure 53 - Touristic port and San Cataldo pier

Although not directly of interest to the port area, there are other projects that involve the surrounding areas.

- Specifically, there is the project concerning the San Cataldo Waterfront, developed by the municipal administration together with citizens (Comune di Bari, n.d.) (Figure 54). The project is an organic urban and environmental regeneration initiative, aimed at restoring a view of the sea, combining public use, sustainability and enhancement of historical and cultural heritage.

There are plans to build a pedestrian and cycle path connecting the San Cataldo Lighthouse to the Fiera del Levante exhibition centre. Near the lighthouse, a square with an open-air theatre will be built for cultural events and performances, creating a new landmark for the population.

At the same time, the Provolina beach will be redeveloped, with the addition of bathing facilities and recreational areas, as well as green spaces equipped for sports, games and relaxation, and new refreshment points. Particular attention has been paid to accessibility, with the removal of all architectural barriers.

Last but not least, the restoration and enhancement of the San Cataldo Lighthouse, through the creation of a museum dedicated to the history of navigation and maritime communications in the Adriatic.

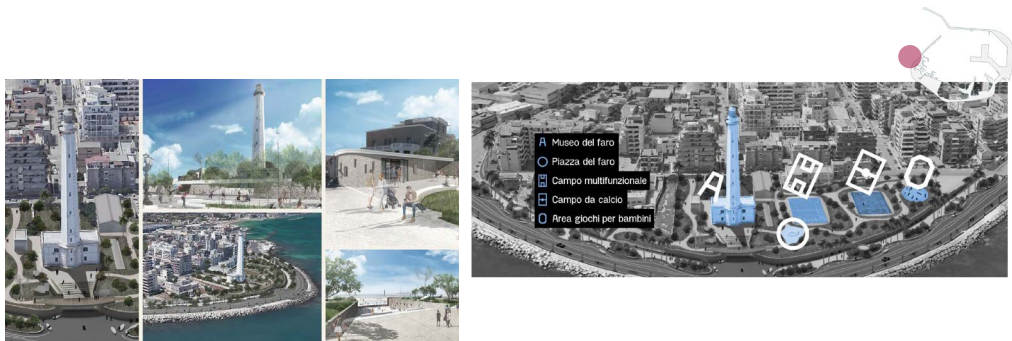


Figure 54 - Waterfront of San Cataldo

- On the opposite side, redevelopment work is planned for the waterfront of Bari's old town (SMN Architetti, n.d.) (Figure 55). The project involves the restoration and completion of the existing quay system between the Margherita Theatre and the Sant'Antonio pier, through the construction of fixed piers, the architectural and functional redevelopment of the pergola building on the San Nicola pier, the installation of fixed multifunctional platforms on the relevant section of the Imperatore Augusto seafront and the construction of a new building for museum and tourist accommodation purposes on the same pier.

Particular attention is paid to the activities of the fresh fish market on the San Nicola pier, for which an architectural adaptation is planned to ensure compliance with current health, hygiene and safety regulations.

The Sant'Antonio pier, currently home to commercial and fishing activities, will be redesigned to ensure compatibility with the new cultural and tourist-accommodation vocation deriving from the new Arts Centre.

The proposal is capable of bringing together the identifying features, as it is conceived as a programme of archaeological heritage, with the Archaeological Museum of Santa Scolastica, the historic coastal defence system, the architectural cultural heritage, the cultural and religious traditions linked to the feast of St. Nicholas, as well as tourist services and accommodation facilities. The result is an integrated and coherent vision that aims to give the community greater enjoyment of the waterfront.



Figure 55 - Redqualification of old city waterfront

Adaptive Reuse design solutions for Palazzo della Dogana

Based on this overview, the process of defining project proposals began. The definition of a new use, whether permanent or temporary, should be compatible with the site and capable of enhancing its historical and cultural significance through tangible (architectural and material construction) and intangible (memories, meanings and practices) features, avoiding abandonment or underuse over time. The project should enhance the historical heritage while looking to the future, through its integration into dynamics of the area and broader regeneration processes. Specifically, in line with processes underway and the need to improve compatibility with the context, new use should contribute to and guide regeneration (heritage-led regeneration) (*Design Guide for Heritage. Implementing the Better Placed Policy for Heritage Buildings, Sites, and Precincts*, 2018) by transforming the asset into a resource capable of connecting the city to the port.

To this end, the methodological approach defined in phase 2.2 was followed to define two design solutions. Starting from the definition of the design concept (a), initially validated through the assessment of compatibility levels in accordance with ph.1.4, to the definition of preliminary design solutions (b) with consultation of the atlas of meta-design strategies, for the definition of possible design solutions (c).

a. Definition of the design concept

In accordance with the results of the cluster analysis, the Palazzo della Dogana falls within cluster 4, for which the design process was geared towards improving the state of conservation and compatibility with the context and the original building. In this case, in addition to conservative intervention, it may be necessary to focus on authenticity and historicity, as well as social and environmental aspects, in order to better respond to the community's needs and improve integration into the contemporary context.

Therefore, in addition to conservative intervention to improve its state of conservation, compatibility levels require improvement. Preliminary investigation highlighted the operational efficiency of the structure, which at the same time requires adaptation to

improve its functional compatibility. Based on context analyses, as well as previous experiences of reuse and redevelopment of port heritage, the project proposals provided for integration of a new function. To this aim, based on the international experience analysed, two project concepts were proposed: a cultural proposal and a commercial proposal. In particular the new function could be localised into a limited portion of the building, i.e. the central portion (Figure 56) developed only on the first floor. In this way, no interference would be caused to the activities currently taking place in the building. In this way, the asset became multifunctional, increasing the compatibility within the service port area.

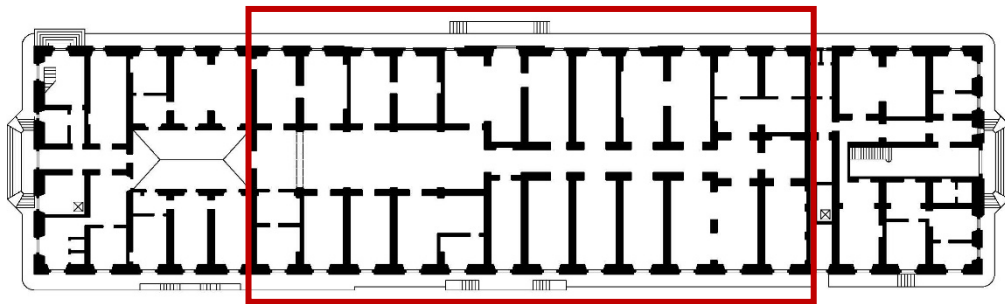


Figure 56 - Area of interest in Palazzo della Dogana

Considering its original historical configuration, this area was used for access to and from the sea, attested by the presence of the central access points and the historic wooden doors. Furthermore, historical investigations reveal that the interior space was reorganised over time through the addition of new internal partitions that altered the original layout. These could be demolished to restore the authenticity of the property. Therefore, the proposal was to restore not only the initial physical condition, but also to re-establish the connection with the sea through the Palazzo della Dogana, creating a permeable public space capable of welcoming passengers into the city of Bari and, at the same time, attracting the city towards the sea.

According to the methodological approach defined in phase 1.4, the introduction of these new functions would result in a change in the levels of functional compatibility.

Specifically, in these configurations, the building would no longer have a logistical function but would be considered multifunctional, allowing it to achieve a value of 5 in the assessment of the level of compatibility with the context. At the same time, restoring the original configuration of the spaces and enhancing the architectural characters would allow for a value of 5 in the assessment of compatibility with respect to the functional building. Although this functional change would result in a minor decrease in the level of compatibility with the original function, from a value of 4 to a value of 5, these interventions, accompanied by an improvement in the state of conservation, would lead to an overall improvement in the situation, moving the building into cluster 1, chapter 5.1.5, relating to properties in use, in good condition and with high levels of compatibility.

SOLUTION 1 – s1 – cultural proposal as museum and research centre

The first design solution concerns the cultural proposal. To define it, exemplary cases of port heritage were investigated, including customs buildings, for which a cultural function as a museum was envisaged.

These include the Palacio de la Aduana in Málaga (Deporte, n.d.), originally a tobacco factory and later a customs building, which now houses the Málaga Museum. The collection includes institutional deposits, private donations and private acquisitions, including works from the 19th century to contemporary art and an archaeological section with important Phoenician, Roman and Hispano-Muslim finds. Inside, there is also a library, as well as catering services such as a restaurant and a café.

In Venice, Punta della Dogana (*La Pinault Collection a Venezia*, n.d.), restored from its state of abandonment, is now a contemporary art centre, including the Pinault Collection. The building, together with Palazzo Grassi, has hosted temporary exhibitions of various types of artistic production, including painting, installations, sculpture, video art, photography and performance, as well as conferences and screenings.

A different experience is offered by the customs building in Amsterdam, which now houses the national maritime museum Het Scheepvaartmuseum (*Het Scheepvaartmuseum. National Maritime Museum*, n.d.). The museum offers not only

exhibitions but also interactive experiences and a visit to a ship of the East India Company. The structure also includes a specialised library and historical collections related to Holland's maritime history and culture, which are open to researchers and the public. In addition, guided tours are regularly organised, as well as conferences and special events during holidays, including private events ranging from meetings to weddings. This ensures the involvement of the entire community, including tourists, families and scholars.

Among these, the function of maritime museum emerged as a widespread use within port areas, serving as a strategy for the redevelopment and enhancement of different types of heritage, from customs buildings to ancient arsenals, as in the case of the Galata Maritime Museum - Genoa (*Galata Museo Del Mare* | *Genova*, n.d.), to disused dry docks, such as M/S Museet for Søfart – Helsingør (*Experience Denmark's Maritime History in Elsinore*, n.d.), to warehouses, such as the Museo del Mare in Warehouse 26 – Trieste (Comune di Trieste, n.d.), to maritime stations, such as the Cité de la Mer – Cherbourg (La Cité de la Mer, n.d.). The exhibition itineraries and planned activities include paintings, nautical charts, atlases, on-board instruments, models, etc., exploring the history and imagery of the sea, with the aim of promoting knowledge and appreciation of maritime culture and strengthening historical identity.

From the experiences analysed, the recurring themes that emerge outline a modern model of a maritime museum based on active involvement and technology.

The planned activities include not only interactive activities, but also exploration with a high level of physical immersion, real-size historical ship reconstructions, such as the 17th-century galley and a 19th-century brigantine in the Galata, or the VOC ship in the Het Scheepvaartmuseum (*Het Scheepvaartmuseum. National Maritime Museum*, n.d.). Moreover, the use of technology is becoming increasingly widespread with the adoption of multimedia and immersive tools, such as multimedia stations with touch screens in Galata, virtual and augmented reality experiences, as in the case of the Museum of the Sea - Porto Recanati (*Museum of the Sea - Porto Recanati* | *ETT - People and Technology*, n.d.) where headsets are used to explore traditional fishing techniques, or La Cité de la Mer, where visitors can relive the atmosphere of a day in

Normandy in 1937. In this way, the process of digitisation is spreading, increasing accessibility through a more engaging experience, through virtual tours and digital archives, as in the case of the South Street Seaport Museum (*Maritime Museums Online - National Maritime Historical Society*, n.d.)^a of German Maritime Museum (*German Maritime Museum*, n.d.).

The first proposal, therefore, could be considered as a point of reference serving the city and the territory, both from the sea and from the urban context, revealing its maritime heritage to the community in the central part of the structure, its 'core'. The space was designed to integrate exhibition, archival and research functions within a unified and accessible system. The proposal transcended the logic of the museum as a container, creating an open space.

A living archive dedicated to the conservation of history and collective memory, as well as the culture related to the practice of the sea, which also contemplates the production and dissemination of historical and contemporary know-how. The idea was to narrate the history of the port of Bari and the Customs House and, at the same time, to provide a research and archive centre, oriented towards the adoption of digital tools and systems in line with contemporary experiences.

The central part of the building could be configured not only as a public space to welcome visitors to the urban context of Bari, but also as a space for permanent or temporary museum exhibitions, with the potential to be converted into a space capable of hosting conferences and events. This was accompanied by smaller spaces dedicated to research, archiving and education, overcoming the dichotomous vision between exhibition space and research space and between traditional approaches and the adoption of digital tools for cultural and educational production. In this way, the centre will be served as an urban catalyst, a civic and cultural hub and a place for the production and dissemination of historical and contemporary knowledge, integrating memory and innovation for and through the social component.

The idea was that exhibitions related to maritime activities, currently housed in other urban spaces such as the Civic Museum of Bari, including historical nautical maps,

documents on maritime trade and various artefacts related to connections with the East, will be relocated to a dedicated museum. Similarly, archival material relating to the Customs House or the port held in the State Archives in Bari could be relocated within the building for direct and public access (Figure 57).



Figure 57 - Events at the civic museum, Bari

SOLUTION 2- s2 - commercial proposal as enogastronomic hub

To define the second solution, representative cases of port heritage were investigated, including customs buildings converted for commercial use, such as shops and restaurants.

Among the examples of customs buildings, Timaru Customs House, in New Zealand, is a former custom office. When the function was relocated, it was restored and converted for commercial use, maintaining the distinctive features of its original neoclassical architecture both internally and externally. The historic building, which is of national importance and registered under the Historic Places Act, still houses a restaurant, specifically a steakhouse.

Another example is Nordre Toldbod a Copenhagen, a former customs building that now houses Seaside, a gastro house with seven independent kitchens offering menus from every continent, as well as organising events. The building overlooks the port and its

interior is decorated with maritime elements, honouring the Danish merchant fleet and the history of the area.

A similar case is Tollboden, a landmark in the port of Stavanger, which is now a space dedicated to catering as well as hosting events and concerts.

Among the port facilities that host commercial activities linked to catering, functional mixing emerges significantly, i.e. there are fewer cases where they are single-purpose. Even where they are mono-thematic, different activities are offered, as in the case of the former wine warehouse in Trieste, Eataly Trieste, a large food and wine centre located in an old wine warehouse on the banks of the port of Trieste, which combines a market, restaurants and educational facilities in a single structure overlooking the sea. There is also a frequent mix with cultural functions, such as the Fondaco dei Tedeschi in Venice, an ancient nerve centre for international trade in Venice. Reviving its ancient vocation of exchanging goods, ideas and culture, its function evolved into that of a commercial and cultural hub, as a luxury shopping centre hosting contemporary art exhibitions; or the Mercado da Ribeira, Lisbon, which houses the Time Out Market, which in addition to restaurants, bars and shops, hosts an events space and a cooking school, a concert hall that often hosts special events, a gallery and a club.

This design solution was configured as a free port, a space free from the logic of borders, open and permeable not only to the circulation of people and cultures, but also to goods.

In this solution, the Palazzo della Dogana was conceived as a logistical hub of taste, overcoming the monofunctional conception of a single restaurant space to design a plural system of stores and kitchens for a barrier-free eno-gastronomic hybridisation, celebrating exchange and conviviality along the border. The idea of a barrier is overcome with the creation of an open place for different cultures and culinary traditions to meet and influence each other. This space was configured with the presence of different points of sale distributed around the perimeter, each dedicated to a tradition or specific products, which converge in the large shared central space for tasting.

In its conception, the space can be interpreted as a more or less permanent place for consumption and meeting. At the same time, the flexibility of the space also allows for the organisation of events and thematic exhibitions on scheduled days, as well as educational culinary workshops. In this way, the mere commercial vocation is also oriented towards cultural production, as testified by the identity tradition of Bari.

This solution constituted a strategy for the regeneration of the area, as well as for social activation and identity preservation, becoming a strong point of attraction for the local community, as in the previous experiences analysed.

b. Definition of preliminary project proposal

The following phase involves the definition of preliminary project proposals, with the definition of space-functional distribution issues, user analysis and the flow of people to assess the feasibility of the intervention.

SOLUTION 1

The concept of the project based on the enhancement of local history and culture, with the aim of reviving historical and traditional memory in a modern, inclusive and multi-level public way. The project aimed to ensure the conservation and enhancement of tangible and intangible heritage. The intervention was developed considering two levels: the physical restoration of the building and the activation of a cultural programme capable of generating long-term civic and social value. The expected effect was to activate port area and urban regeneration processes, strengthening identity recognition and social cohesion through the enhancement of memory of the place.

The project was organised into three main functional areas, as shown in Figure 58. The first was the central distribution area corresponding to the entrances. The intervention involved reopening the two entrances on the long side with free access to the central distribution area, highlighted in red, ensuring a flow to and from the city through the building, which could be essential for re-establishing the connection between the port

area and the urban context. However, access to the exhibition-museum space and the archive-laboratory space will be controlled. In this way, free and direct access was provided for the public, as tourist, visitors and citizens; controlled accesses were required for the museum circuit and for the access to archive for researchers and educational users. This hierarchical organisation of access responded to the flow separation necessity, ensuring operational efficiency.

The museum exhibition space involved the conversion of the spaces currently used as offices into permanent and temporary exhibition spaces (blue area). The visitor tour was designed to promote accessibility and interactivity, which are essential features for offering an engaging and immersive experience. Through multimedia installations and information panels, visitors will have the opportunity to explore the history of Bari through the sea, discovering the traditions and cultural practices that have characterised the port, the city and the Bari area with its dynamics. The large open central space could be also suitable for hosting events, conferences and public-private seminars.

The area of interest of the archive-laboratory space (green area), in the space currently used as storage area, was designed to accommodate the archiving of documentary and iconographic material, as those currently archived in Archivio di Stato or in other urban collection. The space included study and consultation rooms, with digital cataloguing systems. In addition, dedicated space to educational laboratories and workshops related to the centre's purposes were integrated, dedicated also to school groups, researchers and specialists.

The proposal as defined could be involved a wide range of users, from tourists to families and scholars, enhancing the centrality of the building in the port context, not only in relation to port functions. The division into distinct functional areas connected by a central filter space allowed for the separation of flows and hierarchical control of access, ensuring dialogue between the two contexts, port and urban, through free permeability.

The project was conceived to minimise the modification and adopt reversible intervention, without requiring any extensive structural intervention.

Finally, the propose will be involved in a cultural circuit of the city, ensuring greater appeal and functional continuity over the time.

SOLUTION 1

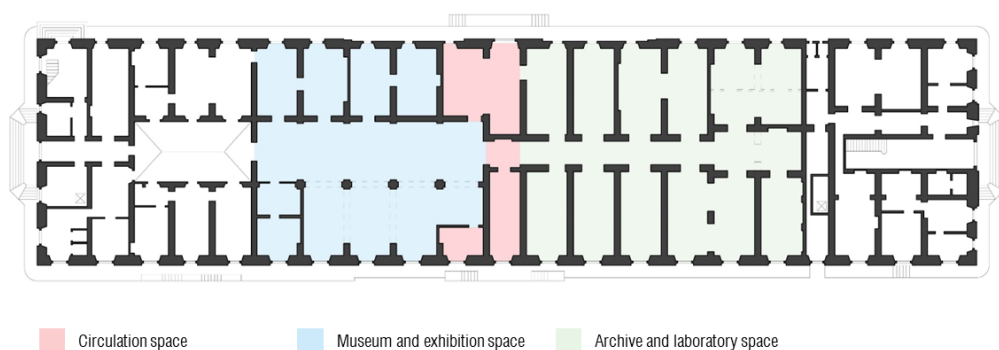


Figure 58 - Functional distribution of solution 1

SOLUTION 2

This solution reinterpreted historical vocation as place of exchange, transit and encounter into a contemporary gastronomic and cultural programme capable of generating urban regeneration and enhancing port-city interaction. The place was conceived as eno-gastronomic hub, operating as an urban catalyst for tourists arriving at port of Bari and for local community, attracting the city towards the sea.

The design solution conceived two main functional areas, as shown in Figure 59, with the central distribution area corresponding to the entrances (red area), ensuring double point of access, as well as a connection between the port and the urban context. Unlike the solution 1, access to the entire space could be completely free, increasing the permeable character, with the aim to encouraging the access. This choice reflects related to the concept view of the space as a port free, without barriers and restriction to a free circulation of people, goods and cultures.

Around the central common space, the peripheral spaces (orange areas), such as the current offices and storage area, were converted into eno-gastronomic shop, dedicated to the sale of local and Mediterranean products, as well as tasting areas.

The central space was conceived as food hall (violet area), as a convivial area with free and shared access, for the consumption, rest and encounter. This large space, as

structured, was suited to accommodate different other functions and activities. For example, it could be reconfigured to accommodate masterclasses or cultural events, conferences or presentations. To this end, it could be necessary reorganise quickly the furnishings and using mobile and demountable equipment occasionally set up for masterclasses or other events. In this way the space remains adaptable and flexible space.

These activities could be organised in specific occasion or moment of the day, ensuring full operational continuity and minimising conflict with ordinary daily activities.

The project involved different users. For the tourists arriving from the port, it could be a first point of contact with the gastronomic culture of Puglia and the Mediterranean, while for locals could be used daily. At the same times, a lot of food operator could be active participants in the programme, transferring the local culture. At the same time the event could attract plurality of user profiles.

In this case, the reuse of the spaces certainly required specific interventions to adapt the ventilation, water supply and food safety systems, in accordance with current regulations on food preparation and commercial use. These interventions were expected to be carried out in accordance with the original structure, without completely altering the perception of the space.

Given the continuous flow of tourists in conjunction with the variety of commercial activities planned and the proximity to the urban context, continuity over time could be guaranteed.

SOLUTION 2

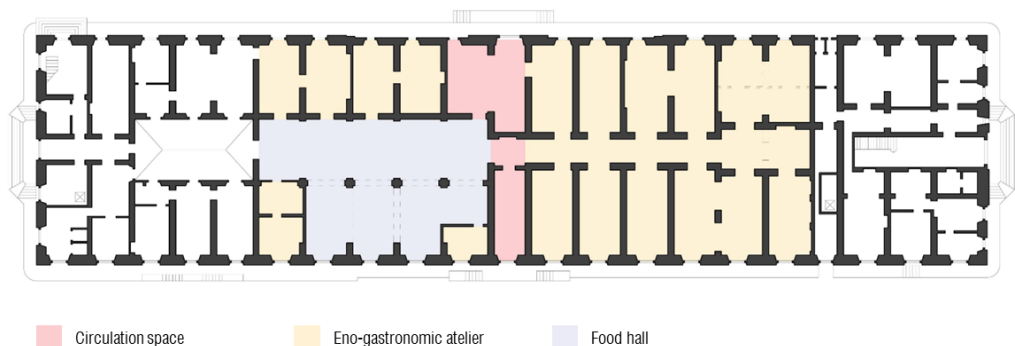


Figure 59 - Functional distribution of solution 2

c. Definition of design solutions

In order to accommodate the new project solutions, common intervention strategies were planned, concerning architectural-structural and construction materials characteristics, with the aim of ensuring the improvement of the state of conservation and the enhancement of the building's identity. To this end, the atlas of meta-project strategies was consulted to define the interventions and refine the proposals.

In accordance with the guidelines provided in relation to the cluster to which the Palazzo della Dogna belongs, the dimension of authenticity (D7) is given particular attention in both solutions. In particular, the interventions involve the conservation of the spatial integrity (S7.2) and, in both cases, the demolition of incongruous stratifications (S7.3) that occurred over time to adapt the building to its current function, restoring its original architectural identity. To this end, the internal partitions, built in the space currently used as offices, and the drywall elements with REI characteristics, in the space used as a warehouse, will be removed to reveal and enhance the original internal portals.

The latter, as well as the entrance doors of the new access, allow the preservation of the building's identity and the enhancement of its intrinsic values (S7.1), through forms of use that evoke its original purpose.

SOLUTION 1

D1: ARCHITECTURAL DIMENSION

From an architectural point of view, the project aimed to respond appropriately to each identified strategy. The *minimum intervention strategy S1.1* involved the conservative restoration of finishes and the preservation of flooring and decorative elements. This also included the restoration of wooden doors. The *architectural harmony and visual compatibility strategy S1.2* was implemented through the preservation of the original architectural composition and the enhancement of the vaults with bubble, avoiding any finishes that could obscure the view. With regard to the *space flexibility strategy S1.3*, the adoption of lightweight movable walls and prefabricated modules was considered, ensuring spatial flexibility over time according to the proposals.

D2: STRUCTURAL DIMENSION

From a structural point of view, any *addition of new structures S2.2* or *removable structures S2.3* were required. Following surveys, *structural consolidation interventions S2.1* could be necessary to improve the state of conservation of the structure.

D3: SOCIO-CULTURAL DIMENSION

The cultural activities proposed intrinsically promote *social integration S3.1*, through the programming of activities capable of involving a wide range of users, from tourists to families to scholars. This would be further enhanced by the presence of workshop and co-working spaces and the organisation of events. The strategy related to *attachment and sense of place S3.2* was carried out through the narration of the history of the port of Bari and the Customs House, and therefore of maritime practices, while maintaining the central role of the Customs House as an essential reference point in the port of Bari. Collective use would also allow the symbolic role within the context of Bari to be maintained.

D4: ECONOMIC DIMENSION

The economic dimension highlighted a significant impact. The activation of a new activity within the building encourages the application of *functional mixes strategy S4.1*, increasing the number of jobs, such as managers, guides, researchers and technicians, as well as attracting different users compared to the current user base. Furthermore, the implementation of recovery and regeneration strategies increases the value of the property. In addition, the presence of this cultural and commercial activity would have an impact on the local economy, generating direct economic benefits. The activity could be managed by public entities or outsourced to private ones, in line with the *public-private partnership strategy S.4.2*. Given the nature of the function, the cultural centre could have a significant impact on the *tourist's attractiveness S4.3*. The effect of cultural purpose could be amplified by integrating it into local circuits in order to make it more attractive.

D5: ENVIRONMENTAL DIMENSION

In line with the critical issues that emerged, this dimension requires particular attention, especially in relation to the *port city interaction strategy S5.1*, where the opening of new access points and the organisation of people flows would ensure direct access from the city and the sea through the building.

Furthermore, in accordance with the area's projects, the building could benefit related to *mobility and accessibility S5.2*, with the improvement of slow mobility and management of vehicular mobility.

The project also requires the refurbishment of the *external areas S.5.3*, with the improvement of the connection with the piers and the refurbishment of the secure external access areas to the assets.

D6: ENERGY DIMENSION

Considering the nature of the asset, its facilities, location and proposed functions, the main *passive design strategy S6.1* involved the installation of adequate internal shading systems. In addition, green areas will be integrated into the outdoor spaces.

Regarding *efficient energy systems S6.2*, the installation of photovoltaic systems is planned, as well as the installation of centralised control systems and rainwater recovery, ensuring maximum integration with the building.

D7: AUTHENTICITY AND HISTORICAL DIMENSION

The new cultural function allowed to respond effectively to the strategy related to *intrinsic values S7.1*, with the preservation of maritime culture and the transmission of knowledge of maritime practices, including through interactive activities and the archive of historical sources. The authenticity of the site also depended on the preservation of its *architectural identity S7.2* It is essential to preserve architectural features that define its identity, such as the vaulted ceiling with lightweight insulating fill, bubble, as well as the spatial conservation of the site. The *significance of heritage S7.3* In this sense, the restoration of the site to its original state contributed to this, as does the preservation of architectural and technical characteristics, using compatible materials.

D9: MANAGERIAL AND FUNCTIONAL DIMENSION

The process of evaluating design solutions could involve the *participation S9.1* of port authorities, as well as *citizens S9.2* in decisional processes, including employees who work within the structure and use the space, in order to highlight any specific critical issues and assess whether it meets contemporary needs. In addition to the academics involved in this process, institutions and those who will manage the structure could also be involved. This can take place through direct personal interaction, as well as through structured initiatives, through the adoption of *digital tools S9.3*, such as the virtual experience structured with this research.

SOLUTION 2**D1: ARCHITECTURAL DIMENSION**

The second solution was also designed while respecting the architectural dimension. The *minimum intervention strategy S1.1* was also applied in this case through the conservative restoration of the finishes and the preservation of the flooring and decorative elements, in addition to the restoration of the wooden entrance doors. At the same time, finishes are to be implemented in the spaces designed for food production to ensure hygienic conditions. Furthermore, in this case, an adequate plant system is to be implemented in some spaces to ensure adequate conditions of use for the purpose, so more invasive interventions may be envisaged in this case. The *architectural harmony and visual compatibility strategy S1.2* is expressed through the preservation of the original architectural composition, flooring, and vaults. As for the *space flexibility strategy S1.3*, the adoption of furniture that allows for the organization of spaces is planned.

D2: STRUCTURAL DIMENSION

As in the previous solution, no *new structures (S2.2)* or *removable structures (S2.3)* will be added. Following investigations, *structural consolidation interventions (S2.1)* may be required to improve the state of conservation.

D3: SOCIO-CULTURAL DIMENSION

The reuse into an eno-gastronomic hub could act as a *social catalyst S3.1*, attracting diverse groups, from locals who can enjoy the space daily to visitors arriving in the Bari area. *Attachment and sense of place S3.2* is achieved through the enhancement of the Palazzo della Dogana as a threshold to the port, which can be freely and daily crossed and enjoyed as a space that remains coherent over time for its distinctive architectural features. Collective use would also allow the symbolic role within the context of Bari to be maintained.

D4: ECONOMIC DIMENSION

As conceived, the inclusion of the new function would favour the *functional mixes S4.1*, increasing the number of jobs, such as specialised positions in the hospitality sector. This function also contributed to economic development, producing effects on an urban scale. In this case too, the value of the asset would increase through recovery and regeneration interventions. The activity could be granted in concession to private companies or managed directly by the Port Authority, with independent companies renting individual spaces. In any case, the new function would have an impact on *tourist attractiveness S4.3*, given its strategic location within the port.

D5: ENVIRONMENTAL DIMENSION

As previously illustrated *port city interaction strategy S5.1* was implemented opening new access points and the organisation of people flows would ensure direct access from the city and the sea through the building. Furthermore, in accordance with the area's projects, the building could benefit related to *mobility and accessibility S5.2*, with the improvement of slow mobility and management of vehicular mobility. The project also requires the refurbishment of the *external areas S5.3*, with the improvement of the connection with the piers and the refurbishment of the secure external access areas to the assets.

D6: ENERGY DIMENSION

Considering the nature of the asset, its facilities, location and proposed functions, the main *passive design strategy S6.1* involved the installation of adequate internal shading systems. In addition, green areas will be integrated into the outdoor spaces. Regarding the *efficient energy systems S6.2*, the installation of photovoltaic systems is planned, as well as the installation of centralised control systems or rainwater recovery, ensuring maximum integration with the building.

D7: AUTHENTICITY AND HISTORICAL DIMENSION

The new cultural function allowed to respond effectively to the strategy related to *intrinsic values S7.1*, with the preservation of local culture and the transmission of knowledge of cuisine, through the experience of producers. The authenticity of the site also depended on the preservation of its *architectural identity S7.2*. It is essential to preserve architectural features that define its identity, such as the vaulted ceiling with lightweight insulating fill, bubble, as well as the spatial conservation of the site. The *significance of heritage S7.3*. In this sense, the restoration of the site to its original state contributed to this, as does the preservation of architectural and technical characteristics, using compatible materials.

D9: MANAGERIAL AND FUNCTIONAL DIMENSION

The process of evaluating design solutions could involve the *participation S9.1* of port authorities, as well as *citizens S9.2* in decisional processes, including employees who work within the structure and use the space, in order to highlight any specific critical issues and assess whether it meets contemporary needs. In addition to the academics involved in this process, institutions and those who will manage the structure could also be involved. This can take place through direct personal interaction, as well as through structured initiatives, through the adoption of *digital tools S9.3*, such as the virtual experience structured with this research

Assessment of design solutions for Palazzo della dogana in port of Bari via AHP

The defined solutions were subsequently evaluated through a multi-criteria analysis, as defined in phase 2.3, using the AHP method. Based on the identified indicators (ph.2.1), each solution was assigned ratings in accordance with the defined evaluation methods. The proposed method allowed individual judgements to be synthesised on the basis of the weights obtained from the experts' judgements, as explained in section 5.2.2. The table below (Table 6) shows the ratings assigned and the weighted values, where the overall weighting $AR_{v,n}$ of each sub-criterion w'_{ij} is multiplied by the score assigned to it in the project p_{ij} .

The assessment results in a higher score for solution 1, determined by the greater capacity of the cultural proposal to enhance the intrinsic and historical-cultural values of the asset, reinforcing its identity and significance in the context. At the same time, the interventions to adapt it to new function are less invasive and more compatible with the architectural characteristics of the asset, with a better preservation of the building.

Table 6 - Evaluation of design solutions

Strategies		w'_{ij}	s1	$AR_{v,1}$	s2	$AR_{v,2}$	$\Delta AR_{v,1}-AR_{v,2}$
ADAPTIVE REUSE OF PORT HERITAGE	I1.1 Minimum intervention	0,027	3	0,08	2	0,05	+0,03
	I1.2 Architectural harmony and visual compatibility	0,030	4	0,12	3	0,09	+0,03
	I1.3 Adaptability and spatial flexibility	0,053	5	0,27	5	0,27	0
	I2.1 Retrofitting of existing structures	0,044	3	0,13	3	0,13	0
	I2.2 Structural integration	0,048	0	0,00	0	0,00	0
	I2.3 Dismantlability/ Flexibility of components	0,072	1	0,07	1	0,07	0
	I3.1 Social integration and inclusion	0,053	5	0,26	5	0,26	0
	I3.2 Attachment and sense to place	0,035	5	0,18	4	0,14	+0,04
	I4.1 Functional mixes	0,028	5	0,14	5	0,14	0
	I4.2 Public-private partnerships	0,024	5	0,12	5	0,12	0
	I4.3 Tourist attractiveness	0,020	5	0,10	4	0,08	+0,02
	I5.1 Port-city interaction	0,045	5	0,23	5	0,23	0
	I5.2 Mobility and accessibility	0,046	5	0,23	5	0,23	0
	I5.3 Public open and green spaces	0,041	2	0,08	2	0,08	0
	I6.1 Passive design strategies	0,050	2	0,10	2	0,10	0
	I6.2 Efficient energy systems	0,067	3	0,20	3	0,20	0
	I7.1 Intrinsic value	0,029	5	0,14	2	0,06	+0,09
	I7.2 Authenticity and integrity	0,038	5	0,19	5	0,19	0
	I7.3 Significance of the heritage	0,053	4	0,21	4	0,21	0
	I9.1 Involment of community	0,031	5	0,15	5	0,15	0
	I9.2 Involment of different stakeholders	0,034	5	0,17	5	0,17	0
	I9.3 Adoption of different tools	0,012	3	0,03	3	0,03	0
	I10.1 Compatibility with the context	0,039	5	0,20	5	0,20	0
	I10.2 Compatibility with original use	0,026	4	0,10	4	0,10	0
	I10.3 Compatibility with the architectural characteristics	0,057	5	0,28	5	0,28	0
				3.80		3,60	

5.3. *Digital ecosystem*

The development of a digital environment was conceived as more than a simple digital reconstruction of a physical space or the mere adoption of digital tools. Rather, it was designed to be an environment capable of systematising knowledge in order to promote cognitive processes for the enhancement of port heritage and support decision-making processes. A digital ecosystem coherent with the previously defined methodological approach allows for the integration of processes and knowledge and collaboration between the different actors involved.

In this scenario, the adoption of codified systems and the creation of a scalable, multidimensional and multi-level architecture enables the definition of a structured system that adopts digital tools to reduce processes fragmentation. The system structured in this way could be implemented and evolve overtime, enabling the definition of a strategic vision of the place over time.

Specifically, in accordance with phase 3, the development of this environment involves knowledge management (ph.3.1), with the systematisation of knowledge within a georeferenced geographic system and the creation of BIM models; followed by design solutions management (ph.3.2) aimed at improving communication of design solutions through the adoption of virtual and augmented reality technologies; everything converges within an integrated digital system (ph.3.3), designed for technical and non-technical users, also providing for the integration of a virtual experience capable of supporting decision-making processes through more realistic and engaging experiences.

5.3.1. Ph. 3.1 Knowledge management

Based on preliminary census and cataloguing of port heritage and area, the data previously collected in the first stages of the cognitive framework (ph.1.1, ph.1.2 and ph.1.3) were systematised in an organic and systemic way within the GIS environment, in order to have a unified and multidimensional system, ensuring an organic and integrated view of the information system on a territorial scale, according to the paradigms of Knowledge Management. To this end, QGIS software was adopted. Initially, each spatial and architectural entity was accurately identified and geolocalised in the reference system. In this context, this structured approach avoids the fragmentation typical of file-based formats in favour of a spatial RDBMS (Relational Database Management System), such as the OGC GeoPackage standard.

The following vector layers were created for each port area surveyed (Figure 60):

- Port area (geometry: polygon)
- Port assets (geometry: multipoint)
- Port accesses (geometry: multipoint)
- Historic urban centre (geometry: polygon)
- Railway line (geometry: line)
- Main road network (geometry: line)

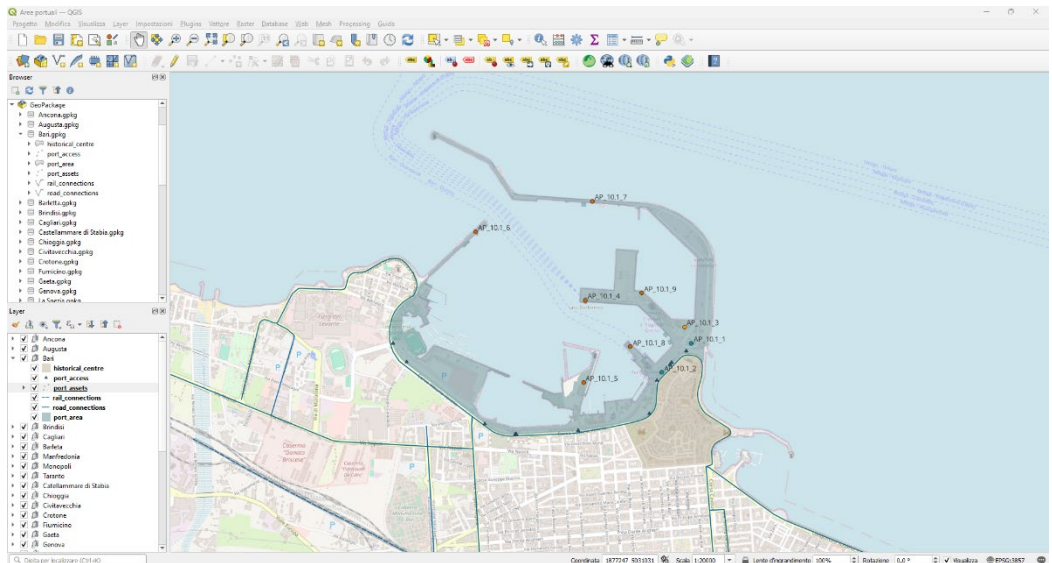


Figure 60 - QGIS project

The information system structure for each layer is fundamental. The port areas were associated with the information collected using the Level 1 and Level 2 cataloguing cards, as described in phases ph.1.1 and ph.1.2.

Specifically, the following information fields were associated with each port area (Figure 61):

- ID_area: identification code as previously defined;
- Compiler: name of the compiler and reviewer, including date of compiling;
- Name: denomination, as commonly identified;
- Location: name of the city where is located;
- Ownership;
- Managing: name of managing authorities;
- Context: urban position (urban/ periurban/ suburban);
- State: state of use (in use/ partially in use/ not in use);
- Use: current use in accordance with specific port documents (commercial and logistics/ industrial and oil-handling / passenger service/ fishing and/or tourism and leisure);
- History: briefly description of evolutionary process;
- Description of the current configuration;
- Cartography: link to available cartography.

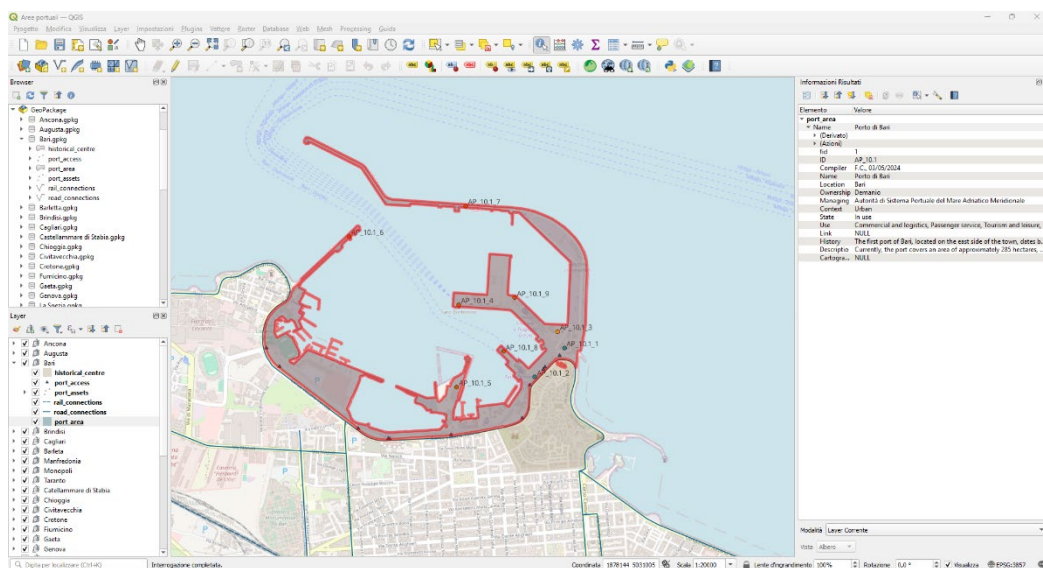


Figure 61 - Informative system at port area scale in QGIS

Instead, the information collected in the Level 3 cataloguing card was associated with each asset, as described in phase ph.1.3. Each asset could be localised as a point element and to each one associated informative fields (Figure 62), such as:

- ID_area
- ID: identification code of the asset;
- Name: denomination of the asset;
- Location
- Address
- Ownership;
- Managing;
- Type: type of asset (type I, type II, type III, type IV, type V, type VI);
- Use: current state of use (in use/partially in use/not in use);
- Cons: current state of conservation (good/discrete/bad);
- Cxt: current function of the context (commercial and logistics/ industrial and oil-hadling / passenger service/ fishing and/or tourism and leisure);
- Cur: current function of the asset;
- Orig: original function of the asset;

The quality of the assessment depends on the quality of the input data, which requires a careful preliminary phase of data collection and implementation, in accordance with the function coding system defined in Table x.

Subsequently, to conduct the clustering, specific parameters associate to each asset in GIS environment were considered according the phase1.5. They were collected during the cataloguing of port heritage (ph.1.3) and evaluated in the functional assessment (ph.1.4). To simplify the analysis, the ordinal scale was converted to a cardinal scale. The algorithmic nature of the method within the GIS environment allows the assessment process to be automated, thereby ensuring efficiency and reliability over time.

5.3.2. Ph.3.2 Design solutions management

The design solutions previously defined in paragraph 5.2.3 were modelled in a BIM environment for the visualisation in virtual environments (ph.5.2).

i. Data processing

To reconstruct the building, firstly laser scanning and photogrammetric techniques were used to acquire data on site (Figure 63).



Figure 63 - Situ survey

Laser scanning survey was conducted using a Leica BLK360 laser scanner produced by Leica Geosystems. It is a Time of Flight (ToF) laser scanner, capable of acquiring high-density point clouds and integrated 360° panoramic images, with a maximum range of approximately 45 metres.

This instrument is capable of acquiring accurate data in a short time. This instrument allows for precise acquisitions with reduced acquisition times and, moreover, has the potential to automatically align stations, by using real-time tracking of movement via

the Visual Inertial System (VIS). The technical specifications of the instrument are as follows:

- weight and dimensions: 0.75 kg (without battery), height 155 mm and diameter 80 mm;
- laser class: 1, wavelength 830nm
- 3D point accuracy: ± 4 mm at 10m
- range: from 0.5 m to 45 m
- acquisition frequency: up to 680,000 points per second
- field of view: 360° (horizontal)/ 270° (vertical)

Data acquiring through laser scanner were processed to generate a point of clouds.

The data acquired with the laser scanner was downloaded and then imported into Cyclone REGISTER 360 PLUS® software. To increase the robustness of the point cloud, pairs of stations characterised by low overlap were selected and then optimised through visual alignment.

The photogrammetric survey, on the other hand, was conducted using an unmanned aerial vehicle (UAV), specifically the DJY Mini 4 Pro drone. This is an ultra-lightweight and compact drone, designed to offer high performance in an extremely easy-to-handle device. It is capable of capturing images in 4K quality, ensuring high quality in the data collected. The technical specifications of the instrument are listed below:

- Weight: less than 249 grams
- Flight time: up to 30 minutes
- Maximum horizontal speed: approximately 16 m/s (normal mode)
- Maximum horizontal speed: approximately 16 m/s (normal mode)
- Maximum flight altitude: 4000 m
- Photo sensor: 1/3" CMOS, 48MP effective pixels
- Image resolution 8064x6048
- Camera stabiliser: 3-axis mechanical

The flight plan for the drone was designed to capture aerial photographs and video of the internal and external area of interest. This approach allowed the rapid and cost-effective acquisition of data with high precision.

The maximum altitude attained by the drone was less than 10 metres above ground level. The acquisition methods were conducted with parallel and converging axes. The drone flew in a series of repeated movements, starting from the ground and proceeding from left to right with movements from bottom to top and from top to bottom. In order to obtain comprehensive coverage, both nadir and oblique images were collected, while any missing shots were extracted from the video. The high-resolution photos and the large number of photos at different heights and at different angles permitted numerous overlaps between the images, thereby ensuring a reliable reconstruction of the entire building, comprising internal and external spaces of interest.

The previously obtained cloud was textured through drone acquisition. This process could be accomplished with the use of various software applications. For this purpose, the Agisoft Metashape was chosen.

ii. BIM modelling of design solutions

Considering the previously defined project solutions, BIM modelling was conducted using Autodesk Revit® 2022 software. To this end, the point cloud was imported in Autodesk Recap® to convert the file into .rcp file format, compatible with Autodesk Revit®. The modelling was limited to a representation of the proposed design solutions (Cassano, Giannuzzi, et al., 2026).

In this specific case, with reference to a space currently used for storage, only the lower part of the structure was modelled, as the vaulted ceiling is not directly affected by the interventions. The floor and internal partitions were reconstructed, and the space was then furnished to provide a view of the environment with its new function. The two new solutions were modelled as parametric objects using as a reference the points cloud. This approach ensured that the solution was rapid and appropriately dimensioned. The

modelling of the solution had a level of detail equivalent to LOD C, aligning with the phase of the building process.

The model has thus been enriched with parametric information. Data such as materials or types of intervention to be carried out could be associated as text and numerical annotations. In addition to technical information, the models were enriched with parameters corresponding to the indicators required to conduct automatic and expeditious evaluation of design solutions (ph.3.2). In particular, each modelled solution was associated with a local, considered as an entity to which the parameter system (Figure 64) was associated in order to allow evaluation through the weights obtained from the AHP.

Proprietà	
	
Locali (1)	Modifica tipo
Vincoli	
Testo	
I1.1_minimum intervention	
I1.2_architectural harmony and visual compatibility	
I1.3_adaptability and spatial flexibility	
I10.1_compatibility with the context	
I10.2_compatibility with the original use	
I10.3_compatibility with the architectural characteristics	
I2.1_retrofitting of existing structure	
I2.3_dismantlability/ flexibility of components	
I3.1_social integration and inclusion	
I4.1_functional mixes	
I4.2_public-private partnerships	
I4.3_tourist attractiveness	
I5.1_port city interaction	
I5.2_mobility and accessibility	
I5.3_public open and green spaces	
I6.1_passive design strategies	
I6.2_efficient energy systems	
I7.1_intrinsic values	
I7.2_authenticity and integrity	
I7.3_significance of the heritage	
I8.1_respect of regulatory	
I8.2_multi-level and participatory governance	
I9.1_involvement of community	
I9.2_involvement of different stakeholders	
I9.2_attachment and sense to place	
I9.3_adoption of different tools	
ctx	
cur	
orig	
intv	
I2.2_structural integration	
Quote	
Dati identità	
Fasi	
Altro	
AR_value	

Figure 64 - Parameters associated to local entity in Revit

iii. Design solutions assessment

The algorithm for evaluating the solution was defined in Dynamo. The programming in Dynamo adopted a VPL language, divided into information blocks called nodes, connected to each other by graphic connectors, polylines or curves, in order to build the script. Each node is characterised by a specific function, including Python codes, and has enabled the management of input or output data, allowing the computational process to be structured in a customised manner in relation to the purposes through a visual and modular logic.

The structure was based on that previously defined in phase 2.1 (paragraph 4.3.1). Therefore, the algorithm was divided into dimensions, containing relative indicators. The weight calculated through the AHP was associated with each of these. The sum of the weighted values of each indicator for each dimension was in turn weighted, in accordance with the methodology, to provide the final value of the solution.

The value obtained was then returned to the same local in Revit, in the specific field (AR_value).

Therefore, the algorithm, as defined in Dynamo, was associated to the model of the present case study using the Dynamo function 'Select Element by Categories' (Figure 65).

Once associated, the model was checked to ensure that the parameters associated with the model local had been defined correctly and were being read properly by the algorithm. This made it possible to conduct the assessment for each solution.

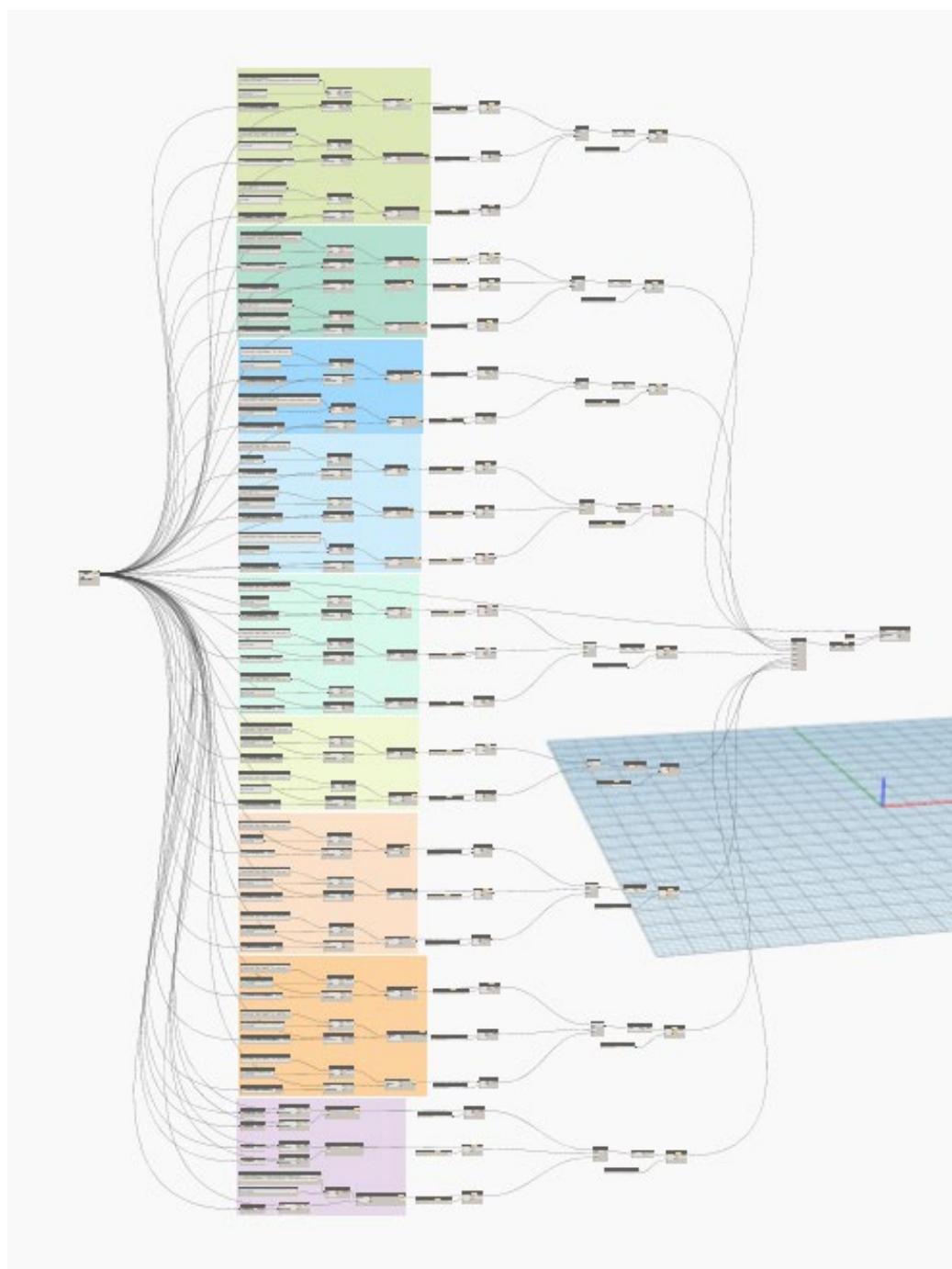


Figure 65 - VPL code in Dynamo

iv. Design solutions communication in AR/VR mode

At the end, the models were exported directly from Revit® in .fbx format to be implemented in AR applications to visualise the solutions. The AR environment used to generate the platform was Unity® 3D (version 2022.3.4f1). The initial step involved the creation of an interface designed to respond to the research objective. A Game Manager script was defined to control the functionality of the buttons, thereby associating each button with the specific solution (asset). In particular, the configuration comprises two principal bottoms, named “Solution 1” and “Solution 2”, each associated with a corresponding asset. This setup enables users to display or hide a solution by pressing the respective button. The user interface was then implemented with additional content and buttons. These included a container in which project-specific information was presented, such as project name and location. Additionally, a bottom labelled “i” for “info” was added to provide technical content related to the specific solution, such as information about materials and estimated costs deriving from the BIM model for each solution. To this end, the 3D object and point cloud were imported in .fbx format file and were aligned with one another. While the point cloud is associated with a PNG image to automatically obtain a coloured point cloud, the BIM models, once imported, appear white. Therefore, materials were created in Unity® to which a texture was assigned, and this was then manually associated with each component of the specific model to make it more realistic. Then, each solution was associated with specific bottoms and related information was implemented.

Finally, the application was exported, generating an AR mobile application. In this specific case, it was exported as ARCore for Android thanks to Vuforia Engine software, a technology that enables the creation of AR applications, permitting to overlap of the AR content in reality. It advanced recognition and tracking capabilities, enables developers to integrate interactive digital content into the real-world context.

For the prototype test, the image target was chosen as a spatial reference for attaching digital content. As conceived, it allows the visualisation of acquired and implemented data related to the building. Thus, it is possible to explore the design solution through mobile devices.

5.3.3. Ph.3.3 Creation of integrated digital system

In order to guarantee an integrated multi-scale and multi-level system capable of supporting the management of port sites and assets, as well as supporting decision-making processes, an innovative workflow was defined that integrates the different systems into a digital ecosystem.

In accordance with the methodological approach defined in section 4.4, different digital systems are integrated to allow experts and non-experts to access the knowledge system.

i. Systematisation of cognitive systems in an external database

First of all, an external database was created in which the data systematised in the GIS environment and the outputs of the assessments conducted in the BIM environment were uploaded. Therefore, the informative system implemented in the GIS environment was transferred to a database via a PostgreSQL plugin (Figure 66). In this way, connection to the database was created and then the project layers were loaded within (Figure 67). This connection ensured a two-way connection from the GIS to the database and vice versa.

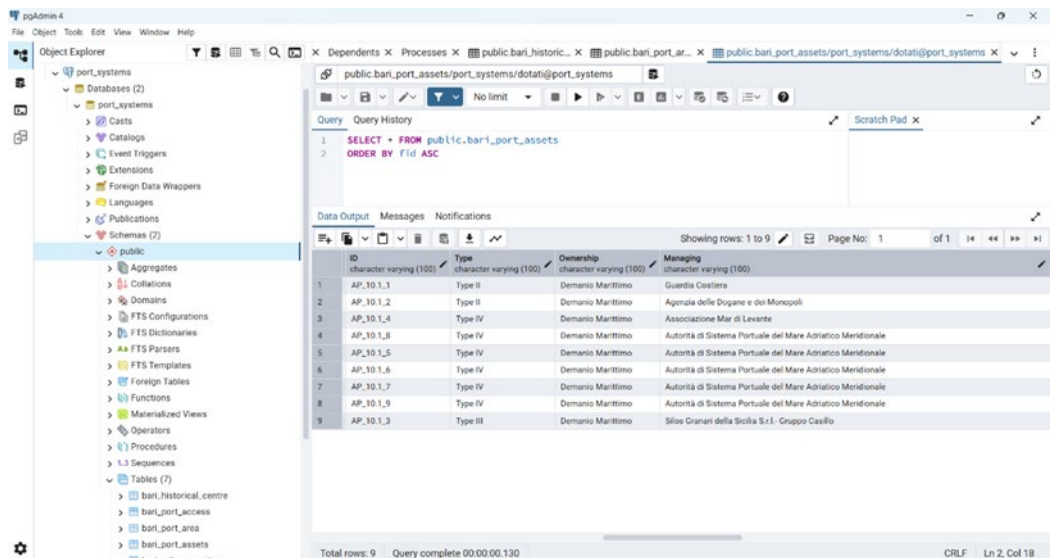


Figure 66 - Visualisation of the database

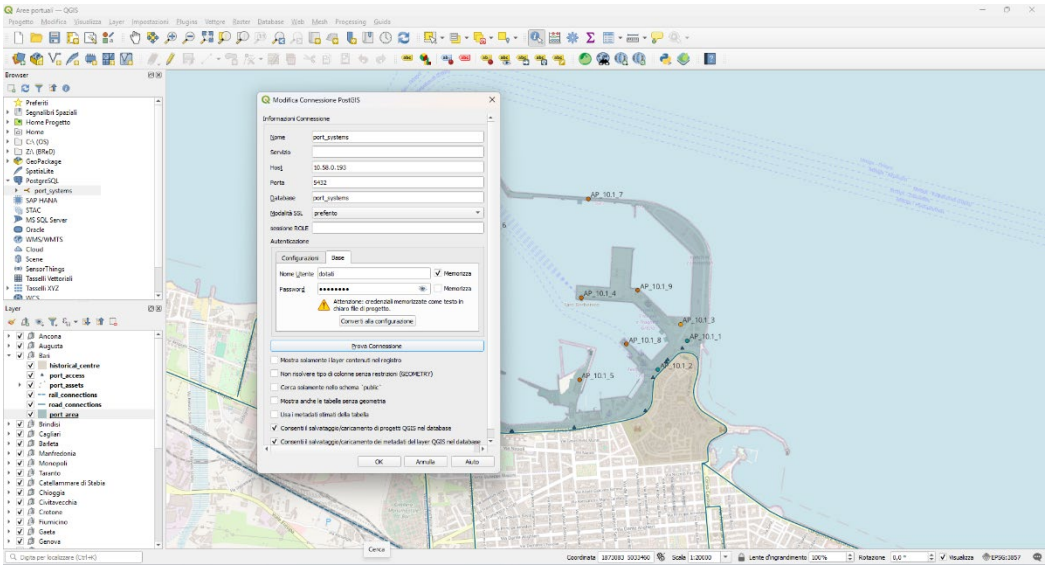


Figure 67 - Connection to postgresQL database in QGIS

In the same way, the parametric data of the BIM model was also transferred to the database. Using the Revit DB Link module, a connection to the database was created and the parameters associated with the local relating to the design solution were transferred (Figure 68).

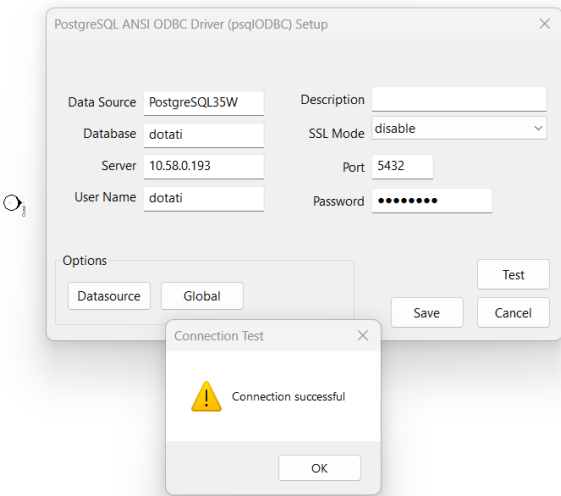


Figure 68 - Connection to Revit DB Link

ii. Development of shared and collaborative digital system

Finally, the integrated digital environment was created according to the defined structure in ph.3.3, as shown in Figure 69.

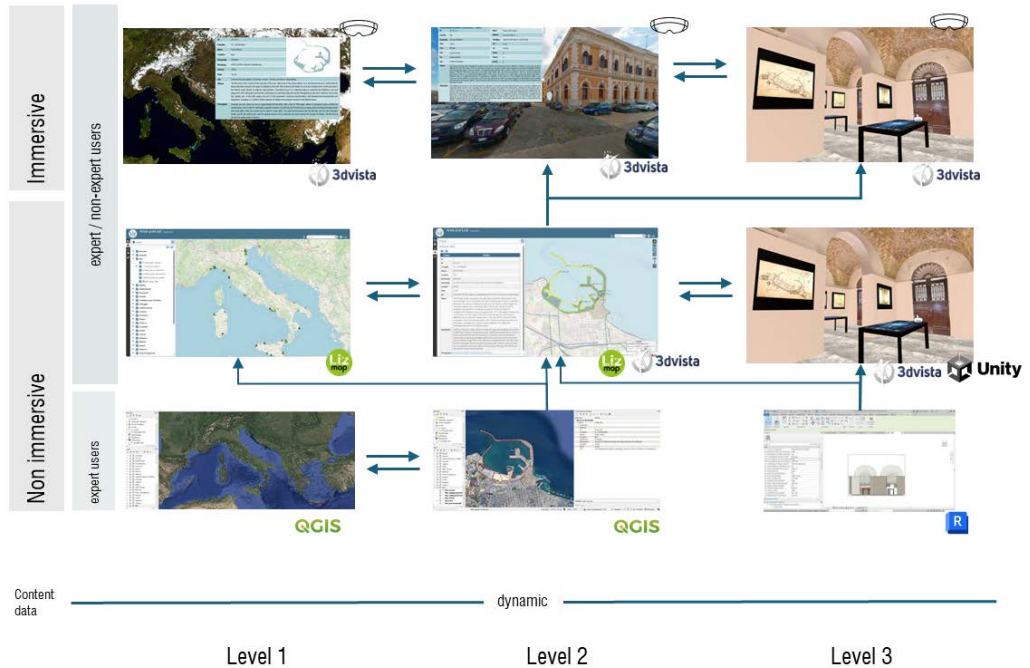


Figure 69 - Structure of integrated digital systems

In particular, the non-immersive level for experts involves the adoption of technical tools such as GIS for the systematisation of the knowledge system and BIM for the modelling of design solutions.

The information implemented in the GIS database subsequently enabled the creation of a webGIS, through the Liz map plugin, as shown in the figures below (Figures 70 – 71). The informative structure, as well as the informative content, derived directly from the GIS environment.

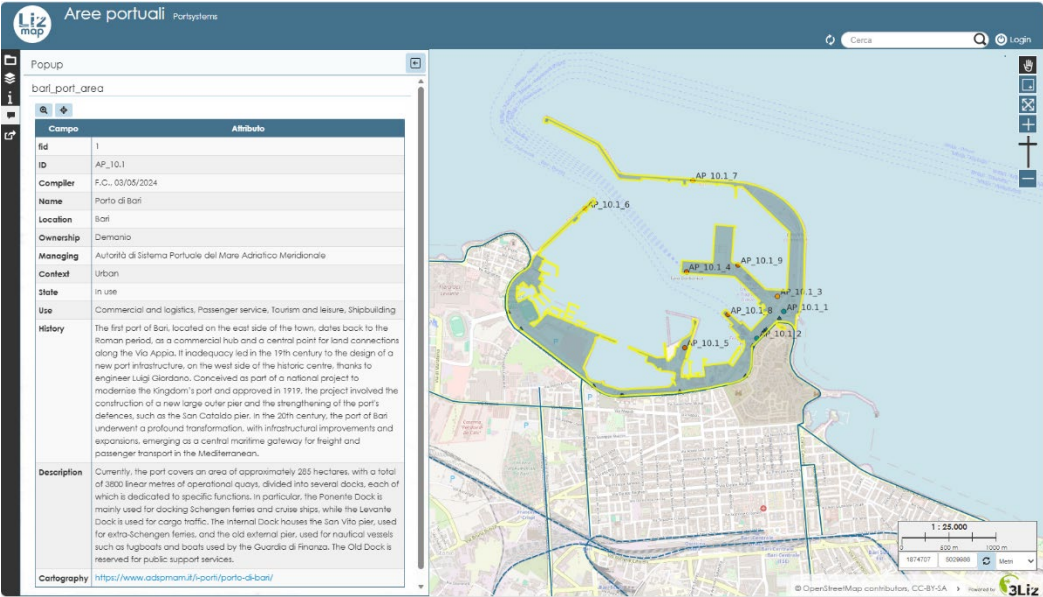


Figure 70 - Visualisation of port area of Bari in webGIS

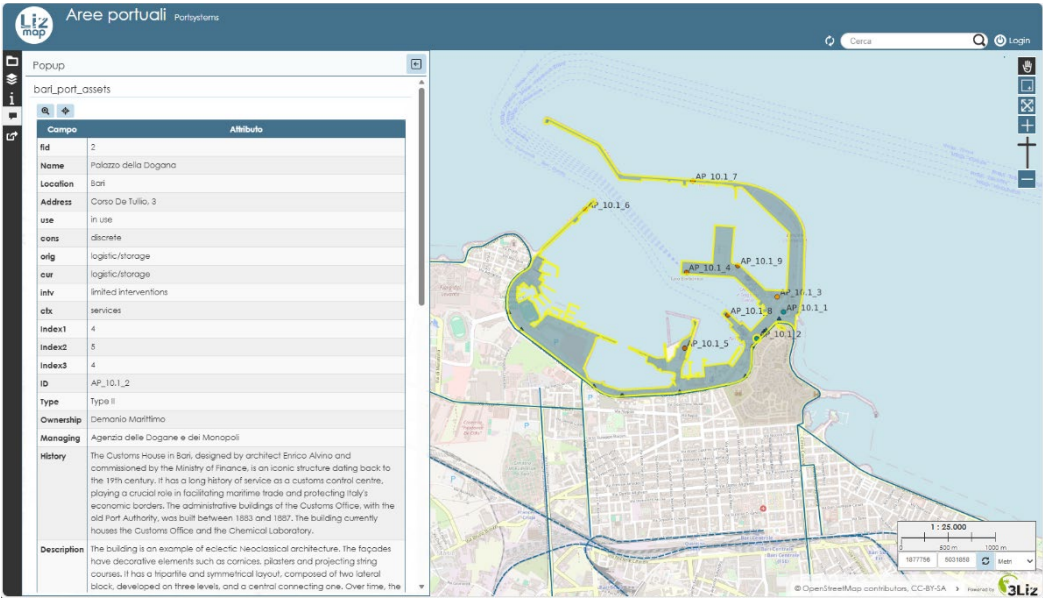


Figure 71 - Visualisation of Palazzo della Dogana in webGIS

To increase the level of involvement of stakeholders in the decision-making process, in accordance with the methodological flow described in paragraph 4.4.3, a virtual experience was created through the development of a virtual tour. For this purpose, 3D Vista Virtual Tour software was adopted, consistent with previous and similar applications, and as an opportunity to further explore and exploit its potential functionalities. Specifically, two modes of use were provided: a non-immersive mode for a PC experience and an immersive mode for an immersive experience with headsets.

In both cases, a realistic exploration of the port area was provided by recreating the port environment using spherical photos obtained with an in-situ survey (phase III) (Figure 72).



Figure 72 - Spherical photo of port of Bari

In each scene, semantic contents were organised for informative levels sourced from the structured databases were display through a specific container in adopted software. The containers were inserted with Level 1 (ph. 1.1) and Level 2 (ph.1.2) information content sourced from databases. This allows users to consult data updated in real time by experts in specialised software and subsequently in the database.

In this way, it is possible to explore the port area and a specific hotspot permitted to consult information about the port of Bari, such as historical information and general information (info hotspot), as well as denomination, location, ownership and

management regime, current state of use and functions, as well as cartographic resources available in regional, urban and port sources (ph.1.3) (Figure 73).



Figure 73 - View of Port of Bari with an exemplification of general information in non-immersive mode

Furthermore, other specific hotspot (in lights blue colour hotspot in Figure 73) permitted to identify in the port area the asset of interest and to access to the second informative level. In particular, it is possible to consult information about it, as denomination, state of conservation and technical documentations, as well as visualising asset specificity, comprising the analyses results and/or the modelled design solutions (Figure 74).

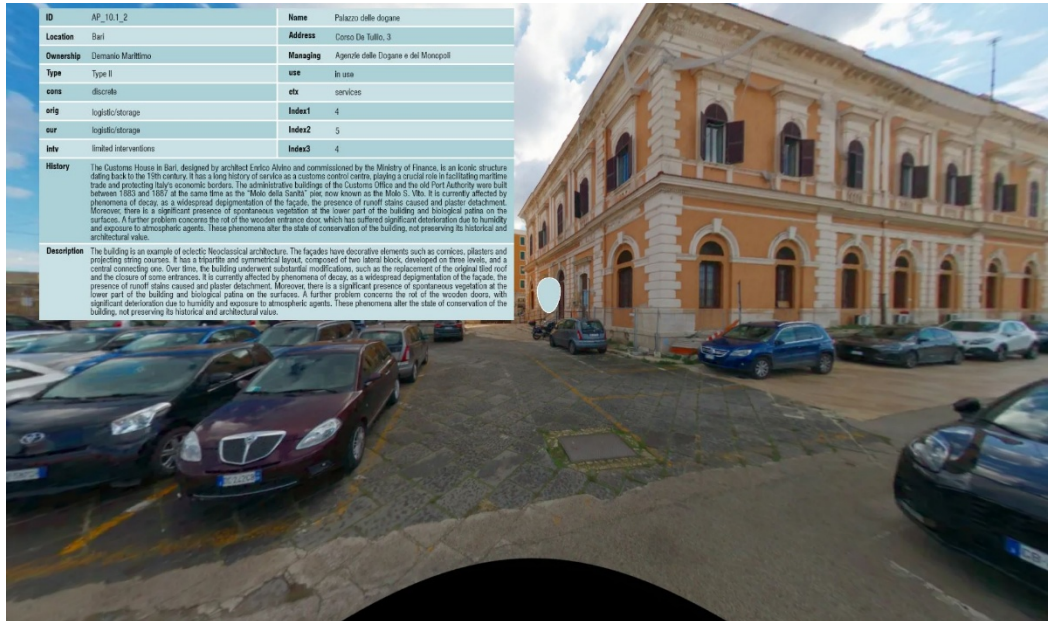


Figure 74 - View of Palazzo della Dogana with content of Level III

From the container of the asset, with other specific hotspot, it is possible to access the visualisation of the model of the selected asset with the modelled design solutions. In this case, a 3D model was displayed which, in accordance with the methodology of ph.3.2, provides for the integration of the textured mesh of the real building integrated with three-dimensional models of the design solutions modelled as parametric BIM objects (Figure 75).



Figure 75 - Visualisation of solution 1 in 3D Vista

Therefore, the visualisation of the current condition of the building as a reconstruction of the existing structure, thus with a adequate level of realism, was implemented with modelled solutions are displayed. In particular, in non-immersive mode, a QR code allowed users to view the virtual model with design solutions in AR mode, developed in Unity, as a museum space in Figure 75. This is associated with level 3 information content (ph.1.3) with the return of the result of the evaluation of each solution carried out in Dynamo (p.2.2) from the database.

This workflow is structured in such a way that it is bidirectional when used in non-immersive mode.

The exploration in non-immersive mode was particularly preferred to easier consultation of technical documentation via external links to technical pages such as the Port Authority's website or other database. At the same time, it offered a greater level of detail, allowing for the viewing of more detailed analyses and visualising and measuring point clouds, as well as the combined use of more technical and specialised software. The result would be a specialised environment designed to meet the requirements of the technicians.

In immersive mode, the contents were consulted in a different mode of use, since the GIS/web GIS work environment is certainly not directly accessible. To this aim, they were simplified for easier and more effective consultation of essential content for rapid access to the main information essential to understanding the project's purpose. Specifically, a three-dimensional model representing the territorial context has been integrated, in which the individual port areas have been manually located and each of these has been associated with Level 1 content (ph.1.1) from the external database. From this, it is then possible to use the three levels of investigation.

Though the adoption of a headset, this experience was designed to offer a more engaging visualisation of the built environment, particularly with regard to design solutions assessment.

No specific expertise is required to explore the built environment in both non-immersive and immersive modes. In this way, technicians and stakeholders, as well as communities, involved in the decision-making process, could explore the virtual environment.

CONCLUSIONS AND FUTURE DEVELOPMENTS

The peculiar complexity and historical-evolutionary dynamics resulting in evident phenomena of degradation and abandonment. In this context, the limitations and unstructuring of traditional processes for managing and enhancing heritage, due to the stratification of values, the multitude of stakeholders involved and the fragmentation of accessible data, need to be overcome through integrated approaches supported by the adoption of digital tools. This research focused on the revitalisation of historical, architectural and industrial heritage within port areas, with the aim of outlining a methodological approach capable of supporting informed decision-making processes in defining for intervention on port heritage. To this end, an integrated approach capable of combining protection and enhancement with sustainability objectives emerged as a necessity. In this scenario, adaptive reuse represents a strategic approach to the recovery, reuse and enhancement of port heritage.

Based on these assumptions, the research aimed to define an integrated multi-scale and multi-level methodological approach to support knowledge, analysis, and decision-making processes, integrating methods and tools.

Through the analysis of port areas managed by Port System Authorities, considered representative of Italian port contexts, it was possible to outline a general overview of port areas and related assets, as a basis for developing a dialectical vision. Each of the 63 ports was surveyed and catalogued (ph.1.1, ph.1.2, ph.1.3), allowing the main characteristics of Italian port areas and related assets to be outlined through the analysis of the most recurring features.

Based on the preliminary survey and cataloguing of the port area and its heritage, a systematic classification of the assets was carried out by assessing the state of conservation and use of each asset, as well as indicators of functional compatibility (ph.1.4).

This analysis considered 260 assets located within the main Italian ports managed by the Port System Authority (AdSP), in order to carry out clustering (ph.1.5), applying

the k-means method, which led to the identification of six clusters relating to port assets.

Subsequently, adaptive reuse strategies were analysed and defined.

The analysis of 27 projects for the recovery, reuse, and redevelopment of national and international port assets made it possible to define an atlas of meta-design strategies (ph2.2), conceived as an open multidimensional tool of meta-design strategies and possible technical solutions for adaptive reuse.

In order to evaluate the adaptive reuse design solutions, each indicator identified as fundamental in the adaptive reuse process (ph.2.1) was evaluated by a panel of 15 academics and experts, using the AHP method (ph.2.3), through the online tool AHP-OS, assigning a weight to express the importance of each aspect in the adaptive reuse projects.

The case study identified for the application of adaptive reuse strategies was the Palazzo della Dogana, located in the port of Bari. Starting from the context analysis, two design solutions were proposed and subsequently evaluated using AHP to identify the potentially most effective solution.

Finally, the research focused on the development of digital tools (ph.3). The data previously collected in the early stages of the cognitive framework was systematised in an organic and systemic manner within the GIS environment in order to obtain a unified and multidimensional system. Based on this cognitive system, using a Python algorithm, it was possible to automatically and quickly assess the levels of functional compatibility. Subsequently, the previously defined design solutions were modelled in a BIM environment and automatically and quickly assessed using a Dynamo code, adopting a VPL language.

Finally, a digital environment was created to systematise data in an integrated and shared virtual environment, with different levels of immersion and for different areas of expertise. In particular, the non-immersive level for experts involves the adoption of technical tools such as GIS for the systematisation of the knowledge system, which enabled the creation of a webGIS, and BIM for the modelling of design solutions, whose information systems converge in a central database.

To increase stakeholder involvement in the decision-making process, a virtual experience was created through the development of a virtual tour using 3D Vista Virtual Tour software. Specifically, two modes of use were provided: a non-immersive mode for a PC experience and an immersive mode for an immersive experience, through which it was possible to make knowledge and digital models accessible.

Therefore, the proposed methodological approach enabled the integration of cognitive processes, analytical tools, and digital environments into a framework oriented toward the recovery, reuse, and enhancement of port heritage. It could be replicated and adapted to the different necessities and skills of different stakeholders involved, considering the influence of these peculiarity contexts not only on the specific urban environment but also on the wider territorial context.

In light of the results presented, the main outputs produced in response to the initial research questions may be summarized as follows:

- 01.1 Expedited census and cataloguing of port areas and their heritage by means of a multi-level cataloguing card;
- 01.2 Conservative-functional clustering of port assets by applying the unsupervised k-means method;
- 02.1 Open and multidimensional atlas of meta-design strategies and technical solutions for adaptive reuse;
- 02.2 AHP evaluation applicable in other adaptive reuse applications, without calibration related to specific case study;
- 03.1 Comprehensive database for integrating cognitive information systems integrated in GIS (03.1) and BIM (03.2) environment, aimed at developing a webGIS and integrated digital environment (03.5);
- 03.2 Integrated digital ecosystem, as a shared, collaborative and multimodal environmental, with innovative approach integrating BIM models and point clouds into VR and AR environment.

Therefore, the proposed methodological approach enabled the integration of cognitive processes, analytical tools, and digital environments into a framework oriented toward the recovery, reuse, and enhancement of port heritage.

The census and cataloguing of port areas and existing heritage have made it possible to outline an overview of built port environments, offering a systemic view of heritage. The process has confirmed the widespread presence of historical, architectural, and industrial heritage that needs to be recovered and redeveloped, even within broader regeneration processes, as well as the inadequacy of existing management systems. In this sense, the data collected on the main areas provide the basis for further consideration, as well as the basis for a knowledge system that could be continuously implemented, also considering smaller Italian ports.

The definition of clusters based on the main characteristics of port heritage is an approach that, through critical analysis and a systemic interpretation of port heritage, guides the definition of project strategies, allowing random interventions to be avoided. This preliminary assessment, accompanied by a multidimensional approach that considers all the fundamental dimensions of adaptive reuse processes, ensures the effectiveness of project proposals through a comprehensive and structured system capable of responding to specific local critical issues.

In this context, the atlas of meta-design strategies was configured as a multidimensional operational tool, open to subsequent implementation and designed to support processes that are not merely simple repurposing, but are oriented towards enhancing historical, architectural, and cultural identity, and capable of supporting decision-making processes relating to intrinsically complex and dynamic contexts, overcoming the widespread “case by case” approach. Its definition, based on the analysis of national and international port assets, allows for transfer to similar contexts. Another innovative contribution concerns the creation of an integrated digital ecosystem, aimed at supporting the management of the knowledge system and design solutions, as well as the management and enhancement of existing assets. The digital environment integrates various parts that converge towards a central database capable of encouraging collaborative processes. By configuring itself as an integrated, shared,

and collaborative environment, it allows us to overcome the proprietary concept, offer a valid solution to the problem of fragmented information, and encourage collaborative processes and informed decisions. The effectiveness of this system is amplified in cases, such as ports, where decision-making processes are multi-scale and multi-level, involving a plurality of actors. The digital systems could be used for different purposes, from awareness-raising and information sharing to technical analysis. Furthermore, the adoption of user-friendly and reality-based tools such as webGIS and virtual tours provides fundamental support in processes where the involvement of communities, as direct users of the space, could be crucial. It also could be useful for users with different levels of expertise, supporting both enhancement and management processes while reducing difficulties and discouragement in data collection and the cognitive overload caused by immersive technologies.

LIMITATION AND FUTURE DEVELOPMENT

The research work presents some limitations that may be opportunities for further study and development in future research activities.

A first limitation concerns the marginal role of the panel of experts in the process of constructing the evaluation metric for the analysis of adaptive reuse strategies. In this study, the process of consulting experts is mainly limited to the phase of assigning weights to the evaluation criteria for the solutions, through the application of the AHP method. Furthermore, this involvement is mainly limited to the academic component in the field of technical architecture, such as composition, to the extent that there is a convergence towards structural issues, even though the topics are those of reuse and enhancement of heritage.

From this perspective, involvement could be extended to a wider and more diverse audience, outlining a vision that integrates different skills to define a shared vision.

A second issue concerns the validation of the digital tools developed. Although the proposed digital environment combines the potential of the technologies involved, there is a lack of validation with feedback and statistical processing tools that would account for their ease of use and effectiveness, but also their technical sustainability within the

bodies responsible for their implementation within administrations and heritage management entities.

Furthermore, another aspect that could be developed concerns the involvement of various stakeholders in the process of defining adaptive regeneration strategies. Within the scope of this work, this has been limited to the academic component alone, whereas, given the importance of the multi-level and participatory nature of regeneration processes, there could be broader consultation with the various stakeholders throughout the entire process developed in relation to the definition of adaptive recovery strategies, but also and above all with the community that has to live in the space. This would help to define shared and sustainable strategies, as well as increase recognition of this heritage and build a shared reconnection between the port and the city.

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CURRICULUM

FORMATO EUROPEO PER IL CURRICULUM VITAE



Dichiarazione resa ai sensi degli art.
46 e 47 DPR N. 445/2000



INFORMAZIONI PERSONALI

Nome

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ISTRUZIONE E FORMAZIONE

- DataDicembre 2025 – in corso
- Istituto di istruzione o formazioneUNIVERSITÀ DI PISA
- Qualifica conseguita**MASTER DI II LIVELLO M329 - BUILDING INFORMATION MODELING - BIM SPECIALIST COORDINATOR MANAGER**

- Dataottobre 2022 – in corso
- Istituto di istruzione o formazionePOLITECNICO DI BARI
- Qualifica conseguita**DOTTORATO DI RICERCA IN RISCHIO E SVILUPPO AMBIENTALE, TERRITORIALE ED EDILIZIO**

- Dataluglio 2022 – ottobre 2022
- Istituto di istruzione o formazioneUNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO
- Qualifica conseguita**PERCORSO FORMATIVO PER L'ACQUISIZIONE DI 24 CFU- RISERVATO A STUDENTI POLIBA**

- Data conseguimento titolo25 luglio 2022
- Istituto di istruzione o formazionePOLITECNICO DI BARI
- Qualifica conseguita**LAUREA IN INGEGNERIA DEI SISTEMI EDILIZI**
- Tesi*"La gestione del rischio nel costruito storico mediante ambienti VR: il caso di Bari"*
- Relatori: prof. Fabio Fatiguso, prof.ssa Mariella De Fino, Correlatrice: ing. Silvana Bruno

- Data conseguimento titolo
- Istituto di istruzione o formazione
 - Qualifica conseguita
 - Tesi

23 luglio 2019

POLITECNICO DI BARI

LAUREA IN INGEGNERIA EDILE

“Innovazioni con la modellazione BIM a supporto del processo edilizio”

Relatore: prof. Guido Raffaele Dell’Osso

**ATTIVITÀ DIDATTICHE ED
ESPERIENZE LAVORATIVE**

- Data
- Istituto di istruzione o formazione
 - Tipo di impiego

Ottobre 2024 – in corso

POLITECNICO DI BARI

Rappresentante in seno al Senato Accademico delle Dottorande e dei Dottorandi

- Data
- Istituto di istruzione o formazione
 - Tipo di impiego

Novembre 2024 – in corso

POLITECNICO DI BARI

Collaborazione al Progetto di Ricerca MUR PRIN RE³WORK - REsilient RETrofitting and REuse of Water heritage and built environments: multi-objective Optimization for Risk mitigation and cultural enhancement

- Data
- Istituto di istruzione o formazione
 - Tipo di impiego

Novembre 2025

POLITECNICO DI BARI

Collaborazione al Progetto di Ricerca ReACT - (planning) Resilient urban and metropolitAn built environments through inClusive mulTi-risk behaviouRal-based models and simulations

- Data
- Istituto di istruzione o formazione
 - Tipo di impiego

2024 - 2025

POLITECNICO DI BARI

CORRELATRICE TESI DI LAUREA

- “Soluzioni tecnico-costruttive per l’efficientamento energetico degli edifici: il blue-green roof”

Felician Accettura. Relatrice: prof.ssa Mariella De Fino. Correlatrice: Federica Cassano

- “Analisi costruttiva e funzionale del patrimonio costruito portuale”
- Guglielmo Maizzi. Relatrice: prof.ssa Mariella De Fino. Correlatrice: Federica Cassano

- Date
- Istituto di istruzione o formazione
 - Tipo di impiego

giugno 2023 – dicembre 2023

POLITECNICO DI BARI - Dipartimento di Architettura, Costruzione e Design

TUTORATO PER DIDATTICA INNOVATIVA A.A. 2022/2023

- Date
- Istituto di istruzione o formazione
- Tipo di impiego

febbraio 2023 – luglio 2024

POLITECNICO DI BARI

TUTORAGGIO nelle attività didattiche dei corsi di:

- ARCHITETTURA TECNICA, della Prof.ssa Mariella De Fino (Corso di Laurea in Ingegneria Edile)
- RECUPERO E RIQUALIFICAZIONE DEGLI EDIFICI, del Prof. Fabio Fatiguso (Corso di Laurea in Ingegneria dei Sistemi Edilizi)
- GESTIONE DEL PATRIMONIO EDILIZIO ESISTENTE del Prof. Fabio Fatiguso (Corso di Laurea in Ingegneria dei Sistemi Edilizi)

- Data
- Istituto di istruzione o formazione
- Tipo di impiego

febbraio 2023

POLITECNICO DI BARI

Collaborazione all'attività di ORIENTAMENTO DEL POLITECNICO DI BARI - POLIBUS

- Data
- Istituto di istruzione o formazione
- Tipo di impiego

Novembre 2022 – luglio 2024

POLITECNICO DI BARI

Collaborazione al Progetto di Ricerca PRIN BE S²ECURe - Built Environment Safer in Slow and Emergency Conditions through behaviorUral assessed/designed Resilient solutions

PUBBLICAZIONI

- Cassano, F., Giannuzzi, G., Rubino, R., Giannuzzi, V. (2026) Toward an Integrated Virtual Model of Port Built Environment. (in stampa)
- Cassano, F., De Fino, M., Fatiguso, F., Andrade Marques, M.J. (2026) Meta design strategies for the adaptive reuse of port industrial heritage. In: Currà E., Fatiguso F., Guida A., Monte A., Docci M., Bernardo G., Cantatore E., Menichelli C., Mattioli A. Stati generali del patrimonio industriale 2026. Gangemi Editore
- De Fino, M., Cassano, F. (2025). Porti e patrimonio costruito storico: metodi di analisi e strategie di riqualificazione. In Modulo, n. 458. Dicembre 2025. BE-MA EDITRICE – Milano. ISSN 0390- 1025
- Cassano, F., De Fino, M., Fatiguso, F. (2025). Uso, disuso, riuso, Valutazione di compatibilità funzionale del patrimonio portuale. In: Atti del Convegno ReUso 2025. Territori marginali patrimonio a rischio. PUBBLICA, 2025
- Cassano, F., Giannuzzi, V., Ambrosio, V. (2025). Towards Digital Transformation for the Built Environment: Preliminary Results of a Synergistic Approach of Point Cloud, BIM and Augmented Reality. In: Lombardo, L., Fatiguso, F., Cassano, F., Renzulli, A., Torriani, G. Results of Dot.AT.i 2025 Knowing and Connecting. Emerging Perspectives on the Built Environment. Springer. ISBN 978-3-032-16018-8

- De Fino, M., Cassano, F., Bernardini, G., Quagliarini, E., & Fatiguso, F. (2025). On the user-based assessments of virtual reality for public safety training in urban open spaces depending on immersion levels. *Safety Science*, 185, 106803. <https://doi.org/https://doi.org/10.1016/j.ssci.2025.106803>
- Cassano, F., De Fino, M., Cantatore, E., Fatiguso, F. (2024). Unveiling the Water Built Heritage: Preliminary Results Towards a Systematic Cataloguing of Italian Ports. In: Corrao, R., Campisi, T., Colajanni, S., Saeli, M., Vinci, C. (eds) *Proceedings of the 11th International Conference of Ar.Tec. (Scientific Society of Architectural Engineering). Colloqui.AT.e 2024. Lecture Notes in Civil Engineering*, vol 610. Springer, Cham. https://doi.org/10.1007/978-3-031-71855-7_11

COMITATI

- Segreteria organizzativa e comitato comunicazione e media in *3° Stati Generali del Patrimonio Industriale*. Bari, Matera, Lecce 5-8 febbraio 2026
- Comitato organizzatore in *Giornata di Studi Conoscere e Connettere. Saperi in sinergia per la ricerca*. Milano, 15 gennaio 2026
- Comitato organizzatore in *Giornata di Studi Conoscere e Connettere*. Catania, 30 gennaio 2025
- Segreteria Scientifica e Organizzativa in *Colloqui.AT.e 2023*. Bari, 14-17 giugno 2023

CORSI E CERTIFICAZIONI

• Date	Dicembre 2025 – gennaio 2026
• Istituto di istruzione o formazione	Associazione Cyber 4.0
• Corso	Cyber 4.0_Seminari NIS 2 per Figure Apicali degli Atenei
• Date	9 marzo 2023
• Istituto di istruzione o formazione	POLITECNICO DI BARI
• Qualifica conseguita	ABILITAZIONE ALLA PROFESSIONE DI INGEGNERE CIVILE E AMBIENTALE, sez. A
• Date	gennaio 2018 - marzo 2018
• Istituto di istruzione o formazione	POLITECNICO DI BARI
• Certificazione	POLIBA SOFT SKILLS – TRAINING ACCADEMY
• Date	2017
• Istituto di istruzione o formazione	Centro Linguistico POLITECNICO DI BARI
• Oggetto dello studio	CORSO DI LINGUA CINESE
• Certificazione	HSK 1 - presso International School of Pollena "Mother Teresa"

GRUPPI E ASSOCIAZIONI

- **ArTec** – Società scientifica di Architettura Tecnica
- **Dot.AT.i** – Dottorandi e Dottori di ricerca Architettura Tecnica
- **ADI** - Associazione dottorandi e dottori di ricerca italiani – Vice coordinatrice della sede locale di ADI Bari

WORKSHOP E SEMINARI

- Date 26 agosto 2023 – 7 settembre 2023
- Istituto di istruzione o formazione UNIVERSITÀ DI PISA
- Evento **THE CITY AND THE WATER** – International summer school

- Date 11 luglio 2023
- Istituto di istruzione o formazione UNIVERSITÀ DI ROMA “La Sapienza”
- Evento **Soluzioni resilienti - per un ambiente costruito più sicuro in condizioni di emergenza a lenta SLOD e improvvisa occorrenza SUOD** - Seminario Master PARES
- Attività Conduzione sessioni di virtual training

- Date 16 giugno 2023
- Istituto di istruzione o formazione POLITECNICO DI BARI
- Evento **Colloqui.AT.e 2023**
- Attività Premio ARTEC. PhD Per la miglior proposta di ricerca sviluppata nell'ambito del Corso di Dottorato “Architectural Engineering Research Methods and Tools” – AA 2022-23 alla proposta D4C di Arianna Latini, Federica Cassano, Giannuzzi Valeria e Graziano Tomasello

- Date 18 maggio 2023
- Istituto di istruzione o formazione POLITECNICO DI BARI
- Evento **Virtual immersive environments for documentation Virtual immersive environments for documentation and conservation of heritage buildings**
- Attività Conduzione sessioni di virtual training

- Date 1-2-3 dicembre 2022
- Istituto di istruzione o formazione POLITECNICO DI BARI
- Evento **POLIBATHON**, vincita secondo premio

Bari, li 16/07/2026

Il dichiarante

ANNEX 1

INTERNATIONAL EXPERIENCES

World Heritage Online Map Platform - UNESCO

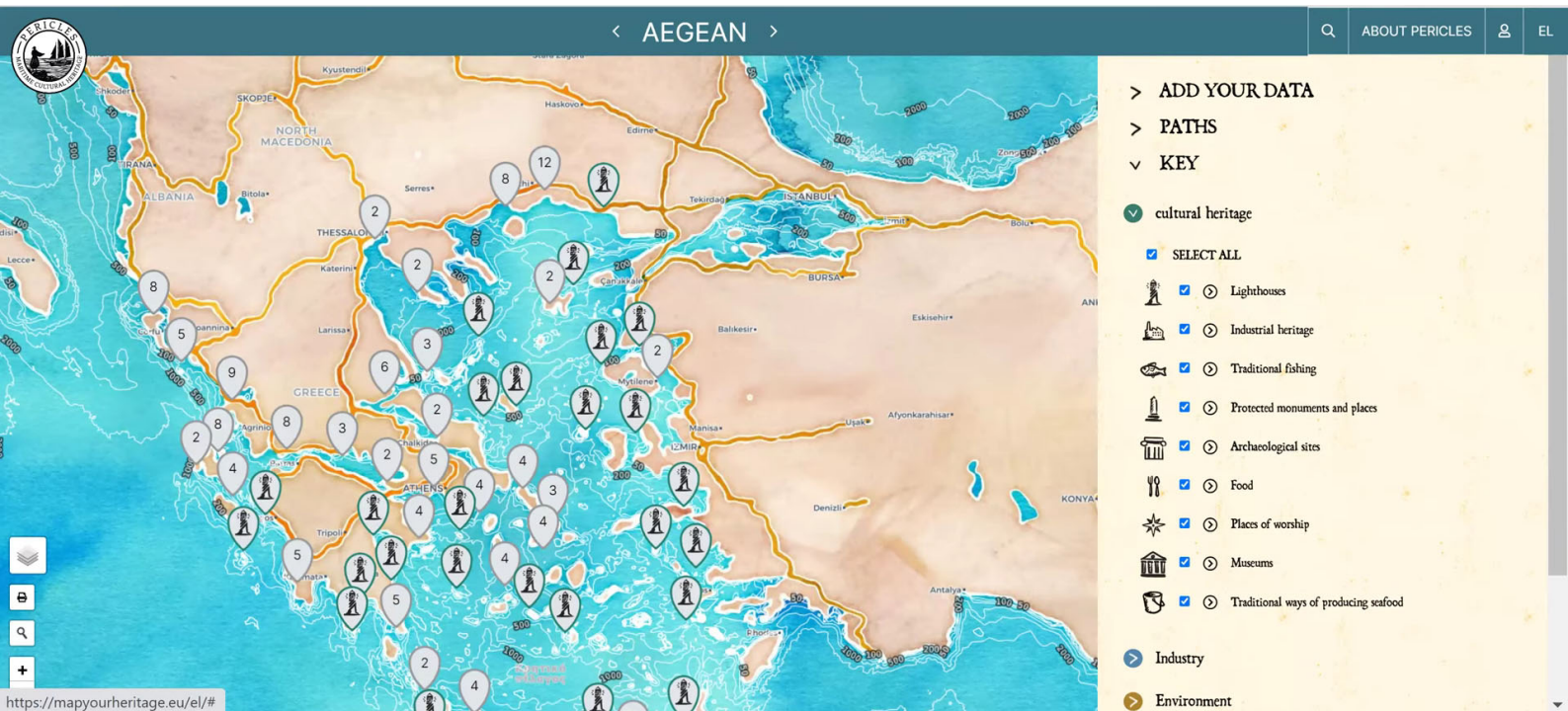
<https://whc.unesco.org/en/interactive-map/>

#	NAME	NAME_MOD	COUNTRY	LATITUDE E	LONGITUD W	FORD M My	Pn	AUTH_Anc	AUTH_Mod	DOC1_Papers	DOC2_papers	DOC3_www	DOC4_www	WIKIPEDIA	PLEIADES	DARE	TROMSØSTEDTOS TOPOTEXT	AM PP RE SI SU PS BW QU PL MD CN SL SH CD LK PH SW FP VM QR FT
1	Tyle, Thule	Iceland? Pitry end Strabo, who cite Pytheas (ca 325 BC), place Thule at 6 navigation days from (down) Britain, which may be 800-900 nautical miles. Iceland is at 450 miles North of Scotland. The mention of six months long days and nights means a position beyond the Arctic Circle, which corresponds better to Iceland than to the Shetland Islands.	Iceland?	63.27477	-14.70331			Polylbius, Hist., 34, 5; Pytheas quoted by: Strabo, Geogr., I, 4 § 2, 5 ; Ptolemy, Hist Nat., 2, 77 & 99 & 4, 27	Sailor locates it in the Shetland Islands	Ipswich (2004)								*
1.1		Alta, Bronze Age rock carvings showing many ships	Norway	69.94740	23.18700	-5000			Bronze Age rock carvings showing many ships; no shipwrecks were found but several ancient paddles, oars and frames were found north of the Arctic Circle	Wikster (2010)	Gjovind (2011)	https://web.archive.org/web/2011/03/04/http://www.wikiwand.com/en/wiki/Alta_stenbilder_i_Alta	https://en.wikipedia.org/wiki/Alta_stenbilder_i_Alta				m	
1.2		Haugvik, on the Isle of Somna, with shipwreck	Norway	65.29600	12.51200	-120			sewn-plank boat wreck at Haugvik farm	Suberfelt (2006)	Gjovind (2011)	Gjovind (2011)					m	X
1.3		Aldene, on the Isle of Goswick, with hundreds of Mesolithic coastal settlements in Central Norway	Norway	62.82000	6.87620	-10000 to -9000				Beck (2017)	Bergsh (2014)						m	
1.4		Toftewæger, on Hvaløya Island, with shipwreck	Norway	59.79850	5.73940	400			sewn-plank boat wreck at Bures	Gjovind (2011)		https://www.riv.no/dokumentasjon/arkiv/beskrivelse/arkivskript	https://en.wikipedia.org/wiki/Brosletten_-_den_sidenfor-2300_jar				m	X
2		Tannum, Bronze Age rock carvings showing many ships	Sweden	58.70129	11.34070	-1000?		Pitry, Hist Nat., 4, 27		http://www.mhl.h.se/forskning-og-afriskrivningen-22		https://web.archive.org/web/2017/03/04/http://en.wikipedia.org/wiki/Hornö_-_Bronze_Age_Carving_in_Tanne	https://en.wikipedia.org/wiki/Hornö_-_Bronze_Age_Carving_in_Tanne				*	
2.1		Tombok, near Kullåsa, Bronze Age rock carvings showing many ships	Sweden	58.54680	11.33720	-1000?			Bronze Age rock carvings showing many ships (panel Kullåsa 150-1)	Jenssen et al (2010)	Lund (2014)		http://www.guidebook.com/england/pubs/travel.html				m	
2.2	Bälsta?	Norrköping, Bronze Age rock carvings showing many ships	Sweden	58.55300	16.14500	-1000?			Bronze Age rock carvings showing many ships (panel Östra Emby 1-1) at Himmelstaklund	Ung (2014)			https://www.guideshook.com/journal/stockholm/Guidebook-Guestbook-ArchaeologicalPage-ChronologyofSwedish-Bronze-Age-rock-carvings				m	
2.3		Björke, with shipwreck	Sweden	60.76600	17.19020	400			shipwreck at Björke Canal				https://www.forskningsnyheter.net/article/view/fulltext/2568				m	X
3	export of amber to the Black Sea, on R. Cheimios, Chersonesus	Odesma, on R. Dniester, Odessa, Ukraine	Ukraine	56.82500	24.41000					Fakhire (2013)							m	

***The catalogue of ancient coastal settlements, ports and harbours* - de Graauw**

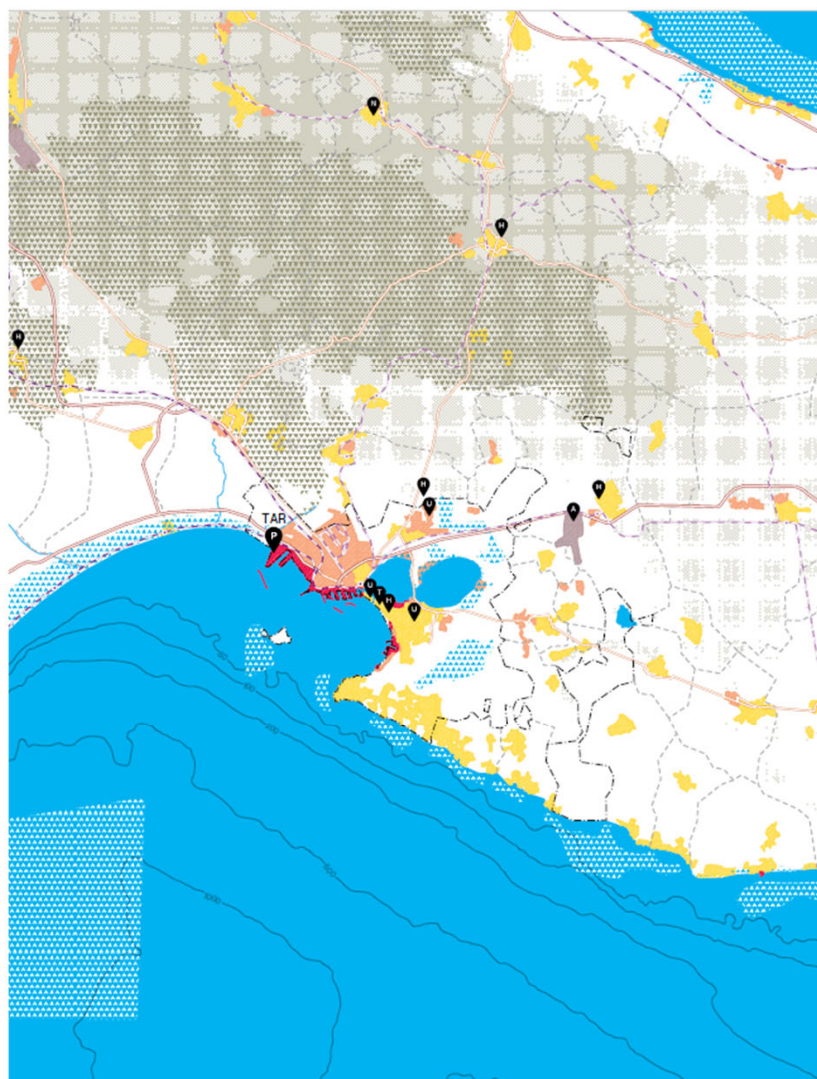
<https://www.ancientportsantiques.com/the-catalogue/>

EUROPEAN EXPERIENCES



PERICLE

https://mapyourheritage.eu/



PORT CITY ATLAS

- LDE PortCityFutures e Facoltà di Architettura di TU Delft

NATIONAL EXPERIENCES

[illegible]**ICCD**[illegible]

Port of Bari Fish market building

Period of construction

First half of XIX century

Number of floors

2 floors

Gross building surface

2400 mq

Gross building volume

9000 mc

Original functional use

Fish market

Present functional use

fruit and vegetable market ('1° floor); offices and archives ('2°)

Present property

Private

Public

Private/Public

Scheduled building

Yes

No

Typology of vertical structures

Masonry

Framework

Mixed

Other

Materials of vertical structures

Stone

Brick

Concrete

Wooden

Other

Typology of horizontal structures

Vault

Flat ceiling

Mixed

Materials of horizontal structures

Stone

Iron/Brick

Conc./Brick

Wooden

Other

Typology of roof structures

Pitched roof

Flat roof

Mixed

Present state of conservation

Poor

Fair

Good

Very good

Coordinates (latitude, longitude)

41.126705, 16.872083

NATIONAL EXPERIENCES

A Dati di archivio		Codice scheda _____
☐ scheda singola ☐ scheda sintetica con n. schede derivate ☐ scheda derivata n.		
B Identificazione		
Località _____	Coordinate I.G.M. _____	
Denominazione del sito _____		
Oggetto _____		
Superficie coperta m ² _____	Superficie di pertinenza m ² _____	
C Utilizzazione		
Uso attuale _____		☐
Usi precedenti _____	_____	☐
_____	_____	☐
D Previsioni di destinazione		
☐ destinazione attuale ☐ demolizione ☐ modifiche ☐ riuso ☐ altro		
Note _____		

Compilatore/i _____		
Data _____	Visto _____	
Revisioni _____		
Pagine n. _____	Note _____	

E Localizzazione		
Indirizzo _____		
Accesso _____		
Proprietà _____		
Fondo accessibile ☐ sì ☐ no	Interno accessibile ☐ sì ☐ no	
Autorizzazione necessaria ☐ sì ☐ no		
Se si indicare come ottenerla _____		
Contatti sul posto _____		
F Oggetti che compongono il sito		
Denominazione	Rif. scheda derivata n.	
1		
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24		
25		
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27		
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30		
G Dati storici		
Data di primo impianto del sito o dell'oggetto _____		
Progettista _____		
Committente _____		
Ditta costruttrice _____		
Note storiche _____		

<i>Bibliografia</i>		

<i>Fonti d'archivio</i>		

<i>Fonti iconografiche</i>		

Esiste un archivio aziendale ☐ sì ☐ no		
Se si indicare periodi coperti _____		
Riferimento scheda archivi aziendali _____		

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ANNEX 2

METHODOLOGICAL APPROACH

Success factors in Adaptive Reuse

National and international experiences

State of the Art

Port area evolution, overview of port heritage and survey of cataloguing systems

Adaptive Reuse assessment approaches and best practices of port heritage

Digital assets management

ph.1_Cognitive framework

I. Data collection

ph.1.1 Census of port sites

- identification and denomination
- location
- ownership and managing authorities
- state of use
- current use

ph.1.2 Cataloguing of port sites

- historical evolution
- current state
- survey of assets

ph.1.3 Cataloguing of port heritage

- ID
- name
- type of asset (..)
- historical information
- architectural description
- state of conservation
- state of use
- current function of the context
- current function
- original function
- type of intervention

II. Assets qualification

ph.1.4 Evaluation of state of use and conservation

- *Index 1: Functional compatibility with the context*
- *Index 2: Functional compatibility with the original function*
- *Index 3: Functional compatibility with the original building*

Clustering

K-means

i. Dataset identification

- *State of conservation*
- *State of use*
- *Index 1*
- *Index 2*
- *Index 3*

iii. Parameters standardisation

iv. Identification of number of clusters

Elbow method

v. Evaluation of clusters stability

Silhouette score, Calinski-Harabasz index, Davies-Bouldin index

vi. Qualification of port asset clusters

ph.1.5 Identification of asset clusters

- CLUSTER 1 → *Typology 1*
- CLUSTER 2 → *Typology 2*
- CLUSTER 3 → *Typology 3*
- ... → ...
- CLUSTER n → *Typology n*

III. Digital survey

ph.2_Analysis and definition of design strategies

ph.2.1 Identification of Adaptive Reuse indicators

10 Dimensions and 27 indicators

D1_Architectural, D2_Structural, D3_Socio-cultural, D4_Economic, D5_Environmental, D6_Energy, D7_Authenticity and historical, D9_Management/decision-making, D10_Functional

ph.2.2 Identification of Adaptive Reuse solutions

i. Identification of cluster-oriented strategies

ii. Atlas of meta design strategies

For n-solutions

a. Definition of design concept

b. Definition of preliminary project proposals

iii. Definition of assets design solutions

ph.2.3 Assessment of Adaptive Reuse solutions

i. Definition of problem analysis

ii. Development of the problem objectives, criteria, alternatives

iii. Construction of the performance profile of each option

iv. Scoring of impacts of each option

v. Weighting of criteria

vi. Combination of scores and weights

Ph.3_Digital ecosystem

ph.3.1 Knowledge management

GIS / BIM environments

i. Data systematisation in GIS environment

ii. Data analyses as asset qualification or clustering

ph.3.2 Design solutions management

BIM / VR / AR environments

i. Data processing

ii. BIM modelling of design solutions

iii. Design solutions assessment

iv. Design solutions communication in AR/VR mode

ph.3.3 Creation of integrated digital system

GIS / BIM / VR / AR environments

i. Systematisation of cognitive system in an external database

ii. Development of shared and collaborative digital system in VR/AR mode

ANNEX 3

Dimension	Strategy		Definition of strategy	Evaluation method	References
D1 Architectural	<i>concerns the preservation of the original identity, including architectural, material, morphological, typological and spatial characteristics related to their capacity to accommodate a new function in coherence with original identity value</i>				
	I1.1	minimum intervention *	preservation of the identity of the structure and reduction of invasive interventions, such as the demolition of parts	• <i>Very high: repairs, renovation and replacement of building finishes and interventions to integrate or maintain the efficiency of existing technological systems; (5)</i> • <i>High: interventions to preserve the property and ensure its functionality, respecting its typological, formal and architectural elements, including the consolidation, restoration and renovation of architectural elements; (4)</i> • <i>Medium: interventions to renovate and replace parts of the building, as well as the addition of necessary accessories and systems; (3)</i> • <i>Low: interventions that may result in an asset that is partly different from the original, including the removal, modification and addition of new elements and systems; (2)</i> • <i>Very low: interventions aimed at transforming the property that may result in an asset that is completely different from the original, including extension (1)</i>	(Bullen & Love, 2011; Cucco et al., 2023; Dabbene et al., 2024; Della Spina, 2021; Djebbour & Biara, 2019; Icomos, 1983; Z. Lin et al., 2024; Vafaie et al., 2023)
	I1.2	architectural harmony and visual compatibility *	conserving architectural elements, preserving their formal and material identity and making alterations explicit	• <i>Very high level of conservation of formal identity and use of original materials (5)</i> • <i>High level of conservation of formal identity and use of materials similar to the original ones (4)</i> • <i>Medium level of conservation of formal identity and use of compatible materials, without altering the perception of the identifying characteristics (3)</i> • <i>Low level of conservation of formal identity and use of different compatible contemporary materials (2)</i> • <i>Very low level of conservation of formal identity and use of different incompatible contemporary materials (1)</i>	(Cucco et al., 2023; Dell'ovo et al., 2021; Pinto et al., 2017; Vafaie et al., 2023)
	I1.3	adaptability and spatial flexibility	capacity of the space to be adapted to different functions over time without compromising legibility, using lightweight and reversible components	yes o no	(Angrisano et al., 2024; Cucco et al., 2023; Dell'ovo et al., 2020, 2021; Ding et al., 2025; Djebbour & Biara, 2019; Jato-Espino et al., 2022; Kutlu et al., 2025; Mohd Abdullah et al., 2020; Nguyen Duc Vinh, 2021; Nocca et al., 2024; Pinto et al., 2017; Ragheb, 2021; Salerno, 2020; Vafaie et al., 2023; Vizzarri et al., 2021)

D2 Structural	<i>interconnected with the architectural one, concerns the structure's ability to ensure stability, durability and adaptability, as well as resilience, to extend its useful life</i>				
	12.1	retrofitting of existing structures	selective conservation and structural consolidation intervention, maintaining the main structures and extending their useful life	• <i>Appropriate</i> (3) • <i>Partially appropriate</i> (2) • <i>Not appropriate</i> (1)	(Bullen & Love, 2011; Giuliani et al., 2018, 2020; B. Mohamed & Marzouk, 2025; Nasr & Khalil, 2022; Sefa Adin & Sirel, n.d.; Vafaie et al., 2023)
	12.2	structural integration	addition of structural elements, with the construction of new structures and volumes	• <i>No areas attached to the original building</i> (5) • <i>New building represents < (less than) 15% of the original building</i> (4) • <i>New building represents ≥ (more than or equal to) 15% of the original building</i> (3) • <i>New building represents ≥ (more than or equal to) 30% of the original building</i> (2) • <i>New building represents ≥ (more than or equal to) 50% of the original building</i> (1)	(Añibarro et al., 2023; Cucco et al., 2023; Dabbene et al., 2024; Sefa Adin & Sirel, n.d.; Vizzarri et al., 2021)
	12.3	dismantlability/ flexibility of components	integration of flexible and removable systems, to easily disassemble unused parts	Yes o no	(Bianchi & De Medici, 2023; Cucco et al., 2023; Sharifi & Farahinia, 2020; Vizzarri et al., 2021)
D3 Socio-cultural	<i>explores the role of adaptive reuse in creating and enhancing collective identity, strengthening the sense of belonging and shared memory of places, through its tangible and intangible identity value of heritage</i>				
	13.1	social integration and inclusion *	design spaces and activities that strengthen cohesion between different groups and contrast processes of exclusion or gentrification, considering gender, class, race, ethnicity, culture	• <i>Very high integration</i> (5) • <i>High integration</i> (4) • <i>Medium integration</i> (3) • <i>Low integration</i> (2) • <i>Very low integration</i> (1)	(Bullen & Love, 2011; Dabbene et al., 2024; De Vita et al., 2022; Giaccardi, 2017; W. Li et al., 2025; Mazzetto & Vanini, 2023; Rohini & Shefali, 2023; Vafaie et al., 2023; Vizzarri et al., 2021)
	13.2	attachment and sense to place *	enhancing identity characteristics that are meaningful to the local community	• <i>High increase in place identity/place attachment/place memory/sense of place considering physical location and human interaction, social network engagement, and cultural connections</i> (5) • <i>Moderate increase in place identity/place attachment/place memory/sense of place considering physical location and human interaction, social network engagement, and cultural connections</i> (4) • <i>No increase or decrease</i> (3) • <i>Moderate decrease in place identity/place attachment/place memory/sense of place considering physical location and human interaction, social network engagement, and cultural connections</i> (2) • <i>High decrease in place identity/place attachment/place memory/sense of place considering physical location and human interaction, social network engagement, and cultural connections</i> (1)	(Bullen & Love, 2011; Dabbene et al., 2024; Ding et al., 2025; Giaccardi, 2017; Rohini & Shefali, 2023; Sharifi & Farahinia, 2020; Vafaie et al., 2023)

D4 Economic	<i>analyses the capacity to generate sustainable economic value at both local and regional levels, focusing on the economic effects related to the recovery and refurbishment project</i>				
	I4.1	functional mixes *	promoting mixed uses that stimulate broad-based economic development, real estate, new job positions and attraction of diverse users	• <i>Very high: the overall score for the increase/decrease of each economic factor is equal to + 4 (5)</i> • <i>High: the overall score for the increase/decrease of each economic factor is equal to +3 (4)</i> • <i>Medium: the overall score for the increase/decrease of each economic factor is equal to +2 (3)</i> • <i>Low: the overall score for the increase/decrease of each economic factor is equal to +1 (2)</i> • <i>Very low: the overall score for the increase/decrease of each economic factor is less than +1 (1)</i>	(Arfa, Quist, et al., 2022; Dabbene et al., 2024; Della Spina, 2021; Gravagnuolo et al., 2024; Metwally et al., 2025)
	I4.2	public-private partnerships	encouraging financial and managerial of public and private actors to support heritage conservation, to improve investments and reduce the economic burden on the institution	Yes o no	(De Vita et al., 2022; Lauro et al., 2025; Metwally et al., 2025)
	I4.3	tourist attractiveness	increase the number of visitors, enhancing heritage as a resource to increase attractiveness and support a sustainable tourism economy	• <i>High increase in the number of visitors/tourists (5)</i> • <i>Moderate increase in the number of visitors/tourists (4)</i> • <i>No increase or decrease (3)</i> • <i>Moderate decrease in the number of visitors/tourists (2)</i> • <i>High decrease in the number of visitors/tourists (1)</i>	(Angrisano et al., 2024; Arfa, Lubelli, et al., 2022; Arjomand Kermani et al., 2020; Dabbene et al., 2022, 2024; Giaccardi, 2017)
D5 Environmental	<i>considers the relationship between industrial assets and the urban and territorial environment, assessing the project's impact on the environment and pursuing sustainable development goals, towards integrated and resilient urban regeneration and often in line with the circular economy</i>				
	I5.1	port city interaction *	defining measures to reconnect the urban contexts to the sea, improving relations between the city and the port area	• <i>Very high: direct free access from both the city and the sea to the asset (5)</i> • <i>High: presence of one free access and one direct access point (4)</i> • <i>Medium: presence of free access points from both the city and the sea (3)</i> • <i>Low: presence of one controlled access point and one free or direct access point (2)</i> • <i>Very low: presence of controlled access points from both the city and the sea (1)</i>	(Nocca et al., 2024)
	I5.2	mobility and accessibility *	ensuring accessibility with vehicular, pedestrian infrastructures, as well as slow mobility, and public transport systems	• <i>Very high: excellent connection, the asset is accessible and has varied, sufficient and adequately frequent public transport (railway station within 2km and bus, metro, tram stops within 1km) (5)</i> • <i>High: good connection, the asset is accessible and has sufficient public transport and with adequate frequency (railway station within 2km and bus, metro, tram stops within 1km) (4)</i> • <i>Medium: medium connection, the asset has accessibility difficulties and has some public transport (railway station within 2km and bus, metro, tram stops within 1km) (3)</i> • <i>Low: low connection, the asset has accessibility difficulties and has little public transport (railway station within 2km and bus, metro, tram stops within 1km) (2)</i> • <i>Very low: no connection, the asset is not accessible and does not have public transport (railway station within 2km and bus, metro, tram stops within 1km) (1)</i>	(Bullen & Love, 2011; Cleempoel & Plevoets, 2013; Cucco et al., 2023; Dabbene et al., 2024; Dabouh & El Shazly, 2020; Dell'ovo et al., 2020, 2021; Metwally et al., 2025; B. Mohamed & Marzouk, 2025; Morandotti et al., 2019; Nocca et al., 2024; Ragheb, 2021; Salerno, 2020; Sharifi & Farahinia, 2020; Vafaie et al., 2023; Vizzarri et al., 2021)
	I5.3	public open and green spaces *	promoting environmental and social regeneration, through open spaces and green areas, contributing to climate mitigation	• <i>Very high: Outdoor public and green space surface in the functional area > (greater than) the total built area (5)</i> • <i>High: Outdoor public and green space surface in the functional area ≤ (less than or equal to) 100% of the total built area (4)</i> • <i>Medium: Outdoor public space surface area ≥ (greater than or equal to) 50% of the built area (3)</i> • <i>Low: Outdoor public space surface area ≥ (greater than or equal to) 10% of the built area (2)</i> • <i>Very low: Outdoor public and green space surface area ≤ (less than or equal to) 10% of the built area (1)</i>	(Angrisano et al., 2024; Añibarro et al., 2023; Cucco et al., 2023; Ding et al., 2025; Gravagnuolo et al., 2024; W. Li et al., 2025; Metwally et al., 2025; Mohd Abdullah et al., 2020; Nguyen Duc Vinh, 2021; Nocca et al., 2024; Sharifi & Farahinia, 2020; Vafaie et al., 2023; Vizzarri et al., 2021)

D6	<i>focuses on the energy performance of the structures and on reducing energy consumption in buildings, preserving their material and constructive integrity</i>				
	Energy				
	I6.1	passive design strategies	ensuring thermal, visual, acoustic comfort and indoor air quality through passive solutions	• <i>Very high improvement (5)</i> • <i>High improvement (4)</i> • <i>Medium improvement (3)</i> • <i>Low improvement (2)</i> • <i>Very low improvement (1)</i>	(Dell'ovo et al., 2020, 2021; W. Li et al., 2025; Nasr & Khalil, 2022; US Green Building Council, 2023)
	I6.2	efficient energy systems	adopting efficient energy systems, including renewable energy resources as a renewable energy system, upgrading/implementation of systems for efficient HVAC (Heating, Ventilation and Air Conditioning), domestic hot water and Smart Controls and Energy Management Systems	• <i>Very high improvement (5)</i> • <i>High improvement (4)</i> • <i>Medium improvement (3)</i> • <i>Low improvement (2)</i> • <i>Very low improvement (1)</i>	(Añibarro et al., 2023; Bullen & Love, 2011; Cinquepalmi et al., 2023; Dabbene et al., 2024; Ding et al., 2025; Giaccardi, 2017; Ismaeel & Mohamed, 2023; B. Mohamed & Marzouk, 2025; US Green Building Council, 2023; Vafaie et al., 2023)

D7 Authenticity and historical	<i>concerns the protection, enhancement and transmission of the tangible and intangible identity values of assets, recognising consolidated and stratified historical and cultural identity values</i>				
	17.1	intrinsic values	safeguarding traditional technical expertise, productive practices and maritime culture	• <i>Very high safeguarding of intrinsic value (5)</i> • <i>High safeguarding of intrinsic value (4)</i> • <i>Medium safeguarding of intrinsic value (3)</i> • <i>Low safeguarding of intrinsic value (2)</i> • <i>Very low safeguarding of intrinsic value (1)</i>	(Andrade et al., 2024; Angrisano et al., 2024; Arfa, Quist, et al., 2022; Arjomand Kermani et al., 2020; Dabbene et al., 2024; Giaccardi, 2017; Nocca et al., 2024; Vehbi et al., 2021; Yu et al., 2025)
	17.2	authenticity and integrity	conserving of its tangible and intangible aspects that define authenticity and integrity through its formal, spatial and functional configuration	• <i>Very high conservation of authenticity aspects (5)</i> • <i>High conservation of authenticity aspects (4)</i> • <i>Medium conservation of authenticity aspects (3)</i> • <i>Low conservation of authenticity aspects (2)</i> • <i>Very low conservation of authenticity aspects (1)</i>	(Abdul Aziz, 2021; Adin & Sirel, 2024; Andrade et al., 2024; Angrisano et al., 2024; Arfa, Lubelli, et al., 2022; Bullen & Love, 2011; Dabbene et al., 2024; Dell'ovo et al., 2020; Ding et al., 2025; Djebbour & Biara, 2019; Ismaeel & Mohamed, 2023; Lauro et al., 2025; W. Li et al., 2025; Mohd Abdullah et al., 2020; Nasr & Khalil, 2022; Vafaie et al., 2023; Vehbi et al., 2021)
	17.3	significance of the heritage	preserving architectural and technical values that reflect the construction respect to productive history and the local culture	• <i>Very high: Legibility, when the interventions between old and new materials and techniques have the quality of being legible (5)</i> • <i>High: Reversibility, when the intervention is able to restore a building and return to its previous condition (4)</i> • <i>Medium: Overshadowing, when the new interventions are more significant when compared to the old structures (3)</i> • <i>Low: Alteration/replacement when are designed change, modification or adjustment and old materials are substituted with new ones (2)</i> • <i>Very low: Anastylis and ruins, when interventions on a ruined building reassemble fallen parts and, where necessary, incorporate new materials (1)</i>	(Angrisano et al., 2024; Arfa, Lubelli, et al., 2022; Arjomand Kermani et al., 2020; Dabouh & El Shazly, 2020; Mazzetto & Vanini, 2023; Metwally et al., 2025; Nasr & Khalil, 2022; Vehbi et al., 2021; Zhang & Zhang, 2023)
D8 Legal	<i>concerns the normative and regulatory provisions at international, national and local levels that constrain and drive adaptive reuse processes, as well as define the legitimacy and feasibility of interventions</i>				
	18.1	respect of regulatory	ensuring consistency with territorial planning and regulatory frameworks, as building code requirements, health and safety regulations, preservation rules and provisions, zoning and planning requirements	Yes/no	(Aigwi, Phipps, et al., 2020; Bullen & Love, 2011; Mohd Abdullah et al., 2020; Ragheb, 2021; Vafaie et al., 2023; Vardopoulos et al., 2021; H. J. Wang & Zeng, 2010)
	18.2	multi-level and participatory governance	activation of forms of multi-level and participatory governance, involving institutional actors, local communities and private stakeholders	Yes/no	(Bullen & Love, 2011; Djebbour & Biara, 2019; Giuliani et al., 2018; Paavola, 2016; Vafaie et al., 2023)

D9 Managerial/ decision- making	<i>concerns the complexity of the processes and actors and governance involved in the assessment, design, implementation and management phases of adaptive reuse interventions to ensure their success and long-term sustainability</i>				
	I9.1	involvement of community	recognition of territorial and local needs, with a proactive engagement of local communities and various stakeholders, to ensure the functional and social sustainability of interventions over time	• <i>Very high: Local communities are empowered (5)</i> • <i>High: Local communities collaborate (4)</i> • <i>Medium: Local communities are involved (3)</i> • <i>Low: Local communities are consulted (2)</i> • <i>Very low: Local communities are informed (1)</i>	(Abastante et al., 2022; Añibarro et al., 2023; Bianchi & De Medici, 2023; Dabbene et al., 2024; Ding et al., 2025; Djebbour & Biara, 2019; International Association for Public Participation, 2018; Martínez et al., 2020; Metwally et al., 2025; Treseder et al., 1997; Vafaie et al., 2023)
	I9.2	involvement of different stakeholders *	supporting integrated and multidisciplinary decision-making, involving different stakeholders (as “investors”, “producers”, “regulators”, and “users” and academics)	• <i>Very high: all stakeholders are involved (5)</i> • <i>High: 4 different stakeholders are involved (4)</i> • <i>Medium: 3 different stakeholders are involved (3)</i> • <i>Low when: 2 different stakeholders are involved (2)</i> • <i>Very low: 1 stakeholder is involved (1)</i>	(Aigwi, Phipps, et al., 2020; Arfa, Quist, et al., 2022; Bullen & Love, 2011; Dabbene et al., 2022; Gravagnuolo et al., 2024; Ragheb & Naguib, 2021; Sharifi & Farahinia, 2020; Vafaie et al., 2023; Yu et al., 2025)
	I9.3	adoption of different tools	employing of innovative technologies during different phases of AR projects, as survey, focus group, workshop as policy labs, and digital tool	• <i>Very high: all tools are adopted (5)</i> • <i>High: 3 tools are adopted (4)</i> • <i>Medium: 2 tools are adopted (3)</i> • <i>Low: 1 tool is adopted (2)</i> • <i>Very low: no tool is adopted (1)</i>	(Bosone et al., 2021; Della Spina, 2020; H. J. Wang & Zeng, 2010)

D10 Functional	<i>concerns the ability to introduce new functions responding to contemporary needs, ensuring flexibility of use and integration over time</i>				
	I10.1	compatibility with the context *	introducing functions coherent and integrated with existing local function of the area	• <i>Very compatible, when the asset is well integrated into the area and its function is functional to the activity of the context (5)</i> • <i>Compatible, when the asset is well integrated into the area and its function supports the activity of the context (4)</i> • <i>Partially compatible, when the function of the asset has no direct implication for the function of the area (3)</i> • <i>Not very compatible, when the function appears isolated, poorly contextualised and does not contribute to the functional dynamics of the area (2)</i> • <i>Incompatible, when the function of the asset is not integrated with the function of the area, entering into operational conflict (1)</i>	(Baqrasham & Al-Khafaji, 2025; Cucco et al., 2023; Vizzarri et al., 2021)
	I10.2	compatibility with the original use *	maintaining a dialogue with the original functional vocation of the asset	• <i>Very compatible, when the same function is maintained (5)</i> • <i>Compatible, when the current function recalls the original function, maintaining a similar operating logic (4)</i> • <i>Partially compatible, when the function is different and there is no direct reference to the original function, but there are consistent aspects of use in terms of space dimensions, people flow, operating processes and similar (3)</i> • <i>Not very compatible, when the current function does not have continuity of use with the original function, but is not very consistent with the functional and operational characteristics (2)</i> • <i>Incompatible, the function is completely unrelated in logic and purpose to the original one (1)</i>	(Bullen & Love, 2011; Dell'ovo et al., 2020; Haroun et al., 2019; W. Li et al., 2025; Mohd Abdullah et al., 2020; Nocca et al., 2024; Vafaie et al., 2023; Vehbi et al., 2021)
	I10.3	compatibility with the architectural characteristics *	exploiting the original spatial-functional logic respecting its architectural identity	• <i>Very compatible, when there is functional continuity and the original layout remains unchanged, with only routine maintenance work carried out (5)</i> • <i>Compatible, when the function is well integrated, but limited functional adaptation and internal spatial reorganisation work has been necessary, respecting the building's identity (4)</i> • <i>Partially compatible, when the function is consistent and the identifying characteristics have been maintained, but with reconstruction of parts using modern techniques and technologies (3)</i> • <i>Not very compatible, when the function is consistent, but the identifying characteristics have not been maintained (2)</i> • <i>Incompatible, when the function is not compatible, requiring renovation work that results in a functionally and structurally new building (1)</i>	(Angrisano et al., 2024; Bullen & Love, 2011; Cucco et al., 2023; Dabbene et al., 2024; Dell'ovo et al., 2021; Giaccardi, 2017; Giuliani et al., 2018; Gravagnuolo et al., 2024; Haroun et al., 2019; Nocca et al., 2024; Vafaie et al., 2023)

* Strategy evaluation method defined by the author

ANNEX 4

D1: ARCHITECTURAL DIMENSION



S1.1 MINIMUM INTERVENTION

- CONSERVATIVE RESTORATION**
- Restoration of original external finishing
 - Restoration of original internal finishing
 - Conservation of decorative elements
 - Conservation of non-structural elements, such as roof finishing
 - Repair of building components

- MAINTENANCE**
- Replacement of non-structural elements, such as cladding, pavement
 - Renovation of building systems/ facilities repair



S1.2 ARCHITECTURAL HARMONY AND VISUAL COMPATIBILITY

- ELEMENTS CONSERVATION**
- Preservation of architectural composition
 - Use of compatible materials, as stone, bricks, steel, glass and concrete
 - Use of the same materials
 - Conservation of constructive technology
 - No finiture for internal spaces
 - Aesthetic integration of systems

- NEW ELEMENTS INTEGRATION**
- Use of glass surface internal/ external elements
 - Use of glass surface and steel elements for internal partition
 - Addition of external cladding in steel and glass
 - Addition of ceramic cladding on steel structure
 - Dry systems for external/internal wall and suspended ceiling



S1.3 SPACE FLEXIBILITY

- SPACE RECONFIGURATION**
- Adoption of lightweight elements
 - Adoption of modular prefabricate elements, as painted cladding panels
 - Construction in mezzanine floors using lightweight steel components
 - Use of flexible furniture to organise the space and accommodate new function

D2: STRUCTURAL DIMENSION



S2.1 RETROFITTING OF EXISTING STRUCTURE

- STATIC CONSOLIDATION**
- Structural consolidation
 - Structural strength improvement
 - Roof reinforcement

- STRUCTURAL CONSERVATION**
- Conservation of constructive element and technologies, as concrete or steel element
 - Conservation and consolidation of foundation

- REGULATORY COMPLIANCE**
- Structural adequacy
 - Fire adequacy



S2.2 STRUCTURAL INTEGRATION

- Inclusion of internal/external structural steel element
- Addition of vertical connections in steel and glass

- INTEGRATION OF NEW INDEPENDENT STRUCTURE**
- Addition of external structures structural steel and glass element
 - Integration of internal structures prefabricate, modular
 - Integration of internal structures prefabricated and dry-built, in wood

- INTEGRATION OF NEW COLLABORATIVE STRUCTURE**
- Addition of internal structures, as walkways
 - Addition of structure in steel at different level using existing industrial structures
 - Addition of elevation structure with the same materials



S2.3 DISMANTABILITY/FLEXIBILITY OF COMPONENT

- Addition of modular prefabricated elements, in cross-laminated timber
- Addition of new floors in steel and glass or in steel and concrete

D3: SOCIO-CULTURAL DIMENSION



S3.1 SOCIAL INTEGRATION AND INCLUSION

- Organisation of public and private events
- Organisation of collaborative activities for educational purpose, workshops for artistic purpose
- Organisation of cultural activities, as theatrical and musical or artistic activities or social activities



S3.2 ATTACHMENT AND SENSE TO PLACE

- CONSERVATION OF INDENTITY CHARACTERISTICS**
- Spatial conservation
 - Conservation of furnishing, as chandeliers

- CONSERVATION OF IDENTITY SIGNIFICANCE**
- Maintenance of symbolic role in the area
 - Design of transversal passage
 - Narration of local identity with artistic implementation, as literary façade, murals

D4: ECONOMIC DIMENSION



S4.1 FUNCTIONAL MIXES

- ECONOMIC DEVELOPMENT**
- Addition of new commercial activities, as bar, restaurants, shopping centre
 - Addition of new services

- CREATION OF NEW JOB POSITIONS**
- Addition of new activities
 - Increase activities related to the same function or operational structure

- ATTRACTION DIVERSE USERS**
- Forecast activities for different categories of users



S4.2 PUBLIC-PRIVATE PARTNERSHIP

- OWNERSHIP AND MANAGEMENT**
- Multilevel governance
 - Multi stakeholders management
 - Public ownership with private management

- FINANCING**
- Use of European funds
 - Use of different public funds
 - Use of public and private funds



S4.3 TOURIST ATTRACTIVENESS

- Use for cultural thematic purpose, as museum of the sea storytelling about identity/history
- Use for commercial purpose, as bar, restaurant
- Integration into tourist circuits
- Promotion of events

D5: ENVIRONMENTAL DIMENSION

S5.1
PORT-CITY INTERACTION

ACCESSIBILITY

- Direct access to the building
- Direct access to the port area by internal walkway, passageways
- Direct access to the port area by external overpasses
- Free access to the building
- Free access to the port area

INFRASTRUCTURE

- Systematisation of connection through direct pathways at different levels, as creation of gallery or overpasses

S5.2
MOBILITY AND ACCESSIBILITY

IMPLEMENTATION OR IMPROVEMENT OF INFRASTRUCTURE

- Implementation or improvement of infrastructure for pedestrian mobility
- Implementation or improvement of infrastructure for vehicular mobility
- Implementation or improvement of infrastructure for bicycle mobility
- Implementation or improvement of integration with public transport
- Integration transport via sea

IMPROVEMENT LEVELS OF ACCESSIBILITY

- Removal of architectural barriers, with ramps, elevators and escalators

S5.3
PUBLIC OPEN AND GREEN SPACES

OPEN AND PUBLIC SPACES

- Systematisation of public spaces, with the installation of benches
- Transformation of open spaces, as courtyards, into public spaces
- Forecast of public access to the panoramic viewpoint on the roof
- Forecast of public functions on the lower levels
- Creation space for sportive activities
- Creation of internal public space

GREEN SPACES

- Integration of internal green spaces, planting trees
- Addition of external green spaces, with greening of the area

D6: ENERGY DIMENSION

S6.1
PASSIVE DESIGN STRATEGIES

THERMAL COMFORT

- Installation of shading devices
- Integration of green walls, trees, gardens
- Adoption of perforated steel elements
- Adoption of direct adiabatic cooling system
- Insulation for building envelopes

VISUAL COMFORT

- Design full-height windows and balconies
- Ensuring direct lighting, not artificial, delocalising activities

QUALITY OF THE AREA

- Ensuring natural ventilation
- Integration of greenery

S6.2
EFFICIENT ENERGY SYSTEMS

RENEWABLE ENERGY

- Installation of solar panels on the glass of windows
- Installation of geothermal systems
- Reuse of rainwater

AIR CONDITIONING

- Installation of a system with heat recovery

D7: AUTHENTICITY AND HISTORICAL DIMENSION

S7.1
INTRINSIC VALUES

PRESERVATION OF WORK CULTURE

- Preservation of skills related to maritime practice
- Preservation of industrial machinery
- Conservation of industrial machinery
- Exhibition and valorisation of working memory original machinery

TRANSMISSION OF LOCAL CULTURE

- Valorisation of the history, for example with historical path
- Narration of history and working memory through museum function and artefact expositions
- Narration of history of the place
- Organisation visit to full-scale reconstruction or artefact

S7.2
AUTHENTICITY AND INTEGRITY

- Conservation of formal integrity
- Conservation of spatial integrity
- Conservation of frescoes, stone inscriptions
- Sharing virtual experience to visit the place, as virtual tour
- Visual and perceptual continuity conservation through the same colours, compatible materials

S7.3
SIGNIFICANCE OF THE HERITAGE

- Realisation of reversible interventions
- Demolition of modern non-structural element, as wall
- Material conservation

D9: MANAGERIAL/ DECISION MAKING DIMENSION

S9.1
INVOLVEMENT OF COMMUNITY

- Adoption of bottom-up approach
- Development of guide with citizen

S9.2
INVOLVEMENT OF DIFFERENT STAKEHOLDERS

- Collaboration between public and cultural centre
- Collaboration between administration and stakeholders
- Involvement of multi-level public stakeholders
- Collaboration between directors and development team

	Port areas, as historical, cultural and identitarian testimonies related to maritime activities, conceal structures in decay or abandonment, due to evolving logistical and management requirements. The research aims to develop a systematic and integrated methodological approach for the revitalisation of historical, architectural and industrial heritage assets, preserving their tangible and intangible value and ensuring their reintegration into the port and urban context. The methodological approach focuses on the recognition of the port's heritage and the systematic organisation of the cognitive system through the census and cataloguing of the assets within the port context. In this scenario, the identification of its conservation and use conditions is a fundamental milestone in the heritage qualification process, achieved through a data-driven approach, employing the k-means method for the identification of clusters of recurring typologies. The results orient decisional adaptive reuse strategies of port assets within the contemporary context. Then, starting from the analysis of successful national and international experiences, the meta-design strategies and technical solutions identified for the adaptive reuse of port assets are systematised within an atlas of meta-design strategies to support the definition of design solutions according to local specificities. The proposed design strategies are then evaluated according to success factors through a selection of qualitative and quantitative criteria capable of investigating key aspects and using the AHP method. The validation of the proposed approach followed the entire methodological workflow and involved the analysis of Italian port areas and their port assets, with a focus on Port of Bari and its Palazzo della Dogana, as a case study for the implementation of the adaptive reuse strategies. The development of an integrated digital environment has finally been designed to integrate the knowledge and design solution management system by adopting GIS/BIM and VR/AR tools. The approach defined and validated for the port context ensures replicability in different contexts and scalability, supporting more informed decision-making processes and collaborative engagement for both expert and non-expert users.		
		From census of port heritage assets to adaptive reuse solutions in digital ecosystem	

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