ABSTRACT THESIS: This dissertation investigates the role of floating architecture as an adaptation measure to flooding and rising sea levels in waterfront cities and settlements. It establishes a multidisciplinary comprehensive performance-based design-support framework for floating buildings meant to assist practitioners in the design process and policymakers in providing reference guidelines and evaluating the quality of design proposals. The research identifies the performance requirements for floating buildings and investigates their interactions and mutual influences. There are three main research questions. How does floating architecture fit into the wide range of urban adaptation strategies implemented in waterfront cities across different times, regions, and climate zones? Which performance requirements, deriving from different disciplinary fields, should be included in the design guidelines for floating buildings? How can we effectively organize, visualize, and share a design support framework (PDSF) for floating architecture with professionals and policymakers? The research findings are proposed as a contribution to the evolution of Environmental Design regarding performance-based design and the reflection on urban adaptation in waterfronts. The first result is a theoretical and methodological overview of the vulnerability of waterfront settlements, and current urban adaptation approaches to rising sea levels and flooding. A specific focus on Italy provides a comprehensive mapping of the vulnerability of waterfront settlements aimed at identifying opportunities for floating urban development. The second result consists of the conceptualization of floating urban development, conceived as the urban extension on water of existing waterfront settlements. A third result is an extensive collection of best practices derived from the analysis, evaluation, and comparison of case studies. A fourth result concerns the development of a methodology and protocol for carrying out the case study analysis. In conclusion, the research has allowed the development of a series of performance-based guidelines for floating architecture and the Proof of Concept of a digital computational design tool to advance the decision-making process underlying the design of floating buildings.

Dottorato di Ricerca | PhD
Progettazione Tecnologica Ambientale | Digital Architecture

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Livia Calcagni

Floating Architecture
for Future Resilient Waterfront Cities

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Floating Architecture for Future Waterfront Cities

A Performance-Based Design-Support Framework

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DISSERTATION

Floating Architecture for Future Waterfront Cities

A Performance-Based Design-Support Framework

submitted in satisfaction of the requirements for the degree of Doctor of Science of Sapienza University of Rome, Faculty of Architecture, Department of Planning, Design and Technology of Architecture (Curriculum of Environmental Technological Design) and of Vienna University of Technology, Institute of Architectural Sciences, Department of Digital Architecture and Spatial Planning

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Vienna, February 2024 Signature

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Declaration of authorship

I, Livia Calcagni, confirm that the work presented in this doctoral thesis is my own. Where the work is based on collaboration or where information has been derived from other sources, I confirm that this has been appropriately indicated in this thesis.

Abstract (EN)

This dissertation investigates the role of floating architecture as an adaptation measure to flooding and rising sea levels in waterfront cities and settlements. It establishes a multidisciplinary comprehensive performance-based design-support framework for floating buildings meant to assist practitioners in the design process and policymakers in providing reference guidelines and evaluating the quality of design proposals. The research identifies the performance requirements for floating buildings and investigates their interactions and mutual influences. There are three main research questions. How does floating architecture fit into the wide range of urban adaptation strategies implemented in waterfront cities across different times, regions, and climate zones? Which performance requirements, deriving from different disciplinary fields, should be included in the design guidelines for floating buildings? How can we effectively organize, visualize, and share a design support framework (PDSF) for floating architecture with professionals and policymakers? The research findings are proposed as a contribution to the evolution of Environmental Design regarding performance-based design and the reflection on urban adaptation in waterfronts. The first result is a theoretical and methodological overview of the vulnerability of waterfront settlements, and current urban adaptation approaches to rising sea levels and flooding. A specific focus on Italy provides a comprehensive mapping of the vulnerability of waterfront settlements aimed at identifying opportunities for floating urban development. The second result consists of the conceptualization of floating urban development, conceived as the urban extension on water of existing waterfront settlements. A third result is an extensive collection of best practices derived from the analysis, evaluation, and comparison of case studies. A fourth result concerns the development of a methodology and protocol for carrying out the case study analysis. In conclusion, the research has allowed the development of a series of performance-based guidelines for floating architecture and the Proof of Concept of a digital computational design tool to advance the decision-making process underlying the design of floating buildings.

Abstract (IT)

La tesi indaga il ruolo dell'architettura galleggiante come misura di adattamento alle inondazioni e all'innalzamento del livello del mare nelle città e negli insediamenti waterfront. Stabilisce un quadro esigenziale-prestazionale multidisciplinare di supporto alla progettazione di edifici galleggianti con l’intento di assistere i professionisti nel processo di progettazione, e i responsabili delle politiche nel fornire linee guida di riferimento e nel valutare la qualità dei progetti. La ricerca individua i requisiti per gli edifici galleggianti e indaga le loro interazioni e reciproche influenze. Le principali domande di ricerca sono tre. Come si inserisce l’architettura galleggiante nell’ampia gamma di strategie di adattamento urbano implementate nelle città waterfront in tempi, regioni e zone climatiche differenti? Quali requisiti esigenziali-prestazionali, derivanti da ambiti disciplinari diversi, includere nelle linee guida progettuali per edifici galleggianti? Come organizzare visualizzare e condividere in modo efficace con professionisti e responsabili delle politiche un quadro esigenziale-prestazionale di supporto alla progettazione (PDSF) per l'architettura galleggiante? I risultati della ricerca si propongono quale contributo all'evoluzione della Progettazione Ambientale per quanto riguarda la progettazione performance-based e la riflessione sull'adattamento urbano nei waterfront. Sei sono i risultati della ricerca. Il primo risultato è una panoramica teorica e metodologica della vulnerabilità degli insediamenti waterfront e degli attuali approcci di adattamento urbano all’innalzamento del livello del mare e alle inondazioni. Un focus specifico sull’Italia restituisce una mappatura completa della vulnerabilità degli insediamenti waterfront, finalizzata a identificare opportunità per lo sviluppo urbano galleggiante. Il secondo risultato consiste nella concettualizzazione dello sviluppo urbano galleggiante, inteso come estensione urbana sull’acqua di insediamenti waterfront esistenti. Un terzo risultato è un'ampia raccolta di best practices derivata dall'analisi, valutazione e confronto di casi di studio. Un quarto risultato riguarda lo sviluppo di una metodologia e di un protocollo per lo svolgimento dell'analisi dei casi di studio. In conclusione, la ricerca nel suo complesso ha permesso l’elaborazione di una serie di linee guida e il Proof of Concept di uno strumento digitale di progettazione computazionale per agevolare il processo decisionale alla base della progettazione di edifici galleggianti.

Abstract (DE)

Die Dissertation untersucht die Rolle schwimmender Architektur als Anpassungsmaßnahme an Überschwemmungen und den Anstieg des Meeresspiegels in Städten und Siedlungen am Wasser. Sie schafft ein multidisziplinäres, umfassendes und leistungsbasiertes Rahmenwerk zur Unterstützung des Entwurfs von schwimmenden Gebäuden, das Praktiker:innen im Entwurfsprozess und politische Entscheidungsträger:innen bei der Bereitstellung von Richtlinien und der Qualitätsbewertung von Entwurfsvorschlägen unterstützen soll. Die Forschung identifiziert die Leistungsanforderungen an schwimmende Gebäude und untersucht deren Wechselwirkungen und gegenseitige Einflüsse. Es gibt drei Hauptforschungsfragen. Wie passt schwimmende Architektur in das breite Spektrum urbaner Anpassungsstrategien, die in Küstenstädten zu unterschiedlichen Zeiten, Regionen und Klimazonen umgesetzt werden? Welche Leistungsanforderungen aus unterschiedlichen Disziplinen sollten in die Gestaltungsrichtlinien für schwimmende Gebäude aufgenommen werden? Wie können wir ein *Design Support Framework* (PDSF) für schwimmende Architektur effektiv organisieren, visualisieren und mit Fachleuten und politischen Entscheidungsträger:innen teilen? Die Forschungsergebnisse werden als Beitrag zur Entwicklung von Umweltgestaltung mit Fokus auf *Performance-Based Design* und die Reflexion der städtischen Anpassung an Wasserflächen vorgeschlagen. Das erste Ergebnis ist ein theoretischer und methodischer Überblick über die Vulnerabilität von Ufersiedlungen und aktuelle städtische Anpassungsansätze gegenüber steigendem Meeresspiegel und Überschwemmungen. Ein besonderer Schwerpunkt auf Italien bietet eine umfassende Kartierung der Anfälligkeit von Siedlungen am Wasser mit dem Ziel, Möglichkeiten für eine schwimmende Stadtentwicklung zu identifizieren. Das zweite Ergebnis besteht in der Konzeptualisierung einer schwimmenden Stadtentwicklung, konzipiert als urbane Erweiterung bestehender Ufersiedlungen auf dem Wasser. Ein drittes Ergebnis ist eine umfangreiche Sammlung von *Best Practices,* die aus der Analyse, Bewertung und dem Vergleich von Fallstudien abgeleitet wurden. Ein viertes Ergebnis betrifft die Entwicklung einer Methodik und eines Protokolls zur Durchführung der Fallstudienanalyse. Zusammenfassend lässt sich sagen, dass die Forschung die Entwicklung einer Reihe leistungsbasierter Richtlinien für schwimmende Architektur und den *Proof of Concept* eines digitalen computergestützten Entwurfstools ermöglicht hat, um den Entscheidungsprozess voranzutreiben, der dem Entwurf schwimmender Gebäude zugrunde liegt.

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To my family, to whom I owe everything, to Stefano, the reason for everything.
To my dad, to whom I would love to recount everything.

Glossary

Accommodation barge. A vessel that is designed and used for navigation but lacks a means of self-propulsion and steering equipment or capability and has been continuously moored and used for residential purposes at a recreational marina [Seattle Municipal Code, 2022].

Accommodation platform. In the petroleum industry it is an offshore platform which supports living quarters for off-shore personnel ["Definition of accommodation platform by The Free Dictionary"accessible at: thefreedic-tionary.com. Retrieved 16 January 2022].

Amphibious building. A structure that normally rests on the ground, but that can eventually float in high waters in the event of flooding [NTA 8111, 2011].

Buoyancy. The ability of the flotation system to support a given weight and avoid the displacement of the floating buildings, by means of the hydrostatic pressure acting on the underwater surfaces, giving rise to the buoyancy force. The buoyancy force is equal to the weight of the fluid (water) that is displaced by the floating object [Space@Sea, Wang, K.F. 2021].

Conformity. Fulfilment of a requirement [ISO-14050-2020].

Ecosystem. Dynamic complex of communities of plants, animals and microorganisms and their non-living environment, interacting as a functional entity [ISO-14050-2020]. Generally ecosystems are defined as communities of organisms and related physical conditions and processes within a specific environment. They constitute hierarchical systems of perpetually interacting agents that accumulate into a complex integrated whole, which is characterized by emergent non-reducible properties [Hensel, 2013]

Environment. Surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships [ISO-14050-2020].

Environmental impact. Change to the environment whether adverse or beneficial, including possible consequences, wholly or partially resulting from an organization's environmental aspects [ISO-14050-2020].

Floating building. Floating architecture refers to stationary (yet movable) buildings and other physical structures which rest on a buoyant base, substructure or foundation semi or entirely submerged underwater, designed to adjust to variations in water levels. Regardless of mobility and transferability characteristics which are part of its nature, it is not intended or usable for navigation [Wang, K.F. 2021; Queensland Development Code, 2007; Columbia Standards 1993].

Floating lot. Floating body on which one or more structures, gardens, parking spaces, mooring for pleasure boats rest. Please note: A floating lot can be within a water lot [NTA 8111, 2011].

Floating sub-structure or **floating body** or **flotation body.** Part of the structure of the floating building that provides the buoyancy of the structure [NTA 8111, 2011].

Floating super-structure. Part of the structure of the floating building that rests on the flotation system.

Floating urban development (FUD). Urban development on water on flotation systems of existing waterfront cities and settelments.

Global mean sea level (GMSL). The change in volume of the ocean divided by the ocean surface area. It is the sum of changes in ocean density and changes in the ocean mass as a result of changes in the cryosphere or land-water storage [Gregory et al., 2019].

Houseboat. A boat that has been modified or designed to be used primarily as a house but not defined as a building. In order to moor at other places, some houseboats are not motorized and operation is under their own power. In order to use utilities, some houseboats are kept stationary at a fixed point beside a land or a marina [Wang, K.F. 2021].

Indicator. Quantitative, qualitative or binary variable that can be measured, calculated or described, representing the status of operations, management, conditions or impacts [ISO-14050-2020].

Key performance indicator (KPI). Indicator of performance to be significant and giving prominence and attention to certain aspects of operations, management, conditions or impacts [ISO-14050-2020].

Marine Renewable Energy source (MREs). Renewable energy source (see REs) that is harnessed from the water (e.g., natural movement of water, temperature differences, salinity gradient).

Mooring piles. Poles driven into the bottom of the waterway with their tops above the water. The floating building is tied to the poles through mooring lines to fix and stabilize its position.

Organization. Group of people that has its own functions with responsibilities, authorities and relationships to achieve its objectives [ISO-14050-2020].

Performance. Measurable result [ISO-14050-2020].

Proof of Concept (PoC). Realization of a certain idea, method or principle in order to demonstrate its feasibility, or viability, or a demonstration in principle with the aim of verifying that some concept or theory has practical potential.

Relative sea level (RSL). The change in local mean sea surface height relative to the sea floor, as measured by instruments that are fixed to the Earth's surface (e.g., tide gauges). This reference frame is used when considering coastal impacts, hazards and adaptation needs [Gregory et al., 2019].

Renewable Energy source (REs). Natural resource which will replenish to replace the portion depleted by usage and consumption, either through natural reproduction or other recurring processes in a finite amount of time in a human time scale [Park & Allaby, 2007].

Requirement. Need or expectation that is stated, generally implied or obligatory [ISO-14050-2020].

Sheltered waters. Water bodies with shorelines that are not subjected to the direct action of undiminished ocean waves [FEMA Guidance on Sheltered Water Flood Hazards]. Partially smooth waters (water areas where the wave height, under normal circumstances, does not exceed 1.5 m from trough to crest) and smooth waters (water areas where the wave height, under normal conditions, does not exceed 0.5 m from trough to crest) [Northern Territory of Australia Marine (sheltered waters) Regulations 1986]. Among sheltered waters, it is possible to include lakes, rivers, deltas, canals, artificial basins, bays, and harbors that meet the following conditions.

Sea Level Rise (SLR). Sea level change arising from processes acting on a range of spatial and temporal scales, in the ocean, cryosphere, solid earth, atmosphere and on land.

Sustainable development. Development that meets the needs of the present without compromising the ability of future generations to meet their own needs [Brundtland, 1987].

Trade-off. Decision-making actions that select from various requirements and alternative solutions on the basis of net benefit to interested parties [ISO-14050-2020].

Very large floating structures (VLFSs). Artificial [floating] islands primarily designed for floating airports and ports, for calm waters on the coast or on open sea. (...) they include other uses: bridges, breakwaters, piers and floating docks, energy storage facilities for oil and natural gas, wind and solar power plants, military purposes and emergency bases, to create industrial space, emergency bases, entertainment facilities, recreation parks, mobile off-shore structures, floating farms and even for habitation [Lamas-Pardo et al., 2015].

Water lot. Completely or partially submerged lot, inside which the floating lot and/or the floating structure is located [NTA 8111, 2011].

Introduction

Scientific Framework

This research focuses on developing a design support system to assist the design of adaptive, resilient, and sustainable floating buildings within urban floating developments that are conceived as extensions of existing waterfront cities.
The research falls within the field of environmental technological design, and relates to the concepts of design for adaptation, time-based design, and performance-oriented design applied to the waterscape. Referring to the context of the disciplinary sector ICAR/12-Architectural Technology this research topic is part of a broader reflection on the need for a holistic and integrated approach to environmental design[1] and for interdisciplinarity (Figure 1). It has its roots in the paradigm of sustainability, as expressed in 1987 in the United Nations Report *Our Common Future* also known as the Brundtland Report, according to which the environment represents the system on which the survival of all humanity depends and must therefore be safeguarded to guarantee the life of future generations (Brundtland, 1987). As argued by Professor Pim Martens[2], the complexity and the multidimensional character of sustainable development require the adoption of a new research paradigm that entails integrated approaches and encompasses different magnitudes of scales (of time, space, and function), multiple balances (dynamics), multiple actors (interests) and multiple failures (systemic faults) (Martens, 2006).
The need to develop feasible, competitive, sustainable, dynamic, and long-term adaptive solutions to respond to necessary urban expansion and to adaptation to rising sea levels and flooding has led within the scientific community to the progressive affirmation of the topic of living on the water.
The research investigates floating urban development (FUD) as a resilient extension of waterfront cities and unfolds the potential of floating architecture as a sustainable and adaptive building typology.
The Performance-based Design-Support Framework for Floating Architecture provides a comprehensive and standardized approach to designing and evaluating floating structures. It is addressed to

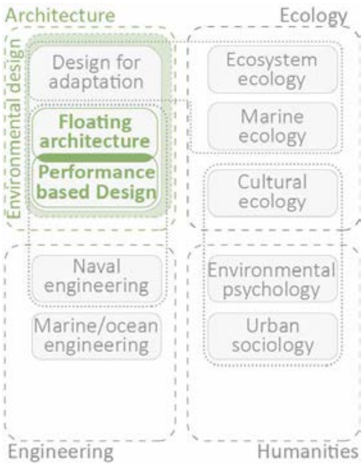


Figure 1. Diagram highlighting the main research domain and the interdisciplinarity of the research topic. Source: Livia Calcagni

1. Borrowing the words of Mario Losasso, “Environmental design was established in the architectural field in the wake of (...) the innovative and anticipatory insights of Tomás Maldonado, Eduardo Vittoria, Salvatore Dierna, Pierluigi Spadolini, Marco Zanuso”. The formalization of Architectural Technology as a disciplinary field in the late 1960s led to a broader cultural and scientific perspective on design and its process (Losasso,

2017). Starting from general areas of building production and sustainability (Schiaffonati et al., 2011), the new field of discipline served as the foundation for reflection on ideas and methods that, starting with ecology, intervened in the definition and governance of compatible relationships between the environment and processes of architectural and urban transformation. The new disciplinary perspective is based on a systemic approach (Losasso, 2017), capable of looking at the habitat construction through "complex processes and experimental or adaptable architectures," expression of the plurality and contemporaneity of design understood as "creation of new relationships between man and the construction of his habitat" (Vittoria, 1976). During the 1980s, we witnessed an evolution in environmental design, with repercussions on a larger scale starting from the principles of compatible transformation of the built environment, of the relationship with the climate and with housing traditions, the use of technologies to ensure the adaptability of living spaces, a new material culture, the bioclimatic design approach, as well as the protection of the environment and ecological balance.

2. Professor of Planetary Health and Dean at Maastricht University College.

governance authorities, planners, and architects involved in floating building design. The framework is also indirectly intended for the general public, as it can raise awareness on the topic and lay the groundwork for social acceptance.

The two overarching concepts underlying the research are time and adaptation. The terms time and architecture form a powerful dichotomy that considers architecture works, their lifetime, their permanence and changes in form and purpose, and the social, productive, and urban transformations of the city and landscape. While nature informs architecture, buildings have been proposed as inert objects that remain static in an evolving world. However, it is no longer conceivable to separate the environment from society, the living nature from humans, and the communities from each other. In a conscious contemporary vision, environment, and both people's and planet's health are collective goods (Jacobs, 1992) that architecture must address. Overcoming the boundaries between humans and ecosystems involves conceiving cities as living organisms and, thus, as dynamic systems. This leads to redefining them in a circular, sustainable, and adaptive way toward conceptualizing a symbiotic relationship between the built and the grown. The concepts of urban metabolism, resilience, adaptation, and mitigation inform the theories and tools of environmental design. The United Nations Intergovernmental Panel on Climate Change defines adaptation as "*the adjustment in natural or human systems in response to actual or expected stimuli or their effects, which moderates harm or exploits beneficial opportunities.*"

In this perspective, architecture should expand to include a fourth dimension: time. Time-based design aims for an architecture that is able to withstand changes through time (Leupen et al., 2005). The constantly evolving demand for space, energy, and services requires buildings and the urban structure to be flexible across spatial, temporal, and functional scales.

The changes expected in the next few decades due to drivers such as artificial intelligence, social and economic tensions, and climate change (CC) will be unprecedented in both scope and speed. Understanding how to manage change in complex systems such as buildings and cities is gaining increased attention. The idea of complex systems is rooted in Jane Jacobs's statement, "*seeing the city as a problem of organized complexity, and therefore [as] a problem of the science of life*" (Jacobs, 1992). This assumption implies the need to change the way we design, construct, occupy, and adapt buildings to accommodate the expected changes. The challenge of adaptation represents a fundamental change in the way we think about design, changing from approaches that are based on past experience to those that are based on calculated projections of future climate and social changes. A product's life, in its broader meaning – component, building, city – can come to an end for a variety of reasons: it can be broken, out of style, inefficient due to technology obsolescence, not able to adapt to change, unable to self-heal, not able to be upgraded for physical, dimensional, or economic reasons. Design for adaptation entails conceptualizing and designing products as dynamic systems with feedback control strategies to respond, or adapt, effectively to changes in product performance criteria (Kasarda et al., 2007). The changing performance requirements may be based on physical, cultural, environmental, and economic considerations. We can trace back the design for adaptation to the following three categories.

Design for climate adaptation can imply high and low-tech environmental and ecological design solutions that make buildings, neighborhoods, landscapes, cities, and regions regenerative, resilient, and adaptive to the effects of CC. This includes direct effects of CC – rising sea levels, increasing extreme weather events such as floods, droughts, wildfires, biodiversity loss, and pollution – as well as indirect impacts that will also influence the shape of future buildings, landscapes, and cities. Indirect impact factors include among others the urgency to decarbonize, social and cultural change, shifts in human migration patterns, changes to economic contexts, and issues related to the changing availability of resources. Thus, Design for Climate Adaptation aims to assist humans in adapting effectively and appropriately in technical and cultural terms by making built environments part of cooperative symbiotic ecologies. In the context of climate adaptation, adaptation can occur through the implementation of theoretical frameworks, policies, codes, standards, and rating systems able to guide practical efforts at a local, regional, national, and international scale through data modeling, simulation, and computation for analyzing, predicting, managing and optimizing strategies for buildings, landscapes, and cities; through bioclimatic and passive design as well as nature-based solutions to achieve a multi-scalar and interdependent climate adaptation and ecological regeneration; through behavior change design strategies able to affect patterns of inhabitation and resources use, including co-design and participatory design as effective agents of advocacy and activism; through the implementation of traditional ecological knowledge (TEK).

Design for adaptability. The primary goal is to lengthen a building's lifespan by allowing it to adapt the space to new purposes with minimal disruption. It concerns adaptation to medium-to-long-term societal and economic needs. A dynamic building or city can evolve and adapt over time according to changing functional, dimensional, performance, and social needs and demands. Design for adaptability involves mobile buildings, flexible multi-purpose buildings, design for deconstruction (disassembly), and adaptive reuse.

Design for real-time performance adaptation. Design for real-time performance adaptation involves designing systems that can adapt their performance to meet changing demands in real-time. Different approaches include using real-time data - which involves collecting data about the system's environment in real-time and using this data to make decisions about how to best adapt - using

predictive models – which involves using models of the system's environment to predict how the system will behave in the future – and using reactive algorithms. Design for real-time performance adaptation is an essential part of developing high-performance systems.
Furthermore, the thesis's main discussion is part of the thematic thread of adaptive waterfront development, which represents a key point of community policies for cities' sustainable and resilient development. Various policy programs, among which strategic documents and European programs, assign great importance to urban planning and design's contribution to achieving climate-resilient cities.

International and European programs and policies

OECD[3] has developed a framework for Resilient cities, which contains Indicators of resilience (Figueiredo et al., 2018). The Resilient Cities Network (R-Cities), built on the 100 Resilient Cities (100RC) initiative pioneered by the Rockefeller Foundation in 2013, enabled cities to hire a Chief Resilience Officer (CRO), develop a resilience strategy, access pro bono services from private and NGO partners, and share ideas, innovation, and knowledge through the global network of CROs. The Sendai Framework focuses on adopting measures that address the three dimensions of disaster risk – exposure to hazards, vulnerability and capacity, and hazard characteristics – to prevent the creation of new risks, reduce existing ones, and increase resilience.
The research can be framed also within the European Green Deal initiative. Approved in 2020, the European Green Deal is a set of policy initiatives launched by the European Commission to make the European Union climate-neutral by 2050. The aim is to review each current law on its climate merits and introduce new legislation on circular economy, building renovation, biodiversity, farming, and innovation. The White Paper *Adapting to Climate Change: Towards a European Framework for Action* (COM, 2009) provides a framework for adaptation to CC, leading to a comprehensive EU adaptation strategy. More closely related to floating development is the UN High-Level Round Table on Sustainable Floating Cities, held in 2019. UN-Habitat convened together with OCEANIX, the Massachusetts Institute of Technology (MIT) Center for Ocean Engineering, the Explorers Club, and other leading innovators, investors, engineers, architects, economists, artists, and scientists to share cutting-edge ideas, collaboration models, and research in this frontier space. The Roundtable had two significant outcomes: the agreement to build a sustainable floating city prototype in collaboration with a host government and the creation of a brain trust of thought leaders, partners, and cities to increase the understanding of the opportunities sustainable floating cities offer to solve pressing challenges faced by waterfront urban areas and inspire cross-disciplinary collaboration.

3. The Organisation for Economic Co-operation and Development (OECD) is an intergovernmental organisation with 38 member countries, founded in 1961 to stimulate economic progress and world trade.

International and European research projects

The interest shown in the decision-making and strategic areas for the topic of investigation is also reflected in the scientific community through various projects financed within the European Horizon 2020 funding. The following projects share the common goal of increasing the resilience of urban environments and their communities to climate change impacts. The ways to achieve resilience and sustainable growth in waterfront areas differ regarding technologies and solutions developed across different disciplines.

The RESIN - *Climate Resilient Cities and Infrastructure* (2015-2018) project aimed to provide standardized methodologies for vulnerability assessments, performance evaluations of adaptation measures, and decision support tools supporting the development of strong adaptation strategies for cities. To this end, RESIN aimed to create a common unifying framework that compares strategies, results, and identification of best practices.

The LifE Project *Long-term Initiatives for Flood-risk Environments*, established in 2005, suggested an integrated design approach to planning and building, which aimed to reduce flood risk through sustainable design. It adopted a non-defensive approach to flood risk management and promoted the creation of space for water. Although the LifE project received UK government funding through the Department for Food and Rural Affairs, the tools and principles developed are transferrable to other countries.

Interreg Mediterranean - Blue Deal is a European project co-financed by the European Regional Development Fund and the Instrument for Pre-Accession Assistance Fund to capitalize Blue Energy. The Interreg MED Program gathers thirteen European countries from the Northern shore of the Mediterranean, working together for sustainable growth in the region. The project plans to increase the transnational activity of innovative clusters and networks of the BE sector, develop links and synergies between small and medium-sized enterprises, public authorities, knowledge institutions, and civil society, and establish transnational and regional Blue Deal Alliances.

Another Horizon2020 funded project is *SOS Climate Waterfront - Linking Research and Innovation on Waterfront through Technology for Excellence of Resilience to Face Climate Change (2018-2023)*. This interdisciplinary project aims to explore waterfronts in Europe facing CC. The project brings together different disciplines to identify new sustainable open solutions for infrastructure and urban planning in Europe's waterfronts.

Horizon2020 grant agreements have also funded a project explicitly related to floating architecture: *Space@Sea - Multi-use, affordable, standardized floating (2017-2020)*. The Space@sea consortium, consisting of seventeen European partners, aimed to provide sustainable and affordable workspace at sea by developing a standardized and cost-efficient modular island with low ecological impact. Space@Sea studied four applications for the maritime

environment: farming, transport and logistics hub, energy hub, and living.
Another project focused on floating development is the *Floating Future Project*, an interdisciplinary and applied research funded by the Dutch Science Council (NOW), which brings together a consortium of five universities, three research institutes, and thirty societal partners. The project aims to offer a climate-proof solution for space limitations in the Dutch Delta and focuses on three waterfront areas: inland, coastal port cities, and offshore.
Such research introduces considerations on how slowly but incrementally increasing the topic of FUD is gradually raising attention among the major scientific funding institutions and International intergovernmental organizations.

National contributions

Alongside the European initiatives, national research contributions to the theme of floating architecture are lacking. Widening the spectrum to climate urban adaptation, the Ministry of University and Research funded several projects known as PRIN[4]. Among these, the project *Adaptive design and technological innovations for the resilient regeneration of urban districts under climate change* has been carried out at the Università degli Studi di Napoli Federico II by coordinator Prof. Mario Losasso. In addition to these contributions, shifting to a more strictly technical and specific line of investigation of the naval and offshore industry, studies relating to naval, civil, and mechanical engineering technologies have been carried out. Amongst these, it is essential to cite CNR-INM MaRELab Marine Renewable Energy Laboratory, which carries out research on the integration of MRE devices for the creation of a floating energy archipelago, and the MORE Lab More Offshore Renewable Energy at the Politecnico di Torino that focusses on the development of analytical methods, design, and evaluation of marine energy floating powerplants technologies.
It is crucial to organize and systematize highly diverse, multidisciplinary, and multiscale contributions from scientific and grey literature to develop a discussion in the synthetically outlined research field. The systematization carried out in Part I does not seek to provide a comprehensive and complete overview of the phenomena. However, it attempts to grasp, in the most structured and articulated way possible, the environmental, ecological, technological, technical, architectural, engineering, economic, social, and cultural features that must be taken into consideration when dealing with such a broad, new and interdisciplinary topic.

Topic and purpose of the research

The ideas set forth in this dissertation are expressed using specific terms that can be understood in various ways. It is therefore

4. PRIN (*Progetti di Rilevante Interesse Nazionale)* stands for publicly funded scientific research projects in Italy (Projects of Significant National Interest).

necessary to clarify the way these terms are used in this dissertation.
The term ***floating architecture*** refers to stationary, yet movable, buildings and other physical structures that rest on a buoyant base, substructure, or foundation semi or entirely submerged underwater, designed to adjust to variations in water levels. Regardless of mobility and transferability characteristics, which are part of its nature, it is not intended or usable for navigation.
The term ***resilient urban frontier*** refers to the potential of floating architecture to expand urban boundaries into water bodies, creating new spaces for living, working, and recreation. This concept has the potential to unlock new sustainable and climate-proof opportunities for urban development and revitalize waterfront areas.
The term ***adaptation measure*** refers to any urban action or strategy that engages a process of adjustment to actual or expected climate impacts and its effects to moderate damage or take advantage of beneficial opportunities. Floating architecture is an adaptation measure as it provides a resilient solution to the challenges of flooding and sea-level rise by adapting to changing water levels.
Waterfront cities include urban areas situated along coastlines, riverbanks, canals, fjords, bays, or the shores of lakes and lagoons. They are characterized by their proximity to bodies of water, which have played a significant role in their development, economy, and culture. Waterfront cities are often major centres of trade, transportation, and maritime activity, and they frequently exhibit a unique blend of urban and natural elements.
Performance-based design refers to a design methodology that focuses on achieving specific performance objectives, providing a structured approach to designing floating architecture projects taking into account the particular needs of a site – conceived in its broader connotation that includes the ecosystem, the human system, and the building system – their relationships and trade-offs.
The term ***decision support system (DSS)*** refers to a computer-based system that provides decision-makers with information and analysis to support the decision-making process of designing floating buildings. A DSS for floating architecture projects is intended to help decision-makers make informed choices about the feasibility and technichal implementation of floating architecture projects.

Climate adaptation in waterfront cities

Climate adaptation is not just about responding to the current impacts of CC; it is also about creating cities that are prepared for future challenges. By integrating climate resilience into urban planning and development, cities can build a more sustainable future that is less vulnerable to the impacts of a changing climate. Waterfront cities, home to over half of the world's population, are particularly vulnerable to CC due to their dense infrastructure, concentration of people and assets, and exposure to water-related hazards. Given their high vulnerability, integrating CC adaptation into policies, strategies, and decision-making processes is becoming increasingly relevant in the policy agenda of waterfront settlements (Few et al., 2007; Francesch-Huidobro et al., 2017; Nicholls et al., 2007; Pörtner et al., 2022). Climate adaptation in planning and architecture is also part of international goals for climate resilience of communities and ecological and energetical transition. The Sendai Framework for Disaster Risk Reduction 2015-2030, adopted by the UN General Assembly in 2015, recognizes the importance of climate adaptation in urban areas, including waterfronts. The framework calls for countries to invest in disaster risk reduction for resilience and strengthen institutional capacities for disaster risk reduction at all levels, including the local community level. The Paris Agreement, adopted by the UN Framework Convention on Climate Change in 2015, also emphasizes the importance of climate adaptation, explicitly focusing on enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to CC. Several international organizations are working to promote waterfront climate adaptation. For example, the UN Office for Disaster Risk Reduction (UNDRR) has developed guidelines for building climate-resilient waterfronts. Many governments implement policies and programs to promote waterfront climate adaptation at the national and local levels. These international, national, and local efforts are helping to promote waterfront climate adaptation and build more resilient coastal communities.

Performance-oriented architecture

Coming to the topic of performance-oriented architecture, the notion of performance emerged in the humanities and social sciences in the mid-20th century. Between the 1940s and 1950s, a paradigmatic shift in theorizing performance as a social and cultural element led to the notion of active human agency. In philosophy and sociology, agency refers to the capacity of a person or entity to act in the world. Moreover, the notion of agency is based on that of environment – a term with greatly varying definitions and implications that, therefore, requires clarification. The German term *Umwelt*[5], coined by Estonian biologist Jacob von Uexküll in 1909 (von Uexküll, 1909), offers an interesting approach to the notion of environment, involving the organism's active agency (Hensel, 2013). Professor Michael Hensel (Hensel, 2010) argues how Uexkuell's notion of Umwelt suggests that "space may be understood as a reflexively produced and immanent condition of subjective experience and therefore contrasts both with objective ideas of space and with phenomenological and post-modern concepts that understand it as constructed by the subject". In architecture, the notion of performance appeared when biology and other scientific fields of knowledge got involved in the architectural discourse. After 1967, when the first Issue entirely dedicated to Performance Design was published, emphasis was placed on methods addressing complex engineering problems that involved mathematical modeling towards optimization and efficiency. In the design process, the focus shifted to problem-solving, efficiency, effectiveness, and optimization. The

5. The concept of '*Umwelt*' (environment) as coined by biologist Jacob von Uexküll in 1909 in his book *Umwelt und Innenwelt der Tiere*, represented an innovation in logic on that strongly affected modern biology, ecology, and systems theory. Uexküll posited that while environments are shared, it is the experience of environments that is different between organisms due to their sensory and affective networks. Organisms create and reshape their reality by interacting with the world.

predominant approach to performance in architecture originates from the entrenched dialectics between form and function that belonged to oppositional discourses.

Another approach to performance in Architecture is that argued by Antoine Picon, architect and professor at Harvard Graduate School of Design. Picon discussed the capacity of architecture to become an event, to participate in a world that is more and more often defined in terms of occurrences rather than as a collection of objects (Picon, 2013). Within this perspective, one should consider that performance-oriented architecture is based on the understanding that "architectures unfold their *performative capacity* by being *embedded* in nested orders of complexity and auxiliary to numerous conditions and processes" (Hensel, 2013). David Leatherbarrow argues that the building cannot be conceived as a “self-sustained and internally defined product of design” (Leatherbarrow, 2009). This approach promotes an integrated design that considers all complex relationships as part of architectural performance. In this regard, Performance-based Design (PBD) approaches and systems should consider the relationship between architecture and the environment in which it is set on a spatial, material, and temporal level, considering context- and time-specific relations. Engaging architecture in the service of the natural environment raises issues of ecology, a sub-discipline of biology established in the mid 19th century by the German biologist Ernst Haeckel that deals with the relationship between living organisms and their surroundings. By adopting an urban ecology perspective, the design must seek to understand the complexities involved at large scales and to investigate the impact of integrated heterogeneous and discontinuous spaces.

However, most of today’s PBD approaches do not envisage the environment as an inherent and integral part of the architecture nor adopt a multi-species approach. Indeed, PBD systems have been addressed by many research establishments over the last 50 years: the Interjurisdictional Regulatory Collaboration Committee (IRCC) and the International Council for Building Research and Innovation (CIB) TG37; CSTB - Centre Scientifique et Technique du Bâtiment (1988); ISO - International Organization for Standardization (ISO 6240:1980 - Performance standards in building). In the context of European standardization in the building sector (CEN and CENELEC standards), the performance approach has been adopted as a priority method based on Directive 89/106/EEC - Council Directive of 21/12/1988 relating to the approximation of laws, regulations and administrative provisions of the Member States concerning construction products. According to this directive, the standards on construction products must be expressed, as far as possible, based on the state of knowledge and market conditions in terms of performance standards. The required performance criteria and levels must be derived from the essential requirements and related performance classes, referring to the works in which the products are used. The performance approach is now adopted in national building regulations for specific fields such as energy, fire safety,

6. The inductive method (from the Latin *inductio*, *in-ducere* which literally means "to bring in", or "to draw to oneself") is used to refer to any method of reasoning in which broad generalizations or principles are derived from a body of observations in individual particular cases.

7. The systemic approach provides an overall and integrated vision of the various topics covered.

structural safety, and acoustics. In the European Union member states, this approach, in many cases, follows provisions contained in specific European Directives. PBD approaches have also been applied in the offshore field since the Norwegian Oil Age started in the early 70s by establishing requirements and guidelines within several disciplines. The offshore industry is indeed known for its thorough and strict health and safety regulations. Recent research has attempted to apply PBD concepts also to wind engineering (Ciampoli et al., 2011). Still, in both fields, the emphasis is mainly on the users and the function.
Although performance-based building regulations are in use or under development in several countries worldwide, significant challenges remain in adequately identifying and defining performance when addressing a new design typology, in understanding and addressing diverse societal expectations, in contributing to fostering new lifestyles more resilient to CC and pandemics, and finally in establishing robust and open-structured performance-based regulatory systems. These challenges become intensified as the building construction market becomes increasingly global, with the resulting expectation that building regulatory instruments remain valid across borders while at the same time addressing local and national needs without compromising local cultural and societal norms (Meacham et al., 2005). Many of these issues are just now beginning to be explored, and there is a significant opportunity and need for future research and development in these areas. Within the context of this thesis, the term performance-based design is not limited to form generation and modification or energy and thermal optimization. However, it expands its domain to safety, wellbeing, usability, management, integrability, rational use of resources, environmental regeneration, buoyancy, and plant system efficiency requirements. Performance-oriented architecture in this work entails adopting a multi-species design approach and a tangible architecture and environment integration.

Overall methodology

The research is developed following an inductive[6] and systemic[7] methodology and its progress can be traced back to five consequential phases.

1. A **preliminary phase** including:
   - the research program overview (research aim and questions, expected results, target group, boundary conditions);
   - the description of the main topics addressed by the research: bibliographic research, literature review, collection of data and information on the main lines of investigation (Chapter 1);
   - the establishment and fine tuning of an operational methodology (Chapter 2);

2. an **investigative-interpretative phase** in which the bibliographic base for developing the main research ex-pected output (Performance-based Design-Support Framework for floating architecture - PDSF) is set up and a first preliminary output is developed;
3. a **synthetical-evaluative phas**e in which the output is verified and further integrated and developed through a case study analysis;
4. an **applicative phase** that allows to test the revised output on a pilot site;
5. a **feasibility assessment phase** of the final output that involves a Proof of concept (PoC) to validate the core concept of the research and pave the way for future studies.

Research questions

The conceptual framework of the research and the set of objectives, structured in general macro-objectives and specific objectives, is established by introducing some fundamental research questions (RQ), related to the identified research gaps (Figure 2), that are further articulated in sub questions.

1. **How does floating architecture fit into the range of urban adaptation strategies that have been implemented in waterfront cities across different times, regions and climate zones?**

    1. What are the key elements that define floating architecture as a building typology?
    2. What are the potential benefits and drawbacks of floating development as an adaptation strategy for waterfront cities?
    3. What are the key design considerations for floating development projects?
    4. How can we ensure that floating development projects are sustainable and resilient?

2. **How should performance-based design guidelines be identified and what requirements should they include to embrace a broad array of aspects arising from different disciplinary fields?**

    1. What are the essential criteria for identifying and selecting successful best practices for floating development?
    2. What are the specific design requirements to consider when designing floating buildings in order to ensure safety, resiliency, sustainability, and inclusiveness?
    3. How can we balance the functional, aesthetic, and environmental considerations of floating architecture?

4. What role does local specificity play in the context of performance-based design for floating architecture and how can we handle the issue of balancing local respondence and site-specific conditions with pre-set generalized performance requirements?[8]

8. This question can be framed in the continual problem faced by contemporary architecture of how to negotiate the problem of architecture's increasing global homogenization and the need to address local specificity. More specifically, as underlined by Professor M. Hensel, "the question is how to unlock the performative capacities of architectures that ate informed by their particular setting" (Hensel & Sørensen, 2014).

3. **How can we effectively organize, visualize and share a performance-based design-support framework (PDSF) for floating architecture with practitioners and policymakers?**

   1. At what point of the design process could the PDSF be integrated?
   2. How can a performance-based design framework be turned into a performance-driven digital platform?
   3. To what extent does a performance-driven design framework for floating buildings demonstrate feasibility and practical potential in a limited PoC implementation?

General and specific objectives

The general objectives (GO) define the theoretical horizon and the cultural assumptions that set the boundaries of the research. These general objectives are further detailed into specific objectives (SO) that are connected to the different phases in which the research work is organized. The specific objectives allow the implementation of the general objectives within the research structure.

GO 1. Understand and classify the effects of CC on waterfront cities and the role of urban adaptation and planning.

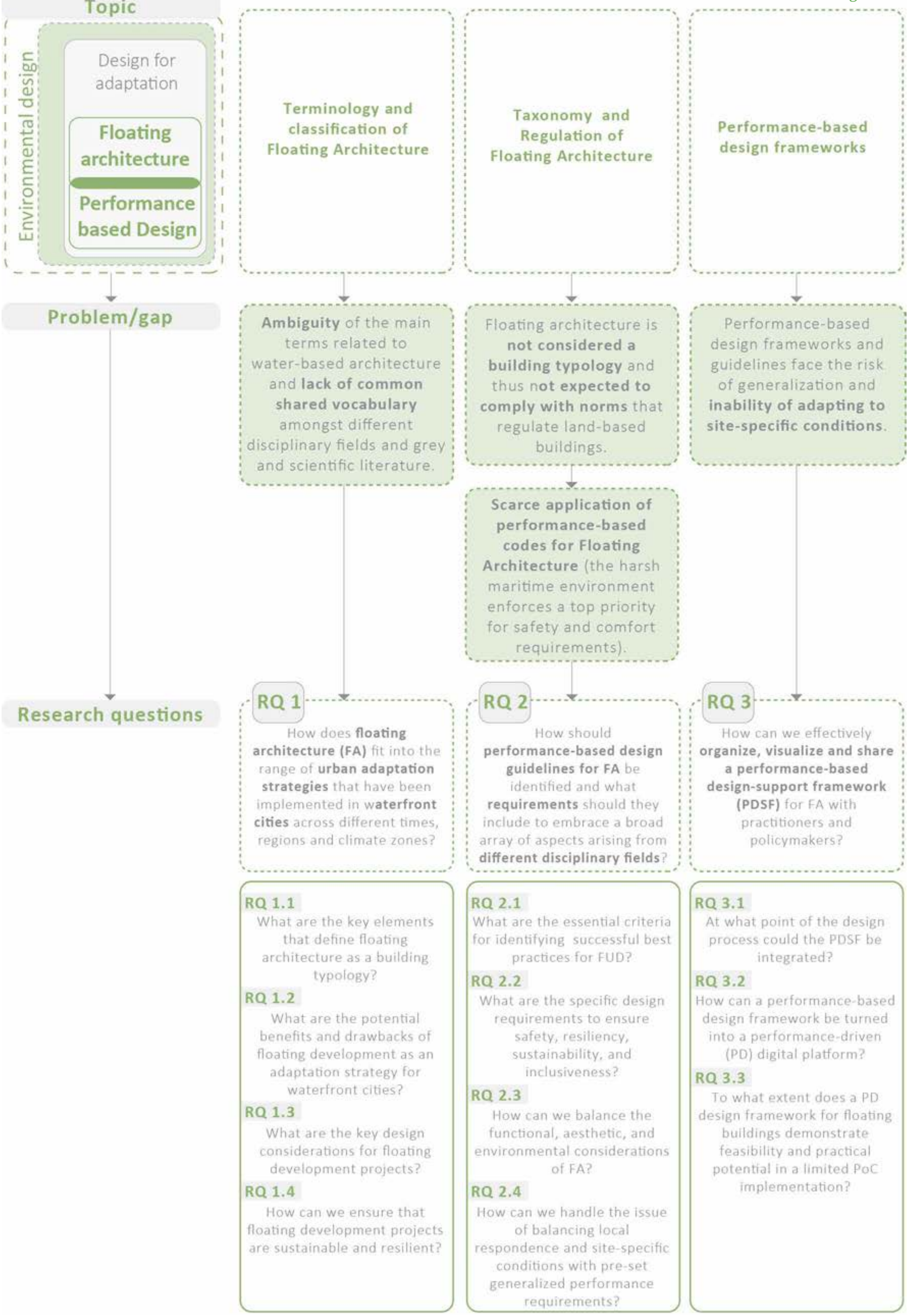
- SO 1.1. Study and analysis of theories, grey and scientific literature on the impact of CC on waterfront cities and settlements.
- SO 1.2. Study and analysis of theories, grey and scientific literature on urban planning and adaptation strategies and responses to CC in waterfront cities.
- SO 1.3. Collection and analysis of regulatory directives at international, European, and national level and strategic directives at urban level.

GO 2. Investigate water as a new urban frontier of resilient living for waterfront cities, in response to the need for climate adaptation and mitigation and for ecosystem regeneration.

- SO 2.1. Study and analysis of theories, grey and scientific literature on the potential of floating architecture for resilient urban development.
- SO 2.2. Evaluation of the potential of floating architecture within grey and scientific literature and within practice (best

Figure 2. Relation between the identified research gaps and the relevant research questions (RQ). Source: Livia Calcagni

Figure 2.


Topic
Environmental design
Design for adaptation
Floating architecture
Performance based Design
Terminology and classification of Floating Architecture
Taxonomy and Regulation of Floating Architecture
Performance-based design frameworks
Problem/gap
Ambiguity of the main terms related to water-based architecture and lack of common shared vocabulary amongst different disciplinary fields and grey and scientific literature.
Floating architecture is not considered a building typology and thus not expected to comply with norms that regulate land-based buildings.
Performance-based design frameworks and guidelines face the risk of generalization and inability of adapting to site-specific conditions.
Scarce application of performance-based codes for Floating Architecture (the harsh maritime environment enforces a top priority for safety and comfort requirements).
Research questions
RQ 1
How does floating architecture (FA) fit into the range of urban adaptation strategies that have been implemented in waterfront cities across different times, regions and climate zones?
RQ 2
How should performance-based design guidelines for FA be identified and what requirements should they include to embrace a broad array of aspects arising from different disciplinary fields?
RQ 3
How can we effectively organize, visualize and share a performance-based design-support framework (PDSF) for FA with practitioners and policymakers?
RQ 1.1
What are the key elements that define floating architecture as a building typology?
RQ 1.2
What are the potential benefits and drawbacks of floating development as an adaptation strategy for waterfront cities?
RQ 1.3
What are the key design considerations for floating development projects?
RQ 1.4
How can we ensure that floating development projects are sustainable and resilient?
RQ 2.1
What are the essential criteria for identifying successful best practices for FUD?
RQ 2.2
What are the specific design requirements to ensure safety, resiliency, sustainability, and inclusiveness?
RQ 2.3
How can we balance the functional, aesthetic, and environmental considerations of FA?
RQ 2.4
How can we handle the issue of balancing local respondence and site-specific conditions with pre-set generalized performance requirements?
RQ 3.1
At what point of the design process could the PDSF be integrated?
RQ 3.2
How can a performance-based design framework be turned into a performance-driven (PD) digital platform?
RQ 3.3
To what extent does a PD design framework for floating buildings demonstrate feasibility and practical potential in a limited PoC implementation?

practices).

- SO 2.3. Collection and analysis of regulatory directives at international, European and national level and strategic directives at urban level.

GO 3. Develop a performance-based design-support framework specifically tailored for floating architecture and conceived as an open and upgradable meta-design tool.

- SO 3.1. Identify performance requirements for floating architecture merging regulations coming from the existing floating buildings standards and codes with those of the naval, offshore and on-land building sectors.
- SO 3.2. Identify correlations and compatibility, complementarity, interchangeability, excludability relationships between requirement criteria.
- SO 3.3. Provide a priority order amongst requirements.
- SO 3.4. Identify best practices amongst case studies through a multi-criteria evaluation matrix.
- SO 3.5. Apply and test the framework on a pilot area.

GO 4. Assess the feasibility and practical potential of a digital performance-driven design tool for floating buildings.

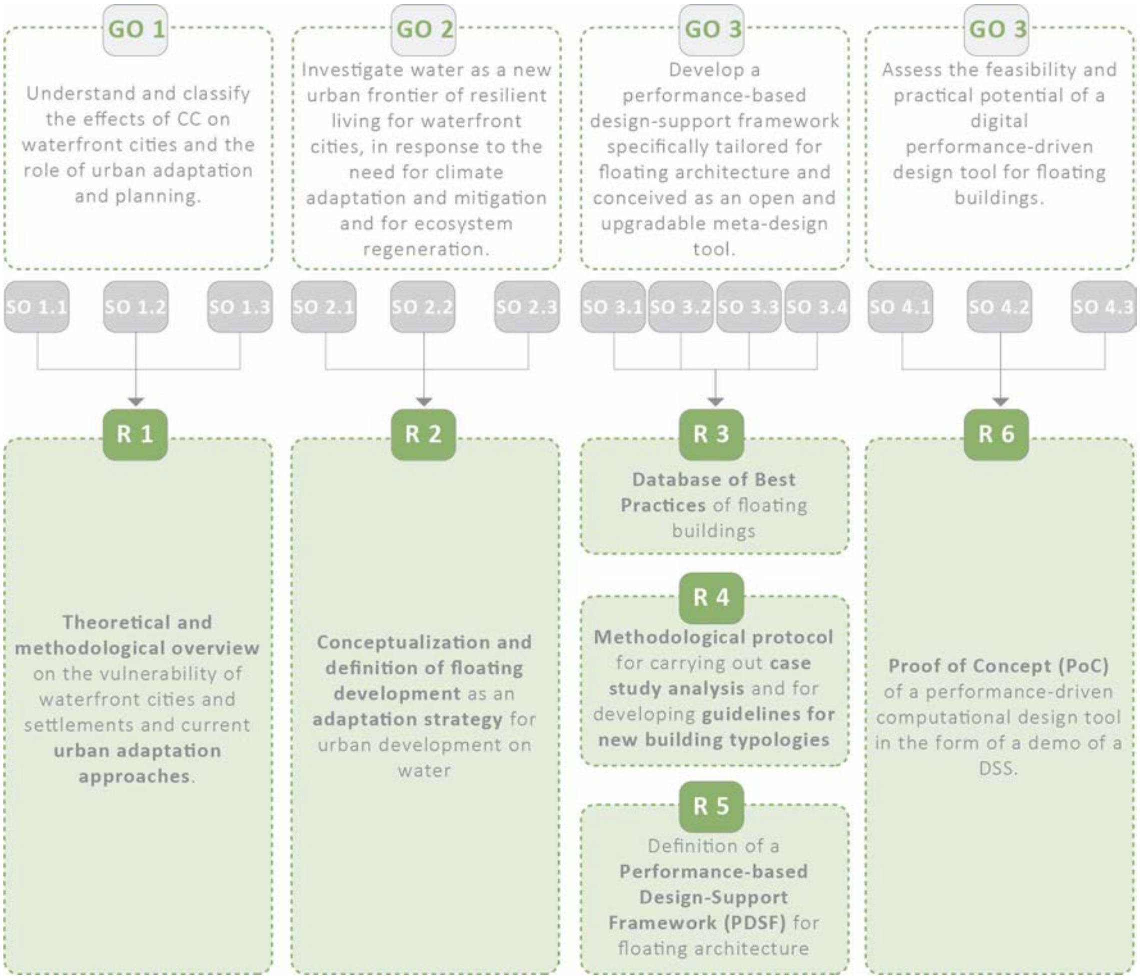
- SO 4.1. Establish a methodology to transform the performance-based design framework into a performance-driven digital platform.
- SO 4.2. Develop a Proof of Concept for a computational design support system to advance performance-driven reasoning in floating building design.
- SO 4.3. Evaluate how effective a digital tool (in a limited PoC implementation) is for practitioners and policymakers.

Results

The research findings are proposed as a contribution to the evolution of Environmental Design regarding the topic of performance-based design and design for adaptation, and in particular, the reflection on urban adaptation in waterfront cities.
The first result (R1) is the **theoretical and methodological overview of the vulnerability of waterfront cities and settlements** and current **urban adaptation approaches**. A specific focus on Italy returns a comprehensive mapping of the vulnerability of Italian waterfront cities and settlements intended for identifying opportunities for floating urban development along Italian waterfronts.
The second result (R2) consists in the **conceptualization and definition of floating development** as an **adaptation strategy for urban development on water**, conceived as extension of existing

waterfront settlements and cities.
A third result (R3) is an **extensive collection of best practices** derived from a case study analysis, evaluation and comparison.
A fourth result (R4) concerns the development of a **methodological protocol for carrying out case study analysis** as well as for **developing guidelines for new building typologies**. The developed methodology assumes autonomous didactic and operational validity as a tool for reading and understanding the technical-scientific progress and design practice of any field of research, allowing the systematization and categorization of parameters in a normalized manner, adapted accordingly to the field of interest.
The principal outcome (R5) is the definition of a **Performance-based Design-Support Framework (PDSF)** and **set of guidelines** for advancing multiple criteria decision making when designing and planning **floating architecture**.
The final outcome (R6) is a **Proof of concept of a digital performance-driven computational design tool** in the form of a demo of a DSS.
Figure 3 displays the relation that occurs between the general objectives (GO) and final results (R).

Figure 3. Correlation between the general objectives (GO) of the research and the final results (R). Source: Livia Calcagni



Target groups

The potential interested parties belong to the broad range of actors involved in designing floating buildings or planning floating urban development, specifically inherent to waterfront areas. It is possible to name three main target groups:

- individual researchers or research institutions who wish to develop national or international investigation programs or act as consultants to the public administration in the general context of floating architecture and urban development
- public bodies and policymakers willing to define programmatic or political guidelines for floating development or floating buildings
- professionals and technicians involved in various capacities in floating buildings' design, construction, and management process.

Phase 1 is primarily addressed to individual researchers and research institutions, as it provides a comprehensive overview of the existing literature on floating architecture, climate adaptation strategies, and performance-based design. This knowledge can be instrumental in developing new research programs and projects and conducting comparative studies.

The Performance-based Design-Support Framework (PDSF) developed in phase 2 represents a valuable tool for all three target groups. It provides a structured approach to identifying, classifying, and prioritizing performance requirements for floating architecture. Researchers can use this framework to analyze case studies, policymakers to establish guidelines, and professionals to design and evaluate floating buildings.

The setup of a case study database in Phase 3 provides guidance for practitioners who can look into it for inspiration before proceeding with their design.

Phase 5 directly addresses professionals and technicians involved in floating building design and construction. A performance-driven interactive design tool for floating buildings holds the potential to streamline the design process, improve decision-making, and reduce the risk of design errors. This tool can serve as a valuable asset for professionals and technicians involved in floating building design and construction and for public authorities seeking to ensure compliance with defined norms and standards. More specifically, the design tool could be transformed into a standard or code that helps authorities evaluate design compliance, supporting regulatory development in floating architecture. Moreover, the Design Tool has the potential to be commercially viable for entrepreneurs, industries, or engineering companies through software licensing or industry-specific integration. Eventually, collaborations between research institutions, software developers, and public bodies could lead to the development and deployment of the tool as a public service or a subsidized commercial product.

In conclusion, the research indirectly benefits the general public by raising awareness about floating architecture and paving the way for social acceptance. The PDSF can be used to educate the general public about the benefits and potential of floating architecture. This awareness could be raised through public engagement workshops, educational programs, and media outreach and dissemination. As public awareness of floating architecture grows, so does the potential for social acceptance. By demonstrating the feasibility, safety, and environmental benefits of floating buildings, the PDSF can help to dispel myths and misconceptions that may hinder public support. This acceptance can be further nurtured through community engagement and pilot project implementation in vulnerable areas.

Boundary conditions

The research focuses on the building scale extended to its relations with the surrounding environment (*Umwelt*). From a geographical point of view, the research is limited to waterfront areas comprising rivers, lakes, deltas and near-shore coastal waters, that are characterized by close proximity to urban medium to high density areas and flood prone conditions.
The decision to focus on the building scale extended to its relations with the surrounding environment is driven by the recognition that floating architecture is not merely about individual structures but also their integration into the broader environmental context. Understanding the dynamic interplay between floating buildings and their surroundings is crucial for ensuring their successful implementation and long-term sustainability. However, it is essential to start from the building scale before moving to the district or urban scale. Understanding the fundamental principles and challenges associated with floating structures and establishing a solid foundation at the building scale lays the groundwork for more complex and comprehensive frameworks at larger scales. Enabling a gradual understanding and progression to broader scales allows for a more systematic and controlled approach to scaling up, minimizing the risk of unforeseen challenges and ensuring the successful implementation of floating infrastructure at larger scales. Moreover, the building scale offers a more tangible and manageable context for developing practical and implementable tools for floating architecture. These tools can gradually be scaled up to address the challenges of larger-scale developments.
The choice to limit the geographical scope to waterfront areas comprising rivers, lakes, deltas, and near-shore coastal waters is motivated by several factors:

- vulnerability to flooding
- proximity to urban areas where population density is high and demand for housing and infrastructure is growing
- unique and suitable environmental conditions for floating

structures: currents and waves are not excessively strong as in offshore waters and marine ecosystems, which pose specific challenges and opportunities.

Research organization and thesis structure

The research has a strong multidisciplinary character, set at the intersection of different fields of study: environmental architecture, landscape architecture, urban planning, civil, marine/ocean, energy and mechanical engineering, ecosystem ecology, marine biology, cultural ecology, urban sociology, environmental psychology.
To achieve the research objectives, it was necessary to refer to different methodological approaches:

- interpretative research, based on a systematic analysis of the sector literature regarding the theoretical-cultural panorama and the contributions that constitute the state-of-the-art on the topic
- data collection and logical argumentation methods for the construction of the PDSF
- quantitative and qualitative research regarding the inductive-deductive analysis of current existing projects from a design and management point of view
- research by design to apply and test the framework on a pilot area.

Particularly meaningful for the development of the thesis has been a series of research experiences carried out in other institutions, including International and European research centers and universities, which allowed for an in-depth study of the themes investigated through different disciplinary and methodological perspectives.

Cotutel PhD Program
A period of study (18 months) spent at TU Wien (Vienna, Austria), Faculty of Architecture, Institute of Architectural Sciences (Head of Institute Univ.Prof. Dipl.-Ing. Peter Bauer), within the Research Unit of Digital Architecture and Planning (PhD Coordinator: Ao.Univ.Prof. Dipl.-Ing. Christian Kühn) under the supervision of the Research Unit Head Univ.Pro.Arch.Dipl.-Ing. Michael Ulrich Hensel PhD.

Research stay - Marie Skłodowska-Curie Actions Secondment Agreement
A period of research (31 days) spent at Centro Cultural de Belém (CCB) - Universidade Lusófona (Lisbon, Portugal). The research stay was granted through a H2020-MSCA-RISE 2018 Secondment Agreement within Marie Skłodowska-Curie Actions co-funded by the Horizon 2020 program of the European Union "SOS CLIMATE WATERFRONT - Linking Research and Innovation on Waterfront through Technology for Excellence of Resilience to face Climate Change" GA # 823901. Principal Investigator: Prof. Arch. Pedro

Ressano Garcia.

COST Action
Participation to COST (European Cooperation in Science and Technology) Action Training School in Estoril MODENERLANDS - Resilience of Modular Sustainable Energy Islands In Face Of Climate Change Challenges (Universidade d Coimbra, Prof. Ing. Carlos Rebelo). The training school was funded by the European Union COST funding program and focused on floating hybrid energy hubs.

Participation as a speaker at International conferences
- WCFS2023 3rd World Conference on Floating Solutions - "Floating Solutions for the Next SDGs, Nihon University College of Science and Technology, Tokyo, Japan. Title of contribution: "A Performance-based Design Framework for Floating Architecture. Trade-offs and correlations between requirements for multiple criteria decision making optimization".
- ICAADE 2023 4th International Conference on Amphibious and Floating Architecture, Design and Engineering, Institute for Floating Buildings (IfSB e.V.) and Brandenburg University of Technology (BTU) in Cottbus, Germany. Title of contribution: "Towards a comprehensive design support framework for floating architecture".
- SOS Climate Waterfront Symposium on sustainable Open Solutions for Waterfronts, Fundação Calouste Gulbenkian - Universidade Lusófona, Lisbon, Portugal. Contribution title: "Floating architecture as a resilient urban frontier and adaptation measure for rising sea levels in waterfront cities".
- DLA2024 Conference of Digital Landscape Architecture: Exploring New Trajectories in Computational Urban Landscapes & Ecology (to be hosted by TU Wien, in Vienna between June 5-7 2024). Contribution title: "A comprehensive computational tool for performance driven reasoning in floating building design and evaluation".

Participation as a listener at International conferences
- Seminario Internazionale di studi Mare Nostrum. La terra tra i mari. La fondazione instabile di nuovi confini jonici e tirrenici calabresi dopo le mareggiate. Università di Reggio Calabria, 05/04/2022.
- Modelli dinamici per la mitigazione dei cambiamenti climatici in architettura. Metodi e strumenti nell'approccio multiscalare al progetto energetico e climatico. Sapienza Università di Roma, 6/05/2022.
- Med Green Forum – 6th edition: Mediterranean Architecture & Green-Digital Transition. DIDA Università di Firenze, 20/07/2022.
- UN 2023 Water Conference and use of national data. United Nations Webinar, 14/09/2022
- Global Knowledge Exchange Event on Floating & Resilient Development. Global Center on Adaptation, 29/09/2022.

- Springer - Nature Water: An Introduction. Springer Nature, 18/10/2022
- MSP-GREEN Launching Conference. CORILA, Università Iuav di Venezia and CNR-ISMAR, 17/01/2023.
- AE8 - 8th International Architecture and Environment Symposium, Decision Support in Urban Social-Ecological Systems. Technische Universität Wien 02/02/2023
- JMSE Webinar | Floating Solutions for Addressing Climate Change Impacts on Coastal Cities. Zurich, 09/02/2023.
- Mobilizing Finance for Climate Adaptation in Deltas. Global Center for Adaptation, 26/05/2023.
- Resilient Delta Cities – Adaptation Analysis, Planning, and Implementation. Global Center for Adaptation, 16/06/2023.

Seminars and Courses attended

- Formazione Sapienza sulle soft skills per dottorandi. Sapienza Università di Roma, 5/11/2021.
- GIS Open Source Base (QGIS) - Certificato di frequenza GIS base. TerreLogiche. Corso di formazione GIS base: introduzione ai GIS e apprendimento software (18 hours)
- GIS Open Source Avanzato (QGIS) - Certificato di frequenza GIS avanzato. TerreLogiche. Corso di formazione GIS avanzato: moduli per una gestione avanzata della componente di database e per un utilizzo approfondito e consapevole delle potenzialità del software (18 hours).
- Ciclo di seminari per dottorandi sui metodi e sugli strumenti della ricerca. Sapienza Università di Roma, Dipartimento di Pianificazione, Design e Tecnologia dell'Architettura
- Ciclo di seminari teorici-metodologici per dottorandi. Sapienza Università di Roma, Dipartimento di Pianificazione, Design e Tecnologia dell'Architettura
- PhD Seminar - Prof. Michael Hensel. Vienna University of Technology.
- PhD Seminar for doctoral candidates, urban design, urban structure studies, urban studies - Prof. Angelica Psenner. Vienna University of Technology
- Interactive Architecture - Asst. Prof. Milica Vujovic. Vienna University of Technology
- How to write a scientific Paper - Prof. Paul Mayrhofer. Vienna University of Technology
- Writing retreat. Prof. Angelica Psenner. Vienna University of Technology
- Digital fabrication methods. Prof. Marco Palma. Vienna University of Technology

Conference Organizing Committee

- Floating Future Symposium, "Inhabiting water as a resilient urban frontier", Sapienza University of Rome, Rome, Italy

Lecturer and teaching activity

- Lecturer at Technische Univeritaet Wien, Master in building

Science and Environment, Head Prof. Michael Ulrich Hensel; Module on Current Topics: *"Design for adaptation: floating architecture"*. Winter semester 2023.
- Master Thesis Co-supervisor within the thesis seminar "Floating Architecture" held by Prof. Alessandra Battisti (Supervisor) on the topic of *"Living on the water. Sustainable Floating houses in Miami"* (Students Cecilia Cipri, Catherine Ciminà) and "*Architectural, environmental and energetic regeneration of a floating settlement. Cua Van village in Ha Long Bay, Vietnam*" (Student Iole Ascione).
- Teaching Assistant at Sapienza University of Rome, Faculty of Architecture, Master in Architecture and Urban Regeneration; Course: Technological Design for urban regeneration, Sommer semester 2023 (Corso di Progettazione Tecnologica per la Rigenerazione Urbana A.A. 2022-2023); Prof. Alesandra Battisti. Topic: *"Regeneration of Passo della Sentinella. Technological and environmental design of a floating cluster"*.

Grants

The following grants have strongly contributed to the development of the research:
- Grant for abroad mobility (Bando per la mobilità all'estero) to carry out research activities at the Research Unit of Digital Architecture and Planning, Institute of Architectural Sciences (TUW), Austria. Institution: Sapienza University of Rome. Principal Investigator: Livia Calcagni. Title: "TALASSA: Tecnologie Architettoniche per L'Acqua e Sistemi decisionali Sostenibili per l'Abitare".
- Research Starting Grant. Institution: Sapienza University of Rome. Principal Investigator: Livia Calcagni. Title: "Abitare l'acqua come nuova frontiera urbana resiliente attraverso sistemi innovativi di insediamenti smart e green galleggianti. Elaborazione di linee guida metaprogettuali"
- Marie Skłodowska-Curie Secondment (GA # 823901). Principal Investigator: Prof. Pedro Ressano Garcia. Title : "SOS CLIMATE WATERFRONT - Linking Research and Innovation on Waterfront through Technology for Excellence of Resilience to face Climate Change".
- COST Action Training School scholarship. Title: MODERN LANDS – Resilience of Modular sustainable Energy Islands in face of climate change challenges.

Scientific publications

Relevant papers and book chapters have been published and have been extremely important in the development of the thesis:
- Springer proceedings "A Performance-based Design Framework for Floating Architecture. Trade-offs and correlations between requirements for multiple criteria decision making optimization" (In press May 2024)
- Book chapter "Experimental living and housing forms: cities of the future as sustainable and integrated places of food

production” (Battisti et al., 2023)

- Book chapter “Chasing the Nexus between Sustainable Strategies and Cultural Heritage” (In press 2024)
- Book chapter "Sistemi produttivi urbani circolari e clima-adattivi" In Progettazione ambientale, sfide globali, scenari di ricerca a cura di M. Losasso, R. Romano (In press May 2024)
- Journal paper (Journal of Digital Landscape Architecture, 9-2024) "A comprehensive computational tool for performance driven reasoning in floating building design and evaluation" (In press 2024)

Part of the work published so far has gained recognition with the Award for “Great contribution of young researcher” at the World Conference on Floating Solutions 2023 on the 29th of August 2023.

As regards the structure of the discussion, it is divided into three parts, corresponding to as many moments of development of the methodological structure.

The first part is about the reference context and the cultural and scientific assumptions of the research. This part includes projected impacts of CC on low-lying areas and waterfronts, waterfront adaptation strategies, and a broader picture of floating architecture as part of waterfront adaptation strategies. The latter involves ontological, taxonomical, and regulatory issues and implications. Vernacular floating architecture and utopias from the 60s and 70s are briefly exposed to frame the topic from a historical point of view. Ultimately, the potential of floating architecture is outlined.

The second part focuses on developing and constructing a Performance-based Design-Support Framework (PDSF) for guiding and supporting the design of floating buildings in sheltered waters near urban areas. The overall methodology of the research is described. This part includes the case study review and the expert feedback review, as they are both functional to the final finetuning of the PDSF. The third part consists of the design experimentation. The analysis of a pilot area where the PDSF is applied and tested is depicted, and design scenarios are proposed. Ultimately, a proof of concept for incorporating a web-based multi-aspect interactive design tool to support performance-driven reasoning in floating building design effectively is provided. The shift from a performance-based design framework to a performance-driven computational design tool is clarified, opening new research questions.

References

Brundtland, G. H. (1987). Report of the World Commission on Environment and Development. Our common future. *Environmental policy and law, 14* (1), 26-30

Ciampoli, M., Petrini, F., & Augusti, G. (2011). Performance-based wind engineering: towards a general procedure. *Structural Safety, 33*(6), 367–378. doi: 10.1016/j.strusafe.2011.07.001

COM (2009). *White paper - Adapting to climate change: Towards a European framework for action*. European Commission.

Columbia, B. (1993). Float Home Standard. Ministry of Municipal Affairs, Building Standards Branch.

Few, R., Brown, K., & Tompkins, E. L. (2007). Climate change and coastal management decisions: insights from Christchurch Bay, UK. *Coastal Management, 35*(2–3), 255–270. doi: 10.1080/08920750601042328

Figueiredo, L., T. Honiden and A. Schumann (2018). Indicators for Resilient Cities, OECD Regional Development Working Papers, No. 2018/02, Paris: OECD Publishing. doi: 10.1787/6f1f6065-en.

Francesch-Huidobro, M., Dabrowski, M., Tai, Y., Chan, F., & Stead, D. (2017). Governance challenges of flood-prone delta cities: Integrating flood risk management and climate change in spatial planning. *Progress in Planning, 114*, 1–27. doi: 10.1016/j.progress.2015.11.001

Hensel, M. U. (2010). Performance-oriented architecture: towards a biological paradigm for architectural design and the built environment. *FORMakademisk, 3* (1). 36-56.

Hensel, M. U. (2013). Performance-oriented design as a framework for renovating architectural practice and innovating research by design. In. M. U. Hensel (Ed) *Design Innovation for the Built Environment: Research by Design and the Renovation of Practice*, 121–143. Routledge. doi: 10.4324/9780203129746-15

Hensel, M.U., & Sørensen, S.S. (2014). Intersecting knowledge fields and integrating data-driven computational design en route to performance-oriented and intensely local architectures. *Footprint, 15*, 59-74. doi: 10.7480/footprint.8.2.812

ISO-14050-2020 (2020). Environmental management - Vocabulary.

Jacobs, J. (1992). *The death and life of great American cities.* New York: Vintage, 321–325.

Kasarda, M. E., Terpenny, J. P., Inman, D., Precoda, K. R., Jelesko, J., Sahin, A., & Park, J. (2007). Design for adaptability (DFAD) – a new concept for achieving sustainable design. *Robotics and Computer-Integrated Manufacturing, 23*(6), 727–734. doi: 10.1016/j.rcim.2007.02.004

Lamas-Pardo, M., Iglesias, G., & Carral, L. (2015). A review of very large floating structures (VLFS) for coastal and offshore uses. *Ocean Engineering, 109*, 677-690. doi: 10.1016/j.oceaneng.2015.09.012

Leatherbarrow, D. (2009). *Architecture oriented otherwise*. New York: Princeton Architectural Press.

Leupen, B., Heijne, R., & van Zwol, J. (2005). *Time-based architecture*. Rotterdam: 010 Publishers.

Losasso, M. (2017). Progettazione ambientale e progetto urbano. *Eco Web Town, 2*(16).

Martens, P. (2006). Sustainability: science or fiction? Sustainability: Science, Practice and Policy, 2(1), 36–41. doi: 10.1080/15487733.2006.11907976

Meacham, B., Bowen, R., Traw, J., & Moore, A. (2005). Performance-based building regulation: current situation and future needs. *Building Research & Information, 33*(2), 91–106. doi: 10.1080/0961321042000322780

Nicholls, R. J., Wong, P. P., Burkett, V., Codignotto, J., Hay, J., McLean, R., Ragoonaden, S., Woodroffe, C. D., Abuodha, P. A. O., & Arblaster, J. (2007) Coastal systems and low-lying areas. In M.L. Parry, O.F. Canzian, J.P. Palutikof et al. (eds) Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge, UK: Cambridge University Press, pp 315–356

NTA 8111_2011-NL (2011). Netherlands Standards for Floating Constructions. VROM Inspectorate

Park, C., & Allaby, M. (2007). *A dictionary of environment and conservation*. 3rd edn. Oxford, New York: Oxford University Press.

Picon, A. (2013). Architecture as performative art. In *Performalism* (pp. 15–19). London: Routledge.

Pörtner, H. O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., Begum, R. A., Betts, R., Kerr, R. B., & Biesbroek, R. (2022). Climate change 2022: impacts, adaptation and vulnerability. IPCC

Queensland Development Code (2007). Queensland Development Code MP 3.1. "Floating Buildings".

Schiaffonati, F., Mussinelli, E., & Gambaro, M. (2011). Tecnologia dell'architettura per la progettazione ambientale. Techne. *The Journal of Technology for Architecture and Environment, 1*, 48–53.

Seattle Municipal Code (2022). 23.60A.204 - Floating structures and standards for house barges.

Vittoria, E. (1976). *Tecnologia dell'Architettura II a.a. 1976-1977 - Guida dello Studente.* Napoli: Facoltà di Architettura, Università degli Studi di Napoli

von Uexküll, J. J. (1909). *Umwelt und innenwelt der tiere.* Berlin: Springer.

Wang, K-F. (2021). An Investigation into Environment-Floating Buildings in relation to Sustainability Indicators for Planning and Design Process. De Montfort University.

PART I

Scientific and cultural reference context

Cultural assumptions and research methodology

CHAPTER 1 Cultural assumptions of the research

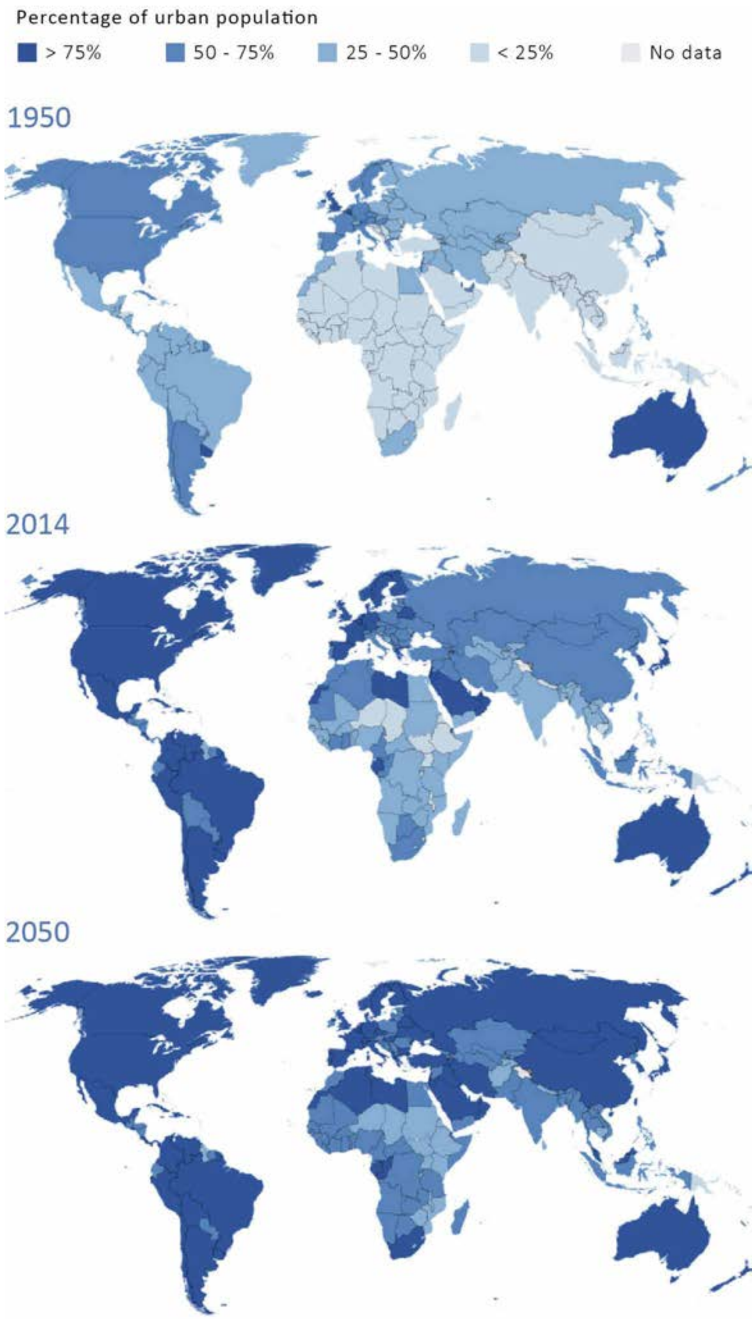
ABSTRACT

This chapter discusses the intertwined relationship between climate change (CC) and urbanization, emphasizing how the rapid expansion of cities has contributed significantly to CC, which in turn poses various challenges for urban areas, including more frequent and intense extreme weather events, sea level rise, heatwaves, and flooding. These impacts have far-reaching consequences for infrastructure, economy, public health, and livability. Addressing this dual crisis requires a comprehensive approach that tackles both CC mitigation and adaptation at the urban level. The chapter focuses on the projected impacts of climate change on low-lying delta and coastal areas, describing the exposure and vulnerability of waterfronts affected by climate-driven and anthropic risks. The importance of adaptation and resilience is argued by introducing relevant global policies, international programs, and national regulations. The four main waterfront adaptation strategies to sea level rise and land subsidence (protect, accommodate, retreat, and advance) are presented in depth, followed by the five main approaches to tackle flood risk at a building scale. The chapter continues by introducing floating architecture and floating urban development as long-term sustainable, resilient, and climate-proof adaptation measures, discussing their advantages, including zero-soil consumption, urban growth capacity expansion, emergency response, mobility, increased resilience to earthquakes, rapidity, flexibility and ease of construction, adaptability to water levels fluctuations, and separation between the economic value of real estate and location. Ultimately, the chapter highlights the lack of cohesive regulation and building standards for floating development, addressing the need for considering floating architecture as a building typology and for the development of appropriate regulatory frameworks to support its growth and development in a sustainable way. The final paragraph argues how floating architecture has been a recurring concept throughout history, providing a historical excursus from ancient vernacular floating settlements in Southeast Asia and South America to the present day, also mentioning the utopian floating city projects from the 1960s and 70s. In conclusion, floating architecture is presented as an opportunity for five different purposes: to support climate refugees and vulnerable communities, to address environmental issues, for energy production, for food production, and to pave the way for the dynamic city.

1.1 Urbanization and climate change: a global crisis

The combination of two of the most significant phenomena of the 21st century – climate change (CC) and rapid urbanization – requires humans to rethink their relationship with the environment (Wang, 2021). While Earth's climate has changed throughout history, current global warming is happening at a rate not seen in the past 10,000 years (Arias et al., 2021; Westerhold et al., 2020). There have been seven cycles of glacial advance and retreat in the last 650000 years. Yet, what distinguishes 20th century CC is that humans have had an unprecedented impact on Earth's climate system and caused change on a global scale, resulting in large-scale shifts in weather patterns. The current warming trend is different because it has been the result of human activities since the mid-19th century (Arias et al., 2021; Ramaswamy et al., 2006; Santer et al., 1996), and it is occurring at an unprecedented rate (Westerhold et al., 2020). It is undeniable that human activities have produced the atmospheric gases that have trapped more of the Sun's energy in the Earth system. This extra energy has warmed the atmosphere, ocean, and land, and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred (NASA, 2021).
The intense urbanization is one of the primary causes of the 20th century climate change (Bazrkar et al., 2015; Maheshwari et al., 2020). Currently, more than half of the world's population lives in urban areas, increasingly in highly dense cities. The 2018 United Nations Department of Economic and Social Affairs report showed that the world population living in urban areas will increase from 54% to 68% by 2050 (UNDESA, 2018). Projections show that urbanization combined with the overall growth of the global population could add another 2.5 billion people to urban areas by 2050 (Figure 1), with 90% of this increase taking place in Asia and Africa. By 2030, the world is projected to have 43 megacities with more than 10 million inhabitants each, most of them in developing regions (Figure 2). The shift in residence of the human population from rural to urban areas has transformed the way we live, work, travel, and build networks (Ritchie & Roser, 2018). Moreover,

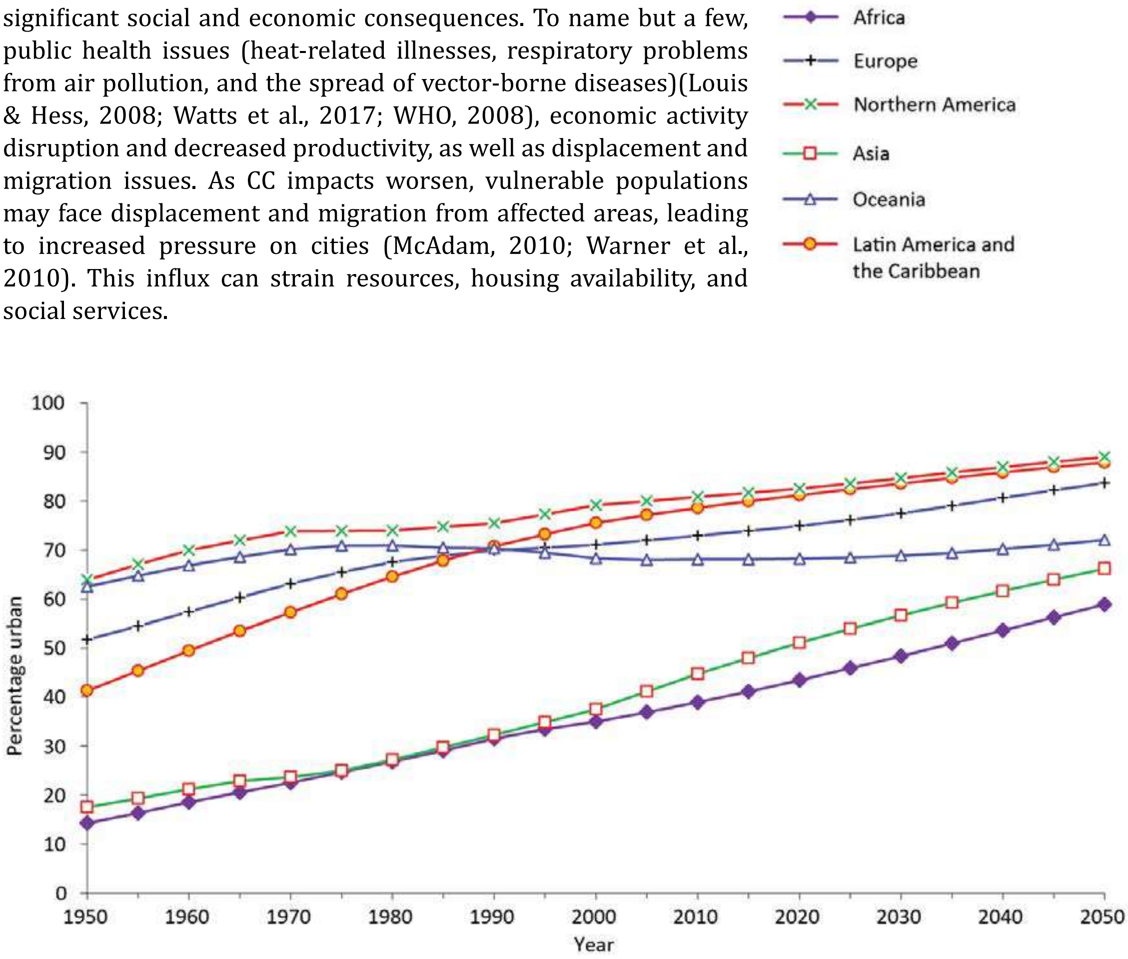
Figure 1. Urbanization prospect: 1950 - 2014 - 2050. Source: UN Urbanization Report 2014 (accesssible at: https://population.un.org/wup/publications/files/wup2014-report.pdf)



urbanization has profoundly affected the environment and climate contributing to intensifying CC impacts. More precisely, urban areas account for more than 70% of greenhouse gas (GHG) emissions from global final energy use (Roberts & Mukim, 2023), resulting in a gradual increase in global temperatures. Amongst the main urban sources of human-induced GHG emissions are fossil fuel burning, deforestation, industrial processes and activities, land use change which reduces the earth's capacity to absorb CO_2, industrial and household energy inefficiency, and improper waste management and disposal (Matthews, 2018). On the whole, urbanization exacerbates the environmental and climate emergency and contributes to the depletion of natural capital and soil consumption, putting urban ecosystems and the wellbeing of their inhabitants increasingly at risk (Umar, 2020).

In turn, CC has various impacts on cities as it affects their infrastructure, economy, public health, and overall livability. Cities are increasingly experiencing more frequent and intense extreme weather events like heatwaves, hurricanes, storms, and heavy rainfall. These events can lead to infrastructure damage, flooding, power outages, and disruptions in transportation systems. Low-lying areas as well as coastal and delta cities face the threat of sea level rise, which can result in coastal erosion, increased flooding, and saltwater intrusion into freshwater sources. CC change intensifies heatwaves and exacerbates the urban heat island effect, due to the abundance of concrete, asphalt, and limited vegetation. Changes in precipitation patterns can reduce water supplies, affecting drinking water, sanitation, and agriculture. Droughts can also increase the risk of wildfires in urban-adjacent areas. These are just some of the direct impacts on cities, but since urban areas represent high concentrations of financial, infrastructure, and human assets and activities that are vulnerable to CC impacts, CC can also lead to significant social and economic consequences. To name but a few, public health issues (heat-related illnesses, respiratory problems from air pollution, and the spread of vector-borne diseases)(Louis & Hess, 2008; Watts et al., 2017; WHO, 2008), economic activity disruption and decreased productivity, as well as displacement and migration issues. As CC impacts worsen, vulnerable populations may face displacement and migration from affected areas, leading to increased pressure on cities (McAdam, 2010; Warner et al., 2010). This influx can strain resources, housing availability, and social services.

Figure 2. Percentage of population residing in urban areas by geographic region, 1950-2050. Source: UNDESA 2018 (https://population.un.org/wup/publications/Files/WUP2018-Report.pdf)



1.2 Projected impacts of climate change on low-lying delta and coastal areas

Although climate change is a global problem, as noted in the previous chapter, it becomes more challenging in more vulnerable cities, notably low-lying delta, and waterfront areas. Waterfront areas are highly dynamic as they are affected by natural and human-induced processes originating from both the land and the sea. The IPCC's Climate Change 2014 report suggests two categories for classifying risks that insist on waterfronts: climate-driven risks and anthropic-driven risks. Climate-driven risks for waterfronts include (Field & Barros, 2014; Fox-Kemper, 2021; Watson et al., 2015):

- sea-level rise (SLR)
- storm surge, floods[1], and increase in frequency and intensity of extreme weather events
- shoreline erosion and coastal degradation (loss of beaches, dunes and protective coastal ecosystems and natural barriers, infrastructure damage) that can also result in reduced resilience to future climate impacts
- hydrogeological instability
- salinization of freshwater resources
- warming water temperatures
- ocean acidification
- heatwaves and urban heat island effect: as urban waterfronts are often highly urbanized and the significant presence of concrete and asphalt absorbs and retains the heat.

Indirect related risks include disruption to infrastructure and services (floods, storms, and other climate-related events can damage transportation networks, power grids, sewage systems, and water treatment facilities); ecological impacts such as habitat loss, reduced biodiversity, and ecological imbalance; existing community abandonment and retreat; cultural heritage damage.

Anthropogenic-driven risks include (Field & Barros, 2014):

- soil consumption and soil sealing
- pollution
- tourism pressure (increase in user fluxes; gentrification, etc.).

Climate-driven risks are the result of complex interactions between

1. Floods are weather-related hazards and their patterns are likely to be significantly affected by CC. Floods are already the most frequent and among the costliest and deadliest natural disasters worldwide (Samsung Electronics, 2015). This is also true in the Mediterranean area. The EM-DAT international disaster database (http://www.emdat.be/) lists for instance 200 billion euros in damages related to various disasters since 1900 in the countries surrounding the Mediterranean Sea, out of which 85 billion are related to river flooding.

phenomena acting on a range of spatial and temporal scales. Sea level change for instance arises from processes acting on the ocean, cryosphere, solid earth, atmosphere, and land. Relative sea level (RSL) change is the change in local mean sea surface height relative to the sea floor, as measured by instruments that are fixed to the Earth's surface (e.g., tide gauges)(Gregory et al., 2019). In contrast, global mean sea level (GMSL) change is the change in volume of the ocean divided by the ocean surface area. It is the sum of changes in ocean density and changes in the ocean mass as a result of changes in the cryosphere or land-water storage (Gregory et al., 2019).

Chapter 9 of the AR6 IPCC Report "Ocean, Cryosphere and Sea Level Change" (Fox-Kemper, 2021) provides a thorough assessment of the physical processes underlying global and regional changes in the ocean, cryosphere, and sea level. The ocean and cryosphere (defined as the frozen components of the Earth system such as sea ice, ice sheets, glaciers, permafrost, and snow) exchange heat and fresh water with the atmosphere and each other. In a warming climate, the combined effects of thermal expansion of seawater and melting of the terrestrial cryosphere result in global mean SLR.

The 4th Chapter of the IPCC special report on the ocean and cryosphere in a changing climate, entitled "Sea level rise and implications for low-lying islands, coasts, and communities" (Oppenheimer et al., 2019) provides technical data on the rise and acceleration of GMSL. The sum of glacier and ice sheet contributions is now the dominant source of GMSL rise. GMSL from tide gauges and altimetry observations increased from 1.4 mm yr^{-1} over the period 1901–1990 to 2.1 mm yr^{-1} over the period 1970–2015 to 3.2 mm yr^{-1} over the period 1993–2015 to 3.6 mm yr^{-1} over the period 2006 –2015 (high confidence) (Oppenheimer et al., 2019).

Founder and Director of the SeaCities Lab, Joerg Baumeister (Baumeister et al., 2020), provides an overview of the main cascading effects of SLR: mean sea level[2] is responsible for coastal hazards like submergence of land, enhanced flooding, erosion of land, salination of soils, groundwater, and surface waters, loss of change in marine and coastal ecosystems and impeded drainage; local extreme sea level[3] can lead to enhanced flooding, erosion of land, loss of change in marine and coastal ecosystems and impeded drainage.

The Cross-Chapter Paper 2 of the AR6 IPCC Report WGII (Pörtner et al., 2022) elaborates how coastal cities and settlements by the sea face a much greater risk than comparable inland settlements. This is because they concentrate a large proportion of the global population and economic activity, despite being exposed and vulnerable to a range of climate- and ocean-compounded risks driven by climate change. The concentration of people, economic activity, and infrastructure combines dynamically with coast-specific hazards to increase the vulnerability of coastal communities to climate risks.

SLR and other climate-related coastal hazards coupled with rapid urban development have significantly amplified risks in coastal urban areas (UNDESA, 2018). Non-climatic anthropogenic drivers, such as urbanization, recent and historical demographic

2. Mean sea level describes the sea level halfway between high and low water.

3. Local extreme sea level refers to the maximum level during a selected period like a year.

and settlement patterns, and high population concentration, as well as anthropogenic subsidence, have played an important role in increasing the exposure and vulnerability of low-lying coastal communities (Oppenheimer et al., 2019) and the pressure on dynamic and fragile coastal-marine ecosystems, often leading to major problems and social conflicts (Muñoz, 2014) due to the loss of important ecosystem services (Agardy et al., 2005; UNEP, 2012). In coastal deltas, for example, these drivers have altered freshwater and sediment availability. In low-lying coastal areas more broadly, human-induced changes can be rapid and modify coastlines over short periods of time, outpacing the effects of SLR (Oppenheimer et al., 2019).

To provide a few figures, the latest IPCC Report predicted that, at the current rate of development by 2100 the planet's temperature will rise of 5.8°C, and by 2050 more than 1.6 billion urban dwellers will be exposed to extreme high temperatures. As a consequence of global warming, as highlighted by UN COP26 on climate change (2021) and by the technical Report *The Future We Don't Want* (UCCRN, 2018), outcome of a collaboration between C40 Cities, Global Covenant of Mayors, Acclimatise, and the Urban Climate Change Research Network (UCCRN), by 2050 the total urban population at risk from SLR, with current emission rates, could number over 800 million people, living in more than 570 cities (Figure 3). More precisely, these coastal cities will be affected by at least 0.5 meters of SLR under a high greenhouse gas emissions scenario.

The figures are high because, as several forecast maps (UCCRN, 2018) on urban population distribution show (Figure 1), a significant portion of the global population is concentrated along the coast. More specifically, 10 % of the world's total population and 13 % of the urban population lives in low elevation coastal zones, defined as contiguous land areas along the coast that are within 10 meters of sea level (McGranahan et al., 2007).

When taking not only low-lying areas into consideration it is estimated that 40% of the world's population lives within 100 km of the coast[4] (Barbier, 2015; Burke et al., 2001; UCCRN, 2018). Furthermore, the majority of the world's megacities are located in

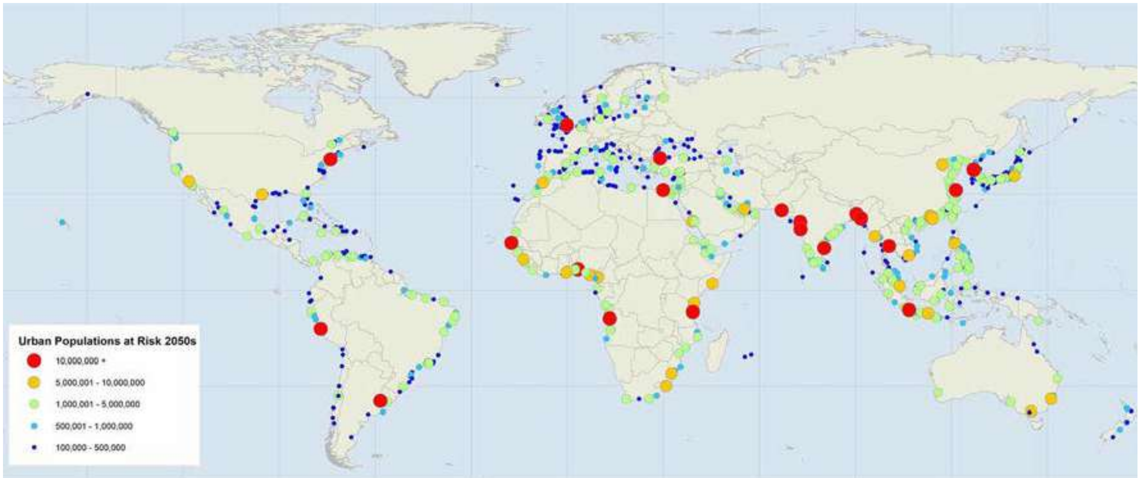


Figure 3. Cities at risk from sea level rise of 0.5 meters by 2050s [cities projected to receive at least 0.5 meters of sea level rise by the 2050s under RCP8.5.]. Source: UCCRN 2018Report.pdf

coastal areas (Brown et al., 2013; Rubiera Morollón & Garrido-Yserte, 2020), including major port cities in strategic geographical locations as well as well-known and vibrant coastal tourism destinations. This results in a large demographic concentration on a small part of the Earth's surface, accounting for between 4%, according to UNEP (Assessment, 2001), and 15% for Cohen and Small (Cohen & Small, 1998). Different international institutions and researchers have highlighted how coastal areas favor the concentration of population (Burke et al., 2001; Creel, 2003; Hinrichsen, 1998; Vallega, 1999). Among other reasons, is the fact that the marine environment facilitates certain activities such as fishing, industry, tourism, and transportation. Historically water proximity has always been a crucial component in the establishment and development of human settlements (EEA, 2018). Many cities were built up along coastlines or at the mouths of large rivers because they served as collection points for raw materials coming from the inner areas, they were supplied by an efficient water transportation network and were guaranteed access to clean water. Moreover, cities lacking permeable and underused soil but located near rivers, lakes, or coasts, could easily host water-based food production facilities (Battisti et al., 2023).

1.2.1. Sea Level Projections based on Shared Socio-economic Pathway Scenarios and Global Warming

In 2014, the 5th IPCC Assessment Report (AR5) adopted the Representative Concentration Pathway (RCP), a greenhouse gas concentration (not emissions) trajectory, concerning four pathways, for climate modeling and research. The pathways describe different potential climate futures depending on the volume of GHG emitted in the years to come. The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labeled after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m^2, respectively) (IPCC, 2014).
In 2021, the IPCC Sixth Assessment Report (AR6) on climate change, introduced Shared Socioeconomic Pathways (SSPs) as scenarios of projected socioeconomic global changes up to 2100. The SSPs are used to derive greenhouse gas emissions scenarios with different climate policies. More precisely, they provide narratives describing alternative socio-economic developments through qualitative description of logic relating elements of the narratives to each other. In terms of quantitative elements, they provide data accompanying the scenarios on national population, urbanization, and gross domestic product (GDP) per capita.
SSPs are a fundamental element of climate change research and a valuable tool for understanding the various impacts of different short term decisions on the long term future on our planet. The scientists examined five possible climate futures, exploring five scenarios with different levels of greenhouse gas emissions, ranging from *very low emissions* SSP1-1.9, *low* SSP1-2.6, and *intermediate* SSP2-4.5, to *high* SSP3-7.0 and *very high* SSP5-8.5. They include:

4. The Millennium Ecosystem Assessment (Agardy et al., 2005) defines "coastal city" as any city or agglomeration that is within 100 km of the coast, even though the 0–100 km zone is rather broad and does not always reflect the area close to the shore.

- SSP1: Sustainability (Taking the Green Road)
- SSP2: Middle of the Road
- SSP3: Regional Rivalry (A Rocky Road)
- SSP4: Inequality (A Road Divided)
- SSP5: Fossil-fueled Development (Taking the Highway).

Compared to previous IPCC reports, a major advance of AR6 is that sea level projections are not based anymore on Representative Concentration Pathways (RCPs) but on the Shared Socio-economic Pathways up to 2150 and on global warming levels up to 2100. Since there is no single model that can directly compute all the contributions to sea level change the contributions to sea level are computed separately and then combined.

By 2050, GMSL is likely to rise by 0.18 mm yr^{-1} according to the best-case scenario (SSP1-1.9), and by up to 0.23 mm yr^{-1} according to the worst-case scenario (SSP5-8.5). Extending projections even further into the future, by 2150, GMSL is likely to rise by 0.57 mm yr^{-1} according to the best-case scenario (SSP1-1.9) and by up to 1.32 mm yr^{-1} according to worst-case scenario (SSP5-8.5).

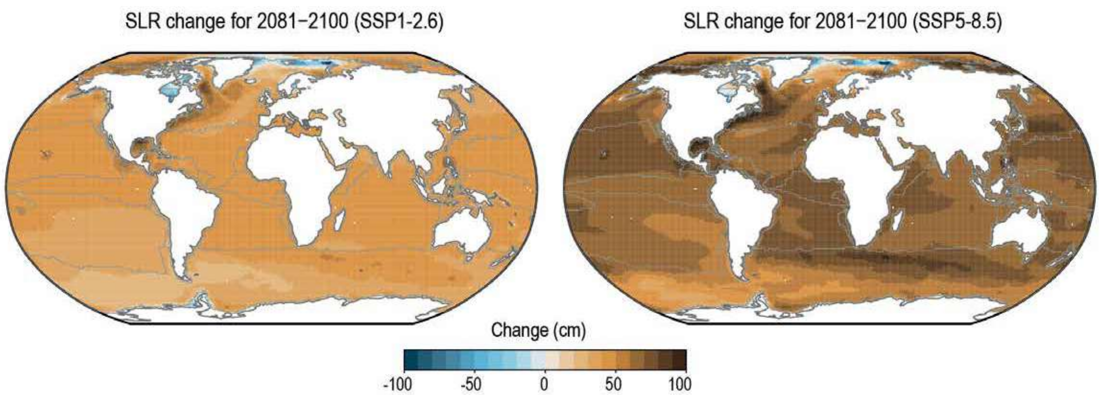
Global warming levels represent a new dimension in the AR6. Based on an analysis of GMSL projections published for 1.5°C and 2.0°C scenarios, the SR1.5 concluded that GMSL in 2100 could be 0.04-0.16 m higher in a 2°C warmer world than in a 1.5°C warmer world based on 17-84% confidence interval projections (0.00-0.24 m based on 5-95% confidence interval projections) with a central value of around 0.1 m.

The SR1.5 did not attempt to define warming-level scenarios or to investigate further warming levels. Since SR1.5, no new integrated GMSL estimates for 1.5°C or 2.0°C scenarios have been released.

On the whole, as Baumeister underlines (Baumeister & Linaraki, 2022), predictions of up to 1 m or more SLR until 2100 (Figure 4) should be taken very seriously, as estimations are still developing upwards. If the world fails to commit to the Paris Agreement's goal of reducing carbon emissions and limiting global average temperature rise to 1.5°C, many of the world's cities will face an extraordinary threat from rising seas and coastal flooding by mid-century.

Figure 4. Sea level rise change for 2081-2100 under scenario SSP1-2.6 ans SSP5-8.5. Source: IPCC Report AR6 (2022)

1.2.2. Dimensions of exposure and vulnerability to sea level rise of waterfront cities and settlements



Following the AR6 definition system, risk[5] provides a framework for understanding the increasingly severe, interconnected, and often irreversible impacts of CC on ecosystems, biodiversity, and human systems, differing impacts across regions, sectors, and communities. In the context of CC, risk can arise from the dynamic interactions among climate-related hazards[6] and the exposure[7] and vulnerability[8] of affected human and ecological systems. Compared to the previous IPCC assessments, approaches to analyzing and assessing vulnerability have evolved: vulnerability is widely understood to differ within communities and across societies, regions, and countries, also changing through time. The effects of climate-driven risks on waterfronts vary depending on urban topography and development patterns, economic make-up, and social structure. Local governments in the Mediterranean region for instance, where roughly 40% of the coastline is built up and affected by increasing encroachment issues, are faced with the increasingly complex task of balancing urban development and managing coastal risks (Moatti & Thiébault, 2018). Almost one-third of the population of the countries surrounding the Mediterranean Sea resides in the coastal zone and more than 70% of it in coastal cities. Based on a regional climate change index (RCCI) calculated from temperature and precipitation projections, the Mediterranean region was revealed to be one of the most prominent hot spots over the globe.
Recent studies assess exposure by considering not only projected SLR, but also expected changes in population size (Hauer et al., 2016; Jongman et al., 2012). It involves different socioeconomic scenarios together with changing growth rates for coastal areas and the hinterland (Neumann et al., 2015). Migration-based changes in population distribution (Hauer, 2017; Merkens et al., 2016) are also considered, as well as simulated future land use (specifically urban growth) to investigate future exposure to SLR (Song et al., 2017). Other studies assess future exposure trends by accounting for the role of varying patterns of topography and development projections leading to different rates of anticipated future exposure (Kulp & Strauss, 2017), which influence how effectively coastal communities can adapt. Recent studies aim to account for the sociodemographic characteristics of potentially exposed future populations (Fumeaux & Rey, 2012; Shepherd & Binita, 2015) and anticipate future risk by projecting the evolution of the exposure of vulnerable populations and groups (Hardy & Hauer, 2018). Increasingly, multi-hazard risk assessments are undertaken at the coast to understand the inter-relationships between hazards (Gill & Malamud, 2014), and by focusing on hazard interactions where one hazard triggers another or increases the probability of others occurring. Liu et al. (2016) provide a systematic hazard interaction classification based on the geophysical environment that allows for the consideration of all possible interactions (independent, mutex, parallel, and series) between different hazards, and for the calculation of the probability and magnitude of multiple interacting natural hazards occurring together.

5. Risk is defined as the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems.

6. Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. Physical climate conditions that may be associated with hazards are assessed in Working Group I as climatic impact drivers.

7. Exposure is defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.

8. Vulnerability in this report is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

SLR and related coastal hazards, such as flooding or salinization vary strongly across ecosystem types, increasing their vulnerability and reducing their ability to support livelihoods and provide ecosystem services like coastal protection. For instance, coastal habitat loss due to human growth and development, as well as human structures that restrict tides and thus interrupt mass flow processes (water, nutrients, and sediments), impact tidal ecosystems depending on the type of restriction, its severity, and the geomorphology of the system (Burdick & Roman, 2012). Coastal dunes, for example, are successfully preserved by protected areas in some locations, such as Italy, but climate change might result in a severe reduction in their protection (Prisco et al., 2013). Furthermore, seagrass and other benthic habitats, for example, are disappearing at unprecedented rates across their ranges (Balestri et al., 2017; Samper-Villarreal et al., 2016; UNEP-WCMC, 2021; Unsworth et al., 2015), due to degrading water quality (i.e., increased nutrient and sediment or dissolved organic carbon loads) from upland-based activities, which include deforestation, agriculture, aquaculture, fishing, and urbanization, port development, channel deepening, dredging and anchoring of boats (Abrams et al., 2016; Benham et al., 2016; Deudero et al., 2015; Ray et al., 2014; Saunders et al., 2013; Thorhaug et al., 2017). The exact magnitude of area loss is still uncertain, especially at smaller scales (Telesca et al., 2015; Yaakub et al., 2014) and the implications of habitat shifts for ecosystem attributes and processes, and the services they deliver, remain poorly understood (Ray et al., 2014; Tuya et al., 2014). Yet, recent global assessments of coastal erosion indicate that land losses currently dominate over land gains and that human interventions are a major driver of shoreline changes (Cazenave & Cozannet, 2014; Luijendijk et al., 2018; Mentaschi et al., 2018). Limiting the scale to the Mediterranean, according to ENEA[9] projections, by 2100, thousands of square kilometers of Italian coastal areas risk being submerged by the sea, in the absence of mitigation and adaptation interventions. By the end of the century, the SLR along the Italian coasts is estimated at between 0.94 and 1.035 meters (conservative model) and between 1.31 meters and 1.45 meters (on a less conservative basis). To these values, we must add the so-called storm surge, i.e. the coexistence of low pressure, waves, and wind, which varies from area to area, which in particular conditions causes an increase in sea level concerning the coast of about 1 meter.

Ultimately, it is important to note that SLR is not only a threat but also a threat multiplier. SLR threatens lives, and jeopardizes access to water, food, and health care, while saltwater intrusion can affect entire economies in key industries like agriculture, fisheries, and tourism (UN, 2023). Mass climate-driven migration from low-lying and coastal areas to inland locations is progressively increasing. Yet, climate migrants are still not recognized as refugees by international conventions and do not enjoy any legal protection.

9. Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (Italian National Agency for new technologies, energy, and sustainable economic development).

1.3 Adapting to climate change: climate-proof and climate-adaptive design

Coastal erosion, flooding, acidification, and water eutrophication are already widespread phenomena and underline the urgency of both safeguarding ecological systems and designing and building resilient habitats. Architects, engineers, scholars and policy makers operating in the field are called to rethink the way we live and provide timely and adequate responses to the phenomenon, not only investigating approaches and methodologies that can improve the urban fabric but also developing flexible strategies capable of planning change and exploring new and unusual frontiers of living. Besides mitigation strategies, adaptation strategies are crucial in dealing with the effects of climate change. Long-term interactions between adaptation and mitigation[10] can lead to synergies able to contribute to advancing sustainable development in the long term. Strengthening climate change mitigation action entails more rapid transitions and higher up-front investments but brings several benefits from avoiding harshening of climate change impacts to reducing adaptation costs.

As the debate concerning climate change has shifted from an emphasis mainly on mitigation to a discussion of combined mitigation and adaptation strategies (Magni, 2019; Meyer, 2010; Penning-Rowsell, 2020; IPCC, 2013), the role of urban planning and especially of environmental design has grown in significance and its effect on possible future urban landscapes increases proportionately (Meyer, 2010). Climate risks can be reduced by accelerating trans-sectoral and multi-level mitigation interventions in parallel with incremental adaptation actions to foster the transition of current territorial and urban structures towards progressive climate resilient conditions (Losasso et al., 2020).

Environmental design entails addressing surrounding environmental parameters when envisioning plans, programs, policies, buildings, or products to design spaces that will enhance the natural, social, cultural, and physical environment. It is amongst the most effective tools in dealing with climate change because it addresses both mitigation and adaptation: mitigation on a global

10. Mitigation refers to any human intervention to reduce emissions or enhance the sinks of greenhouse gases. slowing the pace of climate change. Adaptation, in human systems, is the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities (IPCC, 2021).

scale, and adaptation on a local one. The transition from conventional models towards environment-oriented resilience scenarios requires a strong interscalar relationship between interventions at the territorial and urban scale and specific interventions according to processually integrated downscaling and upscaling actions (Losasso, 2017). Environmental design originated from the awareness that living is an experiential, immersive, and dynamic reality (Arnheim, 1977) that is not limited to a contemplative dimension. The scholars who defined and promoted environmental design as a disciplinary field of study (Alexander, 1964; Asimow, 1962; Blachère, 1966; Chermayeff & Alexander, 1965; Chermayeff & Tzonis, 1971; Fitch, 1948; Gregory, 1966; Jones & Thornley, 1963) envisioned design as a logical correspondence between two entities: the context, that defines the 'problem' and the 'form' that solves it (Alexander, 1964). In this way, they highlighted the need to support and guide the design choices with a solid preliminary and wide-ranging phase, based on cognitive contributions referring to a plurality of disciplinary sectors. These sectors concerned both social sciences and natural sciences: anthropometry, ergonomics, proxemics, physiology, sociology, psychology, economy, technical physics, urban geography, materials science, urban planning and territorial, and architecture. The resulting range of needs and human activities to be considered in the project (Farbstein, 1974) soon proved too complex to be understood and faced intuitively: "The intuitive resolution of contemporary design problems - writes Alexander in 1964 (Alexander, 1964) - simply lies beyond a single individual's integrative grasp". The ideal aspiration to control and manage this complexity required methodologies and tools to support the designer's work to measure factors of interdependence and solve a number of increasing variables (Alexander, 1964; Fitch, 1972). This process gradually led to the environmental design approach. In its original conception, environmental design aimed to guarantee human wellbeing in the living environments. Yet with the emergence of the ecological challenge, this overall vision, comprehensive and rich in meanings and consequences (for example the development of human-centered approaches to design, and performance-based and participatory design methodologies), has suffered a progressive flattening on issues regarding energy savings, environmental sustainability and governance (Lauria, 2017).

Adaptation[11] in ecological systems plays a key role in reducing exposure and vulnerability to climate change as it includes autonomous adjustments through ecological and evolutionary processes. In human systems, adaptation can be anticipatory or reactive. SLR poses a unique and severe adaptation challenge since it requires dealing with both slow-onset changes and increases in the frequency and magnitude of extreme sea-level events (IPCC, 2023). In the context of environmental design, adaptation can be undertaken in the short- to medium-term by targeting local drivers of exposure and vulnerability, notwithstanding uncertainty about local SLR impacts in coming decades and beyond, but at the same

11. Adaptation is defined, in human systems, as the process of adjustment to actual or expected climate and its effects to moderate harm or take advantage of beneficial opportunities. In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this.

time, it is crucial to embrace a long-term vision. With increasing warming, adaptation measures are bound to become more constrained and less effective as human and natural systems reach adaptation limits (IPCC, 2023).

The Working Group II - *Climate Change 2022: Impacts, Adaptation and Vulnerability*[12] - contribution to the Sixth Assessment Report assesses the impacts of climate change, looking at ecosystems, biodiversity, and human communities at global and regional levels and plays special attention to adaptation solutions. In particular, the WGII AR6 report emphasizes the role of cities as places of increasing vulnerability (population growth) but also opportunities for climate adaptation/mitigation action in Chapter 6 (Cities, settlements, and key infrastructure) and Cross-Chapter Paper 2 (Cities and Settlements by the Sea). Chapter 6.3 focuses on Adaptation Pathways, composed of sequences of adaptation actions connected through collaborative learning with the possibility of enabling transformations in urban and infrastructure systems (Werners et al., 2021). Adaptation Pathways include adaptation through social infrastructure (e.g. land use planning, social protection, emergency, and risk management, climate resilient health systems, education and communication, Cultural Heritage/Institutions) through nature-based solutions (e.g. temperature regulation, air quality regulation, stormwater regulation, coastal flood protection, water provisioning and management, food production and security) through grey/physical Infrastructure (e.g. urban morphology and built form, building design and construction, information and communication technology, energy, transport, water and sanitation, flood management and coastal management). It is important to underline how for the first time, floating structures are listed amongst the prevention solutions for flood management. In Chapter 13.2.2. and 13.6.2. "Solution Space and Adaptation Options", the report recognizes that accommodation through elevated or floating houses has been implemented and proposed locally within cities as part of a hybrid strategy together with protection and as an innovative approach to urban development (Penning-Rowsell, 2020; Storbjörk & Hjerpe, 2021a).

Broadening the perspective from risk management to the creation of urban opportunities, entails conceiving cities as complex structures consisting of buildings and spaces, economy, community, infrastructure, and natural environment. More precisely, to shift the approach from "defending from water" (water conceived as a threat) to "living with water" (water as an element, or even a resource), the entire urban ecosystem must be considered. In the last decade there has been an increasing focus on approaches to water management that don't focus only on optimizing the current urban water system, but instead seek to address multiple and integrated challenges by establishing a completely new model of urban development (Dal Bo Zanon et al., 2020). To name but a few, *Cities of the Future* (Novotny & Brown, 2007), *Water Sensitive Urban Design* (Wong & Brown, 2009), but also *Floating Urban Development* (de Graaf, 2012; Z.-Z. Liu et al., 2014; Moon, 2012) and *Floating Productive Developments*

12. IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press

(Dal Bo Zanon et al., 2017), that consider the use of floating foundations able to autonomously adapt to changes in water level. The theme of a water-based habitat could lay the foundation for what is known as the *Blue Revolution*: seizing the opportunities that water offers to solve pressing global problems and positively affect the planet's health. The Blue Revolution concept was originally coined by Takahashi (Takahashi, 1996) to develop a proactive plan for the development of ocean resources. Blue21 has expanded this approach by proposing floating cities with a positive impact on the planet, including local food and energy production and ecosystem development (de Graaf, 2012).

Rutger De Graaf (de Graaf, 2020) from Blue 21 defines climate resilience as the sum of five capacities or pillars: threshold capacity, coping capacity, recovery capacity, adaptive capacity, and transformative capacity. The threshold capacity is a society's ability to prepare and build up a threshold against environmental variation to prevent damage. The ability of a society to build, operate, and maintain threshold capacity is determined by its environmental resources as well as its social, institutional, technological, and economic capabilities. Investing in nature-based solutions improves our resilience by minimizing heat islands and improving the health and quality of our social, environmental, and economic systems and places. Coping capacity refers to the capability of a district, city, or country to reduce damage if a disturbance exceeds the damage threshold and thus to deal with extreme weather conditions and reduce their damage. For flood management for instance, a society's coping capacity is determined by the presence of effective emergency and evacuation plans, the availability of damage-reducing measures, nature-based solutions, a communication plan to raise risk awareness among residents, and a clear organizational structure and responsibility for disaster management. Recovery capacity is a society's capability to recover to a state that is equal or even better – *build back better* – than before the extreme event or emergency. The objective of increasing recovery capacity is to respond quickly and effectively after a disaster. Adaptive capacity refers to a society's capability to anticipate uncertain future developments including catastrophic, non-frequently occurring disturbances like extreme floods or severe droughts. The time orientation of adaptive capacity lies in the future: without adaptive capacity, a society would strive to recover from the impacts of CC until it is no longer possible. Urban structure should be flexible and reversible to allow future changes to be made. Adaptive capacity increases future generations' ability to implement alternative options. Although the exact extent and nature of changes are unknown, solutions will have to be developed for long-term horizons, and financial and spatial reservations must be made to allow for adaptation. Transformative capacity is the capability to create an enabling environment, strengthen stakeholder capabilities, and identify and implement catalyzing interventions to transition proactively to a climate-resilient society. In adaptive capacity, the time orientation lies in the future, but the main difference is that adaptation is more associated with small

incremental changes in the present system, whereas transformation is involved with changing the current system into a fundamentally different one.
Finally, to effectively incorporate resilience into urban design and planning of coastal waterfronts it is necessary to understand under what conditions the system is no longer able to recover and needs to adapt. In other words, it is necessary to understand what the boundary limits of resilience are and, additionally, to what future states the system preferably should develop (Monardo et al., 2024).

1.3.1. Management and regulatory policies and programs

Risks like SLR, coastal flooding, and storm surge can be seen as an important opportunity for re-imagining the future of cities and their resilience. Unsettlement, resettlement, retreat, temporary and permanent relocation, and climate migration are concepts that are rapidly becoming an inevitable urban policy and planning concern. Moreover, oceans and water bodies provide immense ecological services and benefits to all cities, no matter how close they are to the water: they are a major carbon sink, soaking up an estimated 2 billion metric tons of carbon dioxide per year; they provide a significant amount of food; they drive climate and weather and regulate temperature; they hold 97% of Earth's water and embrace 97% of the biosphere (Beatley, 2014). Oceans are the source of natural resources and therefore witness several multifaceted pressures linked to urban consumption and production activities. Professor of Sustainable Communities Timothy Beatley, in his book *Blue Urbanism* (Beatley, 2014), defines the incursion of modern urban life into the marine realm as a form of "ocean sprawl". Extending this definition to all water bodies, including seas, lakes, rivers, streams, and canals, we could name it "water sprawl". On a more optimistic note, oceans and other water bodies also represent our best chance for a more sustainable global future, as they hold great potential as a source of renewable energy that could reduce our current reliance on fossil fuels. Therefore, understanding the causes of coastal urbanization and using them in relevant planning endeavors, ending up with policy measures and institutional regulatory systems is a critical problem in this regard. Several authors underline the need for a multi-dimensional and spatio-temporal approach for assessing coastal urban sprawl and monitoring its effects on the natural and anthropic environment (Lagarias et al., 2022; Lagarias & Stratigea, 2023; Mansour et al., 2023; Onainor, 2019; Theodora & Spanogianni, 2022). An important step will be to begin to draw urban maps that extend beyond the terrestrial borders to the ocean and marine environments. A premise to this is the advancement of the notion that events and activities that occur on land will have impacts on the sea and other water bodies, as land and ocean are intimately and intricately connected. Waterfront management and development is an extremely challenging field for spatial planning and at the same time a key driver for urban development (Theodora & Spanogianni, 2022). Cities are gradually taking measures to

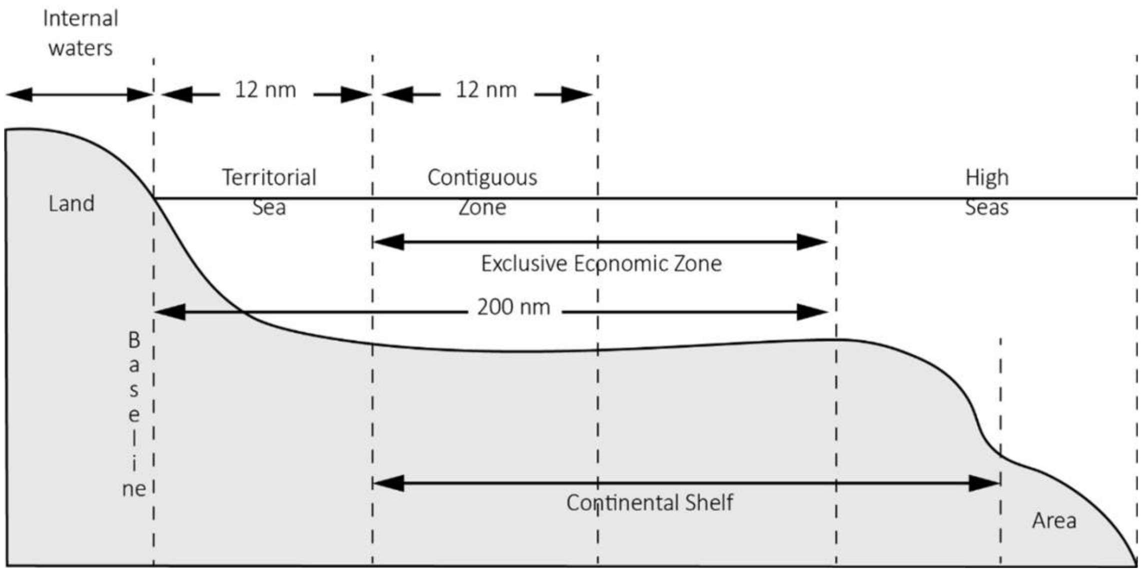
adapt and mitigate SLR impacts by implementing climate action plans, investing in green infrastructure, improving urban planning, promoting renewable energy, and enhancing resilience strategies. Many waterfront cities are exploring and re-designing the interface of water and land following the trend of evolving into water-sensitive cities (Monardo et al., 2024) fostering a new waterfront urban development that attempts to bridge connections between water and land in line with the *sponge city* approach, reconnecting people – physically and visually – with the water. Some cities have extended the concept of greenbelts to include *bluebelts* and are beginning to take into consideration water in their comprehensive plans and visions for the future to make the urban environment more livable while also fostering a healthier nearshore water environment. In the most virtuous International and European contexts, water-based development is gaining increasing attention and becoming part of city programs for sustainable development and climate adaptation (Ernst et al., 2016).
In addition, preserving healthy oceans results in huge economic benefits; large social, environmental, and economic costs are associated with diminishing ocean health, and future urban decisions should reflect on and be driven by an awareness of these costs and benefits.

1.3.1.1. Management and regulatory policies and programs

The possible significant territorial loss resulting from SLR and the parallel urban expansion on water may lead to a range of concerns relating to uncontrolled and unregulated building activity, access to resources and maritime jurisdiction, statehood, national identity, refugee status, and state responsibility (UN, 2023).
Collaborative efforts at the local, regional, and international levels are crucial to address the challenges posed by CC in urban areas and to control the sustainable and resilient use of water. The EU laid the groundwork for the development of a Community policy framework on adaptation with the Green Paper *Adapting to Climate Change* first and later with the White Paper *Adapting to Climate Change: Towards a European Framework for Action* (COM, 2009). These documents have been crucial for identifying the impacts and related vulnerabilities to CC and for outlining a series of measures to increase resilience. The establishment of the Strategy on Adaptation to Climate Change in 2013 supplemented the European adaptation framework providing EU policymakers with comprehensive guidelines on the process of planning, implementing, and reviewing adaptation policies to tackle CC. In recent years, adaptation has become a priority on political agendas, fostering the rapid spread of adaptation strategies and plans. According to the European Commission guidelines, the majority of EU Member States have defined and implemented comprehensive National Adaptation Strategies (NAS), which are broad policy documents that outline the direction of action that a country intends to take in order to adapt to CC (Isoard et al., 2013) and National Action Plans (NAP), more

detailed documents providing a roadmap for the implementation of specific planned adaptation actions.
However, on the legislative level, there is still no reference framework for the regulation of building activity specifically in the marine environment. The United Nations Convention on the Law of the Sea (UNCLOS), which entered into force in 1994, established an international regime of laws and regulations governing the oceans and seas and the use of their resources. The Convention establishes the principle according to which problems of oceanic space are closely related and must be holistically addressed. It also defines guidelines that regulate negotiations, the environment, and the management of the natural resources of the seas and oceans. The sea is divided into different zones between complete freedom and complete sovereignty of the coastal state. As can be seen from the image below (Figure 5), up to 12 nautical miles are the territorial waters, an area of water where a sovereign state has jurisdiction, including internal waters, territorial sea, and part of the Exclusive Economic Zone (EEZ).
Beyond 12 nautical miles are the international waters that include the Contiguous Zone (ZC), the EEZ, the extended Continental Shelf, the High Seas, and the Area. Within the ZC, the coastal State exercises its authority to prevent or repress infringements of its national legislation. States cannot exercise their jurisdiction in waters beyond the exclusive economic zone, which are known as the High Seas. The principle of freedom of the sea applies here, provided that other states' interests are respected. The seabed beyond the EEZ, known as the Area, and the mineral resources found there are considered Humanity's Common Heritage.
Together SOLAS, STWC, MLC, and MARPOL are referred to as the four pillars of the International Maritime Regulatory Regime. SOLAS is the International Convention for the Safety of Life at Sea and states minimal requirements for the construction, equipment, and operation of merchant ships. It places primary focus on safety,

Figure 5. UNCLOS Maritime Areas subdivision. Source: Elaboration by Livia Cacagni



in particular, the structural integrity of the ship structure and the equipment on board to be fit for purpose concerning the sailing environment. SOLAS has been ratified by 164 member states in the IMO (International Maritime Organization). STCW is the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers. MLC is the Maritime Labour Convention. MARPOL is the International Convention for the Prevention of Pollution from Ships. MARPOL and MLC conventions refer to ships and offshore platforms and address the quality of the accommodation, recreational facilities, food and catering, health protection, and hygienic conditions. The competent authority, being the flag state under which the vessel operates, should ensure that quality meets proper demands as defined in relevant national legislation. All the described regulatory regimes are mainly stringent rules, which curb development and limit the quality of life offshore to the minimum.

At a European level, Directive 2014/89/EU establishes a common strategy and framework for maritime spatial planning for EU countries. The rapid and high increase in the demand for maritime space for various purposes, such as installations for the production of energy from renewable sources, the exploration and exploitation of oil and natural gas, maritime transport and fishing activities, the conservation of ecosystems and biodiversity, the extraction of raw materials, tourism, aquaculture facilities, and underwater cultural heritage, as well as the multiple pressures on coastal resources have led to the need to develop an integrated planning and management strategy. Following Directive 2014/89/EU, the approval of the Maritime Spatial Management Plan has become mandatory for all European states, aimed at identifying the spatial distribution of the pertinent activities and the different uses of marine waters, including plants and infrastructures for the exploration, exploitation, and extraction of oil, gas, and other energy resources, and the production of energy from renewable sources. Maritime spatial planning aims to allow public authorities to organize human activities in marine areas to achieve different ecological, economic, and social objectives.

Such a strategy for ocean management and maritime governance has been developed under the Integrated Maritime Policy (IMP) for the European Union, of which the environmental pillar is the Directive 2008/56/EC *Strategy for the marine environment*. In the field of marine environmental policy, it sets out a common EU approach and objectives for the prevention, protection, and conservation of the marine environment given the pressures and impacts of damaging human activities, while allowing for its sustainable use using an ecosystem-based approach[13]. It has been applied since 15 July 2008 and it was supposed to become law in the Member States by 15 July 2010. The objective of the IMP is to foster the sustainable development of the seas and oceans and to develop coordinated, coherent, and transparent decision-making regarding Union sectoral policies affecting the oceans, seas, islands, coastal and outermost regions, and maritime sectors, through

13. According to the Directive 2008/56/EC, an ecosystem-based approach is necessary for achieving or maintaining good environmental status in the Community's marine environment, to continue its protection and preservation, and to prevent subsequent deterioration. Point 3 of the Directive states "The marine environment is a precious heritage that must be protected, preserved and, where practicable, restored with the aim of maintaining biodiversity and providing diverse and dynamic oceans and seas which are clean, healthy and productive. In that respect, this Directive should, inter alia, pro-mote the integration of environmental considerations into all relevant policy areas and deliver the environmental pillar of the future maritime policy for the European Union."

sea basin strategies or macro-regional strategies while ensuring the achievement of a good environmental status as required by Directive 2008/56/EC. The IMP identifies maritime spatial planning as a cross-sectoral policy tool that enables public authorities and stakeholders to apply an integrated, coordinated, and cross-border approach[14]. The application of an ecosystem approach is expected to help promote the sustainable development and growth of maritime and coastal economies and the sustainable use of marine and coastal resources, known as the EU blue economy. Maritime spatial planning aims to allow public authorities to organize human activities in marine areas to achieve different ecological, economic, and social objectives. To foster the sustainable coexistence of uses and, where appropriate, an appropriate allocation of maritime space between the various relevant uses, it is appropriate to put in place a framework that includes at least the development and implementation by the Member States of maritime spatial planning resulting in the definition of plans. Therefore, EU countries were expected to draw up maritime spatial plans by 2021, mapping human activities in their marine waters and identifying their most effective future spatial development.

To promote the sustainable use of maritime space, maritime planning should consider land-sea interactions, allowing for an integrated and strategic vision. Maritime spatial planning can be very useful for determining guidelines regarding the sustainable and integrated management of human activities at sea, the conservation of the living environment, and the fragility of coastal ecosystems. In this perspective, possible activities, uses, and interests may include: aquaculture areas, fishing areas, installations, and infrastructures for the exploration, exploitation, and extraction of oil, gas, and other energy, mineral and aggregate resources and renewable energy production, shipping routes, and traffic flows, military training areas, nature and wildlife conservation sites and protected areas, raw material extraction areas, scientific research, submarine cable and pipeline routing, tourism, underwater cultural heritage.

It is crucial to highlight how the provisions of the Framework Directive specifically refer and regulate maritime areas adjacent to coastal states and do not extend nor interfere with the competence exercised by Member States over territorial land. The Framework Directive is thus without prejudice to the competence of Member States concerning urban and rural planning, including any land-spatial planning system used to plan how the land and coastal area are used. Therefore, if Member States apply land spatial planning to coastal waters or parts of them, this Directive should not apply to those waters.

Documents related to this Directive include the *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions "Innovation in the blue economy: realizing the growth and employment potential of our seas and our oceans"* [COM(2014)0254 final/2 of 8 May 2014] and the Communication from the *Commission to the European Parliament, the Council, the European Economic and*

14. A cross-border approach is essential to ensure cohesion of action across boundaries within the Community as a whole and in relation to commitments at global level.

15. Available at https://www.bmuv.de/en/topics/water-management/overview-water-management/policy-goals-and-instruments/eu-water-policy (last accessed: 02/01/2024)

Social Committee and the Committee of the Regions "Blue growth: opportunities for sustainable growth of the marine and maritime sectors" [COM(2012) 494 final of 13 September 2012].

There are also several other policies[15] of EU environmental law on water protection and water policy as described below.

- Directive 2000/60/CE - *Water Framework Directive* (WDF) (COM, 2012). It aims at ensuring good qualitative and quantitative health, preventing and reducing water pollution, promoting its sustainable use, protecting and improving the aquatic environment, mitigating the effects of floods and droughts and ensuring that there is enough water to support wildlife at the same time as human needs. Since 2000, the WFD has been the main law for water protection in Europe. It applies to inland, transitional, and coastal surface waters as well as groundwaters. It ensures an integrated approach to water management, respecting the integrity of whole ecosystems, including regulating individual pollutants, and setting corresponding regulatory standards. It is based on a river basin district approach to make sure that neighboring countries cooperate to manage the rivers and other bodies of water they share. It requires member States to use their River Basin Management Plans (RBMPs) and Programmes of Measures (PoMs) to protect and, where necessary, restore water bodies to reach good status and to prevent deterioration. Good status means both good chemical and good ecological status. Many European river-basins are international, crossing administrative and territorial borders. Therefore, a common understanding and approach is crucial to the successful and effective implementation of the Directive. River Basin Management Plans are the key tools for implementing the WFD.
- *Floods Directive* 2007/60/EC on Flood-risk management. It established a framework for the assessment and management of flood risk, aiming at the reduction of the adverse consequences of floods for human health, environment, cultural heritage, and economic activities. It requires the Member States to assess if all water courses and coastlines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas, and to take adequate and coordinated measures to reduce this flood risk. The Floods Directive prescribes a three-step procedure: preliminary Flood Risk Assessment (impacts on human health and life, the environment, cultural heritage, and economic activity), Risk Assessment (to identify the areas at significant risk which will then be modeled to produce flood hazard and risk maps), and Flood Risk Management Plans meant to indicate to policymakers, developers, and the public the nature of the risk and the measures proposed to manage these risks. The Directive required each member state to prepare Flood Risk Management Plans (FRMPs), which while contemplating every aspect of the flood risk focused on prevention, protection, and preparedness, including flood forecast and early warning systems.

- Directive 2008/105/EC setting environmental quality standards in the field of water policy. It sets out environmental quality standards (EQSs) for the presence in surface water of certain substances or groups of substances identified as priority pollutants because of the significant risk they pose to or via the aquatic environment. These standards are in line with the strategy and objectives of the EU *Water framework directive* (Directive 2000/60/EC).
- *Habitat Directive* (Council Directive 92/43/EEC) requires all Member States to establish a strict protection regime for species listed in Annex IV, both inside and outside Natura 2000 sites.

Another policy to promote sustainable management of coastal zones is the Recommendation 2002/413/EC concerning the implementation in Europe of the Integrated coastal zone management (ICZM) tool, a dynamic, multidisciplinary, and iterative process that covers the full cycle of information collection, planning (in its broadest sense), decision making, management and monitoring of implementation. ICZM uses the informed participation and cooperation of all stakeholders to assess the societal goals in coastal area and to act toward meeting these objectives. ICZM seeks, over the long term, to balance environmental, economic, social, cultural, and recreational objectives, all within the limits set by natural dynamics. 'Integrated' in ICZM refers to the integration of objectives and to the integration of the many instruments needed to meet these objectives. It means integration of all relevant policy areas, sectors, and levels of administration. It means integration of the terrestrial and marine components of the target territory, in both time and space.

1.3.1.2. National Policies and Regulations

Inclusive, integrated, and long-term planning at local, municipal, sub-national and national scales, together with effective regulation and monitoring systems and financial and technological resources and capabilities foster urban system transition. However, the legislation of most countries does not provide for land use regulation that includes the water surface, therefore there seems to be no real urban planning and building regulatory framework related to urban development and construction on water.

In Italy, Directive 2014/89/EU was implemented by Legislative Decree 201/2016 which establishes a framework for maritime spatial planning to promote the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of resources, ensuring the protection of the marine and coastal environment through the application of the ecosystem approach. It is therefore a tool that provides an appropriate allocation of maritime space between the various relevant uses. However, construction and urban planning activities are not included among these uses. The Italian FRMPs are developed by the Autorità Competenti (competent authorities), are coordinated and prepared by the Autorità di bacino distrettuali (authority of the river basin district) level and detailed by the Unità di Gestione (management units) and relevant competent authorities, constituted by the five Autorità di bacino distrettuali (Po River, Eastern Alps, Northern Apennines, Centrale Apennines and Southern Apennines) and the two Autorità di bacino regionali (regional authorities) for Sicily and Sardinia. The periodic update of the FRMPs allows for the adaptation of flood risk management through new information about changes occurred in the territory and additional measures implemented since the publication of previous plans's versions. The information includes also how CC will affect flooding.

In terms of urban adaptation and risk reduction, there are a range of cross-cutting strategies, such as disaster risk management, early warning systems, climate services and risk spreading and sharing that have broad applicability across sectors and provide greater benefits to other adaptation options when combined. Transitioning from incremental to transformational adaptation, and addressing a range of constraints, primarily in the financial, governance, institutional and policy domains, can help overcome soft adaptation limits. However, adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits (IPCC, 2023). Combining mitigation with action to shift development pathways, such as broader sectoral policies, approaches that induce lifestyle or behavior changes, financial regulation, or macroeconomic policies can overcome barriers and open up a broader range of mitigation options (IPCC, 2023).

Among the most common approaches adopted in different geographical areas we can list:

- the French policy of 'permeable cities' connected with the green and blue frame, which provides for specific urban planning instruments (SDAGE) to reduce pollution, prevent flood risks, and anticipate the effects of CC;
- the 'sponge city' concept initiated in China in 2014 to address urban water issues including surface water floods;
- the 'Sustainable Urban Drainage System' (SUDS) adopted especially in the United Kingdom, which implies an increasingly important role assigned to green infrastructure, minimizing the outflow of surface water and flood risks in an ecological way by imitating natural water systems;
- the 'Water Sensitive Urban Design' (WSUD) strategy implemented in Australia since the 1990s and The Netherlands, integrating engineering design with the principles of the urban water cycle to provide sustainable cities;
- the 'Low-Impact Development (LID)' used in Canada and the United States to describe a land planning and engineering design approach to manage stormwater runoff as part of green infrastructure;
- the 'community-building approach for climate-proof resilient cities' implemented in the Netherlands where SLR is considered not only as a risk but also as an opportunity (Baumeister et al.,

2020).

Recently (January 2024), in Italy, the City of Rome has presented the Climate Adaptation Strategy (Comune di Roma Ufficio Clima, 2024) within the Climate Plan, that identifies the priorities, objectives and adaptation measures which are essential to adapt the territory to ongoing and foreseeable impacts such as consequence of the climate scenarios and impacts that may occur by 2050. The proposed Strategy is conceived as a great opportunity to secure and rethink urban spaces and infrastructures, through innovative solutions that lead to economic growth and wellbeing of citizens.

1.3.2. Waterfront adaptation strategies

Currently, responses to SLR and land subsidence include a wide range of different types of strategies (Few et al., 2007; ICE, 2010; Nicholls, 2011) that can be traced back to four main actions: protection, accommodation, advance, and planned relocation. To give a few examples, shore protection can be provided through shoreline armoring structures and land elevation is used to keep pace with SLR. The World Bank suggests a model (Nicholls et al., 2010; World Bank, 2017) that considers the integration of three adaptation methods in urban coastal areas:

- **protect** to reduce the likelihood of hazards
- **accommodate** conceived as modification of buildings to reduce the impact of the hazard event
- **retreat** to reduce exposure by moving away from the source of hazard.

In other words, **protect** strengthens and conserves the boundary between water and land, **accommodate** moves it vertically, and **retreat** draws the interface back horizontally. The United Nations Environment Programme Sea Level Rise Report (Oppenheimer et al., 2019) follows the World Bank model to which another method is added: **advance**, that is creating new land by building seaward, reducing coastal risks for the hinterland and elevated land. **Advance** also acts horizontally but in the opposite direction by moving the border from land to water. The United Nations model considers also ecosystem-based protection (using nature-based solutions) as a separate adaptation method. As Baumeister (Baumeister et al., 2020) highlights, its main purpose is still to protect, therefore it can be considered as part of this response type. Thus, overall, we can define four major adaptation responses: protect, accommodate, retreat, and advance (Figure 6).

Baumeister (Baumeister et al., 2020) provides a matrix (Figure 7) in which the four adaptation strategies can be applied in the vertical direction and the urban system elements (building/space, production, community, infrastructure, and natural environment) in the horizontal. The matrix returns a combination of twenty different tactics for SLR.

As highlighted by the AR6 IPCC Report (IPCC, 2023), these responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values, and underpinned by

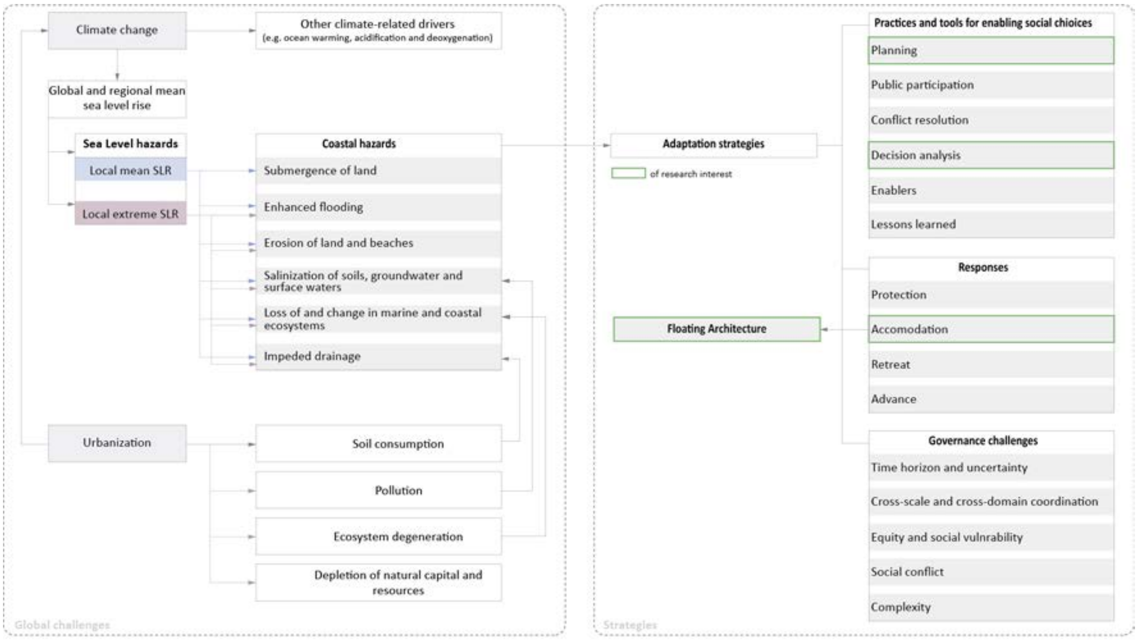


Figure 6. Scientific assumptions. Global challenges and climate adaptation strategies in urban areas.

inclusive community engagement processes. Ecosystem-based solutions such as wetlands provide co-benefits for the environment and climate mitigation, and reduce costs for flood defenses, but have site-specific physical limits (at least above 1.5ºC of global warming) and lose effectiveness at high rates of SLR beyond 0.5^{-1} cm/yr. Seawalls can be maladaptive as they effectively reduce impacts in the short term but can also result in lock-ins and increase exposure to climate risks in the long term unless they are integrated into a long-term adaptive plan. Retreat often entails abandoning existing urban assets and communities.

Coastal ecosystems, including salt marshes, mangroves, vegetated dunes, and sandy beaches, can build vertically and expand laterally in response to SLR, though this capacity varies across sites. These ecosystems provide important services that include coastal protection and habitat for diverse species. However, as a consequence of human actions that fragment wetland habitats and restrict landward migration, coastal ecosystems progressively lose their ability to adapt to climate-induced changes and provide ecosystem services, including acting as protective barriers (Oppenheimer et al., 2019).

Land reclamation is one of the advance strategies and it can be defined as the process of creating new land from a body of water by replacing water with fill material or by pumping it dry, hence contributing to the global concern of running out of land and consuming resources (Wang et al., 2019). Sand is the most extracted resource on the planet. Fifty billion tons of sand are extracted each year, mostly for construction and land reclamation industries (Bendixen et al., 2019; Jiao et al., 2006; Peduzzi, 2014). Land reclamation (Wang et al., 2019) presents several environmental and technical limitations (Bradshaw, 1984; Ohkura, 2003; Wang et al., 2010). From an environmental point of view, land reclamation

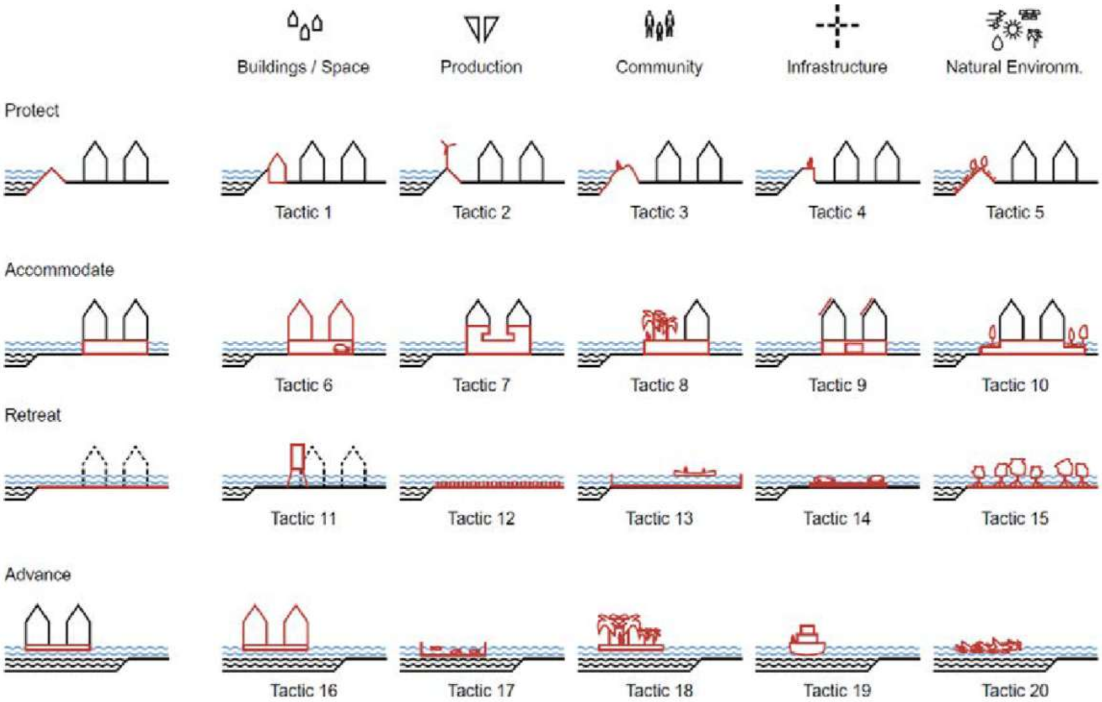


Figure 7. Matrix of adaptation strategies. Source: Baumeister, J., Bertone, E., & Burton, P. (Eds.). (2020). SeaCities: Urban Tactics for Sea-Level Rise. Springer Nature.

implies the use of fill-in materials that can change, and thus damage, the natural landscape and marine habitats with a consistent impact on ecosystems.

Barker and Coutts in their book *Aquatecture* (Baker & Coutts, 2016) highlight five main approaches to tackle flood risk at a building scale:

- **flood avoidance**, which could be compared to retreat and entails the location or relocation of buildings away from the flood-risk areas, also by raising them above the flood level on stilts or raised land;
- **flood resistance**, or dry-proofing, which seeks to keep water outside the building by blocking pathways for water to enter and providing water-resistant building fabric;
- **flood resilience**, also known as wet-proofing, which allows the water into the building in a controlled way and relies on the use of internal water-resilient materials and technical details to prevent permanent damage and allow quick recovery after a flood;
- **floating approach**, by enabling buildings to move up and down with the floodwater;
- **amphibious approach**, which refers to creating buildings fixed to a buoyant base that rests on the ground but is designed to float when flood waters rise, temporarily acting as a floating structure.

Several studies agree that floating architecture is the most advisable solution against SLR in terms of sustainability, lifespan, and cost-effectiveness (Baumeister & Linaraki, 2022; El-Shihy & Ezquiaga, 2019; Magni, 2019). The last IPCC Report (AR6) represents the most comprehensive and up-to-date review of scientific knowledge

16. An advance strategy creates new land by building seaward, which can reduce the risk for the hinterland and the newly elevated land, either by land reclamation through landfilling or by the planting of vegetation to support natural land accretion (Wang et al., 2014; Sengupta et al., 2018).

on CC for governments, the international scientific community, and world public opinion. Compared with previous IPCC assessments, for the first time, floating structures are listed among the prevention solutions for flood management. In Chapter 13.2.2. and 13.6.2. *Solution Space and Adaptation Options*, the report recognizes that accommodation through elevated or floating houses has been implemented and proposed locally within cities as part of a hybrid strategy together with protection measures and as an innovative urban development approach (Penning-Rowsell, 2020; Storbjörk & Hjerpe, 2021). Moving beyond risk management objectives, the transformation of coastal cities and their extension/advancing on water could create more opportunities than threats, presumably less expensive and more sustainable than investments for coastal protection. Although mitigation and adaptation will be fundamental first steps to reduce the threat of SLR, sustainable and self-sustaining communities will be an important strategy for long-term projections (Williams, 2009).

In AR6 Cross-Chapter Paper 2, within the subchapter dealing with cities and settlements by the Sea, advancing seawards through large floating structures is mentioned as a viable option in the future (Setiadi et al., 2020; Wang & Wang, 2020). It is, however, still at an experimental stage, and, so far, only been applied in calm waters within cities as part of an accommodate strategy and not yet as an advance strategy[16] (Penning-Rowsell, 2020; Scussolini et al., 2017; Storbjörk & Hjerpe, 2021). Also Hiltrud Pötz, from Atelier Groenblauw, in his book *Green-Blue Grids, manual for resilient cities* (Potz, 2016), includes floating or amphibious buildings amongst flood-proof measures within the broader domain of flood risk management strategies.

In light of these considerations, it is clear that water constitutes a valid alternative to terrestrial soil, as confirmed by the progressive emergence of the theme of floating and amphibious architecture both in scientific research and in the most in-need European and national contexts. Floating foundations and mooring systems enable multi-functional use of space in densely populated areas, providing a new sustainable surface for urban development (Lin et al., 2019), while acting as a mitigation solution without further increasing flood risk (de Graaf, 2012). Today’s cities only provide 40% of the space required to house the world’s population by 2050 (GCA, 2022). Most cities create space through land reclamation. Floating development offers an alternative to this practice by creating living spaces on the water. Moreover floating development provides a solution also for countries with a deep coastline that are consequently not able to apply land reclamation without a massive amount of resources and expenses, making it inconvenient for depths greater than 20 meters (Wang et al., 2006).

Overall, sustainable floating development provides a significant number of advantages that are listed below.

- Zero-soil consumption: soil consumption is avoided while providing new space for housing, agriculture, industry, energy production, and other purposes.

- Urban growth capacity expansion for cities built along or near the coast and other hydrographic networks.
- Emergency response: during floods floating structures may contribute to coping capacity, also by functioning as emergency shelters.
- Mobility: since floating structures can be easily relocated, their flexibility in terms of location contributes to addressing uncertain (climate and economic driven) future developments. In this sense floating urbanization introduces a new approach to urban planning and development, as the mobility of floating buildings enables a dynamic and flexible urban fabric, able to adjust to the ongoing changing circumstances in terms of demand and requirements of the community, including SLR or changes in economic or spatial needs. Mobility also implies reversibility of intervention, allowing urban planners to remain active in the process of shaping floating developments even after implementation.
- Increased resilience to earthquakes: floating structures grant a high level of safety for occupants and structures as shockwaves are absorbed by the water reducing the impact on floating structures that are inherently base isolated (Lin et al., 2019; Rehman, 2020).
- Rapid deployment and ease of construction: floating structures can be made using prefabricated components built in onshore warehouses and easily assembled once the floating platform is on water.
- Flexibility in deployment: the modular nature of floating structures enables mobility and flexibility. Where and when necessary (obsolete function, demand shift, increase/decrease in dimensional needs, etc.), floating facilities may be towed and relocated to more advantageous sites, expanded and grouped with other floating structures (Rehman, 2020).
- Adaptability to water levels fluctuations (tides, SLR): the mooring system of floating structures allows free vertical movement of the structure to follow and adjust to the changing sea level and to cater to different payloads, while providing stability in horizontal movement (Rehman, 2020).
- Separation between economic value of real estate and location: both components can be sold separately and can be designated for a new function. This prevents premature demolition, keeps the economic value of the buildings intact and enables responding to uncertain developments on the real estate market.

When considering inhabiting the marine environment as a potential alternative for urban expansion, subjective human response (driven from uncertainty and discomfort) and social acceptance become significant factors in its success. For this reason, people will be even more reluctant to inhabit offshore dwellings without the guarantee of an equal level of safety and comfort they are used to (Wang et al., 2019). Currently, near-shore urban floating development is currently the most predictable application of FUD, by virtue of its economic, social, and logistic feasibility. But it is important to highlight some criticalities related to near-shore on water settlements, compared to offshore. For instance, the impact from tsunami is significantly reduced in offshore waters, since tsunamis are less powerful in open water than on or close to the shore because tsunami waves gain height when they hit the shore.

1.3.3. SOS Climate Waterfront: five different European waterfronts and relevant adaptation strategies.

The SOS Climate Waterfront is a H2020 interdisciplinary project that aims to bridge the gap in the understanding of how the different scales of urban and landscape planning, architectural design, and technology are linked in water-related strategies and how they impact each other in the definition of prevention action plans. The project collects different disciplines to create new strategies and Sustainable Open Solutions (SOS) for infrastructure and urban planning in Europe. It builds a new multidisciplinary collaboration network involving top European research institutions[17] in architecture, urban design, regional planning, and landscape architecture as well as non-academic partners[18]: local experts, municipal representatives, and cultural institutions.

This collaboration has allowed a deep understanding of the impacts of CC on urban waterfronts – explored under social, environmental, educational, technological, and urban design perspectives – and to share best practices for five European cities (Figure 8): Stockholm, Thessaloniki, Gdansk, Lisbon, and Rome. The aim was to identify specific vulnerabilities and envision possible solutions for each city enhancing their resilient adaptive and transformative capacity.

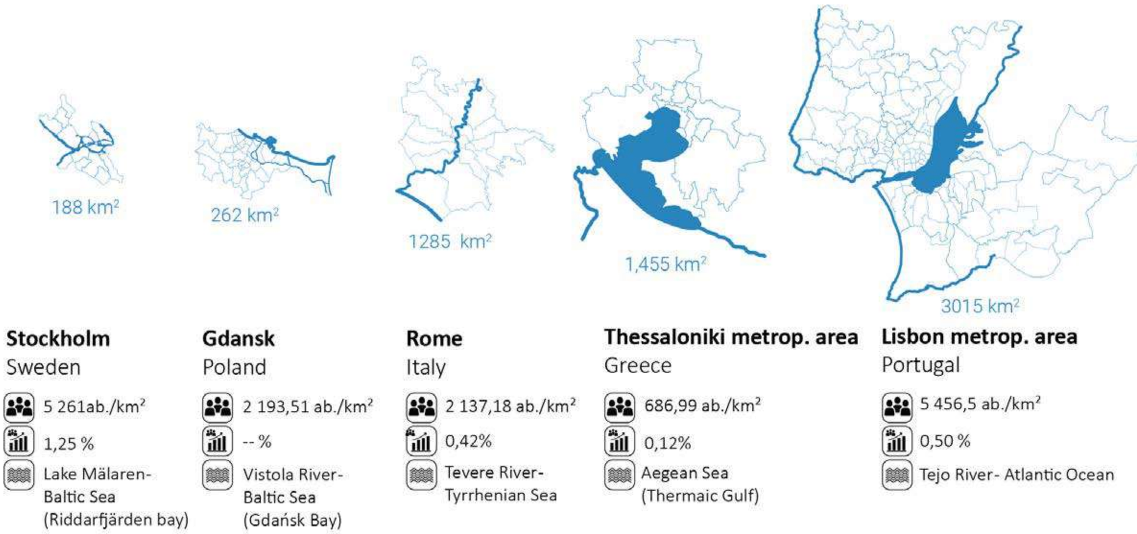
Each city is settled within a particular landscape and is characterized by specific hydrologic conditions. The term waterfront[19] in fact refers to any land, land with buildings, or section of a town fronting or abutting on a body of water, thus it includes coastal cities as well as delta cities or even riverfront cities. Partly for this reason,

17. Sapienza University of Rome (Interdepartmental Research Centre FoCuS) , Aristotle University of Thessaloniki, Gdansk University of Technology, Lusófona University of Humanities and Technologies, KTH Royal Institute of Technology, TOBB University of Economics and Technology. My partecipation to this project, in the capacity of researcher at the Sapienza University FoCuS Research Centre, was funded by a H2020-MSCA-RISE 2018 Secondment Agreement within Marie Skłodowska-Curie Actions co-funded by the Horizon 2020 program of the European Union SOS Climate Waterfront.

18. Alpha Consult, Provincie Noord-Holland, Intercult, Portughese Chamber of Commerce and Industry, MDAT, River//Cities Platform, Municipality of Gdansk, CPO Noord-Holland NGO.

19. According to Miriam Webster Official Dictionary (https://www.merriam-webster.com/dictionary/waterfront)

Figure 8. Comparison of the five European cities studied for SOS Climate Waterfront Horizon 2020 Project. Source: Livia Calcagni



each city holds a complex and unique relation with the water, covering all together a large spectrum of different waterfront urban environments, water management approaches and adaptation paradigms. In Rome, for instance, layers of history and cultural heritage define the urban fabric and play a pivotal role in the relationship with the network of waterways that flow through the city. In all five cities, the transformation of the land resulted in increasing construction of buildings, more impermeable soil and consequently higher floods that destroyed the cities with fewer or greater frequency and intensity.

Lisbon. The city of Lisbon is located at the mouth of the Tagus River. The Tagus Estuary was created after the end of the last glacial period when the SLR drowned the lower Tagus River valley. After being drowned by the rapid post-glacial SLR, the inland delta of the Tagus grew through sediment deposition, and sediment further accreted along the margins of the estuary, allowing the establishment of tidal wetlands (Dias et al., 2014; Vis et al., 2008). The evolution of wetlands and settlement around the Tagus estuary was marked by repeated cycles of reclamation of the coastal prairie that formed behind the advancing pro-delta, located at the upstream section of the estuary. As the mudflats and salt marsh frontier accreted and drifted downstream, it left behind a wide floodplain of fertile soils, which were seized and used for agriculture by all ruling civilizations. This low-land area, reclaimed farmland, along the lower Tagus valley is called the Lezíria. The most substantial landfilling activities for infrastructure, rather than farming, were related to the expansion of the Port along Lisbon municipality’s waterfront, between the last couple of decades of the 19th century and the first three decades of the 20th century (Durão, 2012). In the event of very high SLR, most of the land vulnerable to submersion would therefore be wetlands of low-lying Lezíria farmland. The areas along the Tagus estuary differ in terms of coast, soil, morphology, and urban fabric. The area around Alcochete is close to an old (but still active) military airport base located on the opposite side of the main city of Lisbon. The municipality is considering relocating Lisbon City Airport to the site. The fishing industrial heritage areas suffer intense investment pressure because of suburbanization. The coast here is an alluvial tidal plane with the characteristic anthropogenic landscape of salt pans, which are mostly abandoned nowadays. The contemporary challenges of the site include forgotten salt-production heritage and urban pressure exerted both by the growing neighboring towns (Alcochete and Montijo), as well as by the potential new Lisbon airport relocation. In this case, waterfront adaptation strategies include combining housing and infrastructural demand with historical heritage preservation and enhancement through ecosystem-based adaptation strategies that foster local fauna and flora and leave the unbuilt land to be taken entirely by the ocean waters.
Cascais city waterfront with its’ famous sea promenade suffers instead from touristic pressure and overcrowding as well as urban

pressure caused by the suburbanization of nearby Lisbon. The promenade is exposed to the open tidal water of the ocean. SLR forecasting models indicate that flooding is expected to take place through the Vinha River, that runs through the city. As the urban area was developed with roadways, parking lots, and buildings, to gain more building space and to avoid violent flush floods from rains the river was covered and built up. Covering rivers increases nutrient pollution, degrades habitats, and increases downstream flooding. In this case, the major adaptation strategy involved daylighting the river by removing the artificial impediments and re-establishing the original river where possible or, where development is in the way, creating a new channel for the waterway. The resulting restored river, integrated with the re-permeabilization of nearby soil, provides stormwater benefits and reduces the risk of flooding by increasing its absorption capacity.

Rome. The waterfront in Rome is strongly characterized by numerous archaeological and architectural artifacts, and different shoreline landscapes that are increasingly compromised by a consistent, and often uncontrolled building and touristic pressure. Any action on this territory must be able to combine resilient approaches with the preservation and enhancement of the archaeological-architectural and environmental legacy. To do this, a synergistic and shared strategic vision amongst private and public stakeholders is needed. Rome's waterfront embraces both riverfront and coast, each of which requires site-specific analysis and relevant strategies.

Coastal landscapes represent an environmental resource of extraordinary value for Italy in relation to the forms of territorial, economic, and tourist development, as well as a complex challenge for the intertwining of problems and pressures. The progressive urbanization of coastal areas (coast consumption) combined with the impacts of CC (coastal erosion, SLR), are increasing the vulnerability of these territories (Manigrasso, 2023). Land consumption in Italy reached about 19 hectares per day in 2021, an increase that makes Italy lose almost 2.2 m^2 of land per second (Munafò, 2022).

The Ostiense coastal system stretches along the coast of Rome's metropolitan area in correspondence with the Tiber River delta. It is part of two districts: the 10th Municipality of Rome, covering about 150km^2 and including over 230,000 inhabitants, and the Municipality of Fiumicino, covering about 213.89 km^2 and including more than 80,000 inhabitants. The Ostiense coast is characterized by the presence of ancient vestiges including the archaeological site of Ostia Antica and Portus, streets and harbors that date back to Roman times (via Ostiense, via Appia, via Severiana, Port of Claudius, Port of Trajan), defensive system towers, medieval, and modern settlements, salt pans and forests, historic villas, farmhouses and mansions (Torlonia, Sacchetti), wooded areas and coastal dunes (Cerutti et al., 2017; Turco, 2023). Overall the territory comprises valuable landscape and cultural values, some of which are protected by regulations (Cambi & Terrenato, 2000). Since the end of the

19th century, when land reclamation works started, the landscape has been deeply transformed with several summer residences, urban centers, and road infrastructure being built. In the 1950's the Intercontinental Fiumicino Airport was built, and speculative construction took over transforming Ostia into a suburban district of Rome. In recent years, after the 1990s demographic development, the pressure of commuting to Rome and the increasing of seaside tourism led to a partial redevelopment of the coastal territory, with a consequent increase in land consumption and hydrological risks. The coast of Rome has been partially saved by the presence of the natural areas subject to constraints. Isola Sacra, Macchia Grande di Focene and Macchia dello Stagneto, Traiano Lake (within Fiumicino Municipality) and State Natural Reserve, Castel Porziano presidential estate and Pineta di Castel Fusano (in the 10th Municipality of Rome) provide a unique combination of habitats and are also included within the Natura 2000 Network, as “Site of Community Interest” (SIC) and “Special Protection Areas” (SPA).

In terms of climate-driven pressures, the Ostiense coast is particularly subject to erosion and has been affected by several interventions for hard work protection and nourishment in the last decades. Both near-shore (Ostia Ponente) and spaced-out (Ostia Centro) submerged barriers have been built along the coastline. From 1990 to 2015, the most intense period in terms of protection interventions, the overall erosion of the Ostia coast went from about 50,000 m^2 to 120,000 m^2. Between 2016 and 2018 the situation worsened even more, and the erosion in the section facing the outlet to the sea of the high-water collector channel, led to the ingression of the seawater into the habitat behind, with very serious damage to the ecosystem. The project for the new commercial port of Fiumicino is then grafted onto this dramatic scenario. Due to its geometry and size, it will increase the erosion phenomenon on the entire northern coastal strip, always linked to the acceleration of the bed current flowing northwards along the coast.

All things considered, it is essential to intervene on the triggering causes of the erosion, the escalation of which is, above all, linked to the presence of rigid barriers and consequent alteration of the dynamics of the coastal current (Manigrasso, 2023). Secondly, adaptation strategies may include urban regeneration and de-sealing, balancing the need for infrastructure and housing demand.

Coming to Rome's riverfront, the river Tiber has played a crucial role in shaping this territory by advancing and retreating over time, leading to the formation of ponds and marshes. For 1500 years the coastline moved seaward, because of the deposit and compaction of the river debris, leading the coast to advance to the maximum point of 4 km. Today, an inverse phenomenon, retreat, is observed, especially in the central area where the district of Ostia is located. This process is due to the construction of dams along the river as well as the removal of sand and stones to produce lime carried out by local industries. In addition, because of CC, SLR is significantly endangering the coastal settlements. According to the SSP5-8.5 scenario, the entire hamlet of Isola Sacra, a large part of the area currently used for the international airport infrastructure (Municipality of Fiumicino), parts of Ostia Antica and the Piana del Sole (Municipality of Rome), and up to 200 m of areas adjacent to the coastline that stretches from Fiumicino towards Civitavecchia, will be submerged by water by 2050 (more data is provided in Chapter 5). The internal areas that are expected to be affected by SLR by 2100 are located more than 9 km inwards from the current coastline.

It is essential to free the shoreline from any incongruous and invasive activity, reconfiguring the leftover areas for new forms of nature capable of ensuring ecological continuity.

Dilip da Cunha in his book *The Invention of Rivers* (da Cunha, 2019) argues that rivers understood as perennial watercourses, running between two parallel lines, are a human invention, as they do not exist. What does exist are unstable conditions created by the constantly changing relationship between the land and the spreading-on water as "the line between land and water is not taken for granted" (da Cunha, 2019). Rivers, as we typically imagine them and draw them, are the category through which we have sought to simplify and stop in a stable and reassuring form the inexhaustible negotiation between land and water. Therefore, the Tiber must be considered much more than the watercourse between its two banks. It expands on a much greater depth, encompassing entire parts of Rome. Although the Tiber has a modest average flow rate, compared to other European rivers, floods have been part of Rome's history for over 3600 years (Aldrete, 2007). In ancient times, floods were seen as a phenomenon to adapt to rather than to fight against. Therefore, ports were equipped with docks on different levels, to be usable according to different heights of the river (Lanciani, 1897). Precaution measures included the location of exclusively public functions and buildings in the lowest floodable parts, which could easily be evacuated. The *Circus Maximus* was one of these places, located exactly where the Murcia stream flows into the Tiber, acting as a huge basin able to absorb and collect water in case of flooding and as a game and chariot arena in ordinary days. The hydrographic system of Rome and the peculiar role of the Tiber axe represents one of the 'Strategic Planning Zones' in the General City Plan approved in 2008 and still in force. The strong relationships between the urban historic pattern and its water flow axe, which was neglected with the construction of the embankments soon after Rome became the Capital of the Italian Kingdom (1871), can be at least partly revitalized through the implementation of the Tiber 'Ambito Strategico' regenerating the river banks as continuous, resilient, flood adapting public space ribbons strengthening the morphologic and perceptive relationships with the historic architectures and urban axes (Monardo, 2023). To reconnect Rome to the Tiber and rebuild the relationship between the city and the river, adaptation strategies include nature-based solutions such as floodplains and the reconversion of the river corridor to safe public space. Re-imagining the porosity of the border of the river could lead to rethink the river as an integrated environmental, historical, and social system dotted with hot spots of public spaces at different scales. Green and blue infrastructures, characterized by their multi-functionality, multi-scalability, and connectivity could strengthen the socio-ecological and cultural relationship while improving the urban resilient capacity and efficiency and risk management (Poli, 2023). Potential solutions include not only wetland buffers, permeable paving, rain gardens, and floodable playgrounds and squares, but also terraced waterfront to facilitate pedestrian access to the riverfront and floating platforms for hosting open-air public space to enjoy and mend the relationship with the river and nature.

Gdansk. According to several flood projections models, the city of Gdańsk is one of the most vulnerable places in Europe. It was built on islands and wetlands at the confluence of the Motława and Vistula rivers in the estuary of the Vistula River to the Baltic Sea. The low-lying waterfront territory, located north of the historical city, could be a field laboratory for climate adaptation concepts. Today, the whole area remains dry only due to the constant pumping action by the Nowy Port Pumping Station. The average water pumping height is about 1 meter. Despite this action, the territory is under the constant threat of inundation resulting from the high level of groundwater and is prone to river floods and flash floods caused by water run-off from the higher-located urban territories of Gdańsk. Most of the areas that belong today to the Nowy Port and Letnica districts were covered by the waters of Gdańsk Bay even in the 16th century (Nyka, et al., 2021). Unlike Nowy Port, the Letnica area has never been fully urbanized. It hosted mainly agricultural functions until the 19th century when the first industrial factories were located there, and later houses began to be built. Both Nowy Port and Letnica underwent urban revitalization programs in the second decade of the 21st century. The flood risk maps, based on the seawater level rise scenarios of the Polish IT System of the Country Protection against Extraordinary Threats (ISOK) show the vulnerability of waterfronts along the Vistula and Motlawa rivers. Nowadays, the most visible effects of climate-related changes include increasingly repetitive flash floods, groundwater inundations, risks of saline water intrusion into the groundwater sources, and storm surges that push water back from the sea and threaten the safety of riverine waterfronts. What is more, despite the significant water resources in the area, the city is completely turning away from the Vistula River and existing canals.

Although the study area faces significant challenges, it also presents extraordinary opportunities originating from its authenticity. The major challenges included providing more room for water, particularly storm and rainwater, creating blue-green connections that span the amorphous territory bringing along environmental, hydrological, and social benefits, and providing attractive public spaces with close contact with the water.

With a view to biophilia in urban ecologies, adaptation strategies should involve the integration of existing industrial artefacts, buildings, docks, cranes, and canals with the natural landscape and its enhancement through the creation of new resilient attractive space on the water itself. Land-water boundary transformation models could be enlarged to include the introduction of floating objects as new surfaces of water bodies both for cultural activities and for residential purposes to limit the pressure of high housing demand in Gdansk.

The other two waterfront cities addressed in the project are Thessaloniki and Stockholm.

Stockholm is one of Europe's fastest-growing cities, and its waterfront stands at the forefront of climate change challenges in terms of temperature increases, changing precipitation patterns, and more frequent cloudbursts, in addition to the long-term challenge of rising sea levels and flooding. The three analyzed urban sites, Lövholmen, Frihamnen, and Södra Värtan, are driven by the demand for more housing and face crucial issues related to cultural heritage preservation, climate change, landscape ecology, and social development. Stockholm rests on two different bodies of water, where the Baltic Sea, with brackish water, meets Lake Mälaren, an essential provider of freshwater for two million people. The adaptation strategies explored by the research group emphasized the importance of finding a balance between preserving cultural heritage assets and local community values, while stimulating economic growth, and encouraging interaction and awareness with the surroundings. In this context, it was essential to highlight the interfaces between humans and nature raising questions about how flooding can be used as a resource and catalyst to attract more people to an area.

Thessaloniki is a port city with a long and continuous history that has always retained a strong relationship to its waterfront, which extends today more than 40 kilometers along the southeast coast of the Thermaicos Gulf in northern Greece. Thessaloniki has been a member of the 100 Resilient Cities network since 2014 and has developed a long-term strategy to address current and future challenges with a robust and participatory approach. Thermaikos Bay is an integral part of Thessaloniki's identity as a port city. The Resilient Thessaloniki office cooperated with the World Bank and Deloitte GR in the development of a masterplan for the redevelopment of the waterfront, giving rise to a governmental transformation towards more participatory procedures, embedded resilient thinking, and adaptability to cross-departmental, cross-governmental practices as well as to the civil society of the city.

An in-depth analysis and argumentation of the two cities and relevant adaptation strategies are left out for the purpose of the discussion to avoid subtracting attention from the main topic of floating architecture as an adaptive solution. Both are complex cities, which, like the three cities described above, require the integration of multiple solutions that work in synergy to increase the overall resilience of their waterfronts. Stockholm has a waterfront like that of Lisbon, which is characterized by the intersection of sea and freshwater (in the first case, the lake, and in the second, the river). In contrast, Thessaloniki has a vast historical and cultural heritage and legacy of inestimable value that is partly assimilable to the example of Rome.

The different solutions adopted to overcome climate related waterfront vulnerabilities are specific to geographies and sensitive communities, to their urban environment, natural systems, and local building materials. Moreover, these examples highlight how the knowledge of the history of the place may reveal paths toward creative anti-flood solutions that contribute to urban rehabilitation and enhance the identity of historic neighborhoods.

The SOS Climate Waterfront project has identified several ways waterfront cities can face the challenges of flooding and rising sea levels embedded in vulnerable contexts, often hosting invaluable social, economic, and cultural heritage assets. Among these, floating architecture can be used as an adaptation measure to provide more space for storm and rainwater, to create blue-green connections that span the amorphous territory and bring along environmental, hydrological, and social benefits, to provide attractive public spaces with close contact with the water, to integrate existing industrial artifacts, buildings, docks, cranes, and canals with the natural landscape and its enhancement through the creation of new resilient attractive space on the water. At the same time, it provides a solution to urban issues and pressures, like the high housing demand in Gdansk, finding a balance between preserving cultural heritage assets and local community values, stimulating economic growth, and encouraging interaction and awareness with the surroundings, as in Rome, Lisbon, and Thessaloniki.

In conclusion, the SOS Climate Waterfront project has significantly contributed to the understanding of how the transformation process on urban waterfronts can be perceived as an opportunity for creating a new type of urban ecology. It has highlighted that one solution is not enough to grasp and address the complexity of each context and face such enormous challenges, stressing the need for a site-specific and integrated approach. The combination of several adaptation interventions is often the most effective solution. As evidence of this conclusion, interest in novel multifunctional coastal protection is growing, and studies increasingly suggest their viability (Evans et al., 2017; Valente & Veloso-Gomes, 2020).

1.4 Introduction to floating architecture

Considering the physical boundaries of land and the pressures of urbanization and SLR, water is increasingly becoming a realistic option in terms of urban expansion possibilities. Throughout history, cities were mainly founded and developed close to water, as water is a primary necessity of life and the basis for trade and logistics. Technical innovations, such as floating buildings, plots, and islands, present a considerable potential for new urban development locations. Moreover, spatial pressure and rising land prices in metropolises will strongly contribute to the progressive cost-effectiveness of this innovation (Olthuis, 2010). The existing highly efficient maritime technologies developed in the shipping, oil platform, and offshore industries can be applied to floating constructions, where people could live, work, and enjoy their time.
Floating potential touches different aspects as further described in Chapter 1.5.3., from strengthening community resilience to fostering ecosystem regeneration, from addressing water shortages and food scarcity to harvesting marine renewable energy (MRE) from oceans and other water bodies.
Architect Koen Olthuis states in his book *FLOAT! Building on water to combat urban congestion and climate change* (Olthuis, 2010) that the "ultimate form of urban flexibility is floating buildings". By removing the permanent link between building and location, the building becomes a product that may be used by different owners in different places throughout its lifetime. The possibility of relocation implies that a site can be used for different purposes over time.

1.4.1. Expanding the building typology

"Aquatecture" – meaning water-based architecture (Williams, 2009) – and its implementation in the decision, planning, and design process, requires the introduction of a new architectural typology: water-based buildings and structures.
Since the beginning of the 21st century, we have seen a dynamic growth of water-based architecture, mainly due to the increasing

threat of floods caused by SLR or heavy rains – all correlated with CC. Secondly, the shortage of land available for development also led architects, engineers, and policymakers to reclaim the seabed or to build floating structures. At the same time, the drive to produce energy from renewable resources has expanded the sector of offshore research, mining, and energy industry which seeks new types of water structures. Another reason for substantial amphibious architecture growth is technology. Although building on the water is not a new idea, today, thanks to new materials and construction methods, waterside and floating structures are as durable and as comfortable as their land-based counterparts and are bound to become as affordable, too (Piątek, 2016). Considering these configurations, the time is ripe to consider water-based architecture as a full-fledged building typology[20]. What distinguishes water-based architecture asan autonomous typology is site configuration, and more specifically, the building pad, conceived as the building foundation area, and thus the foundation system.

Both social and academic acceptance take time to include floating buildings as a new typology mainly because, in the past, 90% of buildings have been built on the land. Island countries are already used to this, and in other countries where there has not been sufficient land for building (Baker & Coutts, 2016; Gross et al., 2016).

20. The term typology refers to the study of possible associations of elements to arrive at a classification by type of architectural organisms. Therefore, the building typology classification can be based on different categories depending on whether one refers to functional typology, geometry and morphology, site configuration, scale, and so on.

1.4.2. Definition and Classification issues

Despite the significant amount of historical and contemporary realizations (Flesche & Burchard, 2005), currently, there is no commonly recognized academic definition of a floating building. Research on water-based architecture lacks a proper, commonly shared vocabulary and typology of water-based structures. First, it is overriding to overcome these semantic and typological problems by analyzing the current state of research on the typology of water-based architecture.

A first misleading factor is the ambiguity of the main terms, as underlined by Professor Łukasz Piątek (2016), such as amphibious, water-based, houseboat, and floating building. The term amphibious originates from the Greek word *amphibios* which means the potential of living both on the land and in the sea. In architecture and urban design practice, the term is used either as the general description for aquatecture (Baker & Coutts, 2016; Wylson, 2013), which is the architecture shaped in the water context (Berman, 2010; Venhuizen, 2000), or as a precise definition of a building capable of floating in the case of floods. In addition, the term houseboat may refer to at least three different types of amphibious dwellings: a small motor yacht with a very high level of comfort, a boat or a barge rebuilt into a stationary residence and, especially a floating house (Cable, 1982; Dennis & Case, 1977; Flanagan, 2003; Frank, 2008; Malo, 1974; Newcomb, 1974; Shaffer, 2007).

Moreover, the multidisciplinary nature of water-based architecture results in double terminology proposed by architects and naval engineers. For instance, a floating building according to the

Queensland Development Code (2007) means a permanently moored floating building built on a flotation system and not intended for, or useable in, navigation. In other words, it can be considered an example of an architectural equivalent for the marine hull (Piątek, 2016). According to the British Columbia Float Home Standards, a floating building is defined as a structure incorporating a floatation system, intended for use or being used or occupied for residential purposes, containing one dwelling unit only, not primarily intended for, or usable in navigation, and does not include a watercraft designed or intended for navigation (Columbia, 1993). One must consider that this disciplinary, and consequently lexical, overlap results in merging civil and naval building rules in the new legislation (Baker, 2015; Columbia, 1993; Gerigk, 2013; Nillesen & Singelenberg, 2011; Queensland Development Code - MP 3.1 – FLOATING BUILDINGS, 2007). The Netherlands (most frequently), the United Kingdom, Taiwan, and other countries still define floating buildings as ships or auxiliary spaces (Wang et al., 2021). In the US floating homes are defined as built on a float, planned and built to be used as dwellings, moored or anchored in one specific place and not intended for navigation, constructed with no means of self-propulsion, powered by utilities hooked up to the shore, connected to a sewage system onshore (Lin et al., 2019).

Another frequently used term is very large floating structures (VLFS) or mega floats which can be defined as man-made large naval structures, used as artificial surfaces in the marine environment (Wang et al., 2019). Their dimensions are usually larger than those of the traditional industry scope (ships, barges, or other naval platforms), and can almost be regarded as a standalone discipline that connects aspects of town planning, naval architecture, and civil engineering. Even the term mega-float can be misleading as it is also the name of one of the most important VLFS applications made thus far: the Japanese Mega-Float project, a floating airport (Fujikubo & Suzuki, 2014).

Several authors have attempted to organize the topic of water-based architecture, and more specifically of floating buildings and structures (Table 1). Ryan in *Building with Water. Concepts, Typology, Design* presented the functional (arts and culture, recreation, living, industry, and infrastructure) and natural (lake, river, sea) typology (Ryan, 2010). Flesche and Burchard (Flesche & Burchard, 2005) in *Water House* distinguished between ground-supported, floating, submerged and frozen architecture. Baker (Baker, 2015) in *Built on Water. Floating Architecture + Design* provided insight into aquatic structural concepts (pillars support, stilts elevation, pontoon floatation). To systematically organize the unclear classification of water-based architecture, Professor L. Piątek (2016) suggests a new typology based on three main distinguishing factors: relation to water, buoyancy, and mobility. Thanks to the different perspectives of civil and naval architecture that are taken into consideration, this new typology encompasses architectural objects of all sizes, functions, and movability, built both in the water and on the water, divided into six types: overwater, waterside and amphibious buildings, floating structures and residential and facility vessels (Piątek, 2016). The author makes a first decisive distinction between the following three categories.

- **Amphibious building** – a building located out of a water basin and set on the ground but capable of floating on the rising flood water thanks to its low mass and special structural elements like the buoyant foundation (English, 2009) or a watertight basement that displaces surrounding water, held in place by two or more vertical piles along which it can vertically regulate.
- **Pile building, stilt building** – a building located partly or entirely in the water basin that is supported by a ground-based openwork structure rising it over water for a designed height.
- **Floating building** (building on the water) – a building located in a water basin, partly submerged, floating on the water surface thanks to its low weight and special structural elements like the buoyant foundation or the watertight body (the hull) that displaces surrounding water, kept in place by a variety of systems like mooring piles (dolphins), stopping piles, anchors, mooring lines, and a combination of those.

As a result of extending the field of amphibious architecture to marine structures, and adopting a multidisciplinary approach, Piątek introduces this new typology of floating structure. It embraces structures of different functions, applications, and sizes like floating buildings (buildings on the water, boathouses), living barges, offshore floating platforms, Very Large Floating Structures (VLFS), as well as floating habitats and floating cities.

Table 1. Main definitions of 'floating building' and similar terms organized by year. Source: Livia Calcagni

Year	Reference	Term	Definition
1993	British Columbia Float Home Standards	Floating building	[...] a structure incorporating a floatation system, intended for use or being used or occupied for residential purposes, containing one dwelling unit only, not primarily intended for, or usable in navigation, and does not include a watercraft designed or intended for navigation [...]
2006	Erbguth/Schubert	Floating houses	[...] Floating houses are buildings in the sense of building law, when serving the function of a house fixed to the ground, regardless their potential mobility or solidity with the ground or shore of the water body.
2011	VROM Inspectorate (Floating homes regulation Guide for developers, builders and municipal plan assessors)	Floating building	(falls under the legal definition of building) [...] any construction of any size of wood, stone, metal or other material, which is connected either directly or indirectly with the ground, intended to function and remain (permanently) on site [...] required to be registered with the Land Registry as immovable property.
2012	de Graaf	Floating building	[...] a floating structure should satisfy the structural requirements that address the operating conditions, structural strength, serviceability durability and safety standards and socio-political criteria that address the environmental sustainability, aesthetics, budgetary and legal constraints. [...]

Year	Reference	Term	Definition
2015	Moon		[…] a structure for living/working space that floats on water using a flotation system, is moored in a fixed place, doesn't include a water craft for navigation, and has a premises service system (electricity, water/sewage and city gas) served through the connection by permanent supply/return lines between floating and service station on close land, or has self supporting service facilities for itself […]
2015	Queensland Development Code	Floating building	[…] floating building means a permanently moored floating building built on a flotation system and not intended for, or useable in, navigation. […]
2015	Habibi	Floating architecture	[…] an energy and ecologically conscious approach to a building for living/working space on floatation system without navigation tool.
2015-16	Baker and Coutts	Floating building	[…] a light weight structure, which rests on a buoyant base or foundation designed to rise and fall with the level of the water […]
2016	Piatek L.	Floating building	[…] floating, portable and buoyant, partly submerged structure resting on the water surface thanks to its low weight and special structural elements like buoyant foundation or watertight body (the hull) that displaces surrounding water, kept in place by variety of systems like mooring piles (dolphins), stopping piles, anchors, mooring lines and combination of those; includes structures of different functions, applications and sizes like floating building (building on the water, boathouse), living barge, offshore floating platform, Very Large Floating Structure (VLFS), floating habitat, floating city […]
2017	Society of International Boat experts	Floating houses	[…] Floating houses differ […] first of all in that they do not have their own drive, no steering position and no steering gear. As a result, they are stationary and cannot drive or be moved on their own initiative. […] they are primarily to be understood as a house […]
2020	Penning-Rowsell E.	Floating houses	[…] Despite its mobility, a floating house is 40 not designed to navigate, nor be self-propelling.[…] Floating houses are designed with permanent water in mind, whereas amphibious housing is proactive, constructed to operate in dry land conditions as well as during flood events […].
2021	German Industrial Norm specification (DIN Spec)	Floating building	[…] Building that is built on a floating system or is itself part of the floating system due to its structural formation, is stationary but by an anchorage and does not have its own drive […]
2021	Wang, K.F.	Floating building	[…] a building which has a structure incorporating a floatation system and the foundation substructure submerged underwater […] most of the superstructure and the majorly of it floats above the water, such that it automatically adjusts to the change in water level, be it a river, canal, lake or sea […].
2022	Dresbach	Floating building	[…] a floating building […] is a floating structure anchored and made of construction products, set up or constructed for permanent use […] may be suitable to be entered in the condominium register according to the Condominium Act, if it is permanently fixed. […]
2022	Seattle Municipal Code	Floating home	[…] A floating home is a legally established, single-family dwelling constructed on a float that is moored, anchored, or otherwise secured in waters. […]

1.4.3. Regulatory implications

How are floating cities currently defined legally? It should be noted that different terms are used both in grey and scientific literature as well as in ordinary and technical language, including 'floating cities', 'floating development', 'floating houses', 'floating structures', or 'floating platforms'. None of these terms exist in international law, but they are nonetheless used in this paper, as they are used frequently by most professionals and researchers working in this field (Lin et al., 2022).

Defining floating buildings as a form of building, and not as a ship or boat, means that these are expected to comply with laws and norms that regulate land-based buildings. Widening the building typology to water requires to incorporate floating buildings into building codes (Wang, 2021). Since there is no building code for floating buildings, let alone on-water urban planning regulations or Green Building indicators for floating development (Habibi, 2015; Moon, 2014; Shepherd & Binita, 2015). This legislative vacuum implies that up to now, floating buildings have been built without being compliant with any specific building code or planning constraint, other than the building laws in force in the local on-land area. Finally, there is no blueprint or best practice guidance that would help meet and overcome the challenges and provide support for architects, urban planners, development companies, and policymakers.

Entrepreneur and researcher in climate resilient floating developments, Rutger de Graaf, highlights how floating development must be sustainable, circular, with a positive ecological impact, inclusive and accessible for all income groups. He argues that “if we start building floating cities in the same way as we’ve built cities on land so far, we’re only increasing the problem, not solving it.” Floating buildings must become comparable to traditional on-land buildings in every respect: comfort, safety, sustainability, durability and lifespan, ease of maintenance, and price. Price is another crucial feature as building on water is still relatively expensive at the moment because it only occurs on a limited scale and demand is still low (Olthuis, 2010). Therefore, to ensure that floating structures are safe, long-lasting, economically feasible, and sustainable, a common standard for all to adopt is urgently needed.

Furthermore, to make water-based development a reality from a legal perspective, the floating structures must comply with specific building regulations conceived for development on water, which are currently still missing. More specifically, there is a lack of cohesive regulation and building standards for floating development both at an international level and at a national one. Floating buildings are currently expected to meet conventional building regulations in most countries, which differ according to the different Nations to which the waters legally refer to. Moreover, floating buildings are qualified differently depending on the country they are built in. In the Netherlands, they are considered houses, but in Singapore, they are considered boats and as such, must have an engine. In France, it changes from inland to coastal areas: a floating building on interior waterways is considered a boat and thus expected to meet ES-TRIN 2021, the technical requirements in Europe when building vessels for use on interior waters, while one on seawater is defined as a house. It is important to underline how ES-TRIN 2021 refers specifically to inland navigation vessels (equipped with propulsion devices), not to floating buildings which are anchored in place and not primarily intended for moving. In Italy, some examples of floating buildings in Sardinia and along the north Adriatic coast, are currently registered as houseboats, thus as certified boats.

An interesting issue regarding the permissions for building floating structures in Italy occurred in Rome in 2017. The Corte Suprema di Cassazione[21], with Sentence 12387, stated that the construction of a building on the water surface of the river Tiber, an area subject to landscape constraints, required not only a concession and technical feedback from the Local Health Authority but also a building permit. For the Corte Suprema di Cassazione, the characteristics qualified the floating house as a new construction project according to the *Testo Unico dell'Edilizia* (DPR 380/2001)[22] because they involved a building and urban transformation of the territory. More specifically, the floating house was included among the works defined by the law[23] as "structures or boats used as homes, work environments, warehouses, or similar, not aimed at meeting merely temporary needs". The judges of the Terza Sezione Penale underlined that administrative jurisprudence have recognized the need for a building permit for floating structures anchored to the banks of the Tiber in similar circumstances. Even the underwater seabed, indeed, must be considered as soil. In this case, state property and the structures permanently installed on the water are subject to the consolidated law on construction[24]. The principle dictated by the Court of Cassation does not only apply to floating buildings for residential purposes but also for any other functional use that is not limited in time, thus also certified boats.

To overcome the lack of building regulations in this field, we require a roadmap, a standardized set of rules, for the design and construction of floating buildings or structures, at an International and European level in terms of defining a common roadmap and objectives and at local national level in countries that are still lacking a specific regulation for floating buildings. Overall, currently, the legal status of floating cities involves different scales:

- international (conventions, e.i. UNCLOS, EU directives, e.i. Directive 2014/89/EU *Maritime Spatial Planning*) as described in Chapter 1.3.1.1. Global policies and international programs
- national (laws, civil codes, spatial plan) which will be introduced in Chapter 1.4.3.2. Existing Local Regulatory frameworks and standards
- local (Zoning plan, Permit, Building regulations) which differ according to specific regions and areas within each country.

21. Supreme Court of Cassation

22. Presidential Decree on Building and Construction

23. DPR 380/2001. Article 3 paragraph 1 letter e5

24. DPR 380/2001. Articles 3, 10, and 35

1.4.3.1. Relevant International and European Goals, Conventions and Directives

Considering the urgency of safeguarding ecological systems and designing healthy and sustainable models of urban development, the theme of living not only with but also on water is gradually gaining ground even on a theoretical level and is the subject or tool of most of the objectives of the main international institutions. UN-Habitat's *New Urban Agenda* and the OECD's *Green Cities Programme* are just some of the strategic objectives promoted to foster sustainable urban development. Extending the physical domain of living beyond the Earth's surface enables almost all Sustainable Development Goals to be put into practice, starting with the SDGs to be achieved by 2030: ensuring health and wellbeing for all, promoting actions to combat CC, protecting, and restoring sustainable use of the Earth's ecosystem, and making cities inclusive, safe, resilient, and sustainable.
In April 2019, the first UN High-Level Round Table on Sustainable Floating Cities was held in New York. In this context, sustainable floating city proposals were introduced as “part of a new arsenal of tools” that help to respond to changes in climatic conditions but also to social and economic issues that emerge as consequences of urban growth trends.
In Europe, there is no single unified set of building regulation for all the European Union countries. Even though the *Construction Products* Directive and the EN Eurocodes lead to some harmonization of the technical building regulations of the EU countries, and the purpose and subjects covered by the building regulations are identical in these countries, every EU country still has its specific building regulations. These building regulations, together with the building control system form the so-called 'building regulatory system' (Pedro et al., 2010).

1.4.3.2. Existing Local Regulatory frameworks and standards

Countries like the Netherlands have been working on identifying technical requirements for floating development with the NTA 8111: 2011 NL[25]. In 2008 the former VROM Inspectorate (Ministry of Housing, Spatial Planning and Environmental Management) produced a guide to houseboats and building regulations which explains how building regulations (Building Ordinance, Land Use, Municipal Building Regulations) should be applied to houseboats. It provides a detailed set of functional requirements, performance requirements, points of attention, release equivalents, and determination methods to ensure a minimum required building and housing quality, but it does not establish requirements for aspects such as stability, buoyancy, safety distance, and several others aspects strictly related to the water-based environment. The purpose of this non-mandatory technical agreement is to establish a series of agreements and performance specifications between market and government parties on identified bottlenecks and

25. The *Nederlandse Technische Afspraak NTA 8111 (nl) Drijvende bouwwerken*, published by the Dutch Standardization Institute (NEN), is a non-mandatory technical agreement used in the Netherlands for design, construction, and assessment of floating structures. It focuses on aspects not covered by the Dutch Building Decree (Bouwbesluit), specifically for structures used as dwellings.

subjects of floating construction that are currently not sufficiently regulated by building regulations. NTA 8111 can be used and prescribed in the following situations:

- in the design and implementation of building plans involving floating structures;
- in evaluating whether typical solutions for floating structures satisfy the functional and/or technical requirements of the conventional on-land building decree;
- in private law agreements, for example between clients and designers, between dealers and insured clients, or between the Dutch Apartment owners' associations (VvE) and tenants.

The NTA refers to all types of (semi-)floating structures and functions but with an emphasis on houseboats of up to three floors above the waterline. Different base configurations of the floating body (dock model, square model, island model, or land plot model) could accommodate either a single floating structure (e.g., a floating house, a floating office building, a floating greenhouse) or multiple floating structures, which may or may not be interconnected. The NTA does not refer to structures founded on piles. Another interesting aspect is that in addition to technical-design aspects, also urban planning, water management, health, and safety aspects that can be regulated in zoning plans (e.g., maximum fluctuations in water levels, and accessibility for larger ships) are addressed.

Amongst other regulations, it is important to mention the Queensland Development Code (2007) which features a floating building code for Australia and provides recommendations, design criteria, main principles, and guidelines for permanently moored floating buildings not intended for navigational use and built on a floatation system. It is in addition to – not in substitution for – other provisions of the building regulation or other relevant legislation. The main requirements addressed include accessibility, buoyant stability, mooring, material adequacy, safety (fire and user), and location (hydrographic characteristics and urban distribution).

Title 28 Floating Structures of the City of Portland Building Code has the purpose of promoting health, safety, and welfare through the regulation of floating structures and their appurtenances. The City of Portland recognizes the River Community as an important part of the city's overall vitality and livability, and floating structures as a "water-dependent activity". The City of Portland Building Code recognizes that waterborne structures, by their very nature, confront different environmental factors compared to structures located on land and that they have distinctive design requirements such that strict adherence or application of the land-oriented Specialty Codes is not always appropriate, and that modifications or exceptions should be made in appropriate circumstances in the application of those codes. The code refers to both existing and new constructions and covers mechanical, plumbing, and electrical aspects in addition to architectural requirements. Title 28 does not apply to any buildings or structures located on land above the mean high-water mark.

The Standards for *Float Homes and Live-Aboard Vessels in Victoria*

Harbour British Columbia identifies safety, fire protection, and construction standards for new or existing live-aboard vessels and float homes which are moored within the limits of Victoria Public Harbour, Victoria, British Columbia. The standard is divided into three main sections according to the type of residence and vessel referred to: float homes; live-aboard vessels; and vessels converted to residence. The standard does not replace the Regulation or Standards of the Canada Shipping Act or any other relevant regulation. The standards applies to marinas and public port facilities and may be augmented by additional requirements established by the marina, port authority or operator. The aspects considered for float homes include technical requirements (electrical, plumbing, sewage disposal, buoyancy, stability, and gas management), fire prevention measures, safety equipment, mooring, accessibility, and ultimately aspects related to the construction process.

The *Guidance for Floating Structures* in the Korean Register of Shipping addresses aspects concerning materials, structural stability, corrosion protection, mooring and anchoring, and fire protection and provides a special section regarding the plumbing system.

All these standards follow a performance-based approach: they provide a detailed set of functional requirements, performance requirements, points of focus, or in some cases even the design and implementation of building plans with floating structures.

Moreover, some ordinary building codes include specific guidelines for floating structures. This is the case for the Michigan Code of Ordinances, the Seattle Municipal Code, the Sitka General Code, the St. Helens Municipal Code, the NYC Zoning Resolution, and the NOGA codes. Most of the technical requirements included in the above-mentioned regulations for floating structures refer to the scale of a single building.

Even though it is not a factual code, Deliverable 7.2. of the Horizon 2020 Research Project Space@Sea, provides a catalogue of technical requirements and best practices for the design of floating structures. The report (Lin et al., 2020) provides a list of functional requirements that guarantee a suitable design for living@sea from the users' perspective in terms of comfort, availability, working conditions, design of the living and the outdoor areas, communication, social life, leisure, safety, shopping, energy production, and waste management. The Space@Sea project report raises an issue of crucial importance: the uncertain legal status of floating structures sometimes identified as movable property and sometimes as immovable. In terms of property rights, it is necessary to give a legal form to floating cities by assigning floating platforms a registered "immovable legal entity" (Lin et al., 2022). Fen-Yu, Spijkers, and van der Plank suggest the use of plots registered with the help of the 3D cadaster as a possible solution (Lin et al., 2022).

1.5 Historical excursus on floating architecture

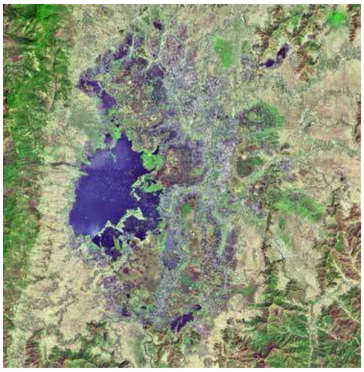
1.5.1. Vernacular floating architecture

Figure 9. Aberdeen Floating Village. Rows of old junks and sampan. Source: https://www.tripchinaguide.com/photo-p792-8856-an-old-picture-of-aberdeen-floating-village.htmlProject.

Figure 10. Ko Panyi floating village. Source: Drone photo by @jordhammond published on Archdaily on January 27, 2021

The idea of living on water is not new, as floating communities date as far back as Ancient Egypt. The phenomenon is ancient and typical of communities characterized by either forced or desired coexistence with this element, where their architecture has constantly been evolving to adapt to life on or with water. Floating villages have thrived in various forms and on a variety of water bodies throughout history (Wang, 2021). In rural areas of south-eastern Asia, particularly in Malaysia, Vietnam, and Indonesia, sampans (*shānban*) are widespread. They are wooden boats equipped with a cover that allows them to be used as homes in inland waters. The fishing community of Koh Panyee is just one of Thailand's many floating villages. Inle Lake, located in the heart of Myanmar, is dotted with floating houses and gardens. Cambodian lakes host several floating villages where large communities engage in aquaculture and fishing. In South America, houses on the water crowd the Amazon River and represent the only strategy for surviving the rainy season when the water level submerges the houses on land. On the Ganvie in Benin, Africa, the Tofinu tribe adopted the form of a floating village from as early as the 16th Century as a protective measure against slave trading. Beyond these examples, China, Peru, and Bolivia also have a history of floating villages.

Aberdeen Floating Village (Figure 9) is in Aberdeen Harbor in the Southern District of Hong Kong. The port contains more than 600 junks and is home to over 6,000 people. The people living on the boats in Aberdeen are mainly Tanka, an ethnic group that arrived in Hong Kong between the 7th and 9th centuries. The word *Tanka* means "egg people", a reference to the payment method used to pay taxes (with eggs instead of money). The overall population in 1841 was estimated to be around 2,000 people, rising to more than 150,000 in 1963. The number fell to 40,000 people in 1982 and declined further in subsequent decades due to the rapid development of fishing in the province of the Guadalong. Currently,



most of the so-called "boat people" do not live permanently in their boats, which now constitute only a means of transport and work.
The floating village of Ko Panyi (Figure 10) in Thailand is hidden in a bay in southern Thailand (Phang Nga) and protected by a huge limestone rock formation about 200 meters high. The village is home to more than 360 families and a total of 1,680 people (Ghisleni, n.d.). Its history begins at the end of the 18th century following a law that limited land ownership to people of Thai national origin only, and which therefore forced the Malay nomads to move onto water. Taking advantage of the calm, rich waters of the bay, they built a floating settlement that has expanded to include several amenities and infrastructures, including a school, a mosque, a health center, and even a soccer field.
The floating huts (Figure 11, 12) of Loktak Lake in Manipur, India, were built before the 18th century. These floating islands called *phumdis* are circular masses made up of vegetation, soil and organic matter (at different stages of decomposition) that have been thickened into a solid spongy form (Singh & Khundrakpam, 2011). Most of the mass of phumdis lies beneath the surface of the water. During the dry season, when the water level drops, the living roots of the islands can reach the bottom of the lake and absorb nutrients. The phumdis are home to around 200 species of aquatic plants and 400 species of animals, including the rare Indian python (NASA, 2018). The largest island hosts Keibul Lamjao, the world's unique floating national park, which is home to several endangered species. The lake's southern dam, built in the 1980s to supply power to India's northeastern states, has ensured that the water level remains high year-round, preventing the phumdis from sinking to the bottom of the lake for nutrients. As a result, the phumdis are slowly getting thinner and breaking.
Shifting attention to the Middle East, the floating islands of Al-tahla (Figure 13) located in the southern wetlands of Iraq (Ma'dan) at the confluence of the Tigris and Euphrates rivers, date back to 4000 BC. The islands are of two types, artificial anchored islands (called *al halif*) and natural floating islands called *tuhul* (Watson & Davis, 2019). On these islands, the Ma'dan can build floating homes without nails, wood, or glass. They are made entirely from qasab reeds harvested locally, in just three days. These reeds are similar to bamboo, about 8 meters tall, and flourish in all swamps. Construction begins in the fall when water is at its lowest.
In South America, on Lake Titicaca in Peru, the Uros civilization

Figure 11. Floating huts of Lotak Late, Manipur's Bishnupur district, India. Source: https://horizons.tatatrusts.org/2020/december/tata-trusts-manipur-loktak-lake-ecotourism.html

Figure 12. Satellite image of Floating huts of Lotak Late, Manipur's Bishnupur district, India.

Figure 13 (a, b). Al-Tahla floating Islands, Southern wetlands, Iraq. Source: (a) https://www.messynessychic.com/2014/11/12/the-floating-basket-homes-of-iraq-a-paradise-almost-lost-to-saddam/; (b) Lo—TEK. Design by Radical Indigenism, bu Julia Watson has been realizing floating islands (Figure 14) out of local organic dove reed since 1600 AD (Watson & Davis, 2019). Each floating island constitutes an autonomous community, a sort of production and housing infrastructure. Each community is equipped with an aquaculture farm. The islands are secured to the lake bottom with rock anchors and ropes. Today, 2,629 people live on 91 islands. The smaller islands, measuring 10 meters, accommodate one to three families, while the larger islands measuring 25 meters accommodate five to ten families in twelve to fifteen huts. The huts are positioned in front of a central outdoor space, occupied by a watchtower, while one side of the island is left open for mooring boats. Scattered among the huts are fish farms, vegetable gardens, and living dove reeds planted for privacy.

Inle Lake, in the center of Myanmar, is dotted with houses and floating gardens (Figure 15) created with ingenious solutions that involve the use of a humus of algae and mud from the lake arranged in thin strips supported by bamboo poles stuck in the ground. It hosts one of the largest floating markets in Southeast Asia.

It is within these existing typologies that several contemporary architects have found inspiration and technical solutions for their projects by integrating them with sustainable materials, innovative techniques, and smart energy systems. More modern floating docks came to the fore during World War II. When securing an existing harbor proved impractical, the idea of a movable harbor was conceived. Mulberry Harbor was an excellent example of a floating dock employed by the British in World War II. The harbor was designed in three sections: breakwaters, pier head, and walkway from the pier to the beach (Rehman, 2020). Since the end of the 18th century, as oil exploration stretched into deeper environments, offshore platforms built on piles began to be replaced by semi-submersible floating structures (Rehman, 2020).

Figure 14. Tortora reed floating islands in Lake titikaka, Peru. Source: https://www.bbc.com/travel/article/20220814-the-floating-homes-of-lake-titicaca

Figure 15. Lake Inle Kay La floating village, farming and fishing arrangements. Source: Flickr, Photo by Toby Harriman

1.5.2. Utopias from the '60s and '70s

The rapidly growing number of offshore structures, which often constitute unconventional settlements, have contributed to an amphibious transformation of Earth's surface over the 20^{th} and 21^{st} centuries (Huebner, 2022). This amphibious transformation means that both terrestrial and aquatic places have turned into human habitats.

Between the 1950s and '70s, the architecture community was fascinated with marine utopias (Kaji-O'Grady & Raisbeck, 2005). The technological optimism of this period led architects to consider whether they could build settlements in inhospitable places like the polar regions, the deserts, and the sea. The theme of using the sea as an alternative space to provide a solution to overcoming demographic, nutritional, and ecological problems was one of the major discussions in different countries. Several urbanists, architects, and visionaries began to rethink water, not only as a surface but as a living environment. Moreover, this vision of use, rather than exploitation, envisaged a perfect man-sea symbiosis and a positive ecological vision aimed to limit, if not eliminate, the problem of sea pollution (Gavric, 2010).

Historian Stefan Huebner emphasizes the role that Asian cities have played in shaping global urbanization ideas and practices, and thus in large-scale marine urbanization (Huebner, 2020). The Japanese Metabolists put forward pioneering projects such as Kenzo Tange's 1960 Tokyo Bay Plan (Figure 16a, b) and the Marine City proposals of Kiyonori Kikutake and Kishō Kurokawa (Lin & Tange, 2010). The first proposal for a Marine city appeared in 1958, as the outcome of the studies related to the pursuit of a replacement system in the urban environment, and a method of renovation of the land.

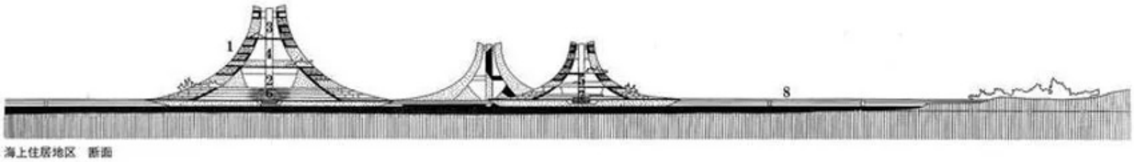


Figure 16a. Section of Tokyo Bay Plan by Kenzo Tange in 1960. Source: https://archeyes.com/plan-tokyo-1960-kenzo-tange/

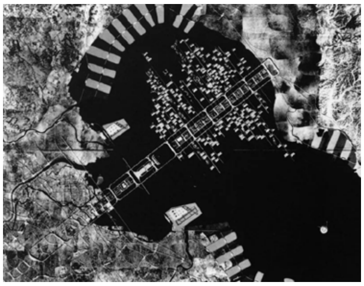


Figure 16b. Plan for Tokyo Bay by Kenzo Tange in 1960. Source: https://archeyes.com/plan-tokyo-1960-kenzo-tange/

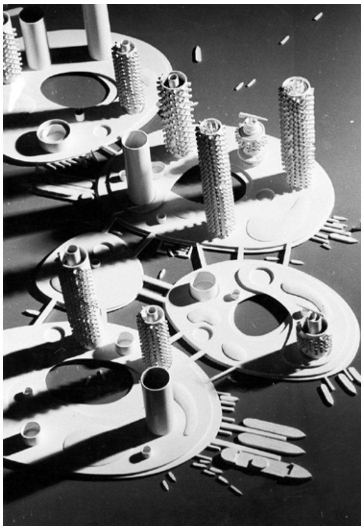


Figure 17. Proposal for Marine City 1963. Source: Special Exhibition on Floating Architecture held at the WCFS2023 - World Conference on Floating Solutions for the Next SDGs (28-30/08/2023)

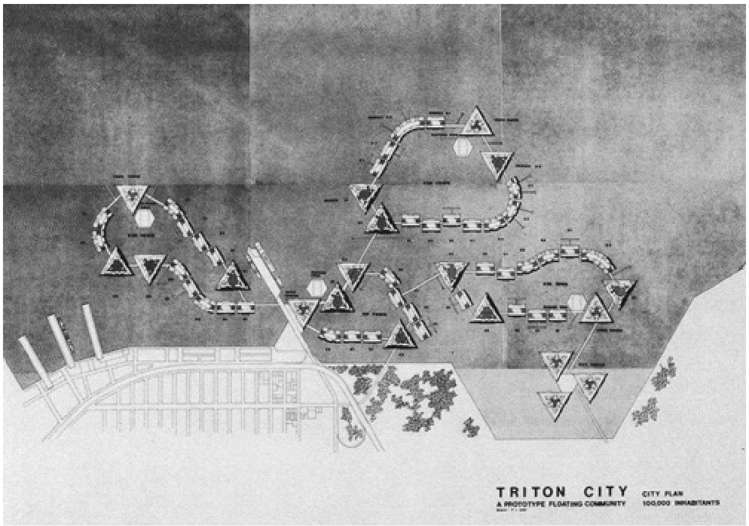
When the Soviet Union's artificial satellite Sputnik was launched successfully in 1958, the idea of developing a floating island to be used as a basis for urban space was announced. This introduced a new urban typology known as the floating city, which would replace the industrial sites of oil, steel, chemicals, and electrical industries. Major production facilities would be submerged underwater where the temperature is constant, and large constructions with several layers would float on top of the water at a height where they wouldn't be affected by waves. Another proposal by architect Kikutake was the Unabara Marine City in 1960. It is meant as an industrial production center for 500,000 inhabitants. It consists of two ring-shaped environmental segments, of which the inner one is defined as a living zone, and the outer as an industrial one. The two rings are connected by a control block where an information control center is placed. A soaring 500 metre-high floating tower stands amid the two rings and serves as the energy center. Installed atop is an artificial sun that lights up the whole city and an antenna for information activities. The island is provided with a seaport and airport. The city is rimmed with a technical circle that collects solar energy and absorbs tidal energy to protect the inner island city. Water space between the production zone and the living zone is used for farming, fishery, and plant culture.

Three years later, in 1963, Japanese Metabolist architects came up with the proposal for another Marine City (Figure 17) that consisted of a giant barge-type floating structure divided into a certain number of segments for stress absorption. There is a living area placed at the center, protected by surrounding industrial areas. Each floating platform meant for living space is a multi-stratum unit about the size of a city block. Each living space unit upholds several cylindrical buildings equipped with floats in water to offset their weight. Space units are linked with bridges which also serve as moorings. In line with the aim of meeting the growing needs of urban space, another plan to use space available on shallow offshore water while providing large-scale capacity was a flat seabed upon which tetrahedral mega-structures rest. Trigonal pyramids for public space are fixed on the seabed. Several of them are joined with bridge-shaped spaces. A high-rise space is laid upon the trigonal pyramids and a floating plaza is moored to the pyramids too. The project was meant for immediate offshore grounds close to urban centers and designed to accommodate free combinations of office buildings, communities, leisure, and touristic facilities.

As part of the Okinawa Marine Exposition in 1975, the Japanese government built a floating steel pavilion 100m x 100m large and 30m high (Figure 18). A flexible bridge was used to provide access from shore. Its capacity accounted for 2,000 visitors per hour. Water,

Figure 18. Aquapolis, Okinawa Marine Exposition in 1975 - World Conference on Floating Solutions for the Next SDGs (28-30/08/2023)

energy, and waste disposal were part of a closed circular system. The pavilion was produced at a ship-building yard in Hiroshima and was installed at Okinawa after being transported by sea.
In the same year, several studies were carried out for the design of a floating ground system intended for urban expansion on shallow calm waters close to big cities, known as the KIK Floating Platform Project. The system was designed to be used as a living space, thus the technical characteristics allow to minimize the motion caused by waves to a level that the human body cannot feel at all. In addition, the floating ground was provided with seismic isolation, contributing to a cost reduction of the upper building structure. Because of this, it can be used for a variety of purposes other than offices and residences, such as disaster relief bases.
In the '60s the American visioner and architect Buckminster Fuller was commissioned by a wealthy Japanese patron to design a floating city for Tokyo Bay to address housing demand problems. He designed a huge housing development on pontoons for 300,000 people using prefabricated modules built on land and shipped into place on the water. The methodology and systems for such a floating neighborhood were eventually labeled Triton City (Figure 19) and a scaled-down version was later considered for construction in Baltimore. In 1968, the United States Department of Urban



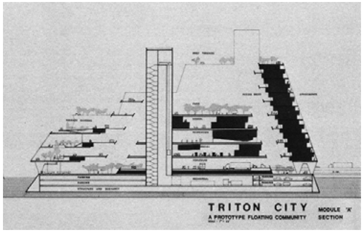


Figure 19. Triton City, project and Design study sketches by Richard Buckminster Fuller, 1968, Baltimore (US).
Top image: Section of one module.
Right image: Overall layout of the City.

Figure 20. Sea Farms by Archigram. Archived version of http://archigram.westminster.ac.uk/project.php?id=128 as of 16:39, 12/04/2013 (UTC). Preserved by the UK Web Archive.

Development commissioned Fuller for further design and analysis to determine the feasibility of developing the water areas of major cities by floating entirely new communities on the water adjacent to the urban core. His designs called for the city to be resistant to tsunamis, provide the most possible outside living, desalinate the very water that it would float in for consumption, give privacy to each residence, and incorporate a tetrahedral shape which provides the most surface area with the least amount of volume. In his technical report (Triton Foundation, 1968) Fuller includes: locational possibilities and site environment; population statistics and organization; area and space requirements; transportation; technical considerations; costs and cost comparisons; city problems and trends; social and economic considerations; recommendations and scope of further study. The findings of this study indicate that it is possible to provide waterfront living for large numbers of city dwellers on floating communities at the shores of USA major cities. However, as municipal, and federal administrations changed, the project languished and was never brought to light.

In the United States the historic attempt of the Hawaii Floating City '76 concept began in 1971 given the 200th anniversary of the independence of the USA and the Hawaii Ocean Exhibition, an event meant to trigger tourism through new attractions. To transform the idea into a built project, the State Government of Hawaii appointed a special team that was led by architect Kiyonori Kikutake and Dr. John P. Craven, system integrator and Dean of the Marine Program at the University of Hawaii. The construction site had to be 3 miles (about 5 km) offshore of Waikiki at a water depth of approximately 1,000 m. The plan envisaged a very large floating structure with a diameter of approximately 800 m hosting a central high-rise building with a diameter of 400 m. Along with architectural solutions, several environmental studies on winds, currents, and waves were carried out in order to provide adequate static stability, as well as several scaled prototype tests.

Always in the West, Archigram, a British neo-futuristic architectural group closely tied to the technocratic ideology of the American designer Buckminster Fuller (Frampton, 2020), proposed underwater sea farms (Figure 20). These proposals were directed at solving the impending urban crises of overpopulation and pressures on land-based resources. Many were even sophisticated enough to be patented.

The first UN Habitat conference (Habitat I), held in Vancouver in 1976, caught the arc of this worldwide architectural debate. In many ways, the UN have returned to the Vancouver Declaration from Habitat I, urging countries to adopt "bold, meaningful, and effective human settlement policies and spatial planning strategies", as well as to treat "human settlements as an instrument and object of development."

Following this architectural utopian thread, in 2008, Belgian ecological visionary architect Vincent Callebaut, proposed Lilypad (Figure 21), a floating 'ecopolis' for ecological refugees conceived as a solution to the loss of low-lying coastal land areas in response to

Figure 21. Lilypad floating ecopolis project by Vincent Callebaut, 2008. Source: Vincent Callebaut Architects (available at https://vincent.callebaut.org/object/080523_lilypad/lilypad/projects).

the threat of rising ocean levels (Rehman, 2019). Lilypad consists of a floating high-density mobile settlement that can thus be relocated according not only to changes in functional, dimensional, or social needs but also to natural growth patterns to reduce the impact on the marine environment. The mobility characteristic introduces a new biotechnological prototype of ecological resilience based on nomadism and the urban ecology in the sea. The multi-purpose facility operates as an amphibious half-aquatic, half-terrestrial city that can house 50,000 people (Beatley, 2014). Fauna and flora find their place around a central lagoon of soft water that collects and purifies rainwater falling on its superstructure. The entire superstructure is covered by a layer of planted houses in suspended gardens and is intersected by an organically outlined network of roadways and alleyways. The emphasis is on creating a harmonious coexistence with the surrounding natural environment and on exploring new modes of living alongside and within the sea by constructing fluid and collaborative spaces in close proximity. The structural elements take inspiration from the highly ribbed leaf of the Lilypad of the Amazonia Victoria Regia. The double skin is made of polyester fibers covered by a layer of titanium dioxide, which reacts to the ultraviolet rays allowing the absorption of atmospheric pollution through photocatalytic action. Entirely sufficient, Lilypad takes up the four main challenges launched by the OECD in March 2008: climate, biodiversity, water, and health. The floating ecopolis is also designed to be in a positive energy balance with zero carbon emission through the integration of all the renewable energies (solar, thermal, and photovoltaic energies, wind energy, hydraulic, tidal power station, osmotic energies, phyto purification, biomass) allowing the production of more energy that it consumes. The floating eco-polis is designed to adopt cutting-edge building services to allow the building to serve its surrounding oceanic ecosystems by producing and softening oxygen and electricity; recycling carbon dioxide and waste; purifying and softening biologically wastewater; and integrating ecological niches, aquaculture fields and biotic

26. Claiming a property to live there in a self-sufficient manner.

corridors on and under its body to meet its own food needs.
With his proposal, Vincent Callebaut launches a question and a provocation at the same time, wondering whether humanity is ready to change its idea of place, to detach itself from atavistic forms of belonging to Mother Earth, replacing the barren soil with the cold ocean waters.
A similar floating city idea, called Recycled Island, has been promoted by Dutch architect Ramon Knoester and the firm WHIM Architecture. Knoester envisions it as being located right on the Great Pacific Garbage Patch, with some half million residents who could help clean it up (Mead, 2011).
The intellectual history of maritime industrialization, its driving forces, and related environmental reflections, as confirmed by these projects, runs parallel to ecomodernism and green growth strategies.
While some early marine utopian plans addressed increasing urban challenges, many others envisioned seaborne leisure colonies. These settlements would be self-contained city-states, allowing residents to avoid tax laws and constraints on medical research in their home countries. These types of floating settlements became known as 'seateads', in other words, permanent homes at sea. Some authors (Sindhu et al., 2021) claim that the contemporary concept of a climate-resistant floating town has its roots in the seasteading movement, a vision led by the Seasteading Institute. Starting from the 1980s, Neumeyer (Neumeyer, 1981) in 1981 and Gramlich (Gramlich, 2014) later on introduced the term 'seasteading'[26], an aplological compound of sea and homesteading. Seasteading expresses the concept of creating seasteads, outside the territories claimed by the governments of existing nations. The Principality of Sealand, off the coast of Britain, established the precedent. A recent attempt to establish a sovereign micronation (seastead) off the coast of Thailand resulted in its supporters becoming fugitives, potentially facing the death penalty. Another interesting case occurred in the Adriatic Sea, 11,612 m from the coast or Rimini, where an artificial floating platform, known as the Island of Roses, was built deliberately located 500 m off the Italian territorial waters. It was conceived and designed by engineer Giorgio Rosa in 1958 and completed in 1967. On the 1st of May 1968, it declared itself an independent State. Although it gave itself an official language (Esperanto), a government, a currency, and a postage stamp, it was never formally recognized by any country in the world as an independent micro-nation. Overall, most of the seasteads proposed so far are modified cruise ships, oil rigs, decommissioned anti-aircraft platforms, and artificial islands.
Throughout the 1960s and 1970s, architects and visionaries were enthralled by the idea of creating floating cities. These utopian visions were driven by a combination of technological optimism, a desire to address growing urban challenges, and a fascination with the potential of the ocean as a new frontier for human habitation. The post-war period was characterized by a surge of technological innovation, which fueled the belief that humans could overcome

any obstacle, including the challenges of creating sustainable and livable communities in the marine environment. Architects like Kenzo Tange, Kiyonori Kikutake, and Archigram proposed ambitious projects that showcased the potential of floating cities to address population growth, resource scarcity, and climate change. The rapid urbanization of the 20th century strained existing cities, leading to overcrowding, pollution, and infrastructure challenges. Floating cities were seen as a way to expand urban space sustainably. The ocean has long been a source of fascination and inspiration for humans. The floating city proposals described above offer a new way to interact with the marine environment that seeks to coexist harmoniously with its ecosystems.

Nevertheless, most projects remained on paper owing to technical engineering challenges and social and economic issues such as property rights, governance, and financial viability. Despite the challenges, the concept of floating cities has continued to attract attention and inspire further innovation. As technological advancements and environmental concerns intensify, the potential of floating cities as sustainable and resilient urban solutions may gain renewed traction in the future. However, careful planning and consideration of the environmental, social, and economic implications will be essential for turning these utopian visions into reality.

1.5.3. Contemporary floating potential

In the most virtuous European and international contexts, water-based development is gaining increasing attention and is becoming a component of city plans for sustainable development and climate adaptation (Ernst et al., 2016). Several authors argue that combining food and energy production facilities with urban development will increase economic feasibility while also providing a climate-proof solution to urban population growth (Ernst et al., 2016; Zanon et al., 2017). The resilience and sustainability of floating habitats are embodied in their ability to withstand any natural disasters, in the use of renewable and self-sufficient energy systems and passive bioclimatic strategies and nature-based solutions, in zero land consumption, in the reduced environmental impact due to prefabrication and modular construction, in the ability to contribute to the decarbonization and regeneration of ecosystems, in the promotion of systems based on the circularity of material and immaterial resources (Moon, 2015).

In fact, floating architecture is characterized by an intrinsic resilience to climate changes linked to SLR – it is climate proof – thanks to a technological design linked to the type of soil. Water is an essential resource for most nature-based solutions: not only does it represent the essential element of blue infrastructure but it also plays a crucial role for green infrastructures. The inevitably isolated location of water-based architecture makes it the ideal space for the actual application of net zero energy and self-sufficiency principles, as the connection to the terrestrial electricity, water, and sewage

networks is not direct and easy.
Energy production through active systems such as algae bioreactors, solar panels, wind turbines, and power generators; food production through algae and fish farms and hydroponic agriculture; and water autonomy through desalination, are now consolidated practices. In addition, oceans are a huge potential source of energy. Global Energy Survey report stated that just 0.1% of ocean wave energy is enough to provide five times the world's energy needs (Lauzon et al., 2007). To date, a substantial number of technologies are being investigated with the aim of exploiting this potential. These include tidal and marine energy, wave energy, temperature difference, and salinity energy.
Shortly, large-scale floating suburbs and floating island cities are expected to be the next evolution of largescale pontoon technology. These urban forms will either be moored as extensions to coastal cities or free-floating cities in international waters (Rehman, 2020). Overall, floating development represents not only a solution for global land shortage but integrated with food and energy systems it provides a climate-proof sustainable urban expansion in delta and coastal areas.

1.5.3.1. Floating solutions to support climate refugees and vulnerable communities

Extreme weather, SLR, and degraded ecosystems are threatening the lives of millions of climate refugees. Between 2008 and 2016, a yearly average of 21.5 million people were forcibly displaced by weather-related catastrophes such as floods, storms, wildfires, and high temperatures (UNHCR, 2016). The term 'climate refugees' has been adopted since 1985, when UN Environment Programme (UNEP) expert Essam El-Hinnawi defined climate refugees as people who have been "forced to leave their traditional habitat, temporarily or permanently, because of marked environmental disruption". However – acknowledging how CC affects communities not only by causing immediate damage to people and infrastructure but also by triggering long-term risks that can slowly destabilize societies and economies – the extent of the definition should be broadened to anyone who has been directly or indirectly impacted by short- or long-term environmental changes. In addition to this, many climate refugees do not fit the definition of 'refugees' and thus cannot access legal protections for their human rights. However, the Global Compact on Safe, Orderly, and Regular Migration, adopted by the UN in 2018, clearly states that one of the main drivers for large-scale movements of people is “the adverse impacts of climate change and environmental degradation,” which includes natural disasters, desertification, land degradation, drought, and SLR. Not all climate-related threats can be addressed by exploring new solutions and technologies that allow us to cope and live with them without having to leave these vulnerable territories. Yet, in areas affected by land degradation or SLR, it is possible and even urgent to build new regions, districts, or single units that are suitable for new climatic conditions preventing migration in the first place. As highlighted by the UN in April 2019 (UN High-Level Round Table on Sustainable Floating Cities) resilient and sustainable floating solutions provide “a new arsenal of tools” to face severe land shortages that are compounded by climatic threats, leading to the next frontier for human habitation.

Serious efforts are underway in many coastal cities to rethink their boundaries considering SLR, population growth, and urban expansion, exploring the idea of a soft edge between land and water. In cities like Dhaka, for instance, the future is only on water, because of the combination of poverty, population density, and vulnerability to climate-related hazards such as cyclones, storm surges, coastal erosion, and SLR (World Bank, 2022). Climate experts predict that by 2050, rising sea levels will submerge around 15 % of Bangladesh according to a generalized radiation or diffusion model, and about 0.9 million people will be displaced. The number of displaced people will reach 2.1 million by 2100 (Davis et al., 2018). For this reason, the government is already working on climate-sensitive adaptation plans. In addition to the government, the non-profit sector has been introducing boats to provide floating schools, libraries, and health centers (Wax, 2007). Yet, some adaptation practices have enabled land capture by elites, public servants, the military, and roving gangs, and resulted in various forms of marginalization that compound vulnerability and risk (Sovacool, 2018); a reality also faced by many other coastal communities around the world.

Extremely ambitious projects are underway regarding the creation of entire floating cities, demonstrating that floating infrastructure can create new land for coastal cities by expanding onto the ocean in a sustainable way. One of them is Oceanix (Figure 22), a prototype of a resilient and sustainable floating city promoted by UN-Habitat, planned to be located near Busan Metropolitan City of the Republic of Korea. It has been designed by BIG (Bjarke Ingels Group) and SAMOO (Samsung Group) as lead architects, with the collaboration of Arup, Bouygues Construction, Helena, the MIT Center for Ocean Engineering, the Korea Maritime and Ocean University, Olafur Eliasson, Studio Other Spaces, Wartsila, Transsolar KlimaEngineering, Mobility in Chain, Sherwood Design Engineers, Agritecture, the Center for Zero Waste Design, Greenwave, and the Global Coral Reef Alliance. Oceanix is expected to host around 12 000 people on 3 platforms for a total of 6.3 hectares, and to be entirely self-sufficient in terms of food, net zero energy, zero waste, and closed loop water systems. The city is designed to grow and adapt organically over time by transforming from district to village and from village to city.

Another pivotal project is the Maldives Floating City, designed by Waterstudio.NL and Dutch Docklands in the Maldives near Male. It is inspired by traditional Maldivian sea-faring culture and developed in close cooperation with Maldivian authorities. It is designed to feature thousands of residences floating along a flexible, functional grid across a 200-hectare lagoon.

Some criticism was raised concerning the risk of discriminating

Figure 22. Oceanix City, Busan. Source: Oceanix (Available at: https://oceanix.com/)

and further marginalizing climate refugees – primarily low-income people of color, who are most often on the frontlines of CC – on remote offshore islands that are out of sight and mind, as stated by Billy Fleming, director of the University of Pennsylvania's McHarg Center for Urbanism and Ecology.

In this regard, the ship docked in the United Kingdom which will host up to 500 asylum seekers has caused great controversy. In July 2023, the barge known as Bibby Stockholm was towed by a tug into the port of Portland, off the southwest coast of England, secured under the Government's plans to reduce the cost of asylum accommodation. It is moored on the same spot as a prison ship, used to ease overcrowding for nine years until 2006. The barge can host 500 people distributed on three floors in 222 cabins of approximately 10 m^2 with one window, hosting 2 people (bunkbed), a desk, a shower, and a wardrobe. The barge contains some indoor communal spaces and a dining room as well as outdoor recreational spaces in two courtyards in the center of the barge. There has been considerable local opposition to the Bibby Stockholm, amid fears about the detention-like conditions in which residents live on board. More than 50 national organizations and campaigners, including the Refugee Council, Asylum Matters, and Refugee Action, defined the barge as "entirely inappropriate and inhumane". In fact, the Bibby Stockholm, built in 1976, was previously used as a temporary residence for offshore energy workers, with the big difference of hosting one person per cabin instead of two.

Regarding the topic of using floating solutions in case of environmental emergencies related to hazardous events, an innovative proposal was developed by the studio So? Istanbul in 2019. Istanbul has privatized up to 70% of its public open spaces designated as emergency assembly points providing shelter in case of earthquakes. The Fold & Float emergency house prototype addresses the opportunity of using water instead of land by virtue of its availability. Its light and foldable structure provides rapid and easy installation in the case of an emergency. It is composed of an upper foldable steel structure integrated with fixed foldable furniture and a floating concrete pontoon. Significant attention on living quality is due to the awareness that earthquake and flooding victims spend at least one year in temporary housing following a disaster.

These examples highlight several limits and potential of floating cities within the humanitarian field. On one hand floating cities could exacerbate social and equity issues by further marginalizing low-income communities and people leading to displacement and dispossession of existing communities. There are a number of legal and regulatory hurdles that would need to be overcome in order to establish floating cities within an inclusive perspective. On the other hand, floating cities could offer a more resilient solution to sea level rise, extreme weather events, and other climate-related hazards, than traditional land-based cities. However, public engagement and collaboration with coastal communities are needed to develop cost-effective, sustainable, and equitable floating city projects.

1.5.3.2. Floating potential to address environmental issues

The current challenge towards more resource-efficient cities is to transform urban metabolism from linear to cyclical. In water-based habitats, the difficulty of using land-based sewage systems, and EU decarbonisation targets, require new floating developments to be zero-waste and circular systems. Discharged nutrients from organic waste and carbon dioxide, produced by coastal cities, can be reused to grow algae for energy, biofuel for energy self-sufficiency, and compost for fish farms and plant products. Algae are able to fix carbon very efficiently by photosynthesis into energetic storage compounds such as starch or lipids (Wang et al., 2008). Oil and feed can be extracted from algae and be used respectively for energy and as input for fish feeding in aquaponic systems.

Other environmental benefits of floating development include:

- river connectivity: floating development can provide longitudinal connectivity along the river length as well as lateral connectivity between a river and the wetlands and floodplains on either side of the river (Australian Government, 2023);
- habitat biodiversity increase: floating development can stimulate diversity in water environments by providing a substrate and protection from wave action (de Lima et al., 2022);
- less pressure on sand mining: up to 50 billion tons of sand and gravel are mined each year to meet soaring demand from construction and land reclamation, making it the largest extractive industry today (Koehnken & Rintoul, 2018).

1.5.3.3. Floating potential for energy production

Floating development is seen as a potential to address not only environmental concerns but especially for harvesting energy from the ocean. Indeed, marine renewable energy (MRE) can provide a huge potential source of energy that is more consistent and predictable than that of other renewable resources such as sun or wind. Ocean energy derives from the potential, kinetic, thermal, and chemical energy of seawater, which can be transformed to provide electricity, thermal energy, or potable water. A wide range of technologies is already available, such as barrages for tidal range, submarine turbines for tidal and ocean currents, heat exchangers for ocean thermal energy conversion (OTEC), wave energy converters (WEC) to harness the energy of waves, and a variety of devices to harness the energy of salinity gradients. Ocean technologies, except for tidal barrages, are at early-stage pilot project phases and many require additional research and further development. Some of the technologies have variable energy output profiles with varying levels of predictability (e.g., wave, tidal range, and current), while others may be capable of near-constant or even controllable operation, like ocean thermal and salinity gradient (Edenhofer et al., 2011).

Energy production and self-sufficiency are crucial for ensuring life on water. As a result, one of the premises for the long-term, cost-effective, and sustainable development of inhabiting water is the on-site production of energy, hence self-sufficiency. Future floating development could pave the way for integrated highly efficient energy hubs. CNR-INM[27] together with NTNU-AMOS[28] have developed a Floating Energy Archipelago (FEA) concept for deep-water marine areas, typical of the Mediterranean Sea (CNR-INM, 2021). FEA is conceived as a floating and modular smart-hub, energetically independent, able to harvest MREs (solar, wind, thermal, and wave energy) and use it for *in situ* human and industrial activity. The integration of multiple renewable sources of energy (REs) harvesting systems, provided with *in situ* use of the stored energy, allows to optimize the overall effectiveness of the hub balancing the inconstancies of each RES with the others. More precisely, the FEA includes a circular system of breakwaters to create an internal protected area against rough sea-weather conditions, that also act as wave energy converters. The breakwater/WEC system defines two areas; an external area where floating wind turbines, able to resist rough sea, are installed, and an internal protected area characterized by milder sea waves. The latter provides an optimal site for hosting floating pontoons for living purposes, food production or water desalinization, electrolysers for green hydrogen production, or even PV solar panels. The balance between energy harvesting and energy use or storage is optimized within an automation management system. The harvested energy is fully or partially used in situ, avoiding the need for costly pipelines or electrical cables.

The H2020 Space@Sea Project has also worked on the development of scalable modular floating islands as renewable energy centers, marine living quarters, aquaculture, and maritime transport.

The COST Action MODENERLANDS[29] aims to merge and systematize the efforts of the European Research and Development groups

27. Consiglio Nazionale delle Ricerche (CNR) is the largest research council aimed at supporting scientific and technological research.

28. Centre for autonomous marine operations and systems (AMOS) of the Norwegian University of Science and Technology (NTNU).

29. COST (European Cooperation in Science and Technology) Action MODENERLANDS - Resilience of Modular Sustainable Energy Islands In Face Of Climate Change Challenges - to which I took part in the occasion of the MODENERLANDS Cost Action Training School, funded by the European Union COST funding program, held in Estoril and organized by the Universidade de Coimbra (Prof. Ing. Carlos Rebelo).

working on Sustainable Energy and the related technologies, in particular wind and wave energy sources, by proposing pathways for integrated energy systems. With a view toward future sustainable energy infrastructure, MODENERLANDS proposes safe, smart, modular, cost-effective, and socially valuable high-performance sustainable floating energy islands. The offshore modular floating platforms are conceived to easily extend their size and capacity according to future energy needs, acting as a platform to maximize the collection and conversion of RES and efficiently transfer them to the network, exploring cutting-edge Green Hydrogen-related technologies for efficient energy storage and transportation. Working Group 2 is coordinating research activities addressing the integrity and sustainability of modular offshore floating platforms including construction issues, incorporation of recycling/reuse strategies, hybrid energy systems integration, floating systems technology development, wind/wave/current structural interaction and loading, fabrication and execution of large structures, operational functionality, structural health and condition monitoring, cost efficiency, regulatory and standardization.

Shifting the focus from hydro-related RES to conventional on-land RES, several authors agree that, compared with traditional terrestrial photovoltaic (PV) systems, floating PV systems can save a lot of land and water resources and obtain higher power generation efficiency than PV panels on land since water and wind cool the panels (L. Liu et al., 2017; Sahu et al., 2016). Current technologies for floating solar PV panels include lightweight supporting structures, storm-safe devices, and special coating to prevent rust or corrosion. Yet, currently, the costs for a floating system are about 10-20% higher than for ground-mounted systems (O'Malley, 2023).

Yet, although a general scientific consensus has been reached about the advantages of floating systems, very few in-depth studies focus on the specifications of floating PV systems. The downside of floating energy production infrastructure is its environmental impact. Even though it has recently become a research concern, the long-term impacts are currently unknown. Since the commercial PV market has expanded significantly, there is a pressing need to continue to monitor the long-term environmental impacts of floating solar, particularly on inland water bodies.

Floating wind turbines represent one of the most important advancements in the RES sector due to the great advantages over onshore wind energy production. Hywind Scotland is the world's first commercial wind farm using floating wind turbines, situated 29 kilometers off Peterhead, Scotland. The farm has five 6 MW Siemens direct-drive turbines on Hywind floating monopiles, with a total capacity of 30 MW (Hill, 2018).

1.5.3.4. Floating potential for the food production

Currently, cities are almost entirely dependent on surrounding regions to provide food and energy to sustain urban populations and activities (Pincetl et al., 2012). Population growth and urbanization are progressively leading to an increase in the global food demand within cities resulting in a rise in global greenhouse gas emissions, land consumption, resource depletion, and social tensions (Battisti et al., 2023). Food and related activities – production, processing, distribution, consumption, and post-consumption – are key contributors to urban-scale unsustainability in environmental, social, and economic terms (Marsden & Sonnino, 2007). Since the relationship between places of production and consumption, between city and rural, metropolitan and peri-urban areas, is a critical node in food policy (FAO, 2011), it is essential to strengthen this link within more globalized and interconnected food production-consumption models. Due to the scarcity of available empty land within cities, agri-food production systems often play a marginal role in temporal (transient), spatial (interstitial), social (women and low-income groups), and economic (financial crisis, food shortage) terms. Floating farming (FF) solutions (Figure 23) represent a zero-land footprint strategy that takes advantage of the continental and tidal hydrographic network (rivers, lakes, basins, deltas, coastline) for housing greenhouses or even farms for local food production (Battisti et al., 2023). Floating farming facilities significantly contribute to reducing the burden on freshwater by using seawater desalination techniques or rainwater collection, providing new cultivable or breeding surfaces where permeable land is scarce, particularly in high-density urban areas, to reducing transport costs; providing the possibility of re-location in more appropriate sites when a given location is no longer suitable for any reason (environmental or pollution risks, political conflicts, urban population shifts). Furthermore, floating greenhouses or breeding farms could be designed as multi-level vertical systems to increase overall farming surface and yield, ensuring the economic viability of the floating farm concept (Battisti et al., 2023).

Floating agriculture is a vernacular soilless practice widely spread over southeast Asia (Lake Inle Kay La floating village with farming and fishing arrangements), the Middle East (Al-Tahla floating Islands in the southern wetlands of Iraq), and South America (Tortora reed floating Islands in Lake Titikaka, Peru). Different low-tech systems have been used for thousands of years and have allowed farmers to grow crops in flood-prone areas, wetlands, or lakes, where no other land use was conceivable. These systems usually consist of plants on rafts made of composted water weeds piled up on water bodies, by simply stripping nutrients released from decomposing organic material (Pantanella et al., 2010). These systems are now seen as a strategy to cope with the combined effects of urbanization, land consumption, soil permeabilization, and CC in areas that are more vulnerable to SLR and coastal erosion, where flooding prevents land from being used for agriculture for extended periods (Parvej, 2007) or where there is no available land for agri-production. In Bangladesh, the age-old tradition of floating agriculture, which dates as far back as the 1600s, is gaining momentum as an innovative climate adaptation strategy and nature-based solution. Supple water hyacinths are used to build a floating base on which

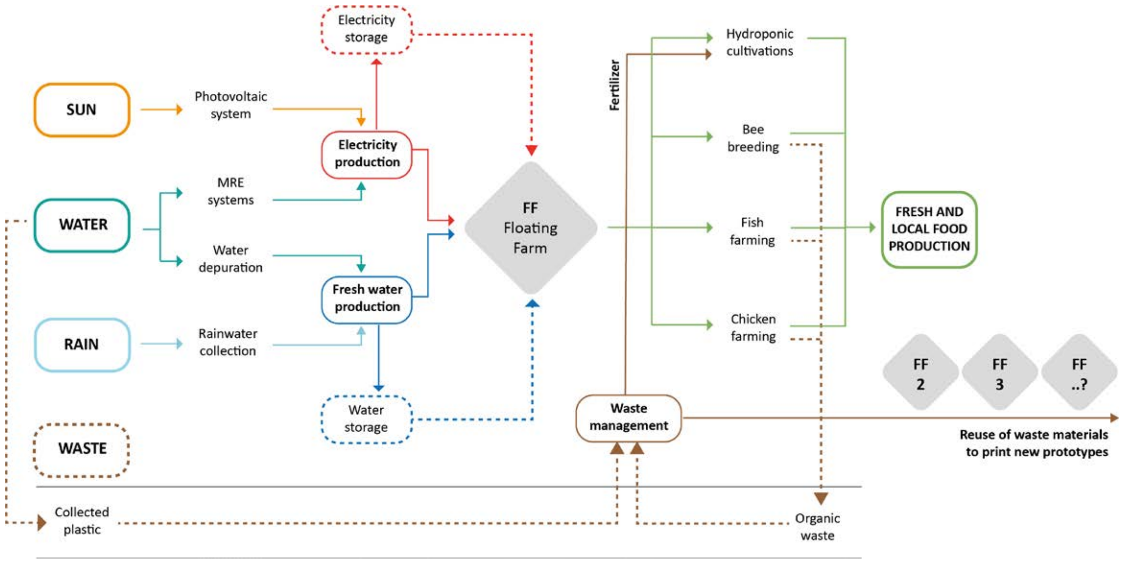


Figure 23. Resource circularity of the floating farm concept. Source: Livia Calcagni, Alberto Calenzo for the chapter "Design for Adaptation: soluzioni circolari clima-adattive per gli insediamenti urbani" in the volume "Progettazione Ambientale, Sfide Globali, Scenari Di Ricerca" SITdA 2024.

to grow seedlings or vegetables without the need for soil, providing a low-cost agricultural method. On the other side of the world, the port of Rotterdam is home to the world's first floating dairy farm. The three-story farmhouses 40 free-range cows and produces cheese and organic fertilizer. Another example of integrated agri-food production in the city is Jellyfish Barge, a floating greenhouse module that aims to minimize energy, water, and soil footprint. Jellyfish barge uses hydroponic cultivation with 70% water savings compared to traditional agriculture (PNAT, 2022).

The Forward Thinking Architecture firm is branching out and transforming the way we think about agriculture and water. Its Smart Floating Farm (SFF) concept consists of an offshore three-story floating facility that will host large hydroponic crops and fish farms beneath them. It is designed to be built off the coast of a city to produce both fish and vegetables using a simple system of linkages between different operational layers. The structure's composition is inspired by traditional Asian fish floating farms, but it also features two additional layers, one for growing any type of plant and another to supply the needed energy through solar energy conversion. Aside from the actual growth of plants (automated hydroponics) and hatching of fish, water-access points, and a desalination plant (to convert ocean water to fresh water and then use it for farming) are provided, as well as an abattoir for the fish and a packaging facility. Solar panels, wind turbines, and WECs have the potential to convert natural forces into useful electricity. It can produce 8.1 tons of fruits and vegetables and 1.7 tons of fish per year. The factory would be almost completely automated using sensor systems to capture data and fine-tune the farms to work as effectively as possible. Currently, it is an extremely ambitious concept. Yet, it raises a significant point: we could feed ourselves with low ongoing costs if we simply used endless and predictable resources such as the sun and the ocean.

Due to the high expense of desalination systems to produce irrigation water, and to the low salt-tolerance of crops, alternative technologies have gradually emerged. Japanese start-up N-ARK has combined salt-tolerant technology with floating architecture to tackle the issues of SLR and salt damage. In partnership with CULTIVERA agri-tech company, they aim to build a prototype of a floating marine farm entitled Green Ocean, conceived to float on the coast along urban areas. The facility makes use of a seawater agriculture technique based on moisculture, a humidity-controlled cultivation technology that reproduces the natural soil surface layer of about 15 cm using special fibers of 5 mm in diameter. Saline agriculture fertilizer is produced thanks to a special circular process that absorbs water and nutrients in the air and mixes and neutralizes alkaline seawater and acidic rainwater. Moisculture requires only one-tenth of the amount of water used in conventional irrigation farming.

Another widespread practice is the integration of aquaculture within wider farming systems, contributing to the development of synergies between farming operators. Such systems are known as Integrated Agri-Aquaculture Systems (IAAS) and can help to improve water nutrient balance through chemical or natural fertilization. IAAS generally comprise three major subsystems: aquaculture, agriculture, and household. Common positive interactions of agri-aquaculture systems include the use of animal manure as pond fertilizer, the use of crop by-products as supplementary feed for fish, the use of pond sediments as terrestrial crop fertilizers, and the use of aquaculture wastewater for crop irrigation.

Overall, combining production facilities with the urban environment on the water is expected to boost the economic feasibility of floating solutions while also providing climate-proof expansion for a growing urban population (Battisti et al., 2023).

1.5.3.4. Floating potential for the dynamic city

Urban structures have a longer lifespan than the program of requirements on which they were based during their development. Building on water changes the whole perspective of city planning (Olthuis, 2010).

Demographic, financial, social, or political developments drive city administrations to find a balance between requirements of city dwellers and the urban environment. Because of the shifting balance between the economic value of a building and the economic value of its location, the economic lifespan of buildings (rather than the technical one) declines. As a result, a building in relatively good condition risks to be demolished because of the changing needs of its location. With floating buildings, districts, and cities, gradually, an increasing number of buildings and functions will no longer be inextricably fixed to their physical location. This opens the way to a future city in which buildings and functions could be moved throughout the duration of their life. For instance, in response to the growing demand for urban services and the need for resilient urban developments, the mobility characteristic of floating structures opens a new potential for water to meet the demands of urban users in a timely and efficient manner as well as a means to activate and improve public spaces. The use of movable floating elements to improve public spaces and raise their attractiveness is an innovative approach that has gained traction in recent years. Floating units could move according to the optimization of weather conditions, day type, urban functions, public transportation stations, and pedestrian networks to establish different scenarios throughout the day, the season, or the years. The result of constantly location-changing floating facilities, for instance, could provide an optimized network for service accessibility. Data-driven technology and machine learning can help to ensure that cities are resilient and adaptive in the face of changing environmental conditions. Data-driven tools would be crucial for analyzing in real-time frequency, demand, and geographic distribution of users as well as floating services over time; for optimizing the movement and relocation of floating services, and for on-site monitoring to provide further data and insights to fine-tune the process.

The components of the building's value are given by its functional and technical characteristics and by its location. The value of the technical components declines at a constant rate, while the value of the location undergoes exogenous and unpredictable shocks and is, therefore, highly variable. By separating the two value components, a mobile structure allows to act (and therefore maximize) on the value component linked to the location.

As Koen Olthuis, founder of Waterstudio.NL, highlights in his book *Float!* (Olthuis, 2010), in this perspective, buildings will no longer be demolished before they have reached the end of their technical life, as they can be relocated to a site where the remaining economic value of the building is more consistent with the value of the location. In this transition, the building is no more immovable property and becomes a product. Waterstudio.NL, within its R&D Urban Water Laboratory, is in the process of developing a tool that can anticipate and respond to the demands of city dwellers within waterfront cities, with a focus on enhancing urban resilience. The tool is fed by statistical data to capture user activities in each area in a particular time frame. The tool can learn and adapt to better meet user demands by iteratively analyzing the data from the time survey. It involves the use of reinforcement learning to improve the deployment time of floating structures to different demand locations.

References

Abrams, J. F., Hohn, S., Rixen, T., Baum, A., & Merico, A. (2016). The impact of Indonesian peatland degradation on downstream marine ecosystems and the global carbon cycle. Global Change Biology, 22(1), 325–337. doi: https://doi.org/10.1111/gcb.13108

Agardy T, Alder J, Dayton P, Curran S, Kitchingman A, Wilson M, Catenazzi A, Restrepo J, Birkeland C, Blaber S, Saifullah S, Branch G, Boersma D, Nixon S, Dugan P, Davidson N, Vorosmarty C (2005) Coastal systems. In Reid W (ed) Ecosystems and human well-being, (Vol 1. Current state and trends, Millennium Ecosystem Assessment Series, pp. 513–549). Island Press, Washington, D.C.

Aldrete, G. S. (2007). Floods of the Tiber in ancient Rome. Baltimore: JHU Press.

Alexander, C. (1964). *Notes on the Synthesis of Form* (Vol. 5). Cambridge: Harvard University Press.

Arias, P. A., Bellouin, N., Coppola, E., Jones, R. G., Krinner, G., Marotzke, J., Naik, V., Palmer, M. D., Plattner, G.-K., & Rogelj, J. (2021). Technical summary. In Climate for Change Non-State Actors and the Global Politics of Greenhouse (Vol. 51). Cambridge University Press.

Arnheim, R. (1977). *The dynamics of architectural form*. Berkeley: University of California Press.

Asimow, M. (1962) *Introduction to design.* New Jersey: Prentice Hall.

Australian Government (2023). River flows and connectivity. Retrieved from: https://www.mdba.gov.au/climate-and-river-health/water-environment/river-flows-and-connectivity

Baker, L. (2015). Built on water: Floating architecture + Design. Switzerland: Braun Publishing

Baker, R., & Coutts, R. (2016). *Aquatecture: Buildings and cities designed to live and work with water.* London: RIBA Publishing

Balestri, E., Vallerini, F., & Lardicci, C. (2017). Recruitment and patch establishment by seed in the seagrass Posidonia oceanica: importance and conservation implications. *Frontiers in Plant Science, 8*. doi: 10.3389/fpls.2017.01067

Barbier, E. B. (2015). Climate change impacts on rural poverty in low-elevation coastal zones. *Estuarine, Coastal and Shelf Science, 165*, A1–A13. doi: 10.1016/j.ecss.2015.05.035

Battisti, A., Calenzo, A., & Calcagni, L. (2023). Experimental living and housing forms: cities of the future as sustainable and integrated places of food production. In A. Battisti (Ed.), *Future Housing*. London: Intechopen. doi: 10.5772/intechopen.113213

Baumeister, J., Bertone, E., & Burton, P. (2020). *SeaCities: Urban Tactics for Sea-Level Rise*. Berlin:

Springer Nature.

Baumeister, J., & Linaraki, D. (2022). *Cities+ 1m: Urban Development Solutions for Sea Level Rise*. Berlin: Springer Nature.

Bazrkar, M.H., Zamani, N., Eslamian, S., Eslamian, A., Dehghan, Z. (2015). Urbanization and Climate Change. In: Leal Filho, W. (eds) Handbook of Climate Change Adaptation. (619–655) Berlin, Heidelberg: Springer. doi: 10.1007/978-3-642-38670-1_90

Beatley, T. (2014). *Blue urbanism: exploring connections between cities and oceans*. Washington, DC: Island Press. doi: 10.5822/978-1-61091-564-9

Bendixen, M., Best, J., Hackney, C., & Iversen, L. L. (2019). Time is running out for sand. *Nature, 571*(7763), 29–31.

Benham, C. F., Beavis, S. G., Hendry, R. A., & Jackson, E. L. (2016). Growth effects of shading and sedimentation in two tropical seagrass species: Implications for port management and impact assessment. *Marine Pollution Bulletin, 109(1)*, 461–470. doi: 10.1016/j.marpolbul.2016.05.027

Berman, I. (2010). Amphibious territories. *Architectural Design, 80(3)*, 66–73. doi: 10.1002/ad.1077

Blachère, G. (1966). *Savoir batir: habitabilité-durabilité, economie des bâtiments.* Paris: Editions Eyrolles.

Bradshaw, A. D. (1984). Ecological principles and land reclamation practice. *Landscape Planning, 11(1)*, 35–48.

Brown, S., Nicholls, R. J., Woodroffe, C. D., Hanson, S., Hinkel, J., Kebede, A. S., Neumann, B., & Vafeidis, A. T. (2013). Sea-Level Rise Impacts and Responses: A Global Perspective. In Finkl, C. (eds) *Coastal Hazards. 1000.* Dordrecht: Springer.doi: 10.1007/978-94-007-5234-4_5

Burdick, D. M., & Roman, C. T. (2012). Salt marsh responses to tidal restriction and restoration: a summary of experiences. In Roman, C.T., Burdick, D.M. (eds) *Tidal Marsh Restoration. The Science and Practice of Ecological Restoration.* Washington, DC: Island Press. doi:10.5822/978-1-61091-229-7_22

Burke, L., Kura, Y., Kassem, K., Revenga, C., Spalding, M., McAllister, D., & Caddy, J. (2001). *Coastal ecosystems*. Washington, DC: World Resources Institute.

Cable, C. (1982). The Houseboat as domestic architecture. Vance Bibliographies.

Cambi, F., & Terrenato, N. (2000). *Introduzione all'archeologia dei paesaggi.* Roma: Carocci Editore.

Cazenave, A., & Cozannet, G. Le. (2014). Sea level rise and its coastal impacts. *Earth's Future, 2(2)*, 15–34. doi: 10.1002/2013EF000188

Cerutti, A., Chiavoni, E., Esposito, D., & Impiglia, C. (2017). Un singolare paesaggio marino come palinsesto storico tra il delta del Tevere e il mar Tirreno. Dall'antico Portus Augusti et Traiani all'Oasi di Porto. In *La Baia di Napoli. Strategie integrate per la conservazione e la fruizione del paesaggio culturale. 2* (pp. 171-176).

Chermayeff, S., & Alexander, C. (1965). *Community and privacy: Toward a new architecture of humanism.* New York: Doubleday.

Chermayeff, S., & Tzonis, A. (1971). *Shape of community: realization of human potential*. London: Penguin.

CNR-INM. (2021). *Report CNR-INM Progetto RDS: Energia elettrica dalmare, 2019-2021*. CNR.

Cohen, J. E., & Small, C. (1998). Hypsographic demography: the distribution of human population by altitude. Proceedings of the National Academy of Sciences, 95(24), 14009–14014.

Columbia, B. (1993). Float Home Standard. Ministry of Municipal Affairs, Building Standards Branch.

COM (2009). *White paper - Adapting to climate change: Towards a European framework for action*. European Commission.

Comune di Roma Ufficio Clima (2024). *Proposta di Strategia di Adattamento Climatico*. Comune di Roma

Creel, L. (2003). *Ripple effects: population and coastal regions*. Washington, DC: Population reference bureau.

da Cunha, D. (2019). *The invention of rivers: Alexander's eye and Ganga's descent.* Philadelphia: University of Pennsylvania Press. ISBN 978-0-8122-4999-6

Dal Bo Zanon, B., Roeffen, B., Czapiewska, K. M., de Graaf-van Dinther, R. E. (2020). Potential of Floating Urban Development for Coastal Cities: Analysis of Flood Risk and Population Growth. In *Lecture Notes in Civil Engineering. 41*. doi: 10.1007/978-981-13-8743-2_17

Dal Bo Zanon, B., Roeffen, B., Czapiewska, K. M., de Graaf-Van Dinther, R. E., & Mooij, P. R. (2017). Potential of floating production for delta and coastal cities. *Journal of Cleaner Production, 151*, 10–20.

de Lima, R. L. P., de Graaf, R. E., & Boogaard, F. C. (2022). Impacts of floating urbanization on water quality and aquatic ecosystems: a study based on in situ data and observations. *Journal of Water and Climate Change, 13(3)*, 1185–1203.

de Graaf, R. (2020). *Climate resilient urban areas: Governance, design and development in coastal delta cities*. Springer Nature.

de Graaf, R. (2012). *Adaptive urban development. A symbiosis between cities on land and water in the 21st century*. Rotterdam: Rotterdam University Press

Dennis, B., & Case, B. (1977). *Houseboat: reflections of North America's floating homes - History, architecture, and lifestyles*. Smugglers Cove Pub.

Deudero, S., Vázquez-Luis, M., & Álvarez, E. (2015). Human stressors are driving coastal benthic long-lived sessile fan mussel Pinna nobilis population structure more than environmental stressors. *Plos One, 10(7)*, doi: 10.1371/journal.pone.0134530

Dias, J. M. A., Rodrigues, A., & Magalhães, F. (2014). Evolução da linha de costa, em Portugal, desde o último máximo glaciário até à actualidade: síntese dos conhecimentos. *Estudos Do Quaternário/Quaternary Studies, 1(1)*. doi: 10.30893/eq.v0i1.8

Durão, V. C. M. (2012). Reclaimed land: an urban analysis–The landfills in Lisbons downtown and riverfront. *Journal of Integrated Coastal Zone Management, 12*, 1–17.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., & von Stechow, C. (2011). Renewable energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change. Cambridge University Press.

EEA. (2018). L'acqua in città. Retrieved from: https://www.eea.europa.eu/it/segnali/segnali-2018/articoli/l2019acqua-in-citta%0A

El-Shihy, A. A., & Ezquiaga, J. M. (2019). Architectural design concept and guidelines for floating structures for tackling sea level rise impacts on Abu-Qir. *Alexandria Engineering Journal, 58(2)*, 507–518.

English, E. (2009). Amphibious foundations and the buoyant foundation project: Innovative strategies for flood resilient housing. *International Conference on Urban Flood Management*, 25–27.

Ernst, L., Dinther, R. E. D. G., Peek, G. J., & Loorbach, D. A. (2016). Sustainable urban transformation and sustainability transitions ; conceptual framework and case study. *Journal of Cleaner Production*, 112, 2988–2999. doi: 10.1016/j.jclepro.2015.10.136

Evans, A. J., Garrod, B., Firth, L. B., Hawkins, S. J., Morris-Webb, E. S., Goudge, H., & Moore, P. J. (2017).

Stakeholder priorities for multi-functional coastal defence developments and steps to effective implementation. *Marine Policy, 75*, 143–155.

FAO (2011). Food , Agriculture and Cities. Challenges of food and nutrition security, agriculture and ecosystem management in an urbanizing world. Rome: FAO

Farbstein, J. (1974). The definition and description of activity. *Journal of Architectural Research, 3*, 18–25.

Few, R., Brown, K., & Tompkins, E. L. (2007). Climate change and coastal management decisions: insights from Christchurch Bay, UK. *Coastal Management, 35(2–3)*, 255–270. doi: 10.1080/08920750601042328

Field, C. B., & Barros, V. R. (2014). *Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects*. Cambridge University Press.

Fitch, J. M. (1948). *American building: the forces that shape it*. Houghton Mifflin Company.

Flanagan, B. (2003). *The houseboat book*. Los Angeles: Universe Publishing Group.

Flesche, F., & Burchard, C. (2005). *Water house*. Munich: Prestel Publishing.

Fox-Kemper, B., H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.L. Edwards, N.R. Golledge, M. Hemer, R.E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I.S. Nurhati, L. Ruiz, J.-B. Sallée, A.B.A. Slangen, Y. Yu, (2021). Ocean, Cryosphere and Sea Level Change. In Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. et al. (eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1211–1362). Cambridge and New York: Cambridge University Press. doi: 10.1017/9781009157896.011.

Frampton, K. (2020). *Modern architecture: a critical history (world of art).* London: Thames & Hudson.

Frank, P. (2008). *Houseboats of sausalito*. Mount Pleasant: Arcadia Publishing.

Fujikubo, M., & Suzuki, H. (2014). Mega-float. In *Large Floating Structures: Technological Advances* (pp. 197–219). Singapore: Springer.

Fumeaux, L., & Rey, E. (2012). Integration of Sustainability Issues into the Design Process of a Temporary Event Infrastructure. In *Proceedings of PLEA 2012, 28th international Conference on Passive and Low Energy Architecture, Lima, Peru, 2012.*

Gavric, M. (2010). *Abitare l'acqua. Architettura galleggiante*. Roma: Sapienza Università di Roma.

GCA, G. C. on A. (2022). 5 reasons why floating development is set to take the world by storm. Retrieved from: https://gca.org/5-reasons-why-floating-development-is-set-to-take-the-world-by-storm/#:~:text=Today's cities only provide 40,planet%2C" said geographer Dr.

Gerigk, M. (2013). Wykorzystanie obszarów morskich pod zabudowę o przeznaczeniu wielofunkcyjnym. *Scientific Journal of Gdynia Maritime University, 82*, 5–14.

Ghisleni, C. (2021). Ko Panyi: A Floating Village in Thailand. Archdaily. Retrieved from https://www.archdaily.com/955269/ko-panyi-a-muslim-floating-village-in-thailand

Gill, J. C., & Malamud, B. D. (2014). Reviewing and visualizing the interactions of natural hazards. *Reviews of Geophysics, 52(4)*, 680–722.

Gregory, S. A. (1966). Design and the design method. In Gregory, S.A. (eds) *The Design Method*. (pp. 3–10). Boston, MA: Springer. doi: 10.1007/978-1-4899-6331-4_1

Gross, J. E., Woodley, S., Welling, L. A., & Watson, J. E. M. (2016). Adapting to Climate Change: Guidance for protected area managers and planners. *Best Practice Protected Area Guidelines Series No. 24*. Gland, Switzerland: IUCN.

Habibi, S. (2015). Floating Building Opportunities for Future Sustainable Development and Energy Efficiency Gains. *Journal of Architectural Engineering Technology, 04(02)*. doi: 10.4172/2168-9717.1000142

Hardy, R. D., & Hauer, M. E. (2018). Social vulnerability projections improve sea-level rise risk assessments. *Applied Geography, 91*, 10–20. doi: 10.1016/j.apgeog.2017.12.019

Hauer, M. E. (2017). Migration induced by sea-level rise could reshape the US population landscape. *Nature Climate Change, 7(5)*, 321–325. doi: 10.1038/nclimate3271

Hauer, M. E., Evans, J. M., & Mishra, D. R. (2016). Millions projected to be at risk from sea-level rise in the continental United States. *Nature Climate Change, 6(7)*, 691–695. doi: 10.1038/nclimate2961

Hill, J. S. (2018). Hywind Scotland, World's First Floating Wind Farm, Performing Better Than Expected. CleanTechnica. Retrieved from https://cleantechnica.com/2018/02/16/hywind-scotland-worlds-first-floating-wind-farm-performing-better-expected/

Hinrichsen, D. (1998). *Coastal waters of the world: trends, threats, and strategies. Washington, DC:* Island Press.

Huebner, S. (2022). Earth's Amphibious Transformation: Tange Kenzo, Buckminster Fuller, and marine urbanization in global environmental thought (1950s–present). *Modern Asian Studies, 56(4),* 1053–1082. doi: 10.1017/S0026749X21000251

ICE. (2010). Facing Up to Rising Sea Levels: Retreat? Defend? Attack? RIBA and ICE

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge, UK: Cambridge University Press.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva, Switzerland: IPCC.

IPCC (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge, United Kingdom and New York, NY: Cambridge University Press. doi:10.1017/9781009157896.

IPCC (2023). Summary for Policymakers. In H. Lee and J. Romero (Eds.) *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, (pp. 1-34,). Geneva, Switzerland: IPCC. doi: 10.59327/IPCC/AR6-9789291691647.001

Isoard, S., Winograd, M., Georgi, B., Kurnik, B., Downing, C., Dige, G., Fussel, H. M., Schilling, J., van Aardenne, J., & Hilden, M. (2013). *EEA Report No 3/2013 Adaptation in Europe: Addressing risks and opportunities from climate change in the context of socio-economic developments*. Copenhagen: European Environment Agency.

Jiao, J. J., Wang, X.-S., & Nandy, S. (2006). Preliminary assessment of the impacts of deep foundations and land reclamation on groundwater flow in a coastal area in Hong Kong, China. *Hydrogeology Journal, 14*, 100–114. doi: 10.1007/s10040-004-0393-6

Jones, J. C. (1963) A method of systematic design. In J. Jones & D. Thornley (Eds) *Conference on design methods: papers presented at the conference on systematic and intuitive methods in engineering, industrial design, architecture and communications* (pp 53–73), London, England.

Jongman, B., Ward, P. J., & Aerts, J. C. J. H. (2012). Global exposure to river and coastal flooding: Long term trends and changes. *Global Environmental Change, 22(4)*, 823–835. doi: 10.1016/j.gloenvcha.2012.07.004

Kaji-O'Grady, S., & Raisbeck, P. (2005). Prototype cities in the sea. *The Journal of Architecture, 10(4)*, 443–461. doi: 10.1080/13602360500285641

Kulp, S., & Strauss, B. H. (2017). Rapid escalation of coastal flood exposure in US municipalities from sea level rise. *Climatic Change, 142*, 477–489. doi: 10.1007/s10584-017-1963-7

Lagarias, A., & Stratigea, A. (2023). Coastalization patterns in the Mediterranean: A spatiotemporal analysis of coastal urban sprawl in tourism destination areas. *GeoJournal, 88(3)*, 2529–2552. doi: 10.1007/s10708-022-10756-8

Lagarias, A., Zacharakis, I., & Stratigea, A. (2022). Assessing Coastal Urban Sprawl and the "Linear City Model" in the Mediterranean – The Corinthian Bay Example. *International Conference on Computational Science and Its Applications*, 439–456.

Lanciani, R. A. (1897). *The ruins and excavations of ancient Rome*. Boston: Houghton Mifflin.

Lauria, A. (2017). Environmental Design and Accessibility: Notes On The Person-Environment Relationship And On Design Strategies. *Techne, 13*, 55–62.

Lauzon, J.-C., Preng, R., Sutton, B., & Pavlovic, B. (2007). 2007 Global Energy Survey. WEC.

Lin, F.Y., Czapiewska, K., Iorga, G., Totolici, D., Koning, J. (2020). A catalogue of technical requirements and best practices for the design- Deliverable. 7.2. Space@Sea.

Lin, F.-Y., Spijkers, O., & van der Plank, P. (2022). Legal framework for sustainable floating city development: a case study of the Netherlands. In *WCFS2020: Proceedings of the Second World Conference on Floating Solutions*, Rotterdam, 433–460. doi: 10.1007/978-981-16-2256-4_27

Lin, Y. H., Chih Lin, Y., & Tan, H. S. (2019). Design and functions of floating architecture–a review. *Marine Georesources and Geotechnology, 37(7)*, 880–889. doi: 10.1080/1064119X.2018.1503761

Lin, Z., & Tange, K. (2010). *The Metabolist movement: urban utopias of modern Japan*. London and New York: Routledge.

Liu, B., Siu, Y. L., & Mitchell, G. (2016). Hazard interaction analysis for multi-hazard risk assessment: a systematic classification based on hazard-forming environment. *Natural Hazards and Earth System Sciences, 16(2)*, 629–642. doi: 10.5194/nhess-16-629-2016

Liu, L., Wang, Q., Lin, H., Li, H., & Sun, Q. (2017). Power generation efficiency and prospects of floating photovoltaic systems. *Energy Procedia, 105*, 1136–1142. doi: 10.1016/j.egypro.2017.03.483

Liu, Z.-Z., Wang, H.-J., Wang, J.-L., & Huang, J. (2014). Risk analysis and management mechanism innovation on Northwest China urban minority floating population - A statistic sample from City of Xi'an. In *Proceedings of the 4th International Asia Conference on Industrial Engineering and Management Innovation, IEMI 2013*, 299–309. doi: 10.1007/978-3-642-40060-5_29

Losasso, M. (2017). Progettazione ambientale e progetto urbano. *Eco Web Town, 2(16)*. Edizioni SUT-Sustainable Urban Transformation.

Losasso, M., Leone, M., & Tersigni, E. (2020). Approcci di computational design per la rigenerazione resiliente dello spazio pubblico. *Techne, 19*, 232–241.

Louis, M. E. S., & Hess, J. J. (2008). Climate change: impacts on and implications for global health. American Journal of Preventive Medicine, 35(5), 527–538. doi: 10.1016/j.amepre.2008.08.023

Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., & Aarninkhof, S. (2018). The state of the world's beaches. *Scientific Reports, 8(1)*, 6641. doi: 10.1038/s41598-018-24630-6

Magni, F. (2019). *Climate proof planning: L'adattamento in Italia tra sperimentazioni e innovazioni.* Milano: Franco Angeli.

Maheshwari, B., Pinto, U., Akbar, S., & Fahey, P. (2020). Is urbanisation also the culprit of climate change?–Evidence from Australian cities. Urban Climate, 31, 100581. doi: 10.1016/j.uclim.2020.100581

Malo, J. W. (1974). *The complete guide to houseboating.* New York: Macmillan.

Manigrasso, M. (2023). Land Consumption and Coastal Erosions in Italy. A Focus about the Lazio Region. In *Waterfront dialectics. Rome and its Region facing climate change impacts* (pp. 71–86). Tab edizioni.

Mansour, S., Ghoneim, E., El-Kersh, A., Said, S., & Abdelnaby, S. (2023). Spatiotemporal Monitoring of Urban Sprawl in a Coastal City Using GIS-Based Markov Chain and Artificial Neural Network (ANN). *Remote Sensing, 15(3)*, 601. doi: 10.3390/rs15030601

Matthews, J. B. R. (2018). Annex I: glossary. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (Eds). *Global warming of 1.5°C, An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* IPCC

McAdam, J. (2010). *Climate change and displacement: Multidisciplinary perspectives.* Bloomsbury Publishing.

McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization, 19(1)*, 17–37. doi: 10.1177/0956247807076960

Mead, D., (2011). Recycled Island Is Hawaii on Floating Trash. Retrieved from https://www.vice.com/en/article/nzzkkb/recycled-island-is-hawaii-on-floating-trash

Mentaschi, L., Vousdoukas, M. I., Pekel, J.-F., Voukouvalas, E., & Feyen, L. (2018). Global long-term observations of coastal erosion and accretion. *Scientific Reports, 8*(1), 12876. doi: 10.1038/s41598-018-30904-w

Merkens, J.-L., Reimann, L., Hinkel, J., & Vafeidis, A. T. (2016). Gridded population projections for the coastal zone under the Shared Socioeconomic Pathways. *Global and Planetary Change, 145*, 57–66. doi: 10.1016/j.gloplacha.2016.08.009

Meyer, B. C. (2010). Climate change and spatial planning. *Landscape and Urban Planning, 98*(3/4), 139–181. doi: 10.1016/j.landurbplan.2010.08.012

Moatti, J.-P., & Thiébault, S. (2018). *The mediterranean region under climate change: a scientific update*. Marseille: IRD Éditions.

Monardo, B. (2023). Interpreting the river through kaleidoscopic glances. In *Waterfront dialectics. Rome and its Region facing climate change impacts* (pp. 109–114). Tab edizioni.

Monardo, B., Luciani, G., Paudice, E., Di Giacomo, T. V., Calcagni, L., Mattogno, C., & Pais, M. R. (in press 2024). Chasing the Nexus between Sustainable Strategies and Cultural Heritage. In Ressano Garcia P., Paka A., Tzaka A., Nyka L., Borucka J., Mattogno M., Di Giacomo T.V., Pais, M.R. Larsen K., Suleiman L. *SOS Climate Waterfront.*

Moon, C-H. (2012). A Study on the Sustainable Features of Realized and Planned Floating Buildings. *Journal of Navigation and Port Research, 36*(2), 113–121. doi: 10.5394/kinpr.2012.36.2.113

Moon, C. (2015). A Study on the Floating House for New Resilient Living. *Journal of the Korean Housing Association, 26*(5), 97–104. doi: 10.6107/jkha.2015.26.5.097

Munafò, M. (2022). Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2022. Report SNPA 32/22.

Muñoz, J. M. B. (2014). *Política, gestión y litoral. Una Nueva Visión de La Gestión Integrada de Áreas Litorales*. Madrid, España: Editorial Tébar Flores.

NASA (2021). Global Climate Change: Vital Signs of the Planet. Retrieved from http://climate.nasa.gov/index

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding - A global assessment. *PloS One, 10*(3), doi: 10.1371/journal.pone.0118571

Neumeyer, K. (1981). *Sailing the Farm*. Berkeley: Ten Speed Press.

Newcomb, D. G. (1974). *The wonderful world of houseboating*. New Jeresey: Prentice-Hall.

Nicholls, R. J. (2011). Planning for the impacts of sea level rise. *Oceanography, 24*(2), 144–157.

Nicholls, R. J., Brown, S., Hanson, S., & Hinkel, J. (2010). Economics of coastal zone adaptation to climate change (World Bank Discussion Papers, 10) Washington: World Bank.

Nillesen, A. L., & Singelenberg, J. (2011). *Amphibious housing in the Netherlands. Architecture and Urbanism on the Water.* Rotterdam: NAi Uitgevers.

Novotny, V., & Brown, P. (2007). *Cities of the future*. London: IWA Publishing. doi: 10.2166/9781780405308

Nyka, L., Simões, R., Garcia, P. R., & Rayss, J. (2021). Designing with Green and Blue–Climate Adaption Proposals for Lowland Areas of Gdańsk. In P. Ressano Garcia, L. Nyka. J. Borucka, J. Szczepański (Eds.), *Climate Change and Creative Solutions for Cities*, Gdańsk.

O'Malley, I. (2023). AP news - Long popular in Asia, floating solar catches on in US. Retrieved from https://apnews.com/article/floating-solar-ramping-up-climate-change-renewable-energy-7316dbfe9db23363aacadcd133cbd408

Ohkura, Y. (2003). The roles and limitations of newspapers in environmental reporting. Case study: Isahaya Bay land reclamation project issue. *Marine Pollution Bulletin, 47*(1–6), 237–245. doi: 10.1016/S0025-326X(03)00057-2

Olthuis, K. (2010). F*loat!: Building on water to combat urban congestion and climate change*. Frame Publishers.

Oppenheimer, M., Glavovic, B., Hinkel, J., Van de Wal, R., Magnan, A. K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., Deconto, R. M., & Ghosh, T. (2019). Sea level rise and implications for low lying islands, coasts and communities.

Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, (2019). Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (Eds.) *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. IPCC.

Pantanella, E., Cardarelli, M., Danieli, P. P., MacNiven, A., & Colla, G. (2010). Integrated aquaculture-floating agriculture: is it a valid strategy to raise livelihood? In XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010), 79–86. doi: 10.17660/ActaHortic.2011.921.9

Parvej, H. (2007). Adapting to Waterlogging Situation Through Promotion of Floating Garden (Hydroponics)-Involving the Affected Community for their Sustainable Livelihood-Security. Project Report. ActionAid.

Pedro, J. B., Meijer, F., & Visscher, H. (2010). Technical building regulations in EU countries: A comparison of their organization and formulation. In *Proceedings of W113 - Special Track 18th CIB World Building Congress May 2010 Salford, United Kingdom*. CIB Publication 345.

Peduzzi, P. (2014). Sand, rarer than one thinks. In *Environmental development 11*, 208–218. doi: 10.1016/j.envdev.2014.04.001

Penning-Rowsell, E. (2020). Floating architecture in the landscape: climate change adaptation ideas, opportunities and challenges. *Landscape Research, 45*(4), 395–411. doi: 10.1080/01426397.2019.1694881

Piątek, Ł. (2016). Displacing Architecture? From Floating Houses to Ocean Habitats? Expanding the Building Typology. In J. Słyk, L. Bezerra (Eds). *Education for Research, Research for Creativity* (pp. 273–280). Warsaw: Faculty of Architecture Warsw University of Technology.

Pincetl, S., Bunje, P., & Holmes, T. (2012). An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landscape and Urban Planning, 107*(3), 193–202. doi: 10.1016/j.landurbplan.2012.06.006

PNAT. (2022). Jellyfish Barge. Retrieved from https://www.pnat.net/jellyfish-barge/

Poli, I. (2023). Regenerating Cities with Blue and Green Networks. Inspirational Models and Rome Potential. In *Waterfront dialectics. Rome and its Region facing climate change impacts* (pp. 139–144). Tab edizioni.

Pörtner, H. O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., Begum, R. A., Betts, R., Kerr, R. B., & Biesbroek, R. (2022). Climate change 2022: impacts, adaptation and vulnerability. IPCC.

Pötz, H. (2016). Groenblauwe Netwerken Handleiding Voor Veerkrachtige Steden: Green-blue Grids Manual for Resilient Cities. Atelier Groenblauw. Retrieved from https://urbangreenbluegrids.com/introduction/historical-importance-and-development-of-parks-and-public-green-grids/

Prisco, I., Carboni, M., & Acosta, A. T. R. (2013). The fate of threatened coastal dune habitats in Italy under climate change scenarios. *PLoS One, 8*(7), doi: 10.1371/journal.pone.0068850

Queensland Development Code (2007). MP 3.1 – Floating Buildings. Retrieved from https://www.epw.qld.gov.au/__data/assets/pdf_file/0011/4313/mp-3-1-floating-buildings.pdf

Ramaswamy, V., Schwarzkopf, M. D., Randel, W. J., Santer, B. D., Soden, B. J., & Stenchikov, G. L. (2006). Anthropogenic and natural influences in the evolution of lower stratospheric cooling. *Science, 311*(5764), 1138–1141. doi: 10.1126/science.1122587

Ray, B. R., Johnson, M. W., Cammarata, K., & Smee, D. L. (2014). Changes in seagrass species composition in northwestern Gulf of Mexico estuaries: effects on associated seagrass fauna. *PloS One, 9*(9). doi: 10.1371/journal.pone.0107751

Rehman, S. (2020). Elective report on Floating architecture. New Delhi: Jamia Millia Islamia.

Ritchie, H., & Roser, M. (2018). Urbanization. Our World in Data. Retrieved from https://ourworldindata.org/urbanization

Roberts, M., & Mukim, M. (2023). *Thriving: Making Cities Green, Resilient, and Inclusive in a Changing Climate*. World Bank Publications.

Rubiera-Morollón, F., & Garrido-Yserte, R. (2020). Recent literature about urban sprawl: A renewed relevance of the phenomenon from the perspective of environmental sustainability. *Sustainability, 12*(16), 6551. doi: 10.3390/su12166551

Ryan, Z. (2010). Building with Water: Concepts Typology Design. Basel: Birkhäuser. doi: 10.1515/9783034610940

Sahu, A., Yadav, N., & Sudhakar, K. (2016). Floating photovoltaic power plant: A review. *Renewable and Sustainable Energy Reviews, 66*, 815–824. doi: 10.1016/j.rser.2016.08.051

Samper-Villarreal, J., Lovelock, C. E., Saunders, M. I., Roelfsema, C., & Mumby, P. J. (2016). Organic carbon in seagrass sediments is influenced by seagrass canopy complexity, turbidity, wave height, and water depth. *Limnology and Oceanography, 61*(3), 938–952. doi: 10.1002/lno.10262

Santer, B. D., Taylor, K. E., Wigley, T. M. L., Johns, T. C., Jones, P. D., Karoly, D. J., Mitchell, J. F. B., Oort, A. H., Penner, J. E., & Ramaswamy, V. (1996). A search for human influences on the thermal structure of the atmosphere. *Nature, 382*(6586), 39–46. doi: 10.1038/382039a0

Saunders, M. I., Leon, J., Phinn, S. R., Callaghan, D. P., O'Brien, K. R., Roelfsema, C. M., Lovelock, C. E., Lyons, M. B., & Mumby, P. J. (2013). Coastal retreat and improved water quality mitigate losses of seagrass from sea level rise. *Global Change Biology, 19*(8), 2569–2583. doi: 10.1111/gcb.12218

Scussolini, P., Tran, T. V. T., Koks, E., Diaz-Loaiza, A., Ho, P. L., & Lasage, R. (2017). Adaptation to sea level rise: a multidisciplinary analysis for Ho Chi Minh City, Vietnam. *Water Resources Research, 53*(12), 10841–10857. doi: 10.1002/2017WR021344

Setiadi, R., Baumeister, J., Burton, P., & Nalau, J. (2020). Extending Urban Development on Water: Jakarta Case Study. *Environment and Urbanization ASIA, 11*(2), 247–265. doi: 10.1177/0975425320938539

Shaffer, K. (2007). *Houseboats: Aquatic Architecture of Sausalito*. Atglen, PA: Schiffer

Shepherd, M., & KC, B. (2015). Climate change and African Americans in the USA. *Geography Compass, 9*(11), 579–591. doi: 10.1111/gec3.12244

Sindhu, B., J. Sree Naga, C., Dr. K., C., & M. Chaitanya, N. K. (2021). Study on Future Floating Cities. *International Journal for Modern Trends in Science and Technology 7*(7), 93-98. doi: 10.46501/IJMTST0707016

Singh, A. L., & Khundrakpam, M. L. (2011). Phumdi proliferation: a case study of Loktak lake, Manipur. *Water and Environment Journal, 25*(1), 99–105. doi: 10.1111/j.1747-6593.2009.00197.x

Song, J., Fu, X., Gu, Y., Deng, Y., & Peng, Z.-R. (2017). An examination of land use impacts of flooding induced by sea level rise. *Natural Hazards and Earth System Sciences, 17*(3), 315–334. doi: 10.5194/nhess-17-315-2017

Sovacool, B. K. (2018). Bamboo beating bandits: Conflict, inequality, and vulnerability in the political ecology of climate change adaptation in Bangladesh. *World Development, 102*, 183–194. doi: 10.1016/j.worlddev.2017.10.014

Storbjörk, S., & Hjerpe, M. (2021). Climate-proofing coastal cities: What is needed to go from envisioning to enacting multifunctional solutions for waterfront climate adaptation? *Ocean and Coastal Management, 210*. doi: 10.1016/j.ocecoaman.2021.105732

Takahashi, P. K. (1996). Project blue revolution. *Journal of Energy Engineering, 122*(3), 114–124. doi: 10.1061/(ASCE)0733-9402(1996)122:3(114)

Telesca, L., Belluscio, A., Criscoli, A., Ardizzone, G., Apostolaki, E. T., Fraschetti, S., Gristina, M., Knittweis, L., Martin, C. S., & Pergent, G. (2015). Seagrass meadows (Posidonia oceanica) distribution and trajectories of change. *Scientific Reports, 5*(1), 12505. doi: 10.1038/srep12505

Theodora, Y., & Spanogianni, E. (2022). Assessing coastal urban sprawl in the Athens' southern waterfront for reaching sustainability and resilience objectives. *Ocean & Coastal Management, 222*, 106090. doi: 10.1016/j.ocecoaman.2022.106090

Thorhaug, A., Poulos, H. M., López-Portillo, J., Ku, T. C. W., & Berlyn, G. P. (2017). Seagrass blue carbon dynamics in the Gulf of Mexico: Stocks, losses from anthropogenic disturbance, and gains through seagrass restoration. *Science of the Total Environment, 605*, 626–636. doi: 10.1016/j.

scitotenv.2017.06.189

Triton Foundation, I. (1968). A study of a prototype floating community (Vol. 180).

Turco, M. G. (2023). The 'Various Landscapes' of the Ostiense Coast. Cultural and Environmental Heritage. In *Waterfront dialectics. Rome and its region facing climate change impacts* (pp. 27–38). Tab edizioni.

Tuya, F., Png-Gonzalez, L., Riera, R., Haroun, R., & Espino, F. (2014). Ecological structure and function differs between habitats dominated by seagrasses and green seaweeds. *Marine Environmental Research, 98*, 1–13. doi: 10.1016/j.marenvres.2014.03.015

UCCRN. (2018). The Future We Don't Want: How Climate Change Could Impact the World's Greatest Cities. In UCCRN Technical Report. C40Cities New York, USA.

Umar, T. (2020). Making future floating cities sustainable: A way forward. *Proceedings of the Institution of Civil Engineers: Urban Design and Planning, 173*(6), 214–237. doi: 10.1680/jurdp.19.00015

UN (2023). SC/15199 14 February 2023 - Climate Change-induced Sea-Level Rise Direct Threat to Millions around World, Secretary-General Tells Security Council.Speakers Warn of Vanishing Coastlines, Endangered Nations, Forced Migration, Competition over Natural Resources. Retrieved from https://press.un.org/en/2023/sc15199.doc.htm

UNDESA. (2018). World urbanization prospects: the 2018 revision. New York: United Nations.

UNEP-WCMC (2021). *Global distribution of seagrasses (version 7.1). Seventh update to the data layer used in Green and Short (2003)*. Cambridge, UK: UN Environment World Conservation Monitoring Centre. doi: 10.34892/x6r3-d211

UNEP. (2005). Millenium Ecosystem Assessment. United Nations.

UNEP. (2012). Global Environment Outlook 5: Environment for the future we want. Nairobi: United Nations Environment Programme.

UNHCR. (2016). Frequently asked questions on climate change and disaster displacement. Retrieved from https://www.unhcr.org/uk/news/stories/frequently-asked-questions-climate-change-and-disaster-displacement

Unsworth, R. K. F., Collier, C. J., Waycott, M., Mckenzie, L. J., & Cullen-Unsworth, L. C. (2015). A framework for the resilience of seagrass ecosystems. *Marine Pollution Bulletin, 100*(1), 34–46. doi: 10.1016/j.marpolbul.2015.08.016

Valente, S., & Veloso-Gomes, F. (2020). Coastal climate adaptation in port-cities: adaptation deficits, barriers, and challenges ahead. *Journal of Environmental Planning and Management, 63*(3), 389–414. doi: 10.1080/09640568.2018.1557609

Vallega, A. (1999). *Fundamentals of integrated coastal management* (Vol. 49). Springer Science & Business Media.

Venhuizen, H. (2000). *Amfibisch wonen*. Rotterdam: NAi Uitgevers.

Vis, G.-J., Kasse, C., & Vandenberghe, J. (2008). Late Pleistocene and Holocene palaeogeography of the Lower Tagus Valley (Portugal): effects of relative sea level, valley morphology and sediment supply. *Quaternary Science Reviews, 27*(17–18), 1682–1709. doi: 10.1016/j.quascirev.2008.07.003

Wang, B., Li, Y., Wu, N., & Lan, C. Q. (2008). CO 2 bio-mitigation using microalgae. *Applied Microbiology and Biotechnology, 79*, 707–718. doi: 10.1007/s00253-008-1518-y

Wang, C.M., & Wang, B. T. (2020). Floating solutions for challenges facing humanity. In *ICSCEA 2019: Proceedings of the International Conference on Sustainable Civil Engineering and Architecture* (pp. 3-29). Singapore: Springer Singapore.

Wang, C. M., Watanabe, E., & Utsunomiya, T. (2006). Very large floating structures.Taylor & Francis.

Wang, G., Goldfeld, Y., & Drimer, N. (2019). Expanding coastal cities–Proof of feasibility for modular floating structures (MFS). *Journal of Cleaner Production, 222,* 520–538. doi: 10.1016/j.jclepro.2019.03.007

Wang, K-F. (2021). An Investigation into Environment-Floating Buildings in relation to Sustainability Indicators for Planning and Design Process. De Montfort University.

Wang, X., Chen, W., Zhang, L., Jin, D., & Lu, C. (2010). Estimating the ecosystem service losses from proposed land reclamation projects: A case study in Xiamen. *Ecological Economics, 69*(12), 2549–2556. doi: 10.1016/j.ecolecon.2010.07.031

Wang, Y., Yue, X., Zhang, H., Su, Y., & Qin, J. (2021). Relationship between urban floating population distribution and livability environment: Evidence from guangzhou's urban district, china. *Sustainability, 13*(23). doi: 10.3390/su132313477

Warner, K., Hamza, M., Oliver-Smith, A., Renaud, F., & Julca, A. (2010). Climate change, environmental degradation and migration. *Natural Hazards, 55*, 689–715. doi: 10.1007/s11069-009-9419-7

Watson, C. S., White, N. J., Church, J. A., King, M. A., Burgette, R. J., & Legresy, B. (2015). Unabated global mean sea-level rise over the satellite altimeter era. *Nature Climate Change, 5*(6), 565–568. doi: 10.1038/nclimate2635

Watson, J., & Davis, W. (2019). *Lo-TEK*. Cologne: Taschen.

Watts, N., Adger, W. N., Ayeb-Karlsson, S., Bai, Y., Byass, P., Campbell-Lendrum, D., Colbourn, T., Cox, P., Davies, M., & Depledge, M. (2017). The Lancet Countdown: tracking progress on health and climate change. *The Lancet, 389*(10074), 1151–1164. doi: 10.1016/S0140-6736(16)32124-9

Wax, E. (2007). For flood-prone Bangladesh, a floating future. NBC News. Retrieved from https://www.nbcnews.com/id/wbna20982307

Werners, S. E., Wise, R. M., Butler, J. R. A., Totin, E., & Vincent, K. (2021). Adaptation pathways: A review of approaches and a learning framework. *Environmental Science & Policy, 116*, 266–275. doi: 10.1016/j.envsci.2020.11.003

Westerhold, T., Marwan, N., Drury, A. J., Liebrand, D., Agnini, C., Anagnostou, E., Barnet, J. S. K., Bohaty, S. M., De Vleeschouwer, D., & Florindo, F. (2020). An astronomically dated record of Earth's climate and its predictability over the last 66 million years. *Science, 369*(6509), 1383–1387. doi: 10.1126/science.aba6853

WHO (2008). Climate change and health. Sixty-First World Health Assembly.

Williams, E. (2009). *Aquatecture: Architectural adaptation to rising sea levels.* Scholar Commons Graduate Theses and Dissertations, 118. Retrieved from http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1084&context=etd

Wong, T. H. F., & Brown, R. R. (2009). The water sensitive city: principles for practice. *Water Science and Technology, 60*(3), 673–682. doi: 10.2166/wst.2009.436

World Bank. (2017). Adaptation to Climate Change in Coastal Areas of the ECA Region: A contribution to the Umbrella Report on adaptation to climate change in ECA. World Bank.

World Bank (2022). Building Coastal Resilience to Protect Lives and Livelihoods in Bangladesh. Retrieved from https://www.worldbank.org/en/results/2022/08/29/building-coastal-resilience-to-protect-lives-and-livelihoods-in-bangladesh

Wylson, A. (2013). *Aquatecture: architecture and water.* Elsevier.

Yaakub, S. M., McKenzie, L. J., Erftemeijer, P. L. A., Bouma, T., & Todd, P. A. (2014). Courage under fire: Seagrass persistence adjacent to a highly urbanised city–state. *Marine Pollution Bulletin, 83*(2), 417–424. doi: 10.1016/j.marpolbul.2014.01.012

CHAPTER 2 Methodology and Methods

ABSTRACT

Chapter 2 outlines the comprehensive operational methodology behind the dissertation and the methods and resources used for each phase. The methodology comprises four phases. The first phase is an investigative-interpretative phase involving document analysis to identify, extract, and organize information, specific requirements or recommendations related to floating buildings, and logical argumentation methods to identify correlations and trade-offs between the different performance requirements. The second phase (synthetical-evaluative) involves a case study analysis to explore the phenomenon of floating architecture embedded in its real-life context. This phase entails constructing a multi-evaluation matrix to identify best practices and prioritize requirements based on their fulfillment in practice. A third applicative phase comprises an initial simulation research using geographic information system mapping to identify Italian waterfront cities vulnerable to flooding and sea level rise and characterized by high urban densities and human, cultural, and economic activity. The mapping is followed by the application and testing of the framework on a pilot case study according to the results of the previous analysis. Applying the framework to develop different design scenarios allows further fine-tuning of the preliminary framework version. The final phase consists of the feasibility assessment of a digital version of the framework through the development of a proof of concept of a performance-driven digital interactive design-support tool in the form of a demo interface. This phase is developed in three steps: conversion of the performance requirements into quantitative, measurable indicators; definition of a computational algorithm for one class of demand using Grasshopper 3D programming language to integrate and control the workflow based on the performance indicators; and creation of a custom user interface with the Human UI plugin. The digital tool is then tested by practitioners involved in the field, and its usability and functionality are evaluated through unstructured interviews to gain a comprehensive understanding of the interviewee's experiences.

As briefly anticipated in the introduction, the research is developed following an inductive and systemic methodology and its progress can be traced back to five consequential phases (Figure 1). The first one is a preliminary phase consisting in providing an overview of the main lines of investigation (Chapter 1) and establishing an operational methodology (Chapter 2). The following four phases are set up in this preliminary phase.

1. **Investigative-interpretative phase: Development of a Performance-based Design-Support Framework**

Bibliographic research, literature review, collection of data and information (Groat & Wang, 2013) on three lines of investigation:

a. performance-based design frameworks and guidelines for on-land architecture
b. offshore and shipping regulatory frameworks and guidelines
c. floating architecture regulatory frameworks, guidelines, blue prints and standards.

The underlying assumption is that floating urban development is mostly likely to take place as extension of existing waterfront cities and settlements. The needs and design criteria are therefore more like those of the urban environment than the ones of the offshore or naval industry. Therefore, the identification and categorization of performance requirements takes the urban-architectural norm, codes and standards as the starting point, integrating the missing aspects from the offshore and shipping regulatory frameworks. This study is carried out through a document analysis, a qualitative research method that involved the systematic examination of written texts to identify, extract and organize information and specific requirements or recommendations related to floating buildings. The sources (written texts) used are mainly of three types, as listed below.

- Regulatory Frameworks: ISO standards, CEN standards, Eurocodes EN, local national standards effective in different countries around the world, maritime regulations, offshore regulations.
- Grey Literature: technical reports, industry guidelines, best practices documents, blueprints.
- Scientific References: peer-reviewed journal articles, conference papers, books.

The document analysis is further explained in Chapter 2.1.1.

The second part of the Investigative-interpretative phase involved

1. The logical argumentation methods are further described in Paragraph 2.1.1.3. Logical Argumentation Methods and in note 8.

logical argumentation methods, supported by literature, for the identification of correlations and trade-offs between different performance requirements.

A document analysis was adopted instead of a systematic literature review because it was deemed more useful and suitable for an in-depth exploration of a limited number of relevant documents, as the work did not involve a comprehensive review of a larger body of literature.

2. Synthetical-evaluative phase: Case Study Analysis

Within this research context, case study research is useful for exploring the phenomenon of floating architecture embedded in its real-life context (Groat & Wang, 2013). The review covered multiple cases and a comparative analysis to draw a set of cross-case conclusions (Yin, 2018). It is both descriptive and exploratory in purpose, as it aims at generating hypotheses for later investigation. In fact on one hand it collects a large database of projects and presents them in a structured-analytical format, on the other it is intended for theory-building (Groat & Wang, 2013). More specifically, it serves to further develop and integrate the framework with inputs from the practice field, in order to merge as much as possible theory and practice. A multi-evaluation matrix is built placing on the alternative axis (x) the case studies, and on the criteria axis (y) the performance requirements grouped in classes of demand. The case study analysis and the multi-evaluation matrix has two objectives and related outputs:

a. identification of best practices amongst case studies, according to their level of compliance with the performance-requirements;
b. identification of the different weight each requirement has in comparison to the others and of a priority order amongst requirements based on their fulfillment in practice.

The methods used to collect information on the case studies include:

- bibliographical research from a broad range of different sources (grey and scientific literature, websites, non-published reports and drawings);
- field observations;
- unstructured interviews with the architects, engineers and designers.

3. Applicative phase: Application and testing of the PDSF on pilot area

This phase included four steps.

a. Simulation research: mapping through geographic information systems of Italian coastal cities more prone to flooding and SLR impact according to SSP5.8.5 (2050, 2100) and characterized by high-intensity levels of economic, social, and cultural activity.
b. Identification of pilot case study (Fiumicino Isola Sacra, Tevere Delta).
c. Research by Design: application and validation of the PDSF on the pilot area. Master students (junior architects) attending the Design Studio in Technological Design for Urban Regeneration

(Progettazione Tecnologica per la Rigenerazione Urbana)[2] apply the PDSF in developing design scenarios for the pilot area.

d. PDSF fine-tuning according to what emerged from its application.

4. Feasibility assessment phase: Proof of concept of a performance-driven web-based interactive design tool

The tool is in the form of a demo interface of a Design Support System (DSS). It can be used for both design and evaluation purposes. The phase involves the following steps.

a. Conversion of the performance requirements into quantitative measurable indicators. This process is carried out for one of the classes of demand – and all the interlinked performance requirements coming from other classes – and serves as a paradigmatic example to prove the feasibility of the process that can be replicated for all the other classes.
b. Definition of a computational algorithm for one class of demand using Grasshopper 3D programming language to integrate and control the workflow based on the performance indicators.
c. Creation of a custom user interface with the Human UI plugin that can be used to control Grasshopper definitions directly from a web-platform.

The methodology is described by the author in the double peer reviewed paper entitled "A Performance-based Design-Support Framework for Floating Architecture. Trade-offs and correlations between requirements for multiple criteria decision making optimization" (Calcagni et al., 2024). This methodological approach is partly consistent with the one adopted by K.F. Wang in his study aimed at identifying a set of sustainable floating building indicators (K.-F. Wang, 2021). He derives the four main categories of indicators from the building life cycle approach: planning, design, use and recycling. The SFBIs (Sustainable Floating Building Indicators) is developed through literature review, field observations and investigation, and case study research. It is then tested by experts and refined accordingly. Before applying it to a pilot study the revised version is tested once more by conducting interviews with experts of the field. As in Wang (2021), research methods including literature review, field observations, investigation, interviews with experts and practitioners, and case study analysis are used for phase 1 and 2. Moreover, the framework is also tested by experts and refined accordingly. However, compared to Wang's methodology, this thesis introduces a further evaluation step which involves the application and testing of the framework on a pilot area (phase 3).

2. The Course is part of the Master in Architecture and Urban Regeneration (ARU) at Sapienza University of Rome, Italy.

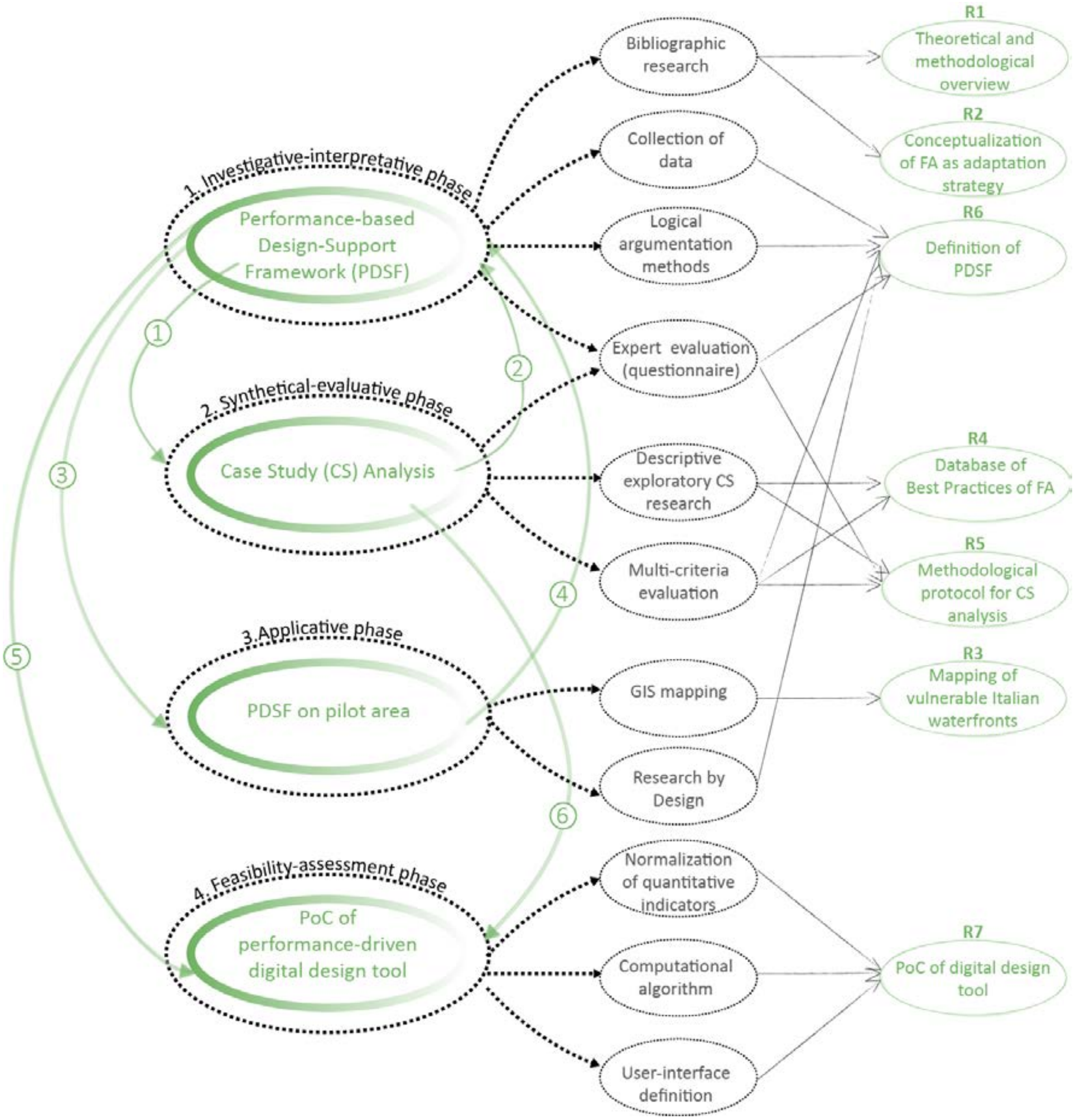


Figure 1. Research structure: phases, methods and related results. Source: Livia Calcagni

2.1 Research methods

2.1.1. Investigative-interpretative phase

The process involved the following steps.

1. **Identification of relevant sources**: selecting the relevant regulatory frameworks, studies, and other grey or scientific literature that may contain relevant requirements for floating buildings. This involved consulting experts, searching online databases, and reviewing bibliographies of existing studies.
2. **Gathering documents**: collecting the identified documents and verifying they are complete and accessible.
3. **Reading and annotating**: carefully consulting each document, taking notes and annotations to highlight relevant requirements, recommendations, or other pertinent information.
4. **Organizing and classifying**: organizing the collected data into a structured format, more specifically a spreadsheet, analysing the requirements to identify overlaps and off-tracks, and identifying categories to group requirements into different classes of demand.
5. **Establishing a framework** of relevant requirements structured in classes of demand.
6. **Evaluating and refining the framework**: the framework (PDSF - Appendix A) is subjected to validation by scientific experts and practitioners involved in floating architecture, hydraulic and mechanic marine engineering, ocean engineering and ship technology, ecology and natural science, urban ecology, and environmental architecture.
7. **Identification of correlations and trade-offs between requirements**: exploring the compatibility, complementarity, interchangeability, excludability relationships between requirements using logical argumentation methods, supported by grey and scientific literature.

As argued in the Introduction chapter, architecture, environment and inhabitants all perform, in the sense that they possess active agency and interact with one another yielding perpetually complex behavior (Hensel, 2013). For this reason, unlocking these intricate relationships requires a synergetic understanding and methodology. It is possible to consider social, cultural, and environmental performance in an integral manner. This introduces a new way of thinking about sustainability along the coordinated statement of performance requirements, in contrast to the present predominant style in which performance is considered as synonymous to functionality (Hensel, 2012). As explicitly stated in the Introduction, performance-oriented design and optimization is a broad domain within the field of environmental architecture. Within this thesis, the term performance is not limited to digital form generation or energy optimization, but encompasses structural performance, performance of the physical environment, aesthetics, and cultural performance on the basis of Shi's classification (Shi, 2010). When aiming to synthesize a large number of parameters and variables it is necessary to adopt a systematic approach rooted in Systems Theory[3] (Hensel, 2010).

2.1.1.1. Bibliographic set up and identification of performance requirements (step 1-5)

The PDSF constitutes a first step towards developing a design support system (DSS) for advancing multiple criteria decision-making (MCDM) for floating architecture. It sets the groundwork for developing the proof of concept (PoC) of a digital interactive computational design tool to effectively support performance-based reasoning in floating building design. An insight into the digital tool is described in Chapter 7.3. Moreover, a video available in appendix D shows a demo of the computational interactive design tool and how to use it. The demo is meant to demonstrate that the framework has practical potential for both practitioners and policymakers or administrative technical staff.
This phase involves steps 1 to 5. The first step (Identification of relevant sources) proceeds from the assumption that there are only a few standards and regulations for floating buildings and that there are few examples of floating developments with the purpose of living. Hence, the process of gathering information (step 2) on the requirements of floating buildings was carried out by looking into the closer and most akin environments: floating offshore accommodation in the offshore industry, ships, and other floating vessels in the shipbuilding industry, and, of course, floating urbanization on calm inland and coastal areas. The rules and regulations for the offshore and shipping industry – such as flotels or accommodation units for offshore platforms – are confined to oil, gas, and shipping industries, which are stricter than ones regulating the urban environment. Thre research approaches were considered based on the field's current state. The first is to develop a framework considering offshore, shipping, and urban perspectives. This process runs the risk of being impractical due to time constraints and the number of resources and legal procedures to develop, rectify, and enact. A second option would be to develop a new framework based

3. Systems Theory originated in the 1920s to tackle the need of explaining the interrelatedness of organisms in ecosystems. It is the transdisciplinary study of systems assuming the interaction of processes and the interrelation and interdependency of components. Changing one component of a system may affect other components or the whole system. In pursuing of a Systems Theory-based design process, Alexander advocated establishing a mechanism for breaking complicated design challenges down into sub-systems and the variables that are specific to each subsystem. As highlighted by M. Hensel, in pursuing a design method based on Systems Theory, C. Alexander, presents a strategy for breaking down complex design problems into sub-systems and their related variables.

on the offshore and naval rules and regulations as the starting point and to adjust them to resemble the urban ones. A third alternative could be to use the urban rules and regulations as the starting point, taking the hydrodynamic aspects such as stability and buoyancy, the water-related safety measures, and all the other features that are missing in the urban regulations as supplementary ones from the offshore and naval regulatory frameworks. Considering that FUD is more likely to take place in the context of existing waterfront cities and settlements rather than as an isolated offshore urban system, the hypothesis is that the needs and design criteria are more like those related to the on-land built environment than to those related to the offshore or naval industry. As a result, the identification and categorization of performance requirements take the urban-architectural prescriptive and performance-based norms as the starting point while addressing the missing aspects from the perspective of offshore and shipping regulatory frameworks (Figure 2). This last option has been considered the most promising approach for three main reasons: closer to urban living standards, less time-consuming, and ongoing law amendments. A similar approach has already been adopted in the Space@Sea European project, in which the concept of Living@Sea is put forward. Living@Sea consists of conceptualizing marine floating islands intended for human habitation located on the high seas, near economic marine activity, or closer to shore as an extension of existing cities or port areas. The approach used to identify requirements – essentially related to comfort, working conditions, outdoor spaces, safety, energy production, and waste management – integrated standards from land-based urban planning with living and building standards from the offshore industry. This process is further clarified in Deliverable 7.2. Report: *A catalogue of technical requirements and best practices for the design* of the Space@Sea project (Lin et al., 2020).

Step 3 (Reading and annotating) and 4 (Organizing and classifying) followed the demand-performance classification system leading to the establishment of a preliminary framework of requirements structured in classes of demand (step 5). The demand-performance approach operates by objectives – what a product should do

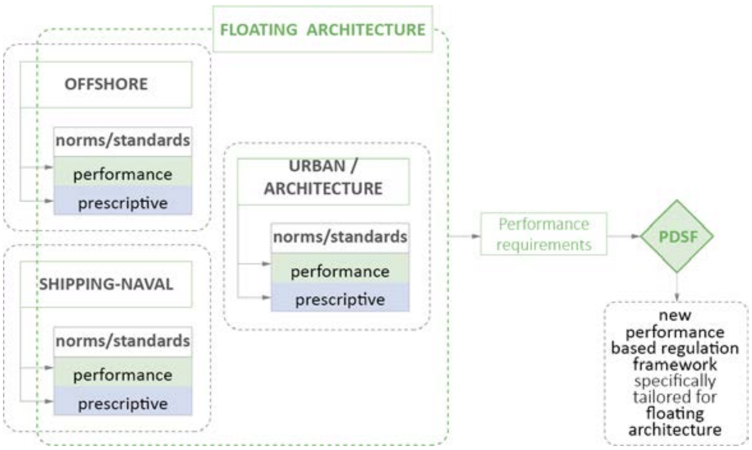


Figure 2. Diagram of the approach adopted to define a new regulation system specifically tailored for floating architecture that combines the land-based built environment standards with living and building standards from the offshore industry Source: Livia Calcagni

or provide – rather than means, at the top of the hierarchy are the design objectives, which can essentially be conceived as a clarification of the needs of the end user, evaluated according to environmental, cultural, and socio-economic factors and constraints that the natural environment places on the built environment. Classes of demand follow objectives, and each class of demand is further articulated into specific classes of requirements. Each class of requirements is addressed by precise performance requirements. The reference model used to structure the framework was taken from the Italian standard UNI 8289:1981 (and its evolution in UNI 11277: 2008). The purpose of the standard is to classify the needs of the users of the building system to unify exposure in regulatory, planning, design, operational, and communication activities relating to the building process and define the reference framework of the end users' needs which, appropriately transposed, identify the requirements or set of requirements. The identification of the classes of demand passes through the analysis of the needs to be satisfied compared with environmental, cultural, and socio-economic factors. The classes of demand represent the first level of analysis of the demand-performance approach. The UNI 8289:1981 classes of demand are further clarified and integrated with new ones taken by other standards and blueprint documents relevant to the on-land building industry:

- ISO standards;
- EN - Eurocodes (European Commission Directives and European standards);
- UNI norms (Italian National Unification norms)[4];
- DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen[5];
- WELL Building standard[6];
- NZEB standard (Sustainable Energy Authority of Ireland);
- Green Building Regulations & Specifications (Government of Dubai);
- SCS Standards *Zero Waste Project Standard*.

Amongst the protocols and blueprint documents used to further support the inclusion of certain requirements are:

- World GBC Protocol *Better Places for People*;
- Nine Foundations of a Healthy Building - Harvard;
- World Health Organization Housing Guidelines.

For what concerns the documents originating from the shipping and naval field, in addition to local government nautical and port codes, the most relevant ones include:

- ABS Rules for Building and Classing Mobile Offshore Units;
- IMO (International Maritime Organization) Codes and Convention[7];
- SOLAS Regulations.

The documents concerning offshore regulations and standards include:

- Bureau veritas *Rules for the Classification of Offshore Units*;
- Det Norske Veritas *Offshore Standard*;
- Lloyds' Register R*ules and Regulations for the Classification of Offshore Units*;

4. The UNI is recognized by the Italian State and by the European Union and represents Italian legislative activity at the International Standards Organization (ISO) and European Committee for Standardization (CEN).

5. German Standards for Sustainable Buildings (certification system).

6. WELL Building Standard is a healthy building certification program, developed by the non-profit WELL Building Institute (IWBI).

7. The International Maritime Organization (IMO) is a specialized agency of the United Nations responsible for regulating shipping.

- NORSOK S–001 *Technical Safety*.

Finally, the only regulations specifically focused on floating structures – that embrace only a few requirements, since the harsh maritime environment enforces a top priority for safety and comfort – include:

- NTA 8111_2011-NL *Netherlands Standards for Floating Constructions*;
- GC-02-E Korean Register (KR) of Shipping *Guidance for Floating Structures*;
- Portland City Code *Title 28 Floating Structures*;
- Queensland Development Code *MP 3.1. Floating Buildings*;
- *Standards for Float Homes and Live-Aboard Vessels in Victoria Harbour British Columbia*.

The Space@sea Deliverable 7.2 Report: *A catalogue of technical requirements and best practices for the design*, although not a regulatory document, was also crucial for identifying relevant performance criteria.

In Chapter 3.1, the criteria behind the selection of each requirement are clarified and supported by literature and regulatory documents. Appendix Ab provides a list of all the regulations and documents and their relevant acronyms.

The design process follows a three-step systematic approach. The first step is the identification of local ecological, social, and economic conditions and constraints that the surrounding environment sets upon the floating building. The designer carries out this task in the very early stage of the design process. Certain location-related constraints, as well as opportunities, are the first elements that shape the project. In the second step, based on those constraints and opportunities, the designer sets his design objectives and boundaries. This implies that the use of the PDSF occurs once the location has already been identified, and so have the design objectives, which in turn define a priority among the classes of demand. The third step consists in the careful selection of the performance requirements the project must meet and in what order (not necessarily all the ones identified in the framework). The designer carries out this selection process in consultation with the owner, client, or any other stakeholders, and accordingly with the location features. For this reason, the PDSF is structured in a way that it only provides a guidance checklist of all the performance requirements that should, in an optimal case, be met without providing prescribed quantitative indicators that could vary according to geographic and political regions. As a result, the requirements are left as guidance principles that can be addressed in any context, regardless of location.

2.1.1.2. Evaluation and refinement of the PDSF (step 6)

The PDSF (Appendix A1) is subjected to validation by scientific experts and practitioners involved in floating architecture, hydraulic and mechanic marine engineering, ocean engineering and ship technology, ecology and natural science, urban ecology,

and environmental architecture. The expert reviewers are asked to evaluate the PDSF by completing an evaluation questionnaire (Appendix C1). Instructions and definitions of keywords are provided to ensure a thorough understanding of each question and related content. The questionnaire administrated to the expert reviewers is structured in multiple choice questions. The respondents are asked to select either "yes", "no", or "more or less". If the respondents answer "no" or "more or less", they are asked to provide suggestions for further specifications or improvement.
The questionnaire is structured according to the funnel technique (Ikart, 2019; Krosnick & Presser, 2010): it starts with broad general questions that are easy for the respondent to answer, and the most complex and significant questions are placed in the middle.
After receiving the feedback (Appendix C2), the PDSF is adjusted and fine-tuned in the version available in Appendix A2.

2.1.1.3. Logical argumentation methods (step 7)

Once experts from different disciplinary fields review the performance requirements, logical argumentation methods, supported by literature, are used to identify correlations and trade-offs between different performance requirements. The logical argumentation methods (Groat & Wang, 2013)[8] used in this research entail framing broad explanatory theories and make use of premises (evidence or reasons) to justify the final propositions. Relational linkages are outlined through syllogism, deduction, induction, association, and analogy.
The fact that local specificity plays a significant role in design emerges from the systematization of the relationships between requirements (Chapter 3). Some examples of how local specificity affects the design include climate-related features (including factors such as wind speed, temperature, humidity, solar radiation, snow and precipitation occurrence, and air salinity), hydrographic, topographic, and geological characteristics of the water on which the building floats (seabed typology, bathymetry, wave height, frequency and period, currents, tides and water fluctuations, and water salinity), as well as social and cultural aspects (vernacular architecture and practices, available techniques and technologies, set of beliefs and values, and history and traditions).

2.1.2. Case study analysis protocol

The case study analysis serves to evaluate the quality of the framework and further develop and integrate it with inputs from the practice field to merge as much as possible theory and practice. The case study assessment is both illustrative and exploratory: it is descriptive in character and intended to complement the framework's quantitative data by providing examples of the overall findings, and exploratory as it is aimed at generating hypotheses for later investigation. Moreover, it also serves to assign different weights to the requirements and to understand their priority order

8. Argumentation theory is the interdisciplinary study of how conclusions can be supported or undermined by premises through logical reasoning. An argument is the process by which one explains how a conclusion was reached. Logic is the science used to explain or represent a consistent argument about a particular topic.

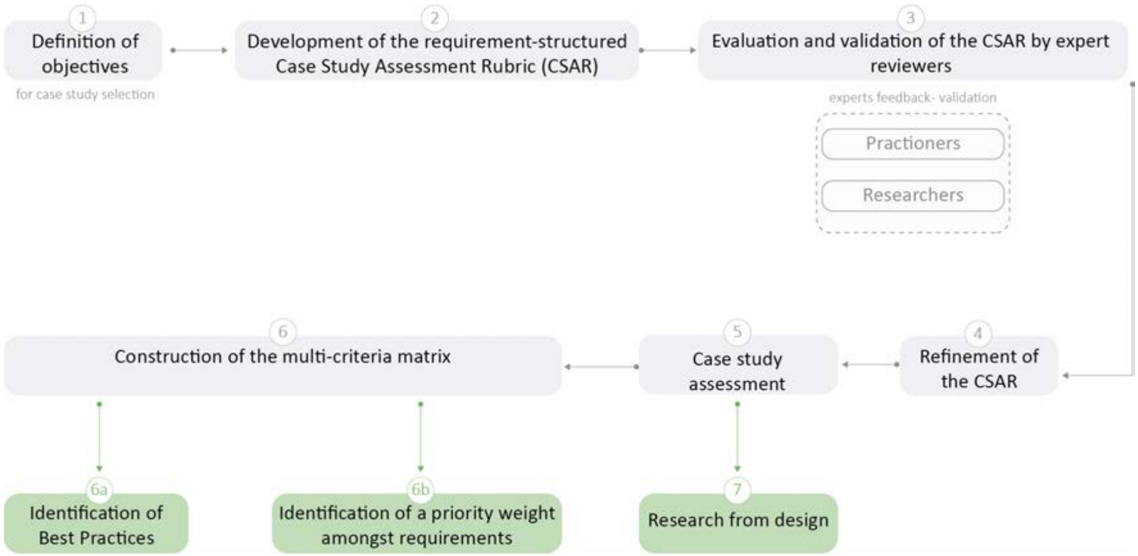


Figure 3. Case study assessment protocol structured in seven phases. Source: Livia Calcagni

within the practice field. A case study assessment protocol has been developed to conduct the twofold evaluation, on one hand of the framework and the other of the best practices. The protocol (Figure 3) is articulated into the following 7 steps.

1. **Definition of the objectives** for the selection of case studies and sampling methods.
2. **Development of the requirement-structured rubric** for the case study assessment.
3. **Evaluation and validation of the case study assessment rubric.**
4. **Refinement of the case study assessment rubric.**
5. **Case study assessment.**
6. **Construction of the multi-criteria evaluation matrix**.
   a. **Identification of best practices** amongst case studies according to their compliance with the rubric.
   b. **Identification of a priority weight** among requirements according to their compliance within the case studies.
7. **Research from design** to further integrate and update the framework.

2.1.2.1. Definition of the objectives for the selection of case studies and sampling methods

A preliminary screening of the case studies' design, implementation, and operation objectives allowed the selection to be directed toward examples that could be considered good practices. Case studies were selected through purposive/selective sampling. Purposive sampling is a non-probability sampling method in which the selected items are chosen by the researcher's discretion (Black, 2010). Researchers working with purposive sampling assert that while probability methods are appropriate for large-scale studies concerned with representativeness, nonprobability approaches are more suitable

for in-depth qualitative research focusing on understanding complex issues (Marshall, 1996; Small, 2009). Purposive sampling methods represent the only appropriate method available if only a limited number of primary data sources can contribute to the study, which is the case for floating buildings.
Nevertheless, one must be aware of the limitations of purposive sampling, such as the vulnerability to errors in judgment by the researcher and the high levels of bias in the selection of case studies. The selection of the projects included a wide-ranging exploratory phase in which over 100 examples of floating structures built worldwide were considered. A first restriction from 100 to 88 was achieved by excluding cases with highly conditioned attributions and cases that did not adhere to the conditions highlighted in Chapter 4.1: built over the last 20 years (from 2003 onwards).

2.1.2.2. Case study analysis: development of the requirement-structured assessment rubric

The case study assessment form combines quantitative and qualitative analysis. Following a geographical overview, identity, and context information (name and details of the designer, geographical position, year of construction) is provided. Immediately after, there is a brief description of the project. General indications about functional and dimensional typology (occupied surface, height) are illustrated. A schematic depiction of the material and construction features of the key technical units is also provided. Ultimately, paradigmatic floor plans, graphic diagrams, and images are displayed. The project's compliance with each objective outlined in Chapter 3 is highlighted in a visual and schematic way through the case study assessment rubric (Appendix B). The assessment rubric is structured based on the design framework: each requirement is listed as a dichotomous option supplemented with a check box. The dichotomous question is a yes/no close-ended question (mutually exclusive) as the aim is to assess whether each requirement is met entirely or not. If the requirement is partially met or presumably met but not explicitly stated within the projects' objectives and documentation, then the checkbox is filled in by half. A percentage-based score indicating the proportion of requirements met is displayed in the top right corner for each class of demands.

2.1.2.3. Evaluation - validation of the case study assessment rubric

The case study assessment form is subjected to validation by scientific experts and practitioners involved in the fields of floating architecture, hydraulic and mechanic marine engineering, ocean engineering and ship technology, ecology and natural science, urban ecology, and environmental architecture. The experts are listed in Paragraph 2.1.3. The expert reviewers are asked to evaluate the case study assessment form (Appendix B), completing an evaluation form (Appendix C1, Q2). The structure and the administration of the questionnaire are explained in Paragraph 2.1.1.2.

2.1.2.4. Refinement of the case study assessment rubric

Once the reviewing process has ended, changes and variations are made to the case study assessment rubric according to the feedback received through the evaluation forms (Appendix C2).

2.1.2.5. Case study assessment

The selected projects are thus analyzed based on the refined case study assessment rubric. General information is acquired mainly through desk research integrated with field research (observational analysis and direct interviews with the main actors involved in the design/construction process). The desk research involves collecting a dataset of textual, graphical, and figurative contributions gathered through hand-searching methods within government/municipal reports, websites of local institutions, of professional organizations and architects, architecture and design online magazines, climate data providers, and other grey literature sources. This data is used to provide general information about the project (identification data, site features, functional typology, dimensional aspects, and construction components) and to assess the project's compliance with the objectives defined in Phase 1. Grey literature is also used for the evaluation of the project's compliance with each requirement. The requirement compliance is further assessed through observational research and direct interviews for a third of the projects. Aside from the case study sheet, the advantages and limitations are discussed for each case study.

2.1.2.6. Construction of the multi-objective optimization matrix

A multicriteria matrix is built, placing on the x-axis the case studies and on the y-axis the classes of requirements. The requirements on the y-axis are included in each case study sheet within the section Requirement Compliance. The construction of the matrix returns two results at the same time.

- **Project evaluation (identification of best practices)**: the matrix assesses and prioritizes different projects. By considering various criteria (performance requirements), decision-makers can objectively evaluate each project's potential benefits and drawbacks. Moreover, the matrix allows to identify best practices among the case studies according to their level of compliance with the requirements.
- **Performance evaluation (priority order among requirements)**: by defining relevant criteria (presence/absence within selected projects), the matrix identifies a priority order amongst the requirements classes according to their observance within the practice field. The multicriteria matrix provides a percentage of fulfillment for each requirement and thus highlights the importance each requirement has compared to the others.

The multi-criteria matrix is thus a helpful tool for comparing the different requirements and the different projects to make informed decisions in a structured and systematic manner.

2.1.2.7. Research from design to further integrate and update the framework.

The case study analysis evaluates the framework's quality and further develops and integrates it with inputs from the practice. It provides information grounded in practice and not necessarily already taken into consideration within the theoretical and regulatory sector. Especially in such a novel field, the practical world is more explored than the theoretical one. Existing projects can highlight some highly significant requirements that floating buildings should meet, but that could still be missing in regulatory frameworks and guidelines. Moreover, the case study assessment provides accurate information regarding the most used and widespread structural and technological components, materials, and construction processes, allowing the development of general considerations on state of the art within the practice field. To ensure the quality and evidence of the conclusions, each case study will have a bibliography section to inform the reader from where the data, insights, and any other information are drawn.

2.1.3. Expert reviewer validation

The experts involved in the PDSF and case study assessment evaluation cover a wide range disciplinary fields related to the topics included in the framework:

1. Environmental Architecture: Full. Prof. Arch. Alessandra Battisti (environmental architect), Department of Planning, Design and Technology of Architecture, Sapienza University of Rome.
2. Energy Engineering: Prof. Ing. Claudio Lugni (hydraulic and mechanic marine engineer), CNR - Institute of Marine Technology INSEAN.
3. Ecology: Prof. Mattia Azzella, (ecological scientist), Department of Planning, Design and Technology of Architecture, Sapienza University of Rome.
4. Structural and safety engineering offloating structures: Prof. Eng. Artur Karczewski (naval engineer), Shipbuilding Institute, Ocean Engineering and Shipbuilding, Gdańsk University of Technology.

Before answering the questionnaire, they are asked to go through the Performance-based Design-Support Framework (Appendix A1) the and the case study data sheet (Appendix B). The reviewers are asked to leave blank the questions that are not relevant to their field of expertise. The questionnaire (Appendix C1) contains 20 items and is structured in two sections:

I. the items (13) pertain to the Performance-based Design-Support Framework (Appendix A1);
II. the items (7) pertain to the case study data sheet (Appendix B).

2.1.4. Pilot study and geospatial mapping

As previously argued, from a strategic point of view, given the need for connection to existing physical and economic infrastructure, floating communities will likely be located near existing human activity hubs. There is a degree of overlap between locations that hold potential for human development and locations in which natural ecosystems are most affected by human activity. This presents an opportunity to design new floating structures to enhance and protect natural systems. Therefore, the site selection strategy could revolve around identifying locations where human and environmental needs resulting from climate change and urban growth intersect. Based on their location and the specific technological and logistic challenges encountered, floating structures can be split into offshore and nearshore structures (Giurgiu, 2022). Considering that the PDSF serves as a tool for designing floating buildings in sheltered waters, it refers to near-shore structures. Site selection is crucial as it reflects the underlying function of the structure and affects several requirements.

The analysis of nearshore areas is carried out within the boundaries of the Italian territorial waters. A preliminary mapping of the Italian coastal areas is carried out to identify Italian coastal urban areas more vulnerable to sea level rise and flooding and characterized by high-intensity economic, social, and cultural activity levels. Geospatial analysis and Geographic Information Systems (GIS) were used. This mapping leads to the identification of one of the most suitable areas for advancing FUD: Isola Sacra, located between the Municipality of Rome and Fiumicino. The second phase involves a deeper analysis of the selected area, considering anthropic and environmental constraints and opportunities. This process requires the integration of different types of data related to different aspects. The data taken into consideration is listed in Table 1.

Ultimately, a research by design approach is used by applying and testing the PDSF on a real specific context like Isola Sacra. The junior architects attending the Master Design Studio in Architecture and Urban Regeneration at the Sapienza University of Rome, held by Prof. Alessandra Battisti, are divided into five groups and asked to develop a design scenario for a floating settlement for the area of Isola Sacra. The aim of the design is to regenerate the area under environmental, social, and economic aspects. The students are given the PDSF as a tool to guide them in the design process.

Table 1. Data types and sources used for the Geospatial analysis.

Data	Description	Source
Anthropic		
Historical maps	Maps dated between 1557 and 1988	*Cartoteca PDTA – Sapienza*
Settlement system	Urban territorial planning maps	*Piano Regolatore Generale di Roma, Piano Regolatore Generale di Fiumicino*
Mobility on water	Main vessel routes, access to bathing waters	*Vesselfinder*
Mobility on land	Main roads, secondary roads, bridges, public transport facilities	/
Environmental		
Flood maps	Land below annual flood level in 2100	*Climate central*
Wind maps	Wind direction and speed	*Global Wind Atlas*
Solar maps	Sun radiation	*Global Solar Atlas*
Wave maps	Wave height and period	*Maestrale Repository*
Bathymetry map	Seabed topography	*Isprambiente (viewer)* *Coastenergy Webgis*
Quality - constraint		
Natural protected areas	Landscape system classification	*Geoportale Lazio – PTPR*
	Natura 2000 protected areas	*Geoportale Lazio - Rete natura 2000*
	Piano di Gestione della Riserva Naturale Statale Litorale Romano.	*Regione Lazio, Parchi Lazio - Tavola 1 - Vincoli.*
	Marine areas precluded to aquaculture and moisculture	*Geoportale Lazio, verificato_Paesaggi_DGR_228*
Archeological protected areas	Archeological constraints	*Geoportale Lazio – Aree archeologiche*
Risk and danger maps	Classification of the level of risk associated with a particular location	*Geoportale Regione Lazio, Mappe di rishio del Tevere*
Buffer zones	Buffer zones within a distance from the hydro-graphic network where building is prohibited.	*Geoportale Regione Lazio - Acque pubbliche rispetto*

References

Black, K. (2010). *Business Statistics For Contemporary Decision Making*. Wiley.

Calcagni, L., Sunguroglu, D., Hensel, M., Battisti, A., (2024). A Performance-Based Design Framework for Floating Architecture. Trade-offs and correlations between requirements for multiple criteria decision making optimization. WCFS2023: Proceedings of the Third World Conference on Floating Solutions, Tokyo. Springer Nature.

Giurgiu, I. C. (2022). Floating Cities and Equitable Grafting onto Marine Ecosystems. In *Lecture Notes in Civil Engineering* (Vol. 158). doi: 10.1007/978-981-16-2256-4_26

Groat, L. N., & Wang, D. (2013). *Architectural research methods.* John Wiley & Sons.

Wang, K-F. (2021). An Investigation into Environment-Floating Buildings in relation to Sustainability Indicators for Planning and Design Process. De Montfort University.

Yin, R. K. (2018). C*ase study research and applications* (Vol. 6). California: Sage Thousand Oaks.

Hensel, M. U. (2010). Performance-oriented architecture: towards a biological paradigm for architectural design and the built environment. *FORMakademisk, 3* (1). 36-56.

Hensel, M. U. (2012). Sustainability from a Performance-Oriented Architecture Perspective–Alternative Approaches to Questions regarding the Sustainability of the Built Environment. *Sustainable Development, 20*(3), 146–154. doi: 10.1002/sd.1531

Hensel, M. U. (2013). Performance-oriented design as a framework for renovating architectural practice and innovating research by design. In. M. U. Hensel (Ed) *Design Innovation for the Built Environment: Research by Design and the Renovation of Practice*, 121–143. Routledge. doi: 10.4324/9780203129746-15

Hensel, M. U. (2012). Sustainability from a Performance-Oriented Architecture Perspective–Alternative Approaches to Questions regarding the Sustainability of the Built Environment. Sustainable Development, 20(3), 146–154.

Ikart, E. M. (2019). Survey questionnaire survey pretesting method: An evaluation of survey questionnaire via expert reviews technique. *Asian Journal of Social Science Studies, 4*(2), 1. doi: 10.20849/ajsss.v4i2.565

Lin, F.Y., Czapiewska, K., Iorga, G., Totolici, D., Koning, J. (2020). A catalogue of technical requirements and best practices for the design- Deliverable. 7.2. Space@Sea.

Marshall, M. N. (1996). Sampling for qualitative research. Family Practice, 13(6), 522–526. doi: 10.1093/fampra/13.6.522

Krosnick, J. & Presser, S. (2010) Question and Questionnaire Design. In P. V. Marsden, J.D. Wright (Eds). *Handbook of Survey Research,*2nd ed. San Diego: Elsevier.

Shi, X. (2010). Performance-based and performance-driven architectural design and optimization. *Frontiers of Architecture and Civil Engineering in China, 4*, 512–518. doi: 10.1007/s11709-010-0090-6

Small, M. L. (2009). How many cases do I need?' On science and the logic of case selection in field-based research. *Ethnography, 10*(1), 5–38.

PART II

Definition of a Performance-based Design-Support Framework

PDSF

CHAPTER 3 Performance-based Design-Support Framework - PDSF (Appendix A2)

ABSTRACT

The Performance-based Design-Support Framework (PDSF) defined and presented in this chapter is a tool for advancing the design of floating buildings and evaluating their performance against a set of nine classes of demand: safety, wellbeing, usability, management, environmental regeneration, rational use of resources, integrability, buoyancy-stability, and plant system. Each class of demand is further articulated into subclasses of requirements, each with its set of performance requirements. The PDSF is user-centered and designed to meet the users' needs of floating buildings. However, it follows a multi-species approach with a view to ecosystem integration, as one of the assumptions behind the framework is that the environment is conceived as a host organism (ecosystem) and the floating facilities as grafts. Moreover, it aligns with the life-cycle approach: the PDSF considers the performance of floating buildings over their entire life cycle, from design and construction to operation and maintenance. Finally, the PDSF is designed to be adaptable to the changing needs of users and the environment.

Overall, the PDSF is a valuable tool for designers, developers, and policymakers to identify and prioritize the performance requirements that are most important for a particular project, evaluate the performance of a floating building against a set of predefined criteria, develop and implement design solutions that meet the performance requirements making informed decisions about the construction, operation, and maintenance of the floating building.

The chapter first introduces the identified classes of demand, providing an extensive description of each one supported by references and relevant regulations from different disciplinary fields. Then, the adjustments made to the PDFS, according to the feedback received by the expert reviewers, are outlined. The updated version of the PDFS can be found in Appendix A2. The last sub-chapter focuses on the compatibility, complementarity, interchangeability, and excludability relationships that bound all the requirements.

3.1 Identification of classes of demands

The classes of demand identified by the Italian norm UNI 8289:1981 are the following: safety, comfort, usability, aesthetics, management, integrability, and environmental protection. The norm UNI 11277:2008 expands the number of classes to consider the eco-compatibility of projects by adding the class Rational Use of Resources and changing the name and content of the class of Comfort into Wellbeing, Hygiene, and Health. The UNI 11277:2008 highlights the importance of considering the different demands and requirements of the environmental protection class and the rational use of resources throughout the building's different phases: design, construction, operation, and demolition. Although it is meant only for newly built and renovated residential and office buildings (or comparable buildings), the PDSF extends its domain to all building typologies in terms of function they host. Overall, the classes of demand taken from the Italian standard classification system are the following: safety, wellbeing, usability, management, integrability, environmental protection, and rational use of resources. The same distinction is made by K.F. Wang who categorizes his Sustainable Floating Building Indicators according to the building life cycle phases (planning, design, use and recycling).
Four significant adjustments have been made compared to the UNI 8289:1981 classification integrated with the UNI 11277:2008. First, the class concerning aesthetics was left out as it was deemed insufficiently technical and too subjective. Secondly, the class of environmental protection underwent a process of further clarification and improvement in terms of content and, thus, terminology. One of the underlying assumptions of the framework is the broad alignment of environmental and health agendas that underlines the close relationship between healthy and green environments or green buildings. In the framework, the concept of wellbeing is extended from the physical domain to include the psychological and social one. As stated by the author in (Battisti et al., 2022), over the years, the concept of health has undergone an epistemological evolution: from health as the simple absence of

disease to health as a state of physical, mental, and social wellbeing, as defined in the 1946 Statute of the World Health Organization (WHO). This paradigm shift has marked a significant turning point in fields of knowledge. The theme of health is no longer conceived within the exclusive domain of medicine. It has become a study subject for all disciplinary sectors that deal with the topic of living in various ways. As highlighted by Professor Fabrizio Tucci, in the last decade, the green building approach has moved from minimizing environmental impacts through reductions in energy usage, water usage, waste production, and CO_2 emissions to implementing resilient and circular processes (Tucci, 2018). Less widely recognized is that green buildings also address human health by designing healthy indoor and outdoor environments. This superimposition of green and healthy concepts requires adopting a human-centric approach, where the planet's health is conceived as part of human health and wellbeing. Therefore, the environment is conceived as a host organism (ecosystem) and the floating facilities as grafts. This implies that the project should meet both human and ecological needs. Various plans and environmental policies have been implemented worldwide to tackle this challenge (COM, 2019). The Green Deal of the European Union prioritizes the development of nature-based solutions as cost-effective solutions that provide environmental, social, and economic benefits while protecting, managing, and restoring ecosystems and building resilience (Bauduceau et al., 2015; Eggermont et al., 2015). As highlighted by Weisser, Hensel et al. (2023), creating sustainable, resilient, and livable cities requires architecture to support biodiversity. This statement paves the way for a multi-species design approach and a tangible architecture and environment integration. In light of these considerations, the Environment Protection class of demand turns into Environment Regeneration with a view to an environment embedded architecture that not only integrates into the environment in a non-intrusive and non-destructive way but is also capable of having a positive impact on it with benefits for the whole multi-species ecosystem. The third change concerns the addition of a new class of demand addressing all those aspects associated explicitly with water-based buildings: the Buoyancy-Stability class. The Buoyancy-Stability class refers exclusively to the sub-structure (barge or pontoon). For this reason, it is provided by all nautical and offshore performance-based codes and guidelines (like IMO or IRPCS[1]), unlike the superstructure designed to adhere to Eurocodes and other national and local building regulations. The last difference is the addition of a class explicitly relating to the plant system. The NTA 8111_2011 *Netherlands Standards for Floating Constructions*[2] provides specific requirements referring to design and prevention measures to avoid (or easily tackle) the damage of pipelines and plant system equipment due to human action, biological and chemical agents, harsh or rapidly changing weather conditions. Other standards and documents supporting the need to introduce this class of demand include the Korean Register of Shipping - *Guidance for Floating Structures* and the Portland City

1. International Regulations for the Prevention of Collision at Sea.

2. See note 25 in Chapter 1.

Code – *Title 28 Floating Structures*.
All things considered, the identified classes of demand composing the PDSF are the following.

1. Safety
2. Wellbeing[3]
3. Usability
4. Management
5. Environmental Regeneration
6. Rational Use of Resources
7. Integrability
8. Buoyancy-Stability
9. Plant system

Hereafter, each class of demand is defined – as suggested by an expert reviewer[4] – and its relevant classes of requirements and requirements are argued. The latter can be conceived as the transposition of a demand into technical terms. The norm UNI 8290-2:1983 defines 63 requirements for buildings. The purpose of the standard is to provide a list of the main requirements to define the reference framework with respect to the agents that motivate them, the demands to which they are transposed, and the technological system[5] to which they refer. According to the norm, a requirement must refer to a particular element of the building system, to a particular agent that motivates it, and to a particular condition of use. Moreover, a requirement must be quantifiable with a system of parameters or indicators. The requirements considered in the PDSF include different typologies: functional-spatial, environmental, technological, and technical, operational, and durability and maintainability. The thesis limits itself to identifying and clarifying the requirements without identifying quantitative indicators for each requirement. Quantitative indicators are identified only for one class of demand as part of the proof of concept exposed in Chapter 7.2. The rationale behind this choice is linked to the intention to focus on the broader picture to delve deeper into the relationships between the different requirements. In Chapter 7.3, a proof of concept is proposed performed only on a class of demand and on its respective requirements, demonstrating that each requirement can be assessed and verified through quantifiable parameters or metrics.
The complete list of requirements can be found in Appendix A2. For each performance requirement, a list of relevant regulations is provided, sorted by color according to the discipline they come from:

- grey: on land architecture and civil engineering
- blue: floating architecture
- red: shipping and naval engineering
- purple: offshore engineering.

3.1.1. Safety (S)

Safety can be defined as the set of conditions relating to the safety of

3. Following the suggestion of expert reviewer 1, this class, previously named Comfort was transformed into Wellbeing. A more comprehensive description of the expert reviewer's feedback is provided in Paragraph 3.2, and the feedback itself can be found in Appendix C2.

4. The expert reviewers feedback was was delivered between March and August 2023. A more comprehensive description of the expert reviewer's feedback is provided in paragraph 3.2, and the feedback itself can be found in Appendix C2.

5. According to UNI 7867-4:1979 (replaced by UNI 10838:1999), the technological system is the structured set of technological units or technical elements according to the operational meta-design phase of the building process.

6. The definition is provided by the UNI 8289:1981 *Edilizia - Esigenze dell'utenza finale - Classificazione.*

users, as well as the defense and prevention of damage depending on accidental factors, in the operation of the building system[6].
The Safety class of demand includes the following classes of requirements.

- 1.1. Structural Stability
- 1.2. Fire Safety
- 1.3. Users Safety from External Actions
- 1.4. Users Safety in Use

Regarding **Structural Stability**, as in Eurocode EN 1990:2002 *Standard Basis of structural design*, a structure shall be de-signed and executed in such a way that it will, during its intended life, with appropriate degrees of reliability and in an economical way sustain all actions and influences likely to occur during execution and use and remain fit for the use for which it is required. In other words, structural stability can be defined as the morphological efficiency in relation to static and dynamic actions (seismic and operational), where the term structure refers to the organized combination of connected parts designed to carry loads and provide adequate rigidity. When a structure is subjected to a sufficiently high compressive force (or stress), it tends to lose its stiffness, experience a noticeable change in geometry, and become unstable (Lui, 2020).
It is important to clarify that this class does not refer to the buoyancy and stability aspects of the sub-structure (floating pontoon) but only to the superstructure and its connection to the sub-structure.
Fire resistance is defined in the EN 1991-1-2:2004 standard Eurocode 1: *Actions on structures – Part 1-2: Actions in general – Actions on structures exposed to fire*, as the ability of a structure to maintain its required performance for a given period under the action of fire. The EN 1991-1-2:2004 standard also provides a set of requirements for verifying fire resistance. These requirements are specific to the type of structure and load to which the structure is subjected. In particular, the standard requires that the structure can:

- resist the thermal actions of fire for a specified period of time;
- maintain its structural integrity for a specified period of time;
- maintain its smoke and gas tightness for a certain period of time.

Fire Safety in the PDSF extends the domain of the EN 1991-1-2:2004 – that is strictly limited to the conditions to be met during a fire – to requirements concerning the fire risk control and prevention and the conditions that allow evacuation in case of emergency.
User Safety from External Actions refers to protection from accidental anthropic actions. EN 1991-1-7 in the category of accidental actions includes impact forces from vehicles, rail traffic, ships, and helicopters; actions due to local failure from an unspecified cause. Paragraph 2.3.3 of the UNI EN 1990:2002 standard Eurocodes: *Basis for the design of structures* defines anthropic actions as "actions due to human causes" and requires the building to be able to resist:

- anthropogenic actions without collapsing or suffering significant damage;

- anthropogenic actions without losing its ability to protect the occupants.

According to the definition of accidental action, given the water environment, accidental actions due to impact forces include a series of requirements specifically focused on collision prevention.
The fourth class of requirement, **User Safety in Use**, is defined in the EN 1990:2002 standard *Basis for the design of structures* as "the ability of a building to be used safely and without risks". In other words, the building must pro-vide a safe environment for activities within the building. Operational Safety includes requirements related to fall protection, surface roughness control, circulation safety, limitation of surface temperatures (max. values), control of electrical leakage, and others.
Given the water environment, aspects related to onboard safety equipment, non-slip walking surfaces, climbing-holding devices, or overtopping reduction (clearance above water) must be considered too. These requirements come from floating building standards[7] as well as shipping regulations and directives[8].
The user protection requirements from anthropic actions are specified in detail in the following UNI standards: UNI EN 1991-1-7:2006 *Eurocode 1: Actions on structures - Part 1-7: Actions in general - Anthropogenic actions*; UNI EN 1991-1-8:2006 *Eurocode 1: Actions on structures - Part 1-8: Actions in general - Anthropic actions - Actions due to explosion*; UNI EN 1991-1-9:2006 *Eurocode 1: Actions on structures - Part 1-9: Actions in general - Anthropic actions - Actions due to vandalism and criminal acts*.

3.1.2. Wellbeing (W)

Wellbeing can be defined as the set of conditions relating to building conditions adequate to the life, health, and performance of users' activities[9].
The wellbeing class of demand includes the following classes of requirements.

- 2.1. Thermal-Hygrometric Comfort.
- 2.2. Visual Comfort.
- 2.3. Acoustic Comfort.
- 2.4. Respiratory-Olfactory Comfort.
- 2.5. Spatial Comfort.
- 2.6. Motion Comfort.
- 2.7. Psycho-Perceptive Comfort.
- 2.8. Hygienic Conditions.

Thermal-Hygrometric Comfort is defined by the EN ISO 7730:2005 as "the condition in which the human body is in thermal equilibrium with the environment, with a sense of wellbeing and without discomfort". The standard provides several methods for evaluating thermal comfort by measuring several environmental parameters, including air temperature, relative humidity, mean radiant temperature, air velocity, and skin temperature.
Visual Comfort is defined by the EN ISO 8995-1:2002 - *Lighting of workplaces - Part 1: Indoor* - as "the condition in which the user

7. NTA 8111_2011 *Netherlands Standards for Floating Constructions*; Queensland Development Code *MP 3.1.Floating Buildings*; Space@Sea Deliverable 7.2 *A catalogue of technical requirements and best practices for the design*.

8. *ABS* Rules for Building and Classing Mobile Offshore Units, *Part 5 Fire and safety*; UK Code of Federal Regulations – *Title 46 Shipping - Part 177 – Construction and arrangement (USA)*, Commission Delegated Regulation (EU) 2020/411 of 19 November 2019 amending Directive 2009/45/EC of the *European Parliament and the Council on safety rules and standards for passenger ships, as regards the safety requirements for passenger ships engaged on domestic voyages* (Text with EEA relevance); Directive 2013/53/EU of the *European Parliament and the Council of 20 November 2013 on recreational craft and personal watercraft* and repealing Directive 94/25/EC (Text with EEA relevance).

9. The definition is provided by the UNI 8289:1981 *Edilizia - Esigenze dell'utenza finale - Classificazione*

can perform the required tasks efficiently and without discomfort". The standard's requirements include general lighting, task lighting, emergency lighting, and signal lighting (in the case of public facilities). In addition to lighting conditions, the PDSF integrates a special requirement concerning the quality of views and sight. This requirement is provided by the WELL Building Standard (L05) and by the World GBC Protocol *Better Places for People*. In further support of this requirement, the Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) also provides a special requirement concerning visual comfort (SOC 1.4) within its DGNV certification system for evaluating sustainable buildings.

As for **Acoustic Comfort**, it is described by the EN ISO 11264-1:2017 standard *Ergonomics of the acoustic environment - Evaluation of acoustic comfort - Part 1: Evaluation of internal environments* as "the condition in which the people who occupy an environment perceive the level and quality of sound positively". Acoustic comfort also considers the morphological and distributional efficiency in relation to noise[10].

Respiratory-Olfactory Comfort mainly consists of the absence of unpleasant odors and thus considers the control of ventilation[11]. Respiratory-Olfactory Comfort considers the concentration of odorous substances in the air, the perception of odors by people, and the perceived quality of the air.

Spatial Comfort can be defined as the feeling of wellbeing and satisfaction in an environment, depending on a series of factors, including the room size, the furniture arrangement, the occupancy, and the crowding level. This class of require-ment is provided not only by on-land conventional building regulations and standards[12] but also by shipping regulations[13].

One of the most apparent differences in living on the sea is the constant presence of movement, that leads to take into consideration **Motion Comfort**. This movement in specific frequencies can lead to discomfort or motion seasickness (MS), also known as *naupathia* or *cinetosi*[14]) and influence daily life quality. One of the oldest and most well-accepted theories of MS is the sensory conflict theory, which ascribes MS elicitation to conflicts between various sensory organs, such as signals from the vestibular system and the optical senses or signals from canals and otoliths (Kumar et al., 2020). This theory is also known as the Neural Mismatch Theory. The converging sensory inputs from the otolith organs, semicircular canals, eyes, and somatosensory receptors are mismatched with the expected sensory patterns in the neural store calibrated by experience. Therefore, spatial orientation is disturbed, leading to motion sickness, a normal physiological response to real or virtual motion stimuli rather than a pathological condition in the strict sense (Schmäl, 2013).

Pitch, yaw, surge, sway, and heave motions are mainly related to the length and block coefficient of the substructure, and generally, the longer and fuller (high block coefficient) the hull, the lower the accelerations for these motions. ISO[15] has developed standards

10. The definition is provided by the UNI 8289:1981 *Edilizia - Esigenze dell'utenza finale - Classificazione*.

11. Information provided by the UNI 8289:1981 *Edilizia - Esigenze dell'utenza finale - Classificazione*.

12. UN-Habitat (Principles and recommendations for population and housing censuses, UN, 2007), World Health Organization Housing Guidelines, Eurostat Overcrowding Rate 2014, American Crowding Index.

13. ABS Rules for Building and Classing Mobile Offshore Units, *Part 5 Fire and safety*.

14. Definition provided by Istituto Superiore di Sanità – Cinetosi - 06 Febbraio 2019. Retrieved from https://www.issalute.it/index.php/la-salute-dalla-a-alla-z-menu/c/cinetosi#link-approfondimento

15. Relevant standards are: ISO 2631–1 *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements*; ISO 2631-2:2003 *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 2: Vibration in buildings (1 Hz to 80 Hz)*; ISO 2631-4:2001 *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems* ; ISO 2631-5:2018 *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 5: Method for evaluation of vibration containing multiple shocks*; ISO 6954:2000 *Mechanical vibration - Guidelines for the measurement, reporting and evaluation of vibration regarding habitability on passenger and merchant ships*; ISO 20283-2:2008 *Mechanical vibration - Measurement of vibration on ships - Part 2: Measurement of*

for both the vibration part and the motion dynamics. The latter is often referred to as whole-body vibrations. They are typically caused by motions of the global structure that could be perceived in a high-rise building, a bus, or a train. Since it is not yet possible to draw up accurate performance requirements specifically for floating structures another option is to draw upon the performance requirements that apply to high-rise buildings, which in some terms could be comparable. The dynamic behavior with low frequencies or long periods is perceived as motions, while behavior at higher frequencies is noted as vibration. Human perception, however, is quite different from motions and vibrations. Motions with frequencies from 0.1 to 1 Hz, particularly at frequencies around 0.2 Hz, are likely to cause disorientation, nausea, and motion sickness. The sensitivity is illustrated by typical weighing factors in ISO 2631-1997.

The perception of nuisance due to the various vibration, motion, and tilt effects is nontrivial, and despite being described in the literature, it has yet to be studied for long-term residence (Dallinga & Bos, 2010). Attempts have been made to define specific indicators for various characteristic behaviors. This is a not fully developed field of expertise for the lower frequencies. The most important parameters are listed below:

- Root Mean Square (RMS) value: mean vibration level typically 1-100 Hz bandwidth;
- Crest factor: relation of max peak value in comparison to mean level;
- MTVV: Maximum transient vibration value (indicative of shock);
- Vibration dose value (VDV): Statistical value related to shock;
- MSI: Motion Sickness Index based on acceleration levels;
- MSDV: Motion sickness dose value based on low-frequency vibrations;
- IR and CR: Illness and comfort ratings.

Quite a lot of parameters were defined and are available to quantify the actual behavior of a structure. Still, the actual human impact of that behavior, however, is less well-defined. It also depends on factors such as age, gender, fitness, fatigue, customization, and the type of function carried out (Lin, et al., 2020). The Space@Sea Report (Lin et al., 2020) depicts an overview of acceleration limits for different urban functions. The limits for residential, office, and leisure functions were set at lower accelerations. Open space can have higher accelerations. For gardens, parks, and other outdoor recreational functions, it was set that in a 1:1-yr event, which is extremely common and will occur with 100% likelihood any given year, people will perceive motions but still be able to walk. The same acceleration limit was set for a 1:100-yr event for residential and office functions. In buildings, it is more important that people do not perceive motions and that objects are not falling. The limit is higher in gardens and other outdoor functions since people are not expected to go to the park or do outdoor sports in bad weather conditions. For streets, lower limits are set compared to parks and outdoor functions. This is done since the motions for streets should

structural vibration; ISO 20283-4:2012 *Mechanical vibration - Measurement of vibration on ships - Part 4: Measurement and evaluation of vibration of the ship propulsion machinery*; ISO 20283-5:2016 *Mechanical vibration - Measurement of vibration on ships - Part 5: Guidelines for measurement, evaluation and reporting of vibration with regard to habitability on passenger and merchant ships.*

enable the safe movement of people and vehicles even during bad weather conditions. In a 1:100-yr event, people are still able to walk on the street. Another important document that introduces motion comfort requirements is the *Cruise ship sea keeping and passenger comfort* paper (Dallinga & Bos, 2010). In general, there are minimal limits in place to safeguard the health, safety and integrity of people and equipment. For maritime applications that has mostly been from an occupational point of view. Motion comfort must be addressed through both technical devices that contribute to stabilizing the structure as well as through architectural strategies that reduce the perception of movement.

Psycho-Perceptive Comfort, following the conception used by Professor Alessandra Battisti in the context of urban health (Battisti et al., 2019), can be conceived as a state of wellbeing resulting from the satisfaction of psychological and perceptual needs encompassing a wide range of factors, including emotional, cognitive, and sensory experiences. Several lines of evidence suggest that lifestyle (in terms of active design that promotes physical activity), behavioral engagement (through participatory design processes, space design to foster social cohesion and connectivity), and contact with nature (in terms of indoor biophilic design and outdoor nature access and biodiversity) strongly contribute to the overall sense of wellbeing of users (Battisti & Marceca, 2020; Bolten & Barbiero, 2020; Capolongo et al., 2018). A saluto-genic[16] approach to design encompasses considering all these elements. In support of this argument, it is essential to mention that biophilic design, for instance, is included in the 9 Foundations of a Healthy Building - Harvard (Allen & Macomber, 2020) and in the ABS Rules for Building and Classing Mobile Offshore Units, while behavioral engagement and active design are mentioned in the WELL Building Standards[17].

As mentioned by the UNI 11277:2008, **Hygienic Conditions** are associated with exposure to indoor air pollutants, with variations in the electromagnetic field from artificial sources. The PDSF expands the standard domain to include air quality, surrounding water quality, drinking water quality, microbe, and mold control. These requirements are mentioned in the WELL Building Standard and the World Health Organization Housing Guidelines. The PDSF takes into consideration also pest and dangerous animals prevention, which are taken respectively the first from the ABS Rules for Building and Classing Mobile Offshore Units, and the 9 Foundations of a Healthy Building - Harvard, and the latter from the NTA 8111_2011-NL - Netherlands Standards *Netherlands Standards for Floating Constructions* and the CDC 24/7: *Saving Lives, Protecting People - Centers for Disease Control and Prevention*.

3.1.3. Usability (U)

Usability refers to the set of conditions relating to the ability of the building system to be adequately used by users in carrying out their daily activities. Ortega y Gasset's well-known phrase,

16. The saluto-genic approach was theorized by Aaron Antonovsky, a sociologist and medical anthropologist (Antonovsky, 1987; Dilani, 2008). Antonovsky's theory was based on the idea that health is not simply the absence of disease, but rather a dynamic state of wellbeing. He posited that health is promoted by a sense of coherence, which is a global orientation that the individual experiences the world and the self as comprehensible, manageable, and meaningful. Antonovsky's theory has been extended to the domain of architecture and design by a number of researchers starting from the context of healthcare design (Golembiewski, 2022; Mittelmark et al., 2022; Pelikan, 2017). The saluto-genic approach has the potential to inform the design of environments that promote health and wellbeing. Saluto-genic design entails the adoption of a number of design features that can contribute to a sense of overall wellbeing, such as views and access to nature, access to daylight, opportunities for privacy, for physical activity, and for social interaction.

17. Behavioral engagement is taken into consideration in the WELL Building Standard - *C02 - Integrative Design and active lifestyle design*, in the WELL Building Standard – *V08 - Physical Activity Spaces and Equipment* and in the WELL Building Standard – *V09 - Physical Activity Promotion*.

"I am myself and my circumstances", underlines the reciprocal influences, the entangled relationships between the person and the surrounding living environment. From a user-centered design perspective, usability implies a reciprocal relationship between the user and the space and, therefore, entails different dimensions: functional, perceptive and proxemic, tangible and intangible. The living environment is not a neutral space, but always an operating factor (Canter & Lee, 1974; Fitch, 1972) in human life. The person-environment fit is a dynamic and two-directional process: it comprises, on the one hand, the transformation of the environment in the direction of human capacities and, on the other, the transformation of the individual towards the requirements of the environment (Edwards et al., 1998). The more the living environment is accessible, the greater the capacity of the person to self-determine his or her own existence. This means that by introducing modifications to the living environment that increase its accessibility, it is possible to positively affect the person's capacity for developing his own life and role in the community (UN DESA, 2013, Lauria, 2017). As a result, design plays a significant role in providing the circumstances for proper interaction between the individual and the environment, as well as constructing accessibility, a necessary prerequisite for effective inclusion (Baratta et al., 2019). The capacity of the living environment – that is not limited to a physical dimension – to adequately support the life of people depends on its physical features, which are more objectively identifiable, and on the efficiency of the social support network available in it. The latter has already been considered in the previous paragraph (3.1.2.). Usability includes three classes of requirements.

- 3.1. Accessibility
- 3.2. Adaptability
- 3.3. Functionality

Within environmental design, **Accessibility** includes a wide range of environmental requirements (including reachability, usability, communicativeness, and circulation) (Laurìa, 2017). Accessibility expresses the level (accessibility degree) to which places, goods, and services guarantee, for every person – regardless of age, sex, culture, health, social status, education, physical, sensory, or cognitive capacities – the possibility of developing their life project (Laurìa, 2012). Environmental accessibility, however, is also a collective resource that can elevate the social capital of a community. More accessible environments expand individual freedom, social opportunities, and knowledge, encouraging every person to participate in the community's life and to contribute to society's growth. This can be reflected in the social and economic development of the area (Buhalis et al., 2005; Darcy & Dickson, 2009). The concept of accessibility has gone through a deep revision due to the evolution of the concept of disability. If in the past disability was considered a condition of the individual, today it is seen as the result of a complex interaction between "persons with impairments and attitudinal and environmental barriers that

18. This definition is provided by the Preamble of the Convention on the Rights of Persons with Disabilities (CRPD) of the United Nations Department of Economic and Social Affairs. Retrieved from https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities/preamble.html

hinder their full and effective participation in society on an equal basis with others"[18]. As a result, the concept of accessible place from a place without architectural barriers, or up to standard, has evolved into an inclusive place, open and receptive to diversity and capable of welcoming with adequate conditions of comfort and safety, people with different specificities and unequal degrees of freedom. From an initial interest in the mobility needs of people in wheelchairs (Goldsmith, 2012), accessibility gradually extended its range of action to include the needs of people with sensory, intellectual, or psychiatric disabilities (Goldsmith, 2007). This widening of the horizon has resulted in the overcoming of the design approach based on special solutions, that is, on the creation of reserved accessibility environments and of specific equipment and facilities destined to this or that disabled user profile, and to the affirmation of specific design methodologies which are aimed at universal design (Mace, 1985, Mace,1991). Universal design aims to "provide adequate use of spaces, products, and services usable by all people, to the greatest extent possible, without the need for adaptation or specialized design"[19].

The **Adaptability** of a building system is its ability to respond and adapt to environmental, social, or economic changes or events. These events include natural disasters or climate change impacts, changing user needs (such as population growth, evolving technologies, or changes in local demand), or requirements for new functions or uses. The adaptability of a building system can be measured based on several requirements, including flexibility of the building structure and components (suitability to transform or integrate new parts), modularity of the building and building components, scalability of the building, and functional and spatial flexibility. ISO standard 20887:2020 Sustainability in buildings and civil engineering works – Design for disassembly and adaptability – Principles, requirements, and guidance, introduces the principles of design for disassembly and adaptability (DfD/A) to optimize both the service life and the design life of buildings and civil engineering works. Introducing aspects of design for disassembly can be used to reduce and prevent waste and increase resource efficiency by encouraging alternative considerations at the project definition phase. Adaptability concepts and principles can minimize the need for unnecessary removal and new construction by repurposing or modifying constructed assets to renew their service life and result in constructed assets that can accommodate a larger variety of uses. From a broader perspective, as stated in the ISO 20887:2020, the recovery and subsequent reuse or recycling of disassembled construction materials and components will support the evolving concept of a circular economy. Incorporating DfD/A concepts early in the design phase will increase the likelihood that activities during the stages of use, maintenance (including repair, replacement, refurbishment), and end-of-life (e.g., disassembly, reuse, recycling, disposal) will be conducted more efficiently from a total resource perspective (i.e., time and associated costs, labour costs, materials, and energy).

19. This definition is provided by the *Article 2 Definitions of the Convention on the Rights of Persons with Disabilities* (CRPD) of the United Nations Department of Economic and Social Affairs – Disability. Retrieved from https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities/article-2-definitions.html

Within this class of requirements, it is essential to add a specific set of requirements that allow the mobility of the structure, conceived to reconfigure the building by its relocation. Mobility is one of the aspects that can drive the sustainable and long-term development of floating solutions. At both local and global scales, mobility can have an impact at multiple levels. On the one hand, it allows the floating facility to be relocated to more advantageous sites (Giurgiu, 2022) in the event of shifts in a specific site's functional and dimensional demand, according to new spatial and functional zoning and shifts in the functional or if maintenance is required. On a larger scale, the design of floating cities as mobile infrastructures that change location over time could truly reduce the impact of human exploitation on marine environments. The floating buildings could change location according to natural timelines, such as cycles, to optimize resource allocation. The following example from the field of marine fishery management provides a convincing argument supporting this. While in land-based scenarios, crop rotations are an established management strategy, it is a less common practice for marine environments. However, research suggests that, regarding harvesting some marine species, rotating harvest sites over periods as long as six years would generate improvement in biological and economic performance and help avoid overexploitation of resources (Plagányi et al., 2015). In terms of the relationship between the city and the ecosystem, the main advantage of the enhanced mobility of floating solutions is, therefore, the ability to optimize the use of space and resources by reconfiguring and relocating the structures in seasonal or longer cycles that correlate with natural growth patterns (Giurgiu, 2022). Floating mobile infrastructures that can change location over time also enable a dynamic and flexible urban fabric that adjusts to the ongoing changing circumstances regarding the community's demand, such as market, social, or spatial requirements.

The **Functionality** of a building system refers to the set of requirements that guarantee that the system complies with its purpose. In other words, the building or environment must be designed to fulfill its intended purpose, for example, living, working, or studying. This class of requirements entails, for instance, occupancy rate according to the function it hosts, minimum heights, areas, and volumes, as well as ease of use and maneuver. A particular requirement that deserves mention is furniture integration. Given the peculiarity of the water environment that entails the constant, yet slight, presence of movement, furniture integrability may represent a solution to avoid even the slightest movement of heavy objects, improving the ease of circulation while reducing the risk of personal injury. Furniture integration also contributes to reducing the risk of unbalancing the floating structure by affecting the stability of its center of gravity. This requirement is introduced, for instance, by the Canada Labour Code *Maritime Occupational Health and Safety Regulations*.

20. The definition is provided by the norm UNI 8289:1981 *Edilizia - Esigenze dell’utenza finale - Classificazione.*

3.1.4. Management (M)

Management refers to the set of conditions relating to the operating economy of the building system[20]. The UNI 8289:1981 standard includes among the management requirements only maintainability and durability (which include cleanability, repairability, and replaceability) and resistance to external agents and operating stresses. It was deemed appropriate to follow the logic adopted by the UNI 11277:2008 standard regarding the division into different phases of the building's life cycle. Taking as reference the classification proposed by ISO standard 14040:2006 *Life Cycle Assessment*, as well as by EN standard 15804: 2013 *Sustainability of construction works – Environmental product declarations*, the management class of demand is structured in the following classes of demand.

- 4.1. Design and Construction Management.
- 4.2. Operational Management (Use and Maintenance).
- 4.3. End of Life Management.

More specifically, the first class of requirements, **Design and Construction Management**, refers to all the features discussed during the design phase that affect the operational phase. These include selecting materials, technologies, and systems that can improve or facilitate the usability of the building. Construction management includes a set of requirements referring to raw material extraction and processing, manufacturing, transportation, assembly or construction, and product finishing.

The **Operational Management** class entails requirements linked to the correct use and feasible maintenance of the building throughout its lifetime. It includes requirements that optimize the efficiency of the building under different aspects, contributing to reducing operating costs while maximizing comfort and wellbeing.

The **End of Life Management** includes all processes and features that are involved in the disposal or recycling of the building.

3.1.5. Integrability (I)

Integrability is the requirement class that identifies the set of conditions relating to the aptitude of the units and elements of the building system to connect functionally to each other[21]. In this context, it mainly refers to the aptitude for functional and dimensional integrability or plant integration. The classes of requirements are two.

- 5.1. Integrability of Technical Elements.
- 5.2. Integrability of the Plant Systems.

The **Integrability of Technical Elements** entails the aptitude of different building components and materials to connect. The morphology and dimensions are designed to facilitate and guarantee their physical integration without requiring further adaptation or adjustment operations. This concerns not only components but also materials that must be able to work together effectively.

21. The definition is provided by the UNI 8289:1981 *Edilizia - Esigenze dell’utenza finale - Classificazione.*

Plant system integration entails the need to allow the passage, accommodation, juxtaposition, suspension, and fixing of technical elements of plant subsystems (ducts and terminals), possibly without the integration of these involving additional breakage and restoration work. Integration between systems entails that the different plant systems must be able to interact with each other effectively. For example, the plumbing system must be integrated with the electrical system to power the pumps and valves, and the heating system must be integrated with the ventilation system to ensure a comfortable environment.

3.1.6. Environmental regeneration (ER)

Anthropogenic-driven impacts, including depletion of natural capital and energy sources, global warming, ocean warming, acidification and deoxygenation, loss and change in biodiversity and ecosystems, pollution, and CO_2 emissions, must be mitigated, if not avoided, through a sustainable design (Habibi, 2015). Sustainable design and construction has emerged as a guiding approach rooted in the paradigm of sustainability, as described in the Introduction section. As emphasized by Ofori and Habibi (Habibi, 2015; Ofori, 2000), architects, technicians, and policymakers working in countries dealing with the design of floating buildings for quite some time have started questioning the need to integrate sustainable floating construction standards. Given this broader picture, the environmental regeneration class of demand is not limited to the set of conditions concerning the preservation of the ecosystem of which the building system is part[22]. However, it extends its domain to the requirements that ensure the enhancement and regeneration of the natural and animal habitat, foster biodiversity, improve air quality and microclimate, integrate in the water cycle and the surrounding landscape and ecosystem. Environmental Regeneration is thus also inextricably related to reducing CO_2 emissions, sustainable and circular waste management, and using sustainable and low-environmental impact materials[23].
Overall, the classes of requirement are the following.

- 6.1. Use of Materials with Reduced Environmental Impact.
- 6.2. Ecology and Habitat Preservation and Enhancement.
- 6.3. Landscape Preservation.
- 6.4. Decarbonization.

Use of Materials with Reduced Environmental Impact refers to the use of materials that are first compatible with the environment (i.e., materials that do not release toxic substances into the environment) and secondly compliant with a Life Cycle Assessment approach. The latter implies the use of materials, the harvesting, manufacturing, and disposal of which minimizes CO_2 and GHG emissions, as well as water and energy consumption. Examples include biodegradable, bio-derived, by-product derived materials, carbon capture materials, or materials that require low water and energy consumption manufacturing processes or with limited leftover waste. Low environmental impact may also

22. As in UNI 8289:1981 *Edilizia - Esigenze dell'utenza finale – Classificazione*.

23. As in UNI 11277:2008 – *Sostenibilità in Edilizia.*

24. Decreto Ministeriale del Ministero dell'Ambiente e della Sicurezza Energetica 23 giugno 2022 recante *Criteri ambientali minimi per l'affidamento del servizio di progettazione di interventi edilizi, per l'affidamento dei lavori per interventi edilizi e per l'affidamento congiunto di progettazione e lavori per interventi edilizi*. The innovation brought by CAM 2022 concerns the assessment of the life cycle of buildings (LCA) prior to design and material choices. The objective is to reduce the impact of buildings as much as possible by using resources in an efficient and circular way, from the composition phase to use, management and disposal or recycling, contributing to the reduction of carbon emissions.

refer to locally sourced materials if their extraction avoids long-distance transportation and if they do not represent a rare local natural resource that should avoid exploitation. Several national building regulations include minimal environmental criteria for sustainable materials, such as the CAM (*Criteri Ambientali Minimi*) in Italy[24], the DGNB (*Deutsche Gesellschaft für Nachhaltiges Bauen*) ENV 1.2 in Germany[25], the BREEAM certification in England, BENG requirements (*Bijna Energieneutrale Gebouwen*) in the Netherlands which are integrated in the NTA 8111 within the Section 13. Environment and water resources management[26].

Ecology and Habitat Preservation and Enhancement class is rooted in the biological paradigm for architecture (Hensel, 2010) which seeks to understand how organisms and environments interact and to pave the way for ecologically-informed architectural design. This approach entails adopting a multi-species perspective to create regenerative urban ecosystems (Canepa et al., 2022). Ecologically informed architectural design challenges the traditional anthropocentric view of the world and acknowledges that all species have inherent value and a right to exist. In the context of architecture, a multi-species perspective means designing buildings that meet the needs of humans and other species and minimize negative impacts on biodiversity. The class of requirements includes a set of requirements concerning the avoidance of any disturbance and interference with aquatic and terrestrial species and the actual promotion of biodiversity through green and blue infrastructures and nature-based solutions. The Space@sea catalogue, for instance, provides requirements regarding the reduction of underwater noise sources (hydroacoustic energy) and avoiding impingement, entrainment, and entanglement. The National Marine Fisheries Service – *Federal Highway Administration – Transportation Activities in the Greater Atlantic Region* (2018) provides a Best Management Practices Manual to avoid and minimize the impacts to ESA-listed species and their critical habitat, EFH, and other NOAA trust resources[27], if present, at a particular site. Some examples include minimizing turbidity and sedimentation disturbance, avoiding reduction/obstruction of incoming sunlight in water, monitoring night artificial illumination, and reducing underwater noise. These requirements could be extended to any other region. The European *Habitats Directive* (Council Directive 92/43/EEC) obliges member states to designate, protect, and manage core areas for habitat types, collectively often referred to as "Natura 2000 sites". These sites are the largest coordinated network of protected areas anywhere in the world, and any building design should avoid interference with these protected areas.

To provide scientific support to some of the requirements listed above, illuminating coastal environments can also alter the bodily functions of many marine animals, and exposure to artificial light can reduce the reproductive success of fish (Fobert et al., 2019). Professor Tim Smyth, Head of Science at the Plymouth Marine Laboratory highlights how lighting from coastal urban centers, oil platforms, and other offshore structures scatters in the atmosphere

25. DGNB System – *New buildings criteria set – Environmental quality ENV1.2. / Local Environmental Impact.*

26. It is specified to avoid using materials such as zinc, copper, and lead, which slowly dissolve when they come into contact with water. Therefore, the rainwater that flows through or on them, as does the surrounding water, becomes contaminated.

27. NOAA stands for the National Oceanic and Atmospheric Administration of the USA and is responsible for the conservation and management of coastal, riverine, and marine ecosystems and resources.

to form artificial skyglow that increases the extent of light pollution from source to hundreds of kilometers into the surrounding marine habitats (Smyth et al., 2021). Scientific research has shown that light pollution can mask the natural cycle of the moon and can affect coastal organisms. Several marine organisms rely on natural light cycles to regulate their physiological and biological processes. The spectral composition of artificial light at night (its red, green, and blue light components) illuminating seafloor habitats may also disrupt visually guided ecological processes. For instance, predators that usually feed in the day may be able to see prey that would ordinarily be camouflaged at night (Marangoni et al., 2022). Moreover, studies on marine light pollution found shifts in hormonal cycles, inter-species behavior, and reproduction (Miller & Rice, n.d.) On the other hand, sunlight plays a very important role in sustaining life in the water. It first penetrates the water column, heats it, generates currents, and finally, is absorbed by phytoplankton, which uses this source of energy captured by pigments such as chlorophylls to synthesize organic matter from water and inorganic nutrients. Beyond a depth of 100 to 200 meters, organisms do not receive enough light for photosynthesis, although sufficient light that reaches depths of up to 1,000 meters remains the most used orientation system (Massana et al., 2021).

In 2008, underwater noise pollution was included as the eleventh Descriptor under the *European Union Marine Strategy Framework Directive* (MSFD). Underwater noise was recognized as a source of pollution, affecting all compartments of underwater ecosystems (Ceyrac et al., 2023). The EC MSFD *Common Implementation Strategy* regarding Underwater noise, defined the Level of Onset of Biological adverse Effects (LOBE) as the sound level (noise) above which an adverse biological effect on an indicator species is expected to occur, leading to avoidance of an area (Sigray et al., n.d.).

Coming to the promotion of biodiversity, it is considered extremely relevant by many sustainable certification systems, including BREEAME and DGNB, and it is included in the World GBC Protocol *Better Places for People* and the CIRIA SUDS Manual (Ballard et al., 2015). The EU guidelines on *Biodiversity-Friendly Afforestation, Reforestation, and Tree Planting* provide a set of practical recommendations to support authorities, forest and landowners, managers, and civil society to better implement biodiversity-friendly afforestation, reforestation, and tree-planting projects, including at the local level. These guidelines could be extended to the urban building scale.

The set of requirements in the landscape preservation class can be framed within the European Landscape Convention of the Council of Europe, also known as the Florence Convention, that applies to natural, rural, urban, and peri-urban areas. The Convention aims at the protection, management, and planning of all landscapes and at raising awareness of the value of a living landscape. One of the most important aspects of the Convention is the extension of the concept of landscape (art. 1) as the combination of natural factors (shape and type of land, water regime, flora, and fauna) with human factors (settlement structures, forms of land use and cultivation) (Pandakovic & Dal Sasso, 2009). The Convention also emphasizes the meaning of protection, management, and planning of landscapes, underlining their importance for controlling landscape transformation processes.

Within the decarbonization class, it is possible to ascribe those requirements aimed at energy saving and heat retention through morphological, material, and technical efficiency in relation to natural energy's exploitation (maximization). Decarbonization also includes aspects concerning transportation and manufacturing processes. More specifically, the separability of components, recoverability, biodegradability, and a-toxicity of materials and components allow for a significant reduction in the environmental impact in terms of waste, CO_2, and other toxic emissions.

3.1.7. Rational Use of Resources (RUR)

The class of demand Rational Use of Resources embraces the set of conditions for coherently using environmental resources towards users and the environment[28]. While Environmental Regeneration concerns the protection and regeneration of natural systems and their balance through the reduction of air, water, and noise pollution, the protection of biodiversity, and the promotion of landscape sustainability, the rational use of resources concerns the reduction of the impact on the environment deriving from the use of natural resources, through the reduction of the consumption of materials, water and energy, the promotion of recycling and recovery of materials and the valorization of renewable resources. The distinction between ER and RUR is functional to the identification and more effective evaluation of the environmental aspects of buildings. This class includes the following classes of requirements.

- 7.1. Circular Use of Materials.
- 7.2. Circular Use and Management of Water Resources.
- 7.3. Circular Waste Management.
- 7.4. Rational Use of Climate Energy Resources.

Circular Use of Materials is very similar to the set of requirements concerning the use of materials with reduced environmental impact. In addition to being biodegradable, bio-derived, and by-product derived, particular attention is paid to them being reusable, renewable, recycled, or recyclable. In addition, the class of requirements also includes using a dry construction process, as it ensures that the building components are easily dismountable, allowing the recovery and reuse of the different materials.

The classes of requirements for rational use of materials, rational use and management of water resources and rational waste management are all linked to the principle of circular economy[29]. In a nutshell, circular economy applied to the building industry implies sustainability of resources (renewable, reuse/recycled, or biodegradable sources and materials in multiple life cycles), an extension of the life cycle of the building components (the asset must be designed and produced to extend its life cycle. Therefore,

28. The definition is provided by UNI 11277:2008 – *Sostenibilità in Edilizia.*

29. The concept of a circular economy first appears in 1966 in the article *The Economics of the Coming Spaceship Earth* by economist Kenneth E. Boulding (Boulding, 2013). Kenneth defines our planet as a spaceship where the availability of resources has a limit so we must behave as in a closed system that regenerates where the only external source allowed is energy.
In 1981 Orio Giarini, an economist from Trieste, publishes a study *Dialogue on wealth and wellbeing* (Giarini, 1981), in which he strongly criticizes the linear economy model, reiterating how the necessity of creating a new economic model conceived as a synthesis between economy and ecology. In 2010 Ellen McArthur founds the Ellen MacArthur Foundation, based on the principle of avoiding waste and pollution, keeping products and materials in use, and regenerating natural systems. In December 2015 the European Commission adopted the first Action Plan for the circular economy which included 54 actions which have largely been implemented. In December 2019, the European Commission adopted the European Green Deal with the aim of adding climate neu-trality by 2050. In March 2020, the European Commission adopted the New Circular Economy Action Plan for a cleaner and more competitive Europe which, in line with the European Green Deal aims to make the European economy greener. The action plan focuses in particular on the design and production system of goods that must be functional to the circular economy. The plan includes stricter rules on recycling and binding 2030 targets on the use and ecological footprint of materials. In particular, the plan provides that all European products progressively become sustainable, designed to last longer, easier to

it must be easily repairable, upgradeable and regenerable, to avoid and limit the use of materials or energy); circular cycles in terms of waste, water and any other resource. The latter also implies that production cycles must be designed to avoid waste or non-recyclable or reusable waste.

For what concerns **Circular Use and Management of Water Resources**, the ISO 24566-1[30], which is currently under development, will require buildings to have a water management plan that identifies and quantifies all water inputs and outputs, and sets targets for reducing water consumption and pollution. LEED v4.1 certification system awards points for buildings that reduce their water consumption by at least 20% below baseline and for buildings that reuse or recycle at least 20% of their wastewater. WELL Building Standard requires buildings to provide access to clean drinking water and implement and maintain appropriate water treatment systems by including carbon filters, sediment filters, and UV sanitization. BREEAM *New Construction 2022* awards points for buildings that reduce their water consumption by at least 10% below baseline and for buildings that reuse or recycle at least 10% of their wastewater. DGNB *New Buildings 2021* awards points for buildings that reduce their water consumption by at least 10% below baseline and for buildings that reuse or recycle at least 10% of their wastewater. French RE 2020 *Sustainable Building Label* requires buildings to reduce their water consumption by at least 40% below baseline. These are just a few examples of the requirements for circular water management in building codes and certification systems. As the world moves towards a more sustainable future, these requirements are likely to become more stringent and widespread, and for this reason, they are included in the framework.

Circular Waste Management refers to a set of requirements related to waste production reduction, waste segregation to facilitate recycling and composting, and safe waste storage. This set of requirements refers to both the construction and use phases. For the use phase, the WELL Building Standard requires buildings to mitigate environmental contamination and associated exposure to hazards present in specific waste. LEED v4.1 addresses both the construction and the use phase by awarding points for buildings that divert at least 20% of their construction and demolition waste from landfills and for buildings that divert at least 50% of their ongoing waste from landfills. The same does BREEAM *New Construction 2023* but with higher percentages (respectively 90% and 60%). The SCS *Zero Waste Project Standard* provides a basis for certification of municipal solid waste diversion from landfills for a time-bound, place-bound project and provides a set of requirements for waste diversion (75% must be achieved for the certification) through reuse, recycling, composting, waste to energy processes, calculated as (diverted waste-residuals) / (total waste). It also takes into consideration the percentage of waste sent to landfills. In the context of this Standard, a project is an activity that takes place at a facility but is not bound by management.

reuse, repair and recycle, and most possibly made of recycled materials. The plan includes rules also on the reduction of waste production by treating goods at the end of their life cycle to transform them into high quality secondary resources with an efficient secondary raw material market.

30. ISO 24566-1 - *Drinking water, wastewater and stormwater systems and services. Adaptation of water services to climate change im-pacts - Part 1: Assessment principles.*

European Union has strongly promoted urban wastewater treatment through several directives, such as the Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment (in which urban wastewater means domestic waste water or the mixture of domestic waste water with industrial waste water and run-off rain water; domestic wastewater means wastewater from residential settlements and services which originates predominantly from the human metabolism and from household activities). Another relevant directive is the European Parliament and Council Directive 2000/60/EC, which establishes a framework for the protection of inland surface waters, transitional waters, coastal waters, and groundwater (as mentioned in Paragraph 1.3.1.1.). Regarding safety storage and waste disposal, the SUDS Manual (Ballard et al., 2015) invites to minimize pollutants mixing with rainfall by ensuring that solid and liquid wastes are disposed of appropriately according to the type of waste. The frequently mentioned Space@sea D7.2 report underlines the importance of specific requirements for waste control and emissions, such as appropriate waste storage and disposal.

According to the UNI 11277:2008, Rational use of climatic and energy sources includes all those requirements pertaining to active energy production from renewable energy sources (REs) on the one hand and the use of passive bioclimatic solutions on the other. Given the water-based environment, the first set of requirements includes marine renewable energy sources (MREs) such as marine current power, osmotic power, ocean thermal energy, tidal power, and wave power. The latter includes all requirements related to the passive use of renewable sources like wind, water, and sun for heating, cooling, ventilating, and lighting (i.e., thermal inertia, thermal transmittance, shading systems, orientation, volume geometry, and nature-based solutions). The EU Commission Recommendation 2016/1318 of 29 July 2016 provides guidelines and best practices for promoting nearly zero-energy buildings. The Directive 2018/844 of the European Parliament and Council – Amendment of Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency – aimed at improving the energy performance of buildings taking into account various climatic and local conditions and set out minimum requirements and a common framework for calculating energy performance.

3.1.8. Buoyancy - stability (BS)

As described in Paragraph 3.1., the buoyancy-stability class refers exclusively to the sub-structure (barge or pontoon). For this reason, it is provided by all nautical and offshore performance-based codes and guidelines such as IMO and IRPCS[31], unlike the superstructure (the building on top of the sub-structure) that is designed in adherence to Eurocodes and other national and local building regulations. Also scholar K. W. Wang considers buoyancy among his sustainable Floating Building Indicators and suggests the same distinction between the super-structure and the sub-structure (K.F.

31. International Regulations for the Prevention of Collision at Sea.

Wang, 2021). The class can be articulated within three classes of requirements.

- 8.1. Buoyancy.
- 8.2. Stability and Trim.
- 8.3. Asset/Position.

Buoyancy is mainly related to freeboard, as found in the IMO - *International Convention on Load Lines*, referring to ships. It has long been recognized that limitations on the draught to which a ship may be loaded significantly contribute to its safety. These limits are given in the form of freeboard, which constitute the main objective of the Convention besides external weathertight and watertight integrity. The first International Convention on Load Lines, adopted in 1930, was based on the principle of reserve buoyancy. However, it was recognized then that the freeboard should ensure adequate stability and avoid excessive stress on the ship's hull due to overloading. In the 1966 Load Lines convention, adopted by IMO, provisions are made for determining the freeboard of ships by subdivision and damage stability calculations. The main purpose of these measures is to ensure the watertight integrity of ships' hulls below the freeboard deck. The Buoyancy class also includes a set of requirements linked to damage and sink prevention. These include watertight integrity and compartmentation and sink risk indicators. These requirements can be found in offshore standards DNV-OS-D301, the EU Commission Delegated Regulation 2020/411 of 19 November 2019 amending Directive 2009/45/EC of the *European Parliament and the Council on safety rules and standards for passenger ships, as regards the safety requirements for passenger ships engaged on domestic voyages*, as well as in the ABS Rules for Building and Classing Mobile Offshore Units, *Part 5 Fire and safety*. Watertight compartmentation or subdivision is strongly recommended also in the Space@sea catalogue of requirements.

The **Stability and Trim** class refers to the ability of the structure to support and adjust to static and dynamic load variation, either due to the addition or removal of weights or to climate agents like wind or snow. These requirements are provided by the previously mentioned IMO within the maritime naval field, by the Lloyds' Register – *Rules and Regulations for the Classification of Offshore Units, Part 7, Ch.1, 3*, within the offshore field, and by the Space@Sea catalogue for floating structures. Considering land regulations, several ISO standards provide determination methods for calculating external climate loads, like snow (e.g., ISO 4355:2013 - *Bases for design of structures. Determination of snow loads on roofs*).

Asset/Position class includes all requirements that ensure the floating structure is kept in place through mooring and anchoring arrangements providing under keel clearance[32]. All standards and regulations for floating structures have a special section for these requirements, like the NTA 8111_2011-NL - N*etherlands Standards for Floating Constructions*, the *Guidance for Floating Structures* within the Korean Register of Shipping, the Portland city Code *Title 28 Floating Structures*, and the Queensland Development Code *MP 3.1. "Floating Buildings"*.

32. Under-Keel Clearance, or UKC, is the vertical distance between the lowest part of the ship's hull and the seabed. Maintaining a min-imum UKC is essential for the safety of navigation. Static UKC is the minimum clearance available between the deepest point on a vessel at rest in still water and the bottom. Static UKC = (Charted Depth of Water + Height of Tide) – (Static Deep Draft) Dynamic factors such as squat, pitch, roll and heave effect a ship's draft and these need to be accounted for in any determination of mini-mum UKC (UKC – Port of Darwin).

3.1.9. Plant system (P)

This section refers to plant systems for power, gas, water (drinking and heating), communication (telephone, radio and television, data), wastewater discharge, and stormwater drainage facilities. It is focused on pipes from the shore to floating constructions and pipelines within floating structures. It is structured in two classes of requirements.

- 9.1. Damage Resistance.
- 9.2. Climate Resistance.

Damage Resistance includes requirements to prevent or easily solve damage caused by natural (biological or chemical) or human agents. This set of requirements is provided by most regulations for floating buildings, such as the NTA 8111_2011-NL *Netherlands Standards for Floating Constructions*, the *Guidance for Floating Structures* within the Korean Register of Shipping, the Portland city Code *Title 28 Floating Structures*.

The **Climate Resistance** requirements involve the suitability of the pipelines and machinery to avoid transformations or damage due to thermal variations or water fluctuations. The NTA 8111_2011-NL mentions these requirements.

3.2 Expert reviewers feedback

The PDSF described in the previous paragraph is already an updated version (Appendix A2) of the PDSF delivered to the expert reviewers (Appendix A1). The following section is meant to outline and clarify the major modifications drawn according to the feedback received by the expert reviewers (Appendix C2). The main comment referring to the overall framework was, "The codes referring to each requirement are not unique. If you want to use codes – that could be useful for the case study datasheet – I suggest using a 3-level coding system that identifies a unique code for each requirement. For instance: 1 Safety; 1.1 Fire Safety; 1.1.1 Fire detection and alarm system". Following this advice, the coding system has been reviewed, as seen in Appendix A2.

Expert reviewer 1[33] suggested inserting a note within the framework to clarify two aspects: first, reminding the reader that the definitions of each class of demand can be found in Chapter 3.1. of the thesis; secondly, specifying that if the framework were given to a designer, the definitions for each class of demand would be integrated directly into the framework. This note has been added in PDSF 2.0 (Appendix A2).

The suggestions concerning each class of demand are listed in order concerning each class.

3.2.1. Safety

Expert reviewer 2[34] underlines there is no requirement mentioning sea loads (dynamic loads) that can represent a significant risk for the structural integrity of the floating building, leading to structural and or mooring lines failure. It is also important to consider local loads that can occur due to water slamming on the deck. Since the proposed floating structure can work both on shallow and deep waters, in coastal areas, water depths are usually lower, and, in the case of long waves, larger loads can occur and must be considered. The requirement concerning dynamic and local loads was meant to be the Load variation adaptability within the buoyancy class

33. Full. Prof. Arch. Alessandra Battisti (environmental architect), Department of Planning, Design and Technology of Architecture, Sapienza University of Rome. As clarified in Chapter 2.1.3.

34. Prof. Ing. Claudio Lugni (hydraulic and mechanic marine engineer), CNR · Institute of Marine Technology INSEAN. As clarified in Chapter 2.1.3.

of demand. Since load adaptability does not embrace dynamic and local load prediction in the design phase in an accurate way, a new performance requirement is added to the stability and trim class of requirements within the buoyancy class of demand: **8.2.2. Adaptability to dynamic load variations (climate agents)**.
Expert reviewer 3[35] suggests adding another requirement for the class of requirement Structural Stability. The assumption is that anything set in a natural context immediately becomes an employable ecological niche. "In our homes, there have been, for thousands of years, more or less welcomed guests, like termites or woodworms, that represent a threat to the structural integrity of wooden buildings, for instance, or like mussel massive colonization, that could compromise the stability of the floating pontoon, shifting the centre of gravity with their weight. Since it is impossible to establish beforehand what the implications of coexistence with marine animals and plants could be, a requirement addressing the risk related to biological agent resistance could be added". As a similar requirement has been considered within the Plant system adequacy class (Biological agents resistance), an analogous requirement has been added to the Management class within the class of requirements Operational management: **4.2.3. Biological agents resistance**. The introduction of this requirement required to re-code the requirements coming after.
These observations have been made within the safety class of demand, highlighting the need to further clarify what each class represents and includes in its domain. In relation to this, the expert reviewer points out that the framework is unclear regarding the boundaries of each class of demand and suggests integrating the PDSF with a brief explanation of each class of demand.

35. Prof. Mattia Azzella, (ecological scientist), Department of Planning, Design and Technology of Architecture, Sapienza University of Rome. As clarified in Chapter 2.1.3.

3.2.2. Wellbeing

Expert reviewer 1 suggested to replace the name of the class, which previously was comfort, into wellbeing. Wellbeing is a broader concept that encompasses physical, mental, emotional, and social health.
Expert reviewer 3 writes: "Regarding requirement 2.8.4 Mosquito prevention, I would not limit myself to mosquitoes, which, in the sea, for instance, are decidedly fewer than other things unless there are accumulations of stagnant fresh water where the larvae can develop. I would leave this category more generic: Pest and dangerous animal prevention, and I would remove the reference to "pest" from requirement 2.8.5. The suggestion has been accepted, as can be seen from the current version of the framework. The two requirements have been replaced with **2.8.4. Pest and dangerous animals prevention** and **2.8.5. Dust prevention/management**.

3.2.3. Management

Expert reviewer 1 suggested to further describe and clarify the information that should be contained in the user manual (requirement **4.2.10. On-board user manual**), such as clear instructions on how to operate the floating building safely and efficiently, how to maintain the floating building properly and how to respond to emergencies.

3.2.4. Environmental regeneration

Following Expert Reviewer 1 suggestion, to avoid overlaps between requirements and make the distinction between Environmental Regeneration and Rational Use of Resources more straightforward, some requirements in the class of demand Environmental Regeneration were eliminated and absorbed by the class Rational Use of Resources. The following requirements were removed:

- 6.2.9. Ecologically friendly waste disposal
- 6.2.10. Environmentally friendly water management.

These requirements (6.2.9. and 6.2.10.) were absorbed by the class Rational Use of Resources. In relation to this, expert reviewer 3 suggested changing the adjective friendly to sustainable because the term sustainability is defined and codified, unlike the term friendly, which is open to interpretation. This led to a change in the terminology in several requirements:

- requirement 6.1.2. Use of environmentally friendly materials became **6.1.2. Use of certified low impact materials**;
- requirement 6.2.9. Ecologically friendly waste disposal became part of **7.3.1. Solid waste reduction and diversion through reuse, recycling, composting, waste to energy processes** (use phase) and **7.3.4. Safe waste storage and disposal**;
- requirement 6.2.10. Environmentally friendly water management became part of **7.2.1. Water collection, treatment and reuse**.

Requirement 6.1.4. Use of local materials was deemed inappropriate by expert reviewer 3, who highlighted that the use of local materials is only sometimes desirable if the area is not impoverished by human impact. To strengthen his argument, he provides the example of black alder wood (*Alnus glutinosa*), which is excellent for water environments as it is water resistant and does not rot. However, if one were to build in an area like Rome where alder forests are rare and therefore protected, locally sourced materials would generate greater ecological damage than importing it from far away where it may still be abundant (if it is cut sustainably). For this reason, he suggests changing this item from Use of local materials to Use of certified low-impact materials, therefore included within requirement **6.1.2. Use of certified low-impact materials**.

Expert reviewer 3 suggested to integrate the class of requirement **6.2.8. Surrounding water quality** with the specification "ensuring low levels of nutrient concentration". Ensuring minimal variations in physical-chemical water parameters (below the local ecological resilience threshold) is essential. The expert reviewer argues that this requirement is crucial since the PDSF generally refers to different potential locations with relevant, diverse ecological systems[36].

36. At the mouths of large rivers, ecosystems are generally established and able to manage a certain quantity of nutrients or suspended materials. By placing a building at the mouth of the Ganges that discharges directly into the water, the ecosystem will absorb the organic waste without even witnessing any difference. In an oligotrophic area, such as coasts – where the ecological conditions of the water are rigidly controlled by other factors – even a minimal deviation from the starting conditions can lead to an ecological disaster.

For what concerns the requirement 6.2.2. Avoid impingement/entrainment and entanglement, reviewer 3 states that it should be further clarified that the entanglement is with vegetation or other aquatic biostructures. He suggests renaming the requirement as follows: **6.2.2. Avoid impingement, entrainment, entanglement, and impairment of biostructure and aquatic vegetation**. In this way, meeting this requirement would imply that the anchoring or movements of the structures pay attention not to damage a Posidonia grove or a coral reef, for instance.
Expert reviewer 3 suggested rephrasing the requirement 6.2.5. Avoid reduction/obstruction of incoming sunlight in water in **6.2.5. Avoid unnecessary reduction/obstruction and facilitate incoming sunlight in water**. The same applies for the requirement 6.2.6. External artificial illumination control, which the reviewers find too generic, could be transformed into **6.2.6. Reduce light pollution and avoid underwater illumination at night**.

3.2.5. Efficient use of resources

Expert reviewer 2 argues that it is scientifically recognized that wind and sun energy devices at sea are expected to be much more efficient than wave energy devices. Tidal and current energy devices are efficient but represent a risk for the floating structure loads. Considering that the floating buildings to which the PDSF is referred are located on sheltered waters – where waves are not that powerful or high – wave energy devices are not cost-effective regarding how much they produce compared to how much they cost. The expert's feedback provides a valuable contribution to this requirement. However, the requirement **7.4.2. Use of renewable marine energy resources** (MREs) is still included, as the choice is left to the decision maker, according to the relevant site-specific constraints and potentials. Moreover, sheltered waters could also be created as the result of an artificial intervention. For instance, it could be possible to create a boundary of breakwaters, working also as wave energy converters, within which the floating building or buildings are set.
Expert reviewer 1 highlighted that the same approach used in the management phase – distinguishing the construction phase from the use phase – should be applied in this class concerning waste management. Therefore, the requirement **7.3.1. Solid waste reduction and diversion** (construction phase) was added, with a consequent re-codification of the requirements within 7.3. Rational Waste Management class of requirements. The requirement 7.3.1. Solid waste reduction and diversion was integrated with the phase specification and changed code **7.3.2. Solid waste reduction and diversion** (use phase).

3.2.6. Buoyancy - Stability

Expert reviewer 4[37] suggested to rename the class of requirements 8.1. Buoyancy into 8.1. Buoyancy and Flotation. Buoyancy is a

37. Prof. Eng. Artur Karczewski (naval engineer), Shipbuilding Institute, Ocean Engineering and Shipbuilding, Gdańsk University of Technology. As clarified in Chapter 2.1.3.

physical force that pushes an object upwards in a fluid like water. It is caused by the difference in density between the object and the fluid. An object will float if its density is less than the density of the fluid. Flotation is the state of an object being supported by a fluid. Furthermore, he proposes to change the requirement 8.1.1. Freeboard stability into **8.1.1. Freeboard** and to add a final guideline principle to the requirement: "[...] This requirement is intended to ensure that the floating building has a sufficient watertight volume above the water (reserve buoyancy) in order to carry a certain amount of overload in addition to the full load displacement".

Expert reviewer 2 argues that it is crucial to take into consideration the periodical changes in the weight and position of the static loads such as goods and structures (i.e., additional weight in the building or storage of food). For this reason, he suggests introducing a new requirement considering the variation of the metacentric height[38], in particular of the center of gravity (COG) position, as well as a specification of the additional payload that can be added and in which position. This requirement is typical for ships that can work in variable load conditions. Instead of adding a new requirement, the variation of the metacentric height has been integrated within the requirement **8.2.1. Adaptability to static load variation description**. Also, the specification of how and where the additional payload can be added is integrated into the requirement guideline.

Expert reviewer 4 underlined that adaptability to static load variation (requirement 8.2.1.) must consider not only additional or removal of weight but also shaft of weights, and that the floating system should have relevant shape to maintain acceptable trim. This has been integrated in the PDSF 2.0.

Expert reviewer 2 underlines the importance of the dynamic behaviour of a floating structure, which can be conceived approximately as the ratio between the typical wave's wavelength and the structure's primary dimension (along the direc-tion of the wave). The resonance condition of the floating structure can be identified through this parameter. Since the wavelength depends on the wave period, the latter and the wave height must be considered. The size of the floating structure is chosen according to the wave period. For instance, a weight compensation system (e.g., a water caisson that can be filled or emptied) could be proposed.

For this reason, the requirement **8.2.2. Adaptability to dynamic load variations** (environmental agents) was further integrated to include parameters referring to adequately designing the primary dimension of the structure (along the direction of the wave), considering the correct ratio with the wavelength of the typical wave. Regarding the same requirement, expert reviewer 4 highlighted that is important to specify that "the floating building shall have sufficient stability considering its environment loads (wind, wave, snow) and the manufacturer's maximum recommended load".

3.2.7. Location

Expert reviewer 2 finds the requirement located in calm waters

38. The metacentric height (GM) measures the initial static stability of a floating body. It is calculated as the distance between the center of gravity of a ship and its metacenter. A more considerable metacentric height implies greater initial stability against overturning. The metacentric height also influences the natural rolling period of a hull, with considerable metacentric heights being associated with shorter periods of roll, which are uncomfortable for users. Hence, a sufficiently, but not excessively, high metacentric height is considered ideal.

misleading. The cited note n. 65339 [39] defines calm water conditions for navigation as "depending on the seasonal condition". More specifically, calm waters are defined as those sea areas within national coastal zones (peninsular or insular) in which the following operational limits occur: summer period, daily hours, good visibility, 1 mile from the coast, and wind not above Force 2 (speed 4-6 nodes). Although these prescriptions work for ships that temporarily sail in a well-described area, they cannot be applied for floating structures that cannot be moved periodically depending on the meteorological and ocean conditions.

The term calm waters has been changed into sheltered waters. According to the *FEMA Guidance on Sheltered Water Flood Hazards*, sheltered waters are water bodies with shorelines that are not subjected to the direct action of undiminished ocean waves. The *Northern Territory of Australia Marine (sheltered waters) Regulations* 1986[40] includes within the term sheltered waters, partially smooth waters (water areas where the wave height, under normal circumstances, does not exceed 1.5 m from trough to crest) and smooth waters (water areas where the wave height, under normal conditions, does not exceed 0.5 m from trough to crest). Among sheltered waters, it is possible to include lakes, rivers, deltas, canals, artificial basins, bays, and harbors[41] that meet the following conditions.

Expert reviewer 1 highlighted how location cannot be considered a parameter referring to the design of the building system, as there is no qualitative standard for climate and hydrographic features. Location features are site-specific and must be considered when addressing all the requirements throughout the design process. The framework represents one of the meta-design tools available to guide the designer through the entire design process of a building. The use of the tool comes into play once the site location is already known. The site, in terms of climate, geological, hydrographic, and socio-economic features, sets several constraints and offers specific opportunities that will shape and define the design objectives that guide the user in the decision-making process carried out using the framework.

For this reason, the location requirement is no longer present in the PDSF 2.0 (Appendix A2), as it does not allow the designer to change or set its requirements according to his needs but rather poses some non-modifiable conditions. However, correlations and trade-offs with location-related features are emphasized in the following chapter (3.3.).

39. The note - issued on July 8th, 2011 by the General Comand of the Body of the Harbor Office – has as title *Personale Marittimo – Serie Tabelle di Armamento, n. 001 del 20/10/2010, relativa all'applicabilità della circolare titolo: Polizia della Navigazione – serie III – n. 92 del 4/1/1994 del Ministero della Marina Mercantile, alle unità da traffico in "Navigazione Speciale – acque tranquille (alle-gato n. 2)*.

40. It can be found at: https://legislation.nt.gov.au/en/Legislation/MARINE-SHELTERED-WATERS-REGULATIONS-1986.

41. The National Geographic encyclopedia includes harbor areas among sheltered waters, as a harbor is a body of water sheltered by natural or artificial barriers (https://education.nationalgeographic.org/resource/harbor/).

3.3 Identification of correlations and trade-offs between classes of requirements

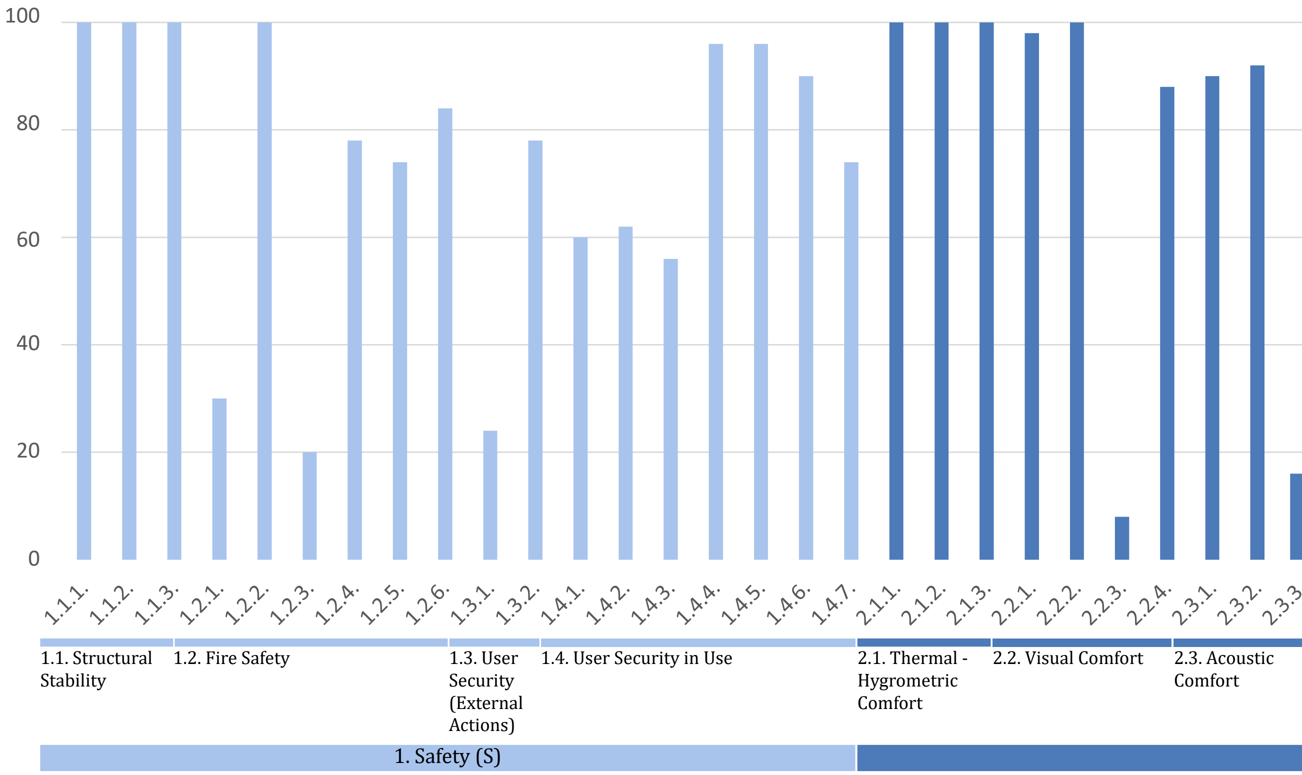
Relationships of compatibility, complementarity, interchangeability, and excludability bound all the requirements. To keep things simple, three different types of relationships were considered to identify correlations and trade-offs between requirements:

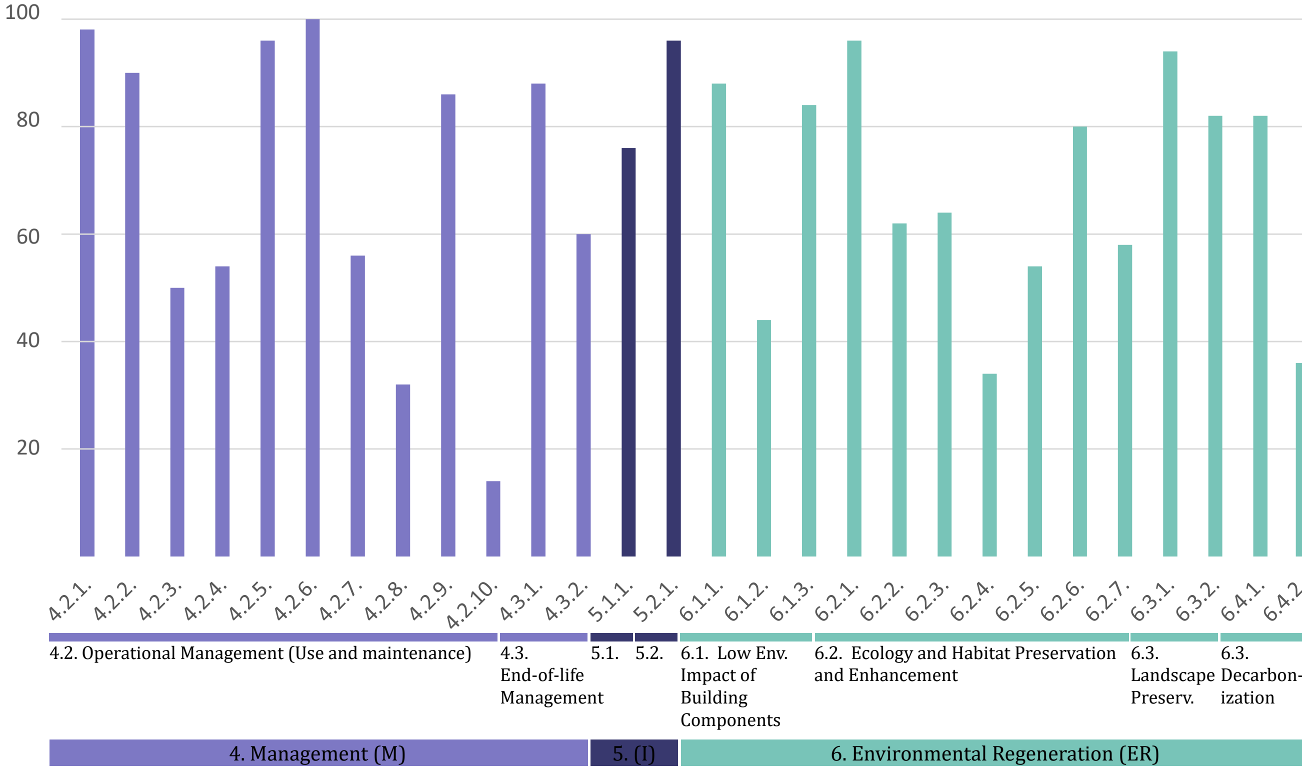
- mutual exclusion or inverse relation;
- mutual influence;
- one-sided influence.

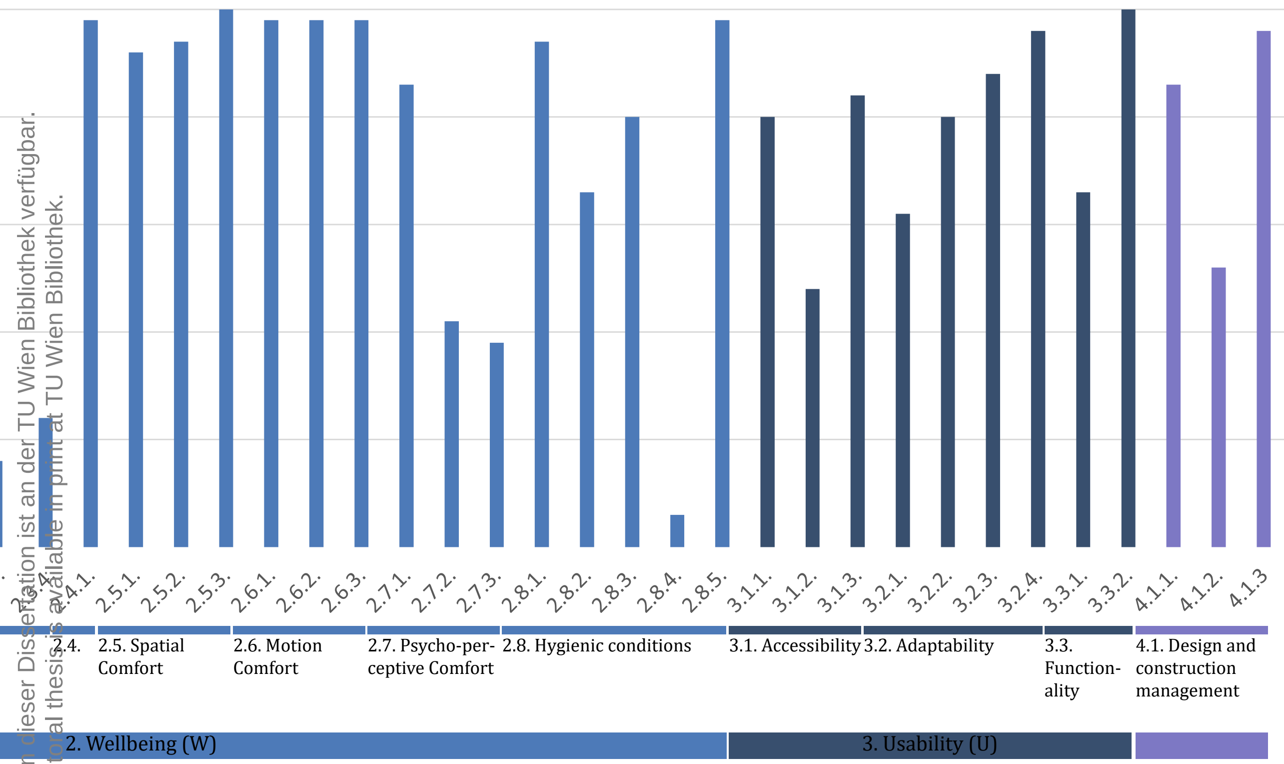
An inverse relationship between requirements occurs when the fulfilment of one requirement directly or indirectly reduces the ability to fulfil another requirement. In other words, when two requirements are inversely related, increasing the satisfaction of one requirement will typically decrease the satisfaction of the other requirement. Inverse relationships between requirements can be challenging to manage because they often represent trade-offs between competing objectives. To manage inverse relationships between requirements, common strategies include prioritization or trade-offs. Prioritization means the designer decides which requirements are more important and prioritizes them accordingly. Requirement prioritization is made easier thanks to the results produced by the multi-evaluation matrix, which returns a priority order amongst requirements (Figure 1). Trade-offs entail the designer agreeing to accept a lower level of satisfaction for one requirement to achieve a higher level of satisfaction for another. The best strategy for managing inverse relationships between requirements will depend on the situation.

Mutual influence between requirements occurs when two or more requirements have a reciprocal effect on each other. In other words, fulfilling one requirement can influence fulfilling another requirement and vice versa. Mutual influence relationships can be either positive or negative. Positive mutual influence occurs when the fulfilment of one requirement facilitates the fulfilment of another. Negative mutual influence occurs when the fulfilment of one requirement hinders the fulfilment of another. Mutual influence relationships can be challenging to manage because they can make

Figure 1. Bar chart with requirements and their relevant priority according to the case study analysis.






2.4.1.
2.5.1.
2.5.2.
2.5.3.
2.6.1.
2.6.2.
2.6.3.
2.7.1.
2.7.2.
2.7.3.
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2.8.3.
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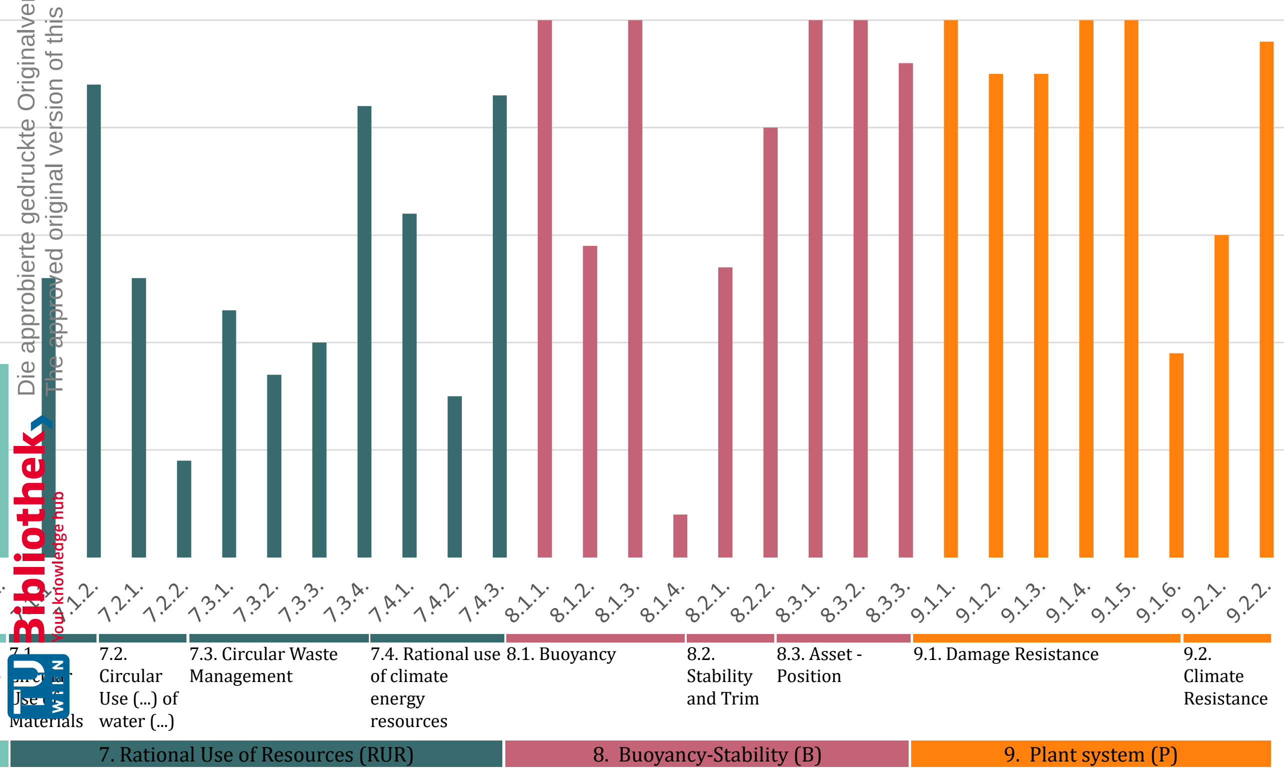
3.1.3.
3.2.1.
3.2.2.
3.2.3.
3.2.4.
3.3.1.
3.3.2.
4.1.1.
4.1.2.
4.1.3
2.4.
2.5. Spatial Comfort
2.6. Motion Comfort
2.7. Psycho-perceptive Comfort
2.8. Hygienic conditions
3.1. Accessibility
3.2. Adaptability
3.3. Functionality
4.1. Design and construction management
2. Wellbeing (W)
3. Usability (U)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9.2.2.
Materials
7.2. Circular Use (...) of water (...)
7.3. Circular Waste Management
7.4. Rational use of climate energy resources
8.1. Buoyancy
8.2. Stability and Trim
8.3. Asset - Position
9.1. Damage Resistance
9.2. Climate Resistance
7. Rational Use of Resources (RUR)
8. Buoyancy-Stability (B)
9. Plant system (P)

it difficult to predict the overall impact of meeting all the desired requirements. For example, suppose a requirement that negatively influences another requirement is met. In that case, this can lead to a cycle of changes in fulfilling the requirements that can be difficult to control for the decision-maker. This is why the computational tool described in Chapter 7 is developed: to help the decision maker have everything under control. Again, prioritization and trade-off approaches are the most useful strategies for managing mutual influence relationships, depending on the situation.

One-sided influence occurs when a requirement unilaterally affects another requirement without the other requirement having any reciprocal effect. This type of relationship can be either positive or negative, as in the case of mutual influence. Identifying and understanding one-sided influence relationships between requirements is crucial for making informed design decisions and anticipating potential conflicts. Another helpful strategy to manage one-sided influence relationships is early identification, in addition to requirement prioritization (Chapter 4.5) and trade-off analysis, provided in the following sections. The PDSF allows the designers to recognize one-sided influence relationships early in the design process, preventing them from encountering problems later on.

The PDSF works as a requirements management tool that enables tracking and managing requirements within a broader picture.

It is important to highlight how requirement **3.2.4.** and **4.3.1.** (both entitled **Disassembly arrangements**) are the same but can be considered by both classes, as well as **6.1.1.** and **7.1.2.** (**Dry construction processes**). Their recurring presence underlines their importance.

Proceeding with the PDSF coding order, the different relations are outlined and clarified hereafter.

3.3.1. Mutual exclusion

Mutual exclusion occurs in rare circumstances. For instance, to maximize wave energy potential, tidal energy potential (requirement **7.4.2. Use of renewable marine energy resources**), or wind energy potential (requirement **7.4.1. Use of renewable energy resources**), motion comfort (requirements **2.6.1 Vertical acceleration level and control** and **2.6.2. Motion control**) would be penalized, as it implies the floating structures are set in calm waters (Douglas scale 0,1 or 2, which means maximum 0.50 m high waves) and no wave frequencies around 0.18-0.25 Hz (as motion sickness occurs more frequently).

Requirement **2.8.4. Pest and dangerous animal prevention** is in contrast (mutual exclusion) with requirement and **6.2.4. Foster biodiversity**, and potentially, yet not necessarily, with **2.7.1. Biophilia** and **6.1.3. Toxic emission control of materials.** Pest and dangerous animal prevention often involves the use of pesticides and other chemicals that can release toxic emissions into the air or water. This can harm ecological systems, hence biodiversity. Pest and dangerous animal prevention can also involve the removal of natural habitats, which can further reduce biodiversity and limit biophilia. It may be possible to achieve pest and dangerous animal prevention without harming biodiversity, for example, using natural pest control methods or creating ecological habitats. However, in many cases, there is a trade-off between the two goals.

3.3.2. Mutual influence

Requirement **1.1.1. Mechanical resistance to static actions** is influenced by **1.2.3. Fire extinguishing facilities** if the fire extinguishing facility involves the presence of wharf hydrants that make use of water to extinguish the fire, as the water could represent extraordinary loads.
Requirement **1.1.1. Mechanical resistance to static actions** is also influenced by variable loads such as fixed furniture and, therefore, by requirement **3.3.1. Furniture integrability**.
Particular attention must be paid to the stiffness of connections and arrangements providing the continuity between super-structure and sub-structure (Requirement **1.1.3. Structural continuity with sub-structure**) in relation to the type and positioning of the anchoring system (requirement **8.3.2. Anchoring provisions and arrangements**).
Requirement **1.4.7. Horizontal walkway illumination**, just like **3.1.3. Uniformity and illumination of walkways' surfaces** must be designed to address requirement **2.2.2. Artificial illumination level and control** that, in turn, has to take into consideration **6.2.6. Reduce light pollution and avoid underwater illumination at night** to avoid disturbing the surrounding natural and animal habitat at night.
Requirement **2.2.4. Quality views** is positively affected by the presence of nature and, therefore, related to biophilia (**2.7.1. Biophilia**), as the fulfilment of one partly results in the fulfilment of the other.
Requirements **2.5.1. Minimum areas**, **2.5.2. Minimum height**, and **2.5.3. Occupancy rate** are related to one another as the number of occupants defines the number of square meters and total volume of indoor spaces according to norms and standards. At the same time, the design of spaces in terms of surface areas and heights is informed by the number of occupants defined by the client and according to the purpose of the building.
Requirements **4.2.3. Biological attack resistance** (exposed materials and components), **4.2.4. Chemical aggressive agents resistance** (exposed materials and components), **4.2.5. Atmospheric agents resistance** (exposed materials and components), and **4.2.6. Hygroscopicity** (exposed materials and components) must be co-designed together with **6.1.2. Use of certified low-environmental impact materials**, **6.1.3. Toxic emission control of materials**, and **7.1.1. Circular use of materials**.
Requirement **9.1.1. Maintainability-repairability** (of the plant system) must be co-designed with the requirement **4.2.1. Ease of**

intervention.
Requirements **6.1.2. Use of certified low environmental impact materials** and **6.1.3. Toxic emission control of materials** must guide the choice of materials and require co-design. Moreover, requirement **6.1.2.** partly contains requirement **7.1.1. Circular use of materials**. This implies that materials must observe both requirements and that these require co-design.
Requirement **7.2.1. Water collection, treatment, and reuse** may include wastewater treatment; therefore, it must be co-designed with requirement **7.3.3. Wastewater treatment optimization**.
Solid organic waste (mentioned by requirement **7.3.2. Solid waste reduction and diversion through reuse, recycling, composting, waste to energy processes** (use phase)) could be used to produce energy, hence contributing to requirement **7.4.1. Use of renewable energy resources** (REs).

3.3.3. One side influence

Requirement **1.1.1. Mechanical resistance to static actions** is affected by variable loads such as anchoring forces and, therefore, by requirement **8.3.2. Anchoring provisions and arrangements**. This means that requirement 8.3.2 must be designed according to requirement 1.1.1.
Requirement **1.1.2. Mechanical resistance to dynamic actions** is affected by machinery vibrations, and therefore, it must be designed and calculated according to the plant system and especially to requirement **9.1.5. Safe placing** (of machinery and plant equipment).
Requirement **1.2.2. Structural fire integrity** includes the choice of fire-resistant materials for structural components. These materials must be in line with **6.1.2. Use of certified low-environmental impact materials**, **6.1.3. Toxic emission control of materials**, and **7.1.1. Circular use of materials**. If the materials are also exposed to water and atmospheric agents, they must observe requirements **4.2.4. Chemical aggressive agents resistance**, **4.2.5. Atmospheric agents resistance**, and **4.2.6. Hygroscopicity**. The same applies to requirement **1.2.4. Non-flammable materials**: the materials must be in line with what is prescribed in requirements **6.1.2. Use of certified low-impact materials**, **6.1.3. Toxic emission control of materials**, and **7.1.1. Circular use of materials**.
Requirements **1.2.5. Safety platforms** and **1.2.6. Escape routes** must be designed in line with **3.1.2. Circulation and accessibility for all users** and with the number of occupants (**2.5.3. Occupancy rate**).
Watertight compartmentation/subdivision of a sub-structure (**8.1.2. Watertight compartmentation/ subdivision**) reduces sinking risks due to collision (**1.3.1. Collision risk reduction arrangements**) by creating multiple isolated chambers within the pontoon. If one chamber is breached, the others remain watertight, preventing the vessel from sinking. Therefore, requirement **1.3.1.**

Collision risk reduction arrangements are strongly affected by requirement **8.1.3. Watertight compartmentation/ subdivision** in terms of risk reduction.
Requirement **1.4.5. Non-slip resistance** is affected by requirement **1.4.4. Overtopping reduction** (clearance above water) because if water (due to overtopping) wets and accumulates on the external walkway surfaces and decks, the risk of slipping increases. Moreover, overtopping may damage the surface materials (in the case of wooden decks) or the coatings.
The occupancy level (**2.5.3. Occupancy rate**) affects the requirement **2.1.1. Indoor temperature level and control**, as the number of people in a room, contributes to increasing the overall indoor temperature. Moreover, heating, and cooling systems must be designed to be integrated within the overall utility plant system (**5.2.1. Plant system integration**).
Failing to fulfil the requirement **2.1.2. Indoor humidity level** and control could lead to mold and microbe formation. This entails that requirement 2.1.2. affects requirement **2.8.2. Microbe and mold control**.
Requirement **2.1.3. Ventilation control** could involve integrating a mechanical ventilation system, which should be designed according to requirement **5.2.1. Plant system integration**.
Requirement **2.2.4. Quality views** is negatively affected by the presence of plant system equipment for harvesting or storing energy, therefore by requirements **7.4.1. Use of renewable energy resources** and **7.4.2. Use of renewable marine energy resources** in terms of where they are placed (more or less visible).
Requirement **2.4.1. Absence of unpleasant odours** is strongly affected by the emission of toxic substances or particles (**6.1.3. Toxic emission control of materials**) and by the safe and enclosed disposal of waste (**7.3.4. Safe waste storage and disposal optimization**), as well as by ventilation (**2.1.3. Ventilation control**).
Requirements **6.2.4. Foster biodiversity** and **6.3.1. Landscape-architecture integration** increase the biophilia effect (requirement **2.7.1. Biophilia**).
Requirement **2.8.1. Air quality** is influenced by the correct fulfilment of requirement **6.1.3. Toxic emission control of materials**, **6.4.1. CO_2 emissions reduction**, and **6.4.2. CO_2 absorption design** solutions. Moreover, air quality can be controlled by ventilation and is therefore influenced by requirement **2.1.3. Ventilation control**.
If water treatment systems include drinking water production, the processes involved should ensure quality (**2.8.3. Drinking water quality**) according to local standards.
Requirement **6.2.7. Reduce underwater noise sources/ hydroacoustic energy** imposes to design the features related to requirement **2.3.1. Noise level limits** as well as the marine energy harvesting devices (**7.4.2. Use of renewable marine energy resources**) and any machinery used for energy production (**7.4.1. Use of renewable energy resources**) to avoid noise levels that could disturb the outdoor environment, creating underwater noise.

In case alarm systems are integrated (**1.3.2. Intrusion protection**; **1.2.1. Fire detection and alarm system**), they must be integrated with the other utility systems and, therefore, in line with requirement **5.2.1. Plant system integration** that affects any utility and plant system facility.

The aspects relating to requirement **1.1.1. Mechanical resistance to static actions** and requirement **1.1.2. Mechanical resistance to dynamic actions** affect the design of requirement **8.1.1. Freeboard**, as the overall buoyancy and stability of the building, obtained by a correct calculation of the freeboard, must consider the super-structure's structural loads.

Freeboard (requirement **8.1.1. Freeboard**) must allow easy access (by land) to the floating building or distribution pier (requirement **3.1.1. Access (reachability) for all users**. This implies that requirement 3.1.1. is affected by 8.1.1.

The potential transformation operated within requirement **3.2.1. Technical flexibility** must meet requirement **5.2.1. Plant system integration**. Moreover, requirement **3.2.1. Technical flexibility** includes the suitability of the building to become barrier-free if necessary and, therefore, must comply with requirement **3.1.2. Circulation and accessibility for all users**.

Requirement **3.2.2. Functional/spatial flexibility** is assured by dimensional integrability (**5.1.1. Dimensional integrability**). It can be met in different ways: by guaranteeing the modularity of the structure and building components and the possibility of disassembling them (requirements **3.2.3. Disassembly arrangements** and **4.3.1. Disassembly arrangements**).

Requirements **3.2.3. Disassembly arrangements** and its equivalent **4.3.1. Disassembly arrangements**) are enabled by dry construction processes (requirement **7.1.2. Dry construction processes**) and facilitate the ease of repairability and maintenance of both the building components and the plant system devices: requirements **4.2.2. Ease of repairability/replaceability** and **9.1.1. Maintainability-repairability**. This implies that also requirements **4.2.2. Ease of repairability/replaceability** and **9.1.1. Maintainability-repairability** are affected by requirement **7.1.2. Dry construction processes**.

Towing arrangements prescribed by requirement **3.2.4. Mobility - Towing arrangements** must be designed in number and load capacity accordingly with the sub-structure and super-structure structural loads (requirements **1.1.1. Mechanical resistance to static actions** and **8.1.1. Freeboard**). Towing arrangements allow the building to be easily transported by water to a dry dock where maintenance activities can occur. This entails that this requirement strongly affects the requirements **4.2.1. Ease of intervention** and **4.2.2. Ease of repairability/replaceability** as well as **9.1.1. Maintainability-repairability** referring to the plant system.

3.3.1. Furniture integration could include foldable furniture, affecting requirement **3.2.2. Functional/spatial flexibility**.

The devices integrated into the building because of requirement **3.3.2. Ease of use and manoeuvre** and their placement must comply with requirement **4.2.1. Ease of intervention**.

Requirement **4.1.1. Cost-effective and efficient processing and manufacturing** should be compliant with requirement **7.1.1. Circular use of materials** and **7.3.1. Solid waste reduction and diversion through reuse, recycling, composting, waste to energy processes** (construction phase).

Requirement **4.1.2. Cost-effective and efficient transportation** must be compliant with requirement **6.4.1. CO_2 emissions reduction**.

Dry construction processes (requirements **6.1.1.** and **7.1.2.**) and controlled environments ensure (and thus positively affect) cost-effective and efficient assembly and construction (requirement **4.1.3.**). In turn, requirement 4.1.3. has a positive effect on limiting water, waste, and emissions, thus, on requirements **7.2.2. Limited water consumption**, **7.3.1. Solid waste reduction and diversion through reuse, recycling, composting, waste to energy processes** (construction phase), and **6.4.1. CO_2 emissions reduction**.

Requirement **4.2.1. Ease of intervention**, in addition to the relations mentioned above, affects requirement **4.2.2. Ease of repairability/replaceability**, which in turn is also affected by the use of dry construction processes (requirements **6.1.1.** and **7.1.2.**) and disassembly arrangements (requirements **3.2.3.** and **4.3.1.**).

Interstitial condensation (controlled by requirement **4.2.7. Interstitial condensation control**) can lead to the formation of mold and mildew, which can reduce the energy efficiency of the building, hence affecting in a direct way requirement **2.1.2. Indoor humidity level and control** and indirectly in a negative way requirement **6.4.1. CO_2 emission reduction** due to higher energy consumption (only in cases where energy is not produced from RES). Interstitial condensation can also damage the structural integrity of a building (i.e., by rotting wood, corroding metal, and weakening masonry), affecting requirement **1.1.1. Mechanical resistance to static actions**.

Moreover, interstitial condensation can also create conditions favorable to mold and mildew growth, which can release allergens and toxins into the indoor air, causing health problems for occupants hence affecting requirements **2.8.1. Air quality**, and **2.8.2. Microbe and mold control**.

Requirement **4.2.8. Real-time/remote control optimization** positively and directly affects **4.2.9. Seasonal efficiency of heating/cooling systems**, **2.1.1. Indoor temperature level and control** and **2.1.2. Indoor humidity level and control**, and **2.1.3. Ventilation control**. Requirement **4.2.8.**, since it optimizes the energy efficiency of the building, has an indirect effect on requirement **6.4.1. CO_2 emissions reduction**. Requirement **4.2.8. Real-time/remote control** must be designed accordingly with all other utilities and systems with which it must be able to connect and inter-operate easily. Therefore, it is affected by requirement **5.2.1. Plant system integration**.

Requirement **4.2.9. Seasonal efficiency of heating/cooling systems** can be positively affected by requirement **4.2.8. Real-**

time/remote control optimization, in turn, affects requirements **2.1.1. Indoor temperature level and control** and **2.1.2. Indoor humidity level and control**, as well as **6.4.1. CO_2 emissions reduction**.

Requirement **4.3.2. Disposal of building components and materials** at the end-of-life of the building can be already planned in the design phase and must comply with (thus is affected by) requirement **7.1.1. Circular use of materials** and **7.1.2. Dry construction processes** to limit as much as possible disposal of waste.

Anchoring and mooring systems (requirements **8.3.1. Mooring arrangements** and **8.3.2. Anchoring provisions and arrangements**) must be designed and realized in a certain way to avoid impingement/entrainment and entanglement (requirement **6.2.2. Avoid impingement/entrainment and entanglement**).

Appropriate maintenance work using nets, tarps, and pans when demolishing, replacing, or maintaining any structure or part of the structure (requirement **4.2.2. Ease of repairability/ replaceability**) positively affects requirement **6.2.3. Minimize turbidity and sedimentation disturbance**.

Surrounding water quality (**6.2.3. Minimize turbidity and sedimentation disturbance**) is affected directly by requirement **6.1.3. Toxic emission control of materials** and potentially also by requirements **7.3.3. Waste-water treatment optimization** that contributes to treating the waters instead of releasing them in the surrounding environment, as well as **7.3.4. Safe waste storage and disposal optimization** as waste could carelessly fall into the water if not stored properly.

Requirement **6.2.4. Foster biodiversity** benefits from requirements **6.3.2. Landscape preservation**, **6.2.5. Avoid reduction/ obstruction** of incoming sunlight in water (ensure adequate water oxygen levels) and **7.4.3. Use of bioclimatic passive solutions**. In turn, it positively impacts biophilia (requirement **2.7.1.**) and quality views (requirement **2.2.4.**).

Requirement **6.2.5. Avoid unnecessary reduction/obstruction and facilitate incoming sunlight in water** affects biodiversity in the underwater habitat and is thus related to requirement **6.2.4. Foster biodiversity.**

Requirement **6.2.6. Reduce light pollution and avoid underwater illumination at night** contributes to reducing disturbance on the surrounding environment and habitat, hence affecting landscape integration (**6.3.1. Landscape-architecture integration**) and contributing to requirement **6.2.4. Foster biodiversity**.

Requirement **6.2.7. Reduce underwater noise sources/ hydroacoustic energy** also reduces disturbance on the surrounding environment and habitat, contributing to requirement **6.2.4. Foster biodiversity**.

Requirements **7.4.1. Use of renewable energy resources** (REs) and **7.4.2. Use of renewable marine energy resources** (MREs) provide the building with clean energy, with no CO_2 emissions, and **7.4.3. Use of bioclimatic passive solutions** contributes to

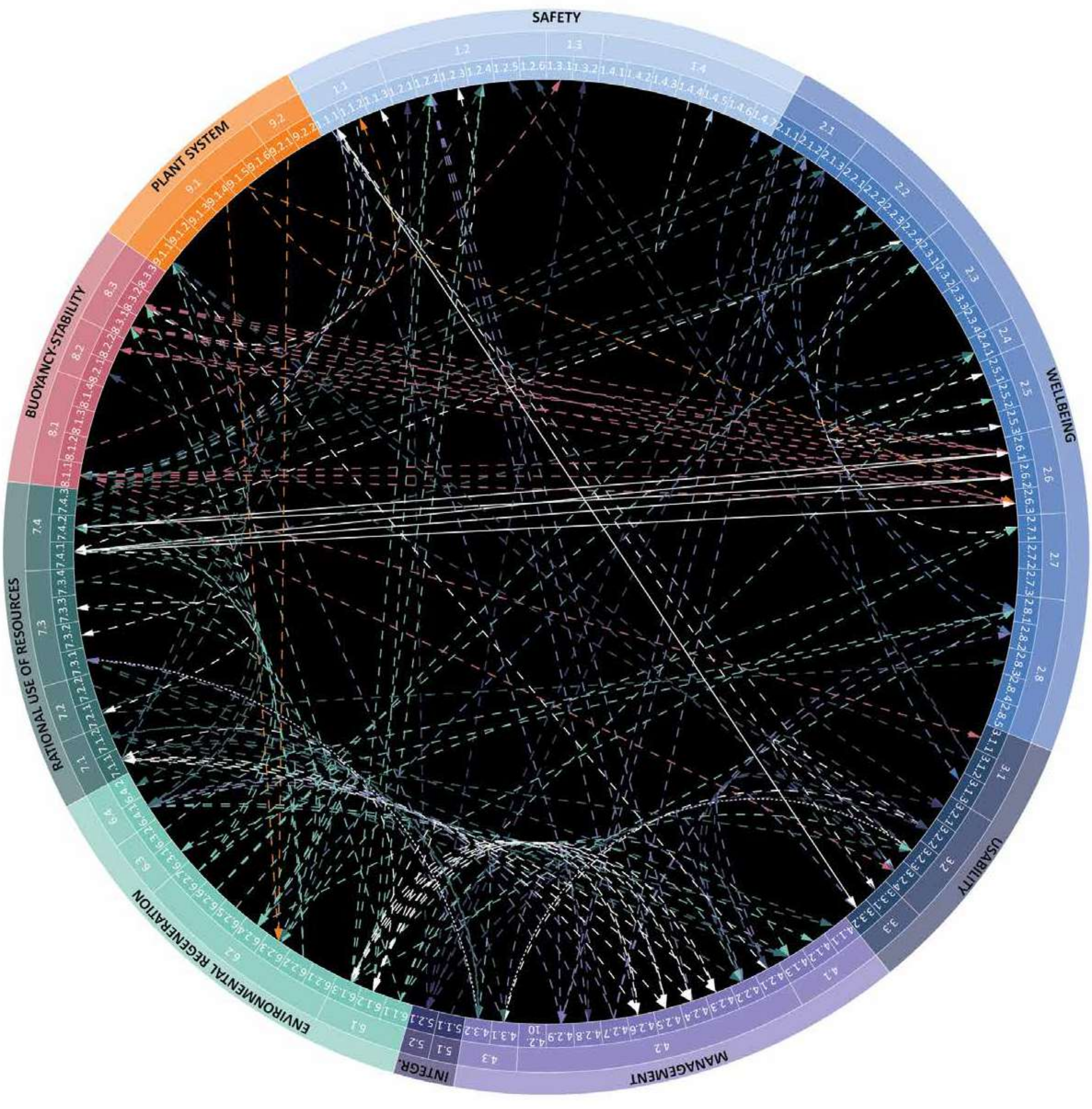
the optimization of the building energy efficiency. Therefore, all three requirements indirectly positively affect requirement **6.4.1. CO_2 emissions reduction**. In addition, requirement **7.4.3. Use of bioclimatic passive solutions** also contributes to CO_2 absorption (hence requirement **6.4.2. CO_2 absorption design solutions**).
Overall, requirements **6.4.1. CO_2 emissions reduction** and **6.4.2. CO_2 absorption design solutions** both significantly contribute to increasing air quality (requirement **2.8.1. Air quality**).
Requirement **7.3.4. Safe waste storage and disposal** contributes to the absence of unpleasant odors (requirement **2.4.1.**).
Even though the relationship is not that direct, to maximize wind potential and fulfill part of requirement **7.4.1. Use of renewable energy resources** (REs), stability (requirement **8.1.1. Freeboard**) of the substructure will be penalized, and as a consequence, motion comfort in terms of vibration and motion (requirements **2.6.1. Vertical acceleration control**, **2.6.2. Motion control**, and **2.6.3. Vibration control**). The same type of process can be followed for the requirement **7.4.2. Use of renewable marine energy resources** (MREs). In order to maximize wave energy potential or current potential, requirement **8.1.1. Freeboard** can be influenced and indirectly requirements **2.6.1. Vertical acceleration control**, **2.6.2. Motion control**, and **2.6.3. Vibration control**.
Requirement **7.4.3. Use of bioclimatic passive solutions** can improve wellbeing requirements, including **2.1.1. Indoor temperature level and control**, **2.1.2. Indoor humidity level and control**, **2.1.3 Ventilation control**, **2.2.1. Natural illumination level and control**, and **2.2.4. Quality views**. Moreover, the use of greenery (trees, plants, grass) and water as bioclimatic solutions includes CO_2 absorption strategies (**6.4.2. CO_2 absorption design solutions**) and contributes to increasing biodiversity (requirement **6.2.4. Foster biodiversity**).
The type of substructure (requirement **8.1.1. Freeboard**) affects the type, design, and connection of the anchoring and mooring systems (**8.3.1. Mooring arrangements** and **8.3.2. Anchoring provisions and arrangements**).
The transformation of the space (requirement **3.2.2. Functional/ spatial flexibility**) represents possible transformations also in terms of weight distribution and thus affects requirement **8.2.1. Adaptability to static load variation**.
Requirement **9.1.4. Pipeline watertight integrity**, together with **9.2.1. Thermal variation resistance of pipelines** reduces the risk of toxic or polluted liquids in the surrounding water, positively affecting requirement **6.2.3. Minimize turbidity and sedimentation disturbance**.
Safe placement of machinery that could provoke slight vibration (**9.1.5. Safe placing**) may contribute to **2.6.3.Vibration control**.

3.3.4. Aspects strongly related to location features

Requirements **1.1.2. Mechanical resistance to dynamic actions** and **8.2.2. Adaptability to dynamic load variations** (climate

agents) are strongly related to wind pressure.
Requirement **1.3.1. Collision risk reduction arrangements** becomes increasingly important if the site is located in areas that are interested by vessel routes.
Requirements like **2.1.1. Indoor temperature level and control**, **2.1.2. Indoor humidity level and control**, and **2.1.3. Ventilation control** are inextricably related to parameters like outdoor temperature and humidity, solar radiation, and wind speed that characterize the specific site.
The access (by land) to the floating building or distribution pier (requirement **3.1.1. Access** (reachability) for all users) must be designed according to water level fluctuations and tides. In other words, the inclination of the ramps and bridges must allow access during the different water level conditions but remain compliant with the inclination percentage prescribed by local laws.
Requirement **4.1.2. Cost-effective and efficient transportation** is strongly affected by the proximity of the site to a dry dock and the local availability of raw materials and building components of the region.
Requirements **4.2.1. Ease of intervention**. **4.2.2. Ease of repairability/replaceability** take advantage of the proximity of the building site to a dry dock where maintenance activities can be carried out.
The requirement **6.2.1. Avoid interference with protected areas** imposes not to implement floating buildings in specific locations classified as protected areas.
Requirement **8.2.2. Adaptability to dynamic load variation** strongly depends on the location in terms of climate features and trends (wind speed, rain and snow occurrence, snow occurrence, wavelength, wave height, period, and frequency).
8.3.3. Under keel clearance is influenced by several location features, including water depth (shallow water can pose a grounding hazard, where the hull keel may touch or strike the waterbed); tide and water level fluctuations; waterbed topography (underwater shoals, sandbars, and other irregularities can create localized areas of shallow water, increasing the risk of grounding).
Requirement **9.2.2. Adaptability of pipelines to water fluctuations** must be designed according to waves and tidal fluctuation of the specific location.

Figure 2. Circular diagram displaying trade-offs and correlations between performance requirements, according to threedifferent types of relation: mutual exclusion or inverse relation; mutual influence; one-sided influence.



IT AFFECTS
(color of acting requirement)

IT IS AFFECTED BY
(color of acting requirement)

MUTUAL INFLUENCE
(white)

MUTUAL EXCLUSION
(white)

References

Allen, J. G., & Macomber, J. D. (2020). Healthy buildings: How indoor spaces drive performance and productivity. Harvard University Press.

Antonovsky, A. (1987). The salutogenic perspective: Toward a new view of health and illness. *Advances, 4*(1), 47–55.

Ballard, B. W., Wilson, S., Udale-Clarke, H., Illman, S., Scott, T., Ashley, R., & Kellagher, R. (2015). *The SUDS manual.* London, UK: Ciria.

Baratta, A. F. L., Conti, C., & Tatano, V. (2019). *Inclusive Living. Design for an Autonomous and Independent Living*. Techne.

Battisti, A., Barnocchi, A., & Iorio, S. (2019). Urban regeneration process: The case of a residential complex in a suburb of Rome, Italy. *Sustainability, 11*(21), 6122. doi: 10.3390/su11216122

Battisti A., Marceca M., (2020). U*rban Health Multidisciplinary Actions Promoting Health in an Urban Environment. Urban Health*. Springer Nature - PMC COVID-19 Collection doi: 10.1007/978-3-030-49446-9_3.

Battisti, A., Calenzo, A., & Calcagni, L. (2022). Regenerating informal habitat in marginal areas through a people-oriented approach. *Techne, 24*, 145-156. doi: 10.36253/techne-12882

Bauduceau, N., Berry, P., Cecchi, C., Elmqvist, T., Fernandez, M., Hartig, T., Krull, W., Mayerhofer, E., N, S., Noring, L., Raskin-Delisle, K., Roozen, E., Sutherland, W., & Tack, J. (2015). Towards an EU Research and Innovation Policy Agenda for Nature-based Solutions & Re-naturing Cities: Final Report of the Horizon 2020 Expert Group on 'Nature-based Solutions and Re-naturing Cities'. Publications Office of the European Union. doi: 10.2777/765301

Bolten, B., & Barbiero, G. (2020). Biophilic design: how to enhance physical and psychological health and wellbeing in our built environments. *Visions for Sustainability, 13*, 11–16. doi: 10.13135/2384-8677/3829

Boulding, K. E. (1966). The economics of the coming spaceship earth. In H. Jarrett (Ed.), *Environmental quality in a growing economy: Resources for the Future. Essays from the sixth RFF forum* (pp. 3–14). Johns Hopkins University Press. ISBN 9781617260278

Buhalis, D., Eichhorn, V., Michopoulou, E., & Miller, G. (2005). Accessibility market and stakeholder analysis. One Stop Shop for Accessible Tourism in Europe (OSSATE). UK: University of Surrey.

Canepa, M., Mosca, F., Barath, S., Changenet, A., Hauck, T. E., Ludwig, F., Roccotiello, E., Pianta, M., Selvan,

S. U., & Vogler, V. (2022). Ecolopes, beyond greening. A multi-species approach for urban design. *Agathón| International Journal of Architecture, Art and Design, 11*, 238–245. doi: 10.19229/2464-9309/11212022

Canter, D. V, & Lee, T. (1974). *Psychology and the built environment*. Architectural Press.

Capolongo, S., Rebecchi, A., Dettori, M., Appolloni, L., Azara, A., Buffoli, M., Capasso, L., Casuccio, A., Oliveri Conti, G., & D'Amico, A. (2018). Healthy design and urban planning strategies, actions, and policy to achieve salutogenic cities. *International Journal of Environmental Research and Public Health, 15*(12), 2698. doi: 10.3390/ijerph15122698

Ceyrac, L., Dellong, D., Le Courtois, F. (2023). Threshold-Based Assessment of Underwater Noise Pollution in French Marine Waters. In A.N. Popper, J. Sisneros, A.D. Hawkins, F. Thomsen (Eds) *The Effects of Noise on Aquatic Life*. Springer, Cham. doi: 10.1007/978-3-031-10417-6_29-1

COM (2019). The European green deal. European Commission Brussels. Belgium.

Dallinga, R.P. & Bos, J.E. (2010). Cruise ship seakeeping and passenger comfort. *International Conference on Human Performance at Sea*, HPAS. Glasgow, UK.

Darcy, S., & Dickson, T. J. (2009). A whole-of-life approach to tourism: The case for accessible tourism experiences. *Journal of Hospitality and Tourism Management, 16*(1), 32–44. doi: 10.1375/jhtm.16.1.32

Dilani, A. (2008). Psychosocially supportive design: A salutogenic approach to the design of the physical environment. *Design and Health Scientific Review, 1*(2), 47–55.

Edwards, J. R., Caplan, R. D., & Van Harrison, R. (1998). Person-environment fit theory. *Theories of Organizational Stress, 28*(1), 67–94.

Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., & Lamarque, P. (2015). Nature-based solutions: new influence for environmental management and research in Europe. *GAIA-Ecological Perspectives for Science and Society, 24*(4), 243–248. doi: 10.14512/gaia.24.4.9

Fitch, J. M. (1972). *American Building: The environmental forces that shape it.* Houghton Mifflin.

Fobert, E. K., Burke da Silva, K., & Swearer, S. E. (2019). Artificial light at night causes reproductive failure in clownfish. *Biology Letters, 15*(7), 20190272. doi: 10.1098/rsbl.2019.0272

Giurgiu, I. C. (2022). Floating Cities and Equitable Grafting onto Marine Ecosystems. In *Lecture Notes in Civil Engineering* (Vol. 158). doi: 10.1007/978-981-16-2256-4_26

Giarini, O. (1981). *Dialogo sulla ricchezza e il benessere*. Mondadori, Milano.

Goldsmith, S. (2007). *Universal design.* Routledge.

Goldsmith, S. (2012). *Designing for the disabled: the new paradigm*. Routledge.

Golembiewski, J.A. Salutogenic Architecture. In M.B. Mittelmark, G.F. Bauer, L. Vaandrager, J.M. Pelikan, S. Sagy, M. Eriksson, B. Lindström,C.M. Magistretti(Eds.)*The Handbook of Salutogenesis*. Springer: Cham, Switzerland, 2016; pp. 259–274.

Habibi, S. (2015). Floating Building Opportunities for Future Sustainable Development and Energy Efficiency Gains. *Journal of Architectural Engineering Technology, 04*(02). doi: 10.4172/2168-9717.1000142

Hensel, M. U. (2010). Performance-oriented architecture: towards a biological paradigm for architectural design and the built environment. *FORMakademisk, 3* (1). 36-56.

Kumar, G. P., Anilakumar, K. R., Mallesha, Y. C., & Sharma, R. K. (2020). Motion sickness: manifestations and Prevention. *Defence Life Sci. J., 5*(3), 230–237.

Lauria, A. (2017). Environmental Design and Accessibility: Notes On The Person-Environment Relationship And On Design Strategies. *Techne, 13*, 55–62.

Lin, F.Y., Czapiewska, K., Iorga, G., Totolici, D., Koning, J. (2020). A catalogue of technical requirements and best practices for the design- Deliverable. 7.2. Space@Sea.

Lui, E. M. (2020). Structural stability. *Structural Engineering and Geomechanics, 1*, 198.

Mace, R. (1985). Universal design: Barrier free environments for everyone. *Designers West, 33*(1), 147–152.

Mace, R., G. Hardie, and J. Plaice. 1991. Accessible environments: Toward universal design. In W.E. Preiser, J.C. Vischer, and E.T. White (Eds.) *Design interventions Toward a more humane architecture*, 155–175. New York: Van Nostrand Reinhold.

Marangoni, L. F. B., Davies, T., Smyth, T., Rodríguez, A., Hamann, M., Duarte, C., Pendoley, K., Berge, J., Maggi, E., & Levy, O. (2022). Impacts of artificial light at night in marine ecosystems - A review. *Global Change Biology, 28*(18), 5346–5367. doi: 10.1111/gcb.16264

Massana, R., Labarre, A., López-Escardó, D., Obiol, A., Bucchini, F., Hackl, T., Fischer, M. G., Vandepoele, K., Tikhonenkov, D. V, & Husnik, F. (2021). Gene expression during bacterivorous growth of a widespread marine heterotrophic flagellate. *The ISME Journal, 15*(1), 154–167. doi: 10.1038/s41396-020-00770-4

Mittelmark, M. B., Bauer, G. F., Vaandrager, L., Pelikan, J. M., Sagy, S., Eriksson, M., Lindström, B., & Meier Magistretti, C. (2022). *The handbook of salutogenesis*. Springer. doi: 10.1007/978-3-030-79515-3

Ofori, G. (2000). Greening the construction supply chain in Singapore. *European Journal of Purchasing & Supply Management, 6*(3–4), 195–206.doi: 10.1016/S0969-7012(00)00015-0

Pandakovic, D., & Dal Sasso, A. (2009). *Saper vedere il paesaggio.* Novara: De Agostini Scuola SpA

Pelikan, J.M. (2017). The application of salutogenesis in healthcare settings. In M.B. Mittelmark et al. (Eds) *The handbook of salutogenesis*, 261–266. New York: Springer.

Plagányi, É. E., Skewes, T., Murphy, N., Pascual, R., & Fischer, M. (2015). Crop rotations in the sea: Increasing returns and reducing risk of collapse in sea cucumber fisheries. Proceedings of the National Academy of Sciences, 112(21), 6760–6765. doi: 10.1073/pnas.1406689112

Schmäl, F. (2013). Neuronal mechanisms and the treatment of motion sickness. *Pharmacology, 91*(3–4), 229–241. doi: 10.1159/000350185

Smyth, T. J., Wright, A. E., Mckee, D., Tidau, S., Tamir, R., Dubinsky, Z., Iluz, D., & Davies, T. W. (2021). A global atlas of artificial light at night under the sea. *Elementa Science of the Anthropocene, 9*(1), 49. doi: 10.1525/elementa.2021.00049

Sigray, P., Andersson, M., Andre, M., Azzellino, A., Borsani, J., Bou, M., Castellote, M., Ceyrac, L., Dellong, D., Folegot, T., Hedgeland, D., Juretzek, C., Klauson, A., Leaper, R., Le Courtois, F., Liebschner, A., Maglio, A., Müller, A., Norro, A., Novellino, A., Outinen, O., Popit, A., Prospathopoulos, A., Thomsen, F., Tougaard, J., Vukadin, P. and Weilgart, L., (2023). Setting EU Threshold Values for impulsive underwater sound, Druon, J., Hanke, G. and Casier, M. (Eds). Luxembourg: Publications Office of the European Union, ISBN 978-92-68-03343-2, doi:10.2760/60215, JRC133477.

Tucci, F. (2018). Resilienza ed economie green per il futuro dell'architettura e dell'ambiente costruito. *Techne, 15*, 153–164.

UN DESA. (2013). Accessibility and Development. Mainstreaming disability in the post-2015 development agenda. Retrieved from https://www.un.org/disabilities/documents/accessibility_and_development.pdf

Wang, K-F. (2021). An Investigation into Environment-Floating Buildings in relation to Sustainability Indicators for Planning and Design Process. De Montfort University.

Weisser, W. W., Hensel, M., Barath, S., Culshaw, V., Grobman, Y. J., Hauck, T. E., Joschinski, J., Ludwig, F., Mimet, A., & Perini, K. (2023). Creating ecologically sound buildings by integrating ecology, architecture and computational design. *People and Nature, 5*(1), 4–20. doi: 10.1002/pan3.10411

CHAPTER 4 Case study review

ABSTRACT

The chapter provides a list of existing projects distributed across different scales (villages, districts, multi-units, single units), countries, water types (lakes, canals, bays and harbors, rivers, straits, lagoons, coasts, and offshore waters), times, and functions (residential and the non-residential). A preliminary screening based on specified criteria led to select 25 case studies (10 residential and 15 non-residential of which 5 were for touristic temporary residential purposes) that are presented more thoroughly and analysed following a requirement-structured rubric. The requirement-structured rubric and case study analysis protocol are evaluated by experts in different disciplinary domains and refined accordingly. The case studies illustrate the different technical and technological advancements in the field of floating architecture, the challenges and opportunities that are associated with floating buildings and their aggregation in districts, and most importantly their compliance with each requirement. The chapter concludes each section (residential and non residential case study review) by outlining some of the key findings from the case study research. Among these the fact that floating buildings can be more expensive to build than on-land buildings due to the specialized engineering and construction techniques required and that the legal and regulatory challenges associated with floating buildings complicate the acquisition of permits and financing for floating projects. A conclusive paragraph presents the multi-criteria evaluation matrix that returns best practices among the case studies according to their compliance with the requirement rubric and the priority distribution among requirements according to their fulfilment among the case studies.

Many architectural firms involved in floating buildings are based in the Netherlands. Waterstudio.NL is an architectural firm based in The Hague that tackles the challenge of developing solutions to the problems posed by urbanization and climate change. The first municipality where they developed this vision is The Westland, near The Hague, with a project incorporating floating social housing, floating islands, and floating apartments. They have completed projects in several European countries, China, the United Arab Emirates, and the Maldives. Blue 21, formerly Delta-Sync, is a world leading company providing research, design, engineering, and consultancy for floating urban and maritime projects in Delta cities across the world. Their expertise in floating innovations is rooted in a multidisciplinary team of architects, civil mechanics, hydraulic and maritime engineers, and environmental experts. They are committed to promoting the blue revolution through sustainable use of the oceans to build cities, produce food and energy, and create new ecosystems. Baca Architects is a London-based practice that has built the UK's first amphibious house. They design and build flood-resilient homes and communities on, in, near, and underwater. MAST Design Studio was founded by Australian architect Marshall Blecher and Danish maritime designer and architect Magnus Maarbjerg to improve the relationship between the city and the sea. They work with all typologies and scales, from small finely crafted installations to piers and parklands to the development of plans for new waterfront districts. Bartels & Vedder is an interdisciplinary engineering and consultancy agency specialized in innovative solutions for the construction industry, especially floating and offshore.

Various architectural practices have developed isolated projects or entire urban communities on water. These include among others Pan Projects, Grimshaw, Goldsmith, Studio Fokstrot, Powerhouse company, BIG-Bjarke Ingels' Group, MVRDV, and Mos Architects.

Identifying and cataloging available and exemplary existing projects lays the foundations for creating an open-source archive of projects and solutions. The projects are presented following a methodology based on a comparative analysis. The database can be used and constantly updated using the same methodology by designers and stakeholders, who will thus be able to expand their field of knowledge.

The projects are listed in Table 1 organized by date of realization. The table provides information regarding:

Table 1. Database of projects organized by date of realization, including information relevant to the designer, the location, the country, the function, the scale and the water typology.

- designer, studio or firm;
- location;
- country;
- (main) function: civil (C), commercial (Co), Cultural/educational (CE), food production (FP), green (G), infrastructure (I), leisure (L), tourism (T), tertiary (Te), residential (R);
- scale: single unit (SU), multi-unit (MU), district (D), village (V);
- water type: bay/harbor (B-H), canal (C), lagoon (La), lake (L), offshore (Of), river (R),strait/fjord (S-F).

Project	Designer	Location	Country	Date	Func.	Scale	Water
Tanka Floating Village	/	Luoyan Bay	Cina	VIII cen.	R	V	B - N
Floating Village on Tonle Sap	/	Krong Siem Reap	Cambodia	IX-X cen.	R	V	La
Kompong Khleang Floating Village	/	Kampong Khleang	Cambodia	IX-XV cen.	R	V	La
Floating Islands	/	Lake Titicaca	Peru	XV cen.	R	V	La
Floating Village on Amazon River	/	Iquitos	Peru	XVII - XVIII cen.	R	V	Ri
Ganvie Floating Village	/	Lake Nokoué	Benin Republik	XVIIcen.	R	V	La
Aberdeen Floating Village	/	Aberdeen	Hong Kong	XIX cen.	R	V	B - N
Koy Panyee Floating Village	/	Koy Panyee	Thailan	XIX cen.	R	V	B - N
Cua Van Floating Village	/	Ha Long Bay	Vietnam	XIX cen.	R	V	B - N
Lotak Lake Floating Huts	/	Lotak Lake	India	before 1886	R	V	La
Isola delle Rose	Giorgio Rosa	Rimini	Italy	1958 - 1968	R	SU	Of
Floating prison	Royal Haskoning	Zaandam	Netherlands	1990	C	SU	Ca
Villa Nackros	Strindberg Arkitekter	Kalmar	Sweden	2003	R	SU	S - F
Mur Island Bridge	Acconci Studio	Graz	Austria	2002-2003	CE	SU	Ri
Watervilla	Waterstudio.NL	Aalsmeer	Netherlands	2004	R	SU	La
Floating Ghouse	Dura Vermeer	Naaldwijk	Netherlands	2005	R	D	Ca
Fennel Residence	Robert Oshatz + EcoFloLife	Portland	United Kingdom	2006	R	SU	Ri
Badeschiff (Swim ship)		Vienna	Austria	2006	L	SU	Ri
Floating Hotel	Sabbagh Arquitectos	Fjords of Aysen	Chile	2006	T	SU	S - F
Marina Geierswalde Floating Homes	AUTARTEC consortium	Geierswalde Lake	Germany	2006	R	MU	La
Seattle Floating Home	Vandeventer + Carlander Architects	Seattle	United States of America	2008	R	D	La
Houseboat Haarlem Shuffle	vanOmmeren-architects	Amsterdam	Netherlands	2009	R	D	Ca
Floating church Vineta	/	Neu-seenland	Germany	2010	CE	SU	La
Water Villa Omval	Architects +31	Amsterdam	Netherlands	2010	R	SU	Ri
Nautilus houseboat	Nautilus Hausboote GmbH (company)	Königs Wusterhausen	Germany	2010	R	SU	Ri
Floating Pavillion	Blue 21	Rotterdam	Netherlands	2010	L	SU	Ca

Project	Designer	Location	Country	Date	Func.	Scale	Water
The Sayboat	Milan Řídký	Nelahozeves	Czech Republic	2012	R	SU	Ri
Ijburg	Marlies Rohmer	Amsterdam	Netherlands	2001-2012	R	D	Ca
Brockholes Visitor Centre	Akdamkhan	Lancashire	United Kingdom	2008-2012	CE	SU	La
Boat's House at Millstätter La	MHM architects	Millstätter Lake	Austria	2012	R	SU	La
MFS I	NLE'	Makoko	Nigeria	2012	CE	SU	Lag
Exbury Egg	PAD studio + SPUD Group + Stephen Turner	Hampshire	United Kingdom	2013	R	MU	Ri
Bokodi Lake Floating Houses	/	Budapest	Hungary	2013	R	MU	La
Viktoriakai Floating Homes	Matthäi	Hamburg	Germany	2014	T	MU	Ca
Watervilla	Architects +31	Amsterdam	Netherlands	2015	R	SU	Ca
Floating Seahorse	Kleindeinst Architects	Dubai	United Arab Emirates	2015	T	SU	B - N
Floating Kayak Club	FORCE4 Architects	Vejle Fjord	Denmark	2015	L	SU	S - F
Ca Swimmer's Club	Atelier Bow-Wow + Architectuuratelier Dertien 12	Bruges	Belgium	2015	L	SU	Ca
Alqueva Floating House	Friday SA	Alqueva	Portugal	2015	R	SU	La
Floating Houses Marina Azzurra	Studio Starkel + Adria	Lignano Sabbiadoro	Italy	2015	T	MU	Lag
Eco-barrio Flottante	Fabian de Martino	San Fernando	Argentina	2015	R	D	Ri
Jellyfish Barge	Studiomobile + Stefano Mancuso	Florence, Milan	Italy	2015	FP	SU	Ri
Meripaviljonki Floating Restaurant	Simo Freese Architects	Helsinki	Finland	2015	Co	SU	B - N
Floating Eco-homes Hannaschpolder	Blue 21	Delft	Netherlands	2013-2015	R	MU	Ca
Houseboat PRORETA 12	Deutsche Composite GmbH (Holding)	Hamburg	Germany	2015	R	SU	La
Uszohaz	Oszkar Vagi and Csinszka Cserhati	Budapest	Hungary	2015	R	SU	Ri
MFS II - Venice biennale	NLE'	Venice	Italia	2016	CE	SU	Ca
DD16	BIO-Architects	Moscow	Russia	2016	R	SU	La
DOC - Temporary Floating House	Lime Studio	Călărași	Romania	2016	R	SU	La
Pavillion of Reflection	Studio Tom emerson	Zürich	Switzerland	2016	CE	SU	La
Floating House	Carl Turner	London	United Kingdom	2016	R	SU	Ri
Urban Rigger	Bjarke Ingels Group	Copenhagen	Denmark	2016	R	MU	B - N
Wa-sauna	Goc studio	Seattle	United States of America	2016	L	SU	La
Egreta Complex	/	Berzasca	Romania	2016	T	MU	Ri
The Chichester	Baca architects	Chichester Canal	United Kingdom	2016	R	SU	Ca
Ferry Terminal	Bartels & Vedder	Terengganu Kenyir Lake	Malaysia	2016- 2017	I	SU	La
Houseboat Svendborgsund	MAST	Copenhagen	Denmark	2016-2017	R	SU	Ca
Floating Villa	Admares + Kudos Design	Dubai	United Arab Emirates	2017	R	SU	B - N

Project	Designer	Location	Country	Date	Func.	Scale	Water
Energy Neutral Floating Villa	vanOmmeren-architects	Haarlem	Netherlands	2017	R	MU	Ri
Buoyant Ecologies Float Lab	College of the Arts Architectural Ecologies Lab	California	United States of America	2017	CE	SU	B - N
Tatami House	Julius Taminiau	Amsterdam	Netherlands	2017	R	SU	Ca
Floating Hotel Pods	Huis Ten Bosch	Nagasaki	Japan	2018	T	MU	B - N
Floating Pavillion	Bruno Rossi Arquitetos	Sao Paulo	Brazil	2018	CE	SU	La
House Boats Su Siccu	Home Boat Company	Cagliari	Italy	2018	T	MU	B - N
Fold & Float	SO?	Nomadic	Turkey	2018	C	MU	Ri
House Boats Parque das Nações	Home Boat Company (Rodrigo Rubin + Stefano Fiori)	Lisbon	Portugal	2018	T	MU	B - N
Floating Office Rotterdam	Powerhouse Company	Rotterdam	Netherlands	2018	Te	SU	Ca
MFS III - 'Minne Floating School'	NLE'	Bruges	Belgium	2018	CE	SU	La
KBHØ1	MAST	Copenhagen	Denmark	2018	L	MU	B - N
Botel	Botel Diffuso dei Laghi srl	Lugano	Italy	2018	T	MU	La
Humpy Dumpy	Hollands Zicht + Bartels & Vedder	Knollendammervaart Oostknollendam	Netherlands	2018-2019	R	SU	Ca
Floating Farm 2.0	Goldsmith Company	Rotterdam	Netherlands	2019	FP	SU	Ca
WaterLilliHaus	SysHaus	San Paulo	Brazil	2019	R	SU	La
Floating House	Studio DIIA	Seattle	United States of America	2019	R	SU	La
Innozowa	Blue21	Weurt	Netherlands	2019	I	SU	La
Anthenea	Jean-Michel Ducancelle	Côte de Granite Rose	France	2019	T	SU	B - N
Blue Habitats in Tongelreep	Waterstudio.NL	Eindhoven	Netherlands	2020	G	SU	Ri
Schoonship	Space & Matter	Amsterdam	Netherlands	2020	R	D	Ca
Acqua Resort Giulianova	/	Giulianova	Italy	2020	T	MU	B - N
Pvrok/Protozoa	Scoolpt	Prague	Czech Republic	2020	R	SU	Ri
Hortus BOATanicus	Waterstudio.NL	Amsterdam	Netherlands	2020	T	SU	Ca
Eco-Pavillion Arlington Business Park	Eco-pavillions + TP Bennett	Shepperton	United Kingdom	2021	CE	SU	La
Prefab Sauna	Lausanne University - Trolle Rudebeck	Geneva	Switzerland	2021	L	SU	La
Bruges Diptych	PARA Project	Bruges	Belgium	2021	CE	SU	Ca
Teahouse Ø	Pan Project	Copenhagen	Denmark	2021	L	SU	Ca
Floating Eco-park	SOM + Urban Ris	Chicago	United States of America	2016-2021	G	SU	Ri
Vlotkamp Floating Pop-up Hotel	Tobias Knockaert & Kika Merlin	Zuienkerke	Belgium	2020-2021	T	SU	La
Floating Home	i29 interior architects	Amsterdam	Netherlands	2021	R	SU	Ca
Floating Houses 44.3	floating house GmbH	Grabendorfer	Germany	2021	R	MU	La
Art Pavillion M	Studio Ossiana	Almere	Netherlands	2022	CE	SU	La

Project	Designer	Location	Country	Date	Func.	Scale	Water
Adidas Tennis Court	Parley for the Oceans	Great Barrier Reef marine park	Australia	2022	L	SU	Of
Floating Theatre Lyon	Waterstudio.NL	Lyon	France	2023	CE	SU	Ri
"Joyous" Floating Sauna	ACT! Studio + Borhaven Arkitekter	Oslo	Norway	2022	L	SU	B - N
Water Cabin	Olson Kundig	Seattle	United States of America	2022	T	SU	B - N
Two Floating Homes 504 H11 V	Adria	Natters	Austria	2022	T	SU	La
La sirenetta Blue Village	Crippaconcept	Savigliano	Italy	2022	T	MU	La
Havneklippen 'The Harbour Cliff'	MAST	Copenhagen	Denmark	2023	L	SU	B - N
Sauna KFF	MAST	Copenhagen	Denmark	2023	L	SU	B - N
Floating Homes	Public domain Architects	Rotterdam	Netherlands	2023	R	MU	Ca
Waterdream	Crippaconcept	Rimini	Italy	2023	T	MU	B - N
Wikkelboat	Sander Waterval	Rotterdam	Netherlands	2023	T	MU	Ca
Land on Water	MAST	nomadic	Denmark	ongoing	R	D	Ca
Salmon eye	Kvorning Design	Rosendal	Norway	ongoing	CE	SU	S - F
8th Continent	Lenka Petráková (Zaha Hadid)	Garbage Patch	/	2017 - ongoing	CE	SU	Of
Green Ocean (Marine Farm)	N-ARK	/	/	2021 - ongoing	FP	SU	B - N
Floatlab	Höweler + Yoon	Philadelphia	United States of America	2021 - ongoing	CE	SU	Ri
Enclaves on Vistula River	Monolight Studio	Krakow	Poland	2021- ongoing	Te	MU	Ri

The alluvial diagrams in Figures 1 and 2 show the correlations between function and water typology representing them as flows. Each rectangle represents a unique value in the selected dimension, and its height is proportional to its value. Correlations are represented with curved lines whose width is proportional to their value. Out of 109 projects, the most common function is residential buildings, accounting for 45% of the total. Residential projects include single units (50%), multi-units (15%), districts (15%) or villages (20%). The non-residential projects add up to 53% of the total, and the remaining 2% are outdoor spaces. Among the non-residential projects, the most common are touristic facilities including temporary accommodations (17% of the projects). And cultural-educational facilities (16%). Non-residential projects also include leisure facilities (11%), food production (2%), tertiary buildings like offices (2%), commercial activities (1%), civil buildings (2%) and infrastructure (2%). The most common water bodies are lakes, accounting for 29% of the projects in the database. More than one out of five (22%) is located in a canal. Therefore, over half of the projects are located in waters which do not witness great wave or current pressure. Yet especially canals are subject to great water level fluctuations. Bays and harbors host 20% of the projects and rivers 19%. Only a few are in straits/fjords (4%), or lagoons (2%). As the projects are mainly related to living activities, and thus to an urban context, only 3% of them are located offshore.

Figure 1. Alluvial diagram showing the correlations between marco-function (residential, non residential and outdoor spaces) and water typology.

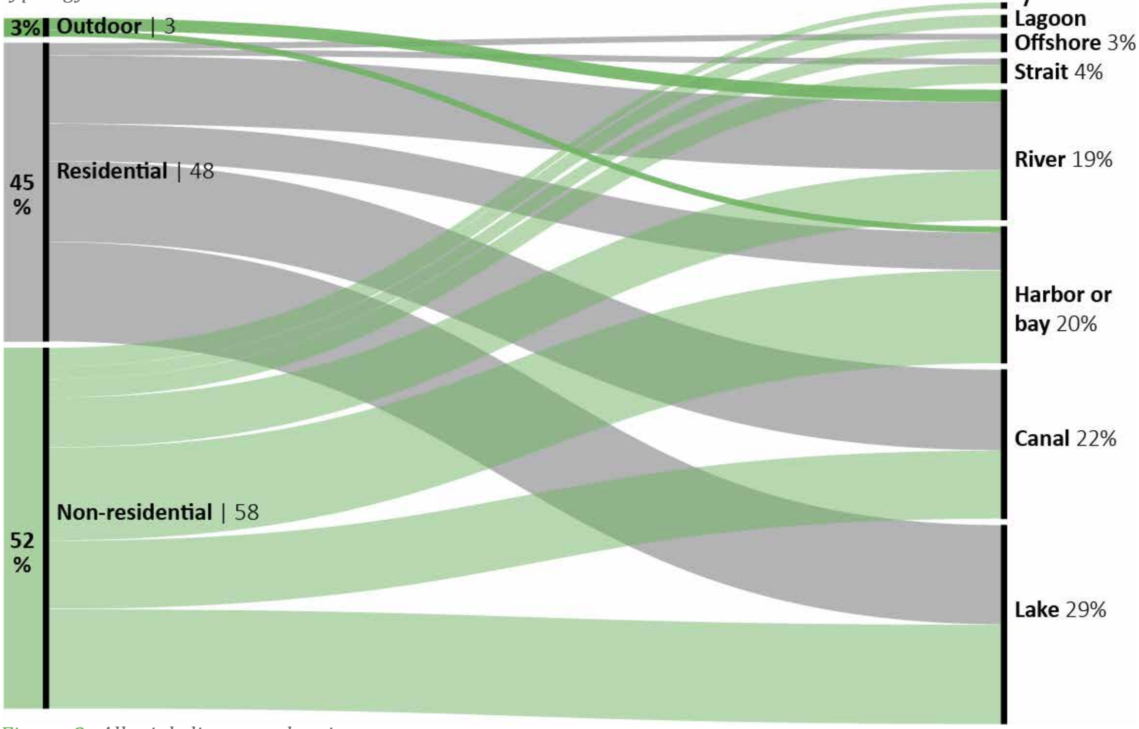
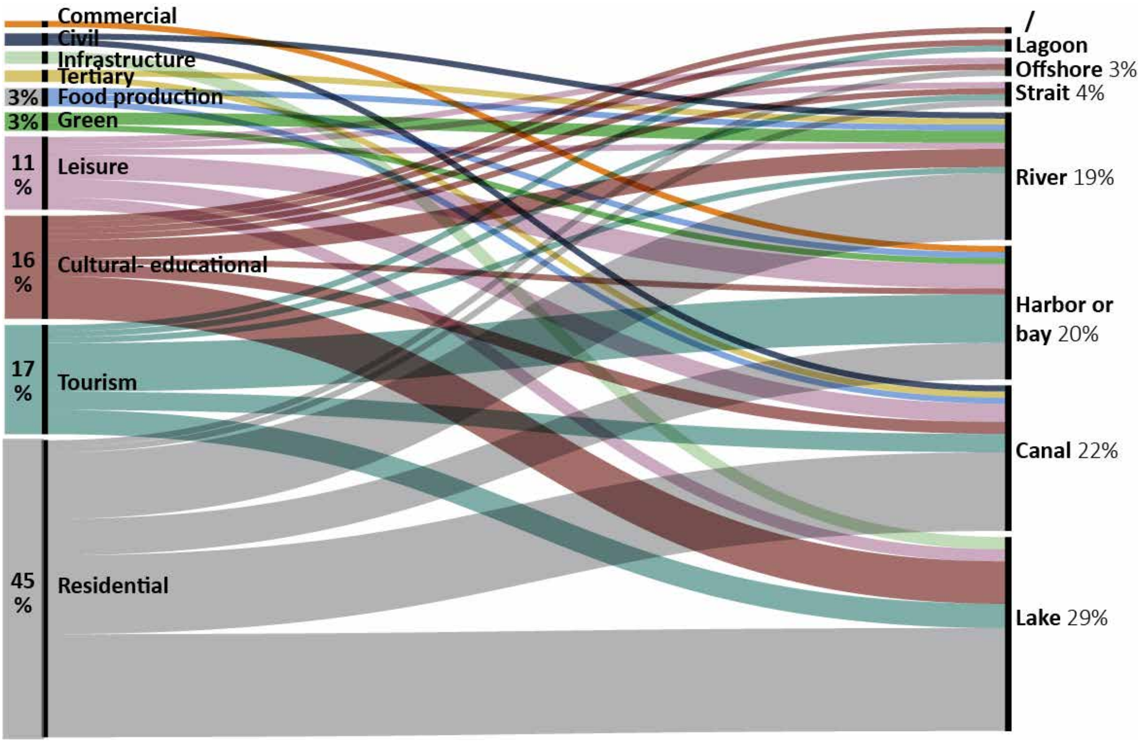


Figure 2. Alluvial diagram showing the correlations between specific function and water typology.



4.1 Definition of objectives for the selection of case studies

The objectives guiding the selection of case studies led to a preliminary restriction screening out the cases that do not adhere to the following conditions:

1. status: built (and still existing);
2. time frame: realized over the last 20 years;
3. location: inland and intermediate sheltered waters[1];
4. quality: compliance with minimum occupancy[2] and indoor comfort[3] conditions;
5. data availability: sufficient material, data, and sources to complete the assessment rubric described in Paragraph 2.1.2.2.

According to the first criteria, 8 of 109 projects were excluded as they are still ongoing, reducing the list to 101 case studies. Of these 101 case studies, 15 projects have been left out from the selection as they were realized more than 20 years ago (before 2003), leaving 87 projects. Another project was removed because of its offshore location (criteria 3). All 86 case studies meet minimum occupancy and comfort standards (criteria 4). Most vernacular projects would have been excluded according to this criterion, but they had already been excluded based on the time frame (criteria 2). Finally, data availability (criteria 5) was revealed to be a determining condition for selecting the remaining case studies.

A second boundary condition involved the compliance (either declared or not) of case studies with at least four of the following objectives:

- ecosystem preservation/regeneration;
- resource circularity;
- energy efficiency;
- high levels of comfort and wellbeing;
- economic feasibility (implementation and maintenance).

To succeed in the identification of the criteria that are relevant to the field of study, it was necessary to delve deeper into various topics relating to community policies, international goals, and cutting-edge technologies. This operation has proven to be fundamental in compiling a database of architectural and technological solutions to

1. In this thesis the term “sheltered waters” includes inland waters (non-tidal rivers, lakes, dams, billabongs, lagoons, artificial canals) and intermediate waters (tidal rivers, sheltered sea waters areas, bays, fjords).

2. This indicator follows the EU (Eurostat, 2021) wide agreed definition of overcrowding. A household is considered overcrowded if it does not have at its disposal a minimum number of rooms equal to one room for the household, one room per adult couple in the household, one room for every single person aged 18 and over; one room per pair of single persons of the same sex between 12 and 17 years of age; one room for every single person between 12 and 17 years of age and not included in the previous category; one room per pair of children under 12 years of age.

3. Indoor comfort refers to the conditions within an enclosed space that provide occupants with satisfactory thermal, visual, acoustic, and air quality comfort. It involves maintaining an environment that promotes human wellbeing, productivity, and overall satisfaction.

design floating buildings.

The database does not claim to provide a complete collection of all existing floating buildings. However, it sets up an initial repertoire of projects that can be further integrated and completed. Nevertheless, this collection provides a decent number of projects, considering how floating buildings and similar structures are relatively rare compared to traditional buildings. The 25 case studies presented more thoroughly represent the broader picture and constitute best practices as they were selected according to their compliance with the objectives listed above. Moreover, the 25 case studies represent a snapshot of the database considering the distribution between residential and non-residential projects. To highlight the most suitable solutions for a residential application, the ten selected housing projects range from single housing units to multi-unit or entire districts and are all characterized by permanent living. Temporary accommodations, like touristic facilities (hotels, resorts, short-rental apartments), are not considered part of this category but fall within the touristic sub-category within the non-residential group. The 15 non-residential projects include leisure, food production, infrastructure, tertiary, cultural-educational, commercial, and touristic applications. More specifically, 5 are touristic accommodations that could be considered between residential and non-residential typologies since they are meant for short-term living purposes.

The intention of looking at different functions, in addition to residential buildings, is to provide a framework suitable for living and, later, for all those services necessary and complementary to living. Moreover, the division into ten residential projects, ten non-residential, and five touristic ones also reflects the distribution of functions among the total number of case studies (Figure 1). Despite all presented projects being complex solutions, they are presented within the scope of the research with a particular focus on their (primary) function, scale, morphology, compliance to selection criteria, material and construction components of the key technical units, and eventually, requirement compliance.

4.2 Case study assessment rubric and expert reviewers' validation

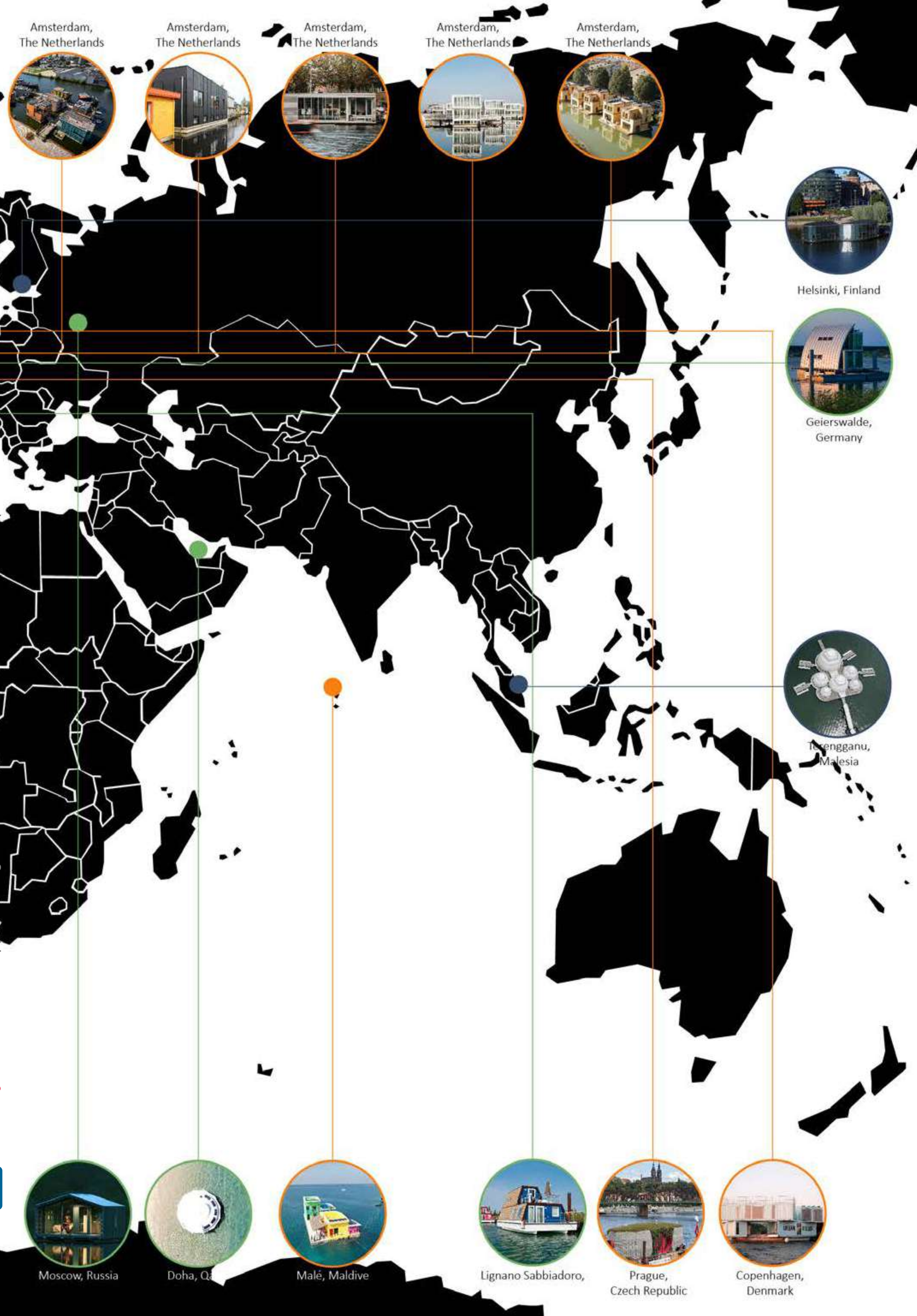
To outline a simplified and structured reading method in order to facilitate the comparison between the different types of design solutions presented, an attempt was made to develop an analysis sheet that highlighted the objectives that qualified them as best practices as well as their compliance with the performance requirements. The case study assessment sheet is structured as described in Paragraph 2.1.2.2. (Appendix B). The scoring system for the compliance of the case study to each requirement works as follows:

- full square: requirement is met;
- half-full square: requirement is partially met, or unintendedly met;
- diagonal bar: no information is available;
- empty square: requirement is not met.

A full square corresponds to 100%, a half-full square to 50%, and an empty square to 0%. When information is not available, it is most likely because the requirement has not been met. Hence, it corresponds to 0%. However, the bar highlights that this could change. The total score at the top left corner of each class of demand returns the overall score out of a hundred, where 100 represents the fulfillment of all requirements within that class of demand.

According to the expert reviewers' evaluation and validation, the Case Study Assessment Rubric (CSAR) was fairly well-structured and sound. As mentioned previously, expert reviewer 3, suggested changing the coding system to make it more clear and readable. He also recommended adding an explanation of how the squares "turn on" according to the compliance with the requirements. This has been added in Paragraph 2.1.2.2. Expert reviewer 1 suggested to uniform the data regarding the site features among case studies and using the Köppen Climate classification to describe the climate of the sites, as it is one of the most well-established and widely recognized systems used for climate classification in the world. Its comprehensive system makes it easy to compare climates from different regions.

Figure 3. Political map showing the distribution across the world of the analyzed case studies: permanent residential projects, non-residential, and temporary residential projects.



Amsterdam, The Netherlands
Amsterdam, The Netherlands
Amsterdam, The Netherlands
Amsterdam, The Netherlands
Amsterdam, The Netherlands
Helsinki, Finland
Geierswalde, Germany
Terengganu, Malesia
Moscow, Russia
Doha, Qa
Malé, Maldive
Lignano Sabbiadoro,
Prague, Czech Republic
Copenhagen, Denmark

4.3 Contemporary floating residential buildings

The residential case studies distributed on the political map (Figure 3) include:

1. Ijburg, Amsterdam (Netherlands)
2. Schoonship, Amsterdam (Netherlands)
3. Tatami house, Amsterdam (Netherlands)
4. Harnaschpolder, Delft (Netherlands)
5. Harlem Shuffle, Haarlem (Netherlands)
6. Urban Riggers, Copenhagen (Denmark)
7. Seattle floating home (United States of America)
8. Floating homes in Nassauhaven (Netherlands)
9. Pvrok, Střelecký Island (Czech Republik)
10. Maldive floating house (Maldive)

4.3.1. Permanent residential projects

4.3.1.1. IJburg, Amsterdam (Netherlands)
Architectenbureau Marlies Rohmer
2001-2012

IJburg is part of the 75-home floating district Waterbuurt West, located immediately behind the Enneüs Heerma Bridge, which provides an essential connection between IJburg and the rest of Amsterdam. Given the significant housing shortage in the early nineteen nineties, the plans for IJburg concerned the development of a high-density area intended to be a lively and vibrant new district of Amsterdam, comprising both on-land and on-water buildings. Floating IJburg is an archipelago of twenty-five housing units moored to seven connected jetties. The protected basin in the Ijsselmeer is subject to water level fluctuations up to a maximum of 60 cm. To create a mixed-use urban neighborhood that coexists harmoniously with the surrounding natural areas and water bodies, IJburg was built through an innovative public-private cooperation. The floating buildings are legally and financially classified as immovable properties, so they abide by the same dimension standards, comfort levels, and safety measures applied to land-based dwellings. The strictly geometrical structure of the triangular allotment is defined by the diagonal slicing of the basin by suspended power lines. This rigid structure is made more flexible by varying distances between the dwellings as well as their orientation, providing constantly changing views of the surrounding water and a sense of individual identity to each unit. The floating houses are supported by concrete tubs submerged in the water to a depth of half a story. On top is a lightweight supporting steel structure that may be covered in glazing and brightly colored plastic paneling.

Safety. To prevent rubbing between components, steel plates placed at three points keep buildings at a distance of at least 2.5cm. Onboard safety equipment is along public walkways, and descending systems allow direct access to and from the water. Handrails protect the outside edges of the public pathways on the decks by the water. Fender devices protect the floating foundation bodies and decks from eventual collision with other structures or vessels, allowing easy boat docking. Cameras in front of door entrances provide remote video surveillance. Heavy components, such as restrooms and toilets, were placed in specific locations, calculated separately, and, where necessary, compensated.

Wellbeing. The internal distribution spreads on three floors. The lowest level, hosting several bedrooms, is partly submerged. The next floor is an elevated ground floor that offers privacy from the jetty and the heavily trafficked waterway. It provides access to the terrace and views of the interior patio. Each house is separated from its adjoining jetty by at least a meter-wide water gap, accentuating the watery context, fostering biophilia, and ensuring quality views. Wide glazed openings provide adequate natural lighting in all indoor spaces. The windows facing public walkways are obscured to ensure indoor privacy without reducing the entrance of light. Thermal comfort standards are met by providing insulated opaque components and glazed surfaces that maximize heat absorption during the winter yet are openable in summer. Several strategies are used to ensure acoustic comfort: the entrance building, which provides car parking space for residents, acts as an acoustic barrier from the main on-land streets; steel spacers avoid contact between buildings and reduce resulting noises. Each unit is anchored to two mooring poles in a diagonal configuration, which provides maximum stability; sliding connections allow for vertical movement of the house to changing water levels. These sliding connections reduce the movement and vibration of the floating body, contributing to motion comfort. The walkways are enlarged to create public spaces between the housing units and are equipped with benches and swimming decks to foster casual meetings and social interaction among residents. Terrace roofs provide outside space for each housing unit.

Usability. Differences in height between the jetty, water, and front door on the ground floor are bridged by a boardwalk that wraps around the house and slopes down to the water, guaranteeing accessibility and circulation in the entire floating neighborhood. Jetties that connect to on-land road infrastructure (and public mobility) and the pedestrian and bike lanes provide public access to the district, which is conceived as part of the city rather than a gated community on water. An entrance building offers car parking space for residents. All walkways are equipped with bicycle parking spots. Management. An automatic flushing mechanism prevents solar heating of the drinking water pipes. The materials used require low maintenance. The concrete tub foundation is cast as a unit to avoid maintenance-sensitive seams.

Integrability. The highly versatile building system gives future owners considerable control over the interior layout and finish of their floating house. A pre-designed extension package allows occupants to add extensions – including sunrooms, verandas, floating terraces, and awnings – that can be easily attached to this skeleton frame. For instance, each occupant can change the sides on which he desires a view or privacy. Meter cupboards for gas and electricity are integrated into the parapet rails and connected to the flexible trucking of the house.

Efficient Use of Resources. The construction process involved the construction of the building components on a dockyard and the transportation across the Ijsselmeer to the current location. The majority of the building components are prefabricated and are suitable for being disassembled. Several passive strategies increase indoor comfort. Rainwater collection systems installed in some units provide domestic water.

Environmental Regeneration. IJburg is situated just outside the protected zone of IJsselmeer (Natura 2000 area). For this reason, the involvement of environmental experts in the planning and design process ensured the new extensive development would not threaten the ecological balance of Lake Ijmeer and the adjacent Diemerpark Nature Reserve. Its shallow, sheltered, nutrient-rich water and abundant crustaceans and water plants make the area attractive for waterfowl and other species. Several other autochthon species are growing spontaneously on the floating bodies that are partly submerged. The materials used for the components in contact with water have non-pollutant-release properties.

Buoyancy - Stability. Given a light superstructure over a concrete tub, the low center of gravity increases the structure's stability. The houses are anchored to the lakebed for legal reasons since they are registered as floating houses and not as houseboats. Each house is anchored to two mooring poles in a diagonal configuration, which provides maximum stability. A sliding connection allows for vertical movement of the house to changing water levels and avoids horizontal movement.

Plant System. Flexible and extensible cables and pipes can adapt to the required lengths that change according to water fluctuations. A heating ribbon around the pipes prevents them from freezing in winter.

4.3.1.2. Schoonship, Amsterdam (Netherlands)

Space and Matter, Waterstudio.NL, Metabolic, + 31architects, Amber Architecture & KUUB, Chris Collaris Design & I29 interior architects, BO6 Architecten, Hans Kuijpers, Hollandshuis, Jeroen Apers Architect, John Kusters, KPMV Architects, Loco-Motief, Metabolic, MTBarchitecten, Studio Valkenier, Smeele Architecture, Spectral, and TWWB
2008-2021

Schoonship is a large-scale floating (nearly) self-sufficient, energy-neutral circular residential district arising in the Johan van Hasselkanaal, a branch of the IJ-canal in Amsterdam. The canal in Buiksloterham (Johan van Hasseltkanaal) has a bathymetry between 2-4 meters and daily water level fluctuations up to 2 meters high. It includes 30 water plots, 46 households, and over 144 residents. The Schoonschip community acquired the plot to build on and then developed the project through the CPO approach (CPO stands for *Collectief Particulier Opdrachtgeverschap* or collective private commissioning). Together with a team of experts (Watertstudio. NL and Metabolic) and future residents, Space&Matter developed the urban plan, the design codes for the plots, and the design of the smart jetties that provide the infrastructure for the whole development. The sustainability masterplan and codes set out the principles for regenerative design: orientation optimization, energy storage provision, amount of photovoltaics, materials, and other technologies. For instance, each unit had to provide the same contribution to biodiversity, energy generation, water storage, and green roofing. If one resident would like more terrace, green roof, or photovoltaic, he would have to exchange it with neighbors to keep the overall proportion.

Safety. Onboard safety equipment is located along public walkways, and descending systems allow direct access to and from the water. The elevation structure is in timber frames joined to the concrete pontoons.

Wellbeing. Maximum Energy Performance Certificate (EPC) is achieved through active and passive strategies, including high-insulated perimetral building opaque components and windows. Each house is positioned in such a way that it has an unobstructed view of the water and the neighborhood. Green roofs and floating gardens intensify the biophilia effect and provide 60-70% of vegetables and fruit consumption (30,000 kg per year) using locally recovered nutrients. The community-based process and design have established a cohesive neighborhood and a strong community identity. The jetties dedicated to public space foster encounters between community members.

Usability. A sharing mobility system includes electric cars, cargo bikes, and e-bikes. Walkways allow the transit of bikes. Access to the floating jetties is public. Electric boats are supposed to be connected to the smart grid.

Management. The technical infrastructure for all the households is the same and easily accessible (under the central jetty). The wooden cladding (horizontal or vertical) and the concrete prefabricated panels used for cladding allow easy replacement and maintenance operations.

Integrability. The entire district is designed to easily integrate the passage, housing and fixing of the components of the plant systems within the non-plant engineering building elements, as most building components are prefabricated.

Efficient Use of Resources. It is an energy-neutral circular district where decentralized and renewable solutions to water, energy, and waste systems are implemented. Electricity is generated from more than five hundred PV panels, hot water is heated from sixty solar thermal panels, and space heating is provided by thirty heat pumps that extract heat from the canal water (aquathermie), working alongside heat storage tanks and submerged heat exchangers for heating and cooling. Energy efficiency technologies are deployed to cut demand, including high levels of insulation, infrared heating panels, and mechanical ventilation with heat recovery. The housing units are all connected to a private (district) smart grid that optimizes supply and demand between photovoltaics, the bank of lithiumion batteries, and energy demand between the dwellings. The system exchanges energy within the community before exporting it or importing it from the grid. The smart microgrid enables the community to act as the energy supplier for the residents who become prosumers. An aggregator (Spectral) manages the transactions among network operators and creates links with other networks[4]. This process must be underpinned by blockchain technology that can track the transactions and provide secure trading. Rain-water collection offers for the non-potable water demand (toilet flushing and irrigation), and storage tanks are set at the center of the raft to keep the overall balance. Lighting is optimized using low-consuming LEDs and cut-off switches distributed in each house to cut power to non-vital electronic equipment. Moreover, several passive strategies to optimize indoor comfort include large, insulated glazing, solar atriums, winter gardens, and green roofs.

Environmental regeneration. Several devices limit the ecological impact of the overall district: vacuum flush toilets that use only

4. Dave Cheshire. (2019, March 05). Net zero buildings and the rise of the 'prosumer'. Retrieved July 14, 2023, from Linkedin: https://www.linkedin.com/pulse/net-zero-buildings-rise-prosumer-dave-cheshire/

1.5 liters of water per flush linked to a bio-digestor; recirculating showers that reuse water and heat from the wastewater (filtered and disinfected with UV lamps before being reused), saving up to 90% of water and reducing carbon emissions; heat recovery system integrated into showers; each houseboat collects two streams of human waste, which are pumped to the modular treatment system installed in the jetty (there are separate streams for the disposal of grey water from the shower and washing machine and black water from the toilets. A bio-digestor[5] distills biogases from the blackwater to use for generating electricity and extracts phosphate from wastewater to use as fertilizer. Overall, 60-80% nutrient recovery is ensured: nutrients collected from the wastewater and organic waste treatment system can be used on-site for food production, creating a closed cycle between nutrient collection and food production. Organic waste can feed animals or be composted in an aerobic worm compost for personal garden use. Sedum green roofs and floating gardens provide growing space and habitats for waterbirds like grebes, ducks, swans, and coots. Bio-based, locally sourced, and recycled materials (wood fiber, burlap, hempcrete, and straw insulation) are used for construction and building components.

5. The bio-digestor has been procured and is in place, nut it is not yet being used for permission issues.

Buoyancy - Stability. Houses are moored to cylindric piles anchored to the seabed. Sliding connections allow for vertical movement of the house to changing water levels and avoid horizontal movement.

Plant System. The central jetty contains the technical infrastructure and connects all the households. There is a sensor network and real-time system performance displays. Each housing unit is supplied with a battery that stores temporary surpluses for up to two days storage capacity, providing a high degree of resilience.

4.3.1.3. Tatami house, Amsterdam (Netherlands)

Julius Taminiau Architecten (+ Oranje Arkenbouw)
2017- 2018

Tatami House is part of a floating village of 200-300 affordable floating homes located on the Schinkel, a canalized river near the old Olympic stadium in Amsterdam. Tatami house is a compact house distributed on three floors, of which the ground floor is 1.5 m below water level. Internal proportions and the entire grid are based on the traditional Japanese tatami ratio and layout, like those of plywood panels, as well as the maximum span of the timber beams. This layout allows to reduce the use of space to the minimum with significant advantages in terms of cost because of the low budget availability.

Safety. The elevation system in timber beams and pillars fixed to a concrete box guarantees the building's structural stability. The space between the houses and the access to fire-safe areas meet fire regulations for on-land buildings. The stairs are equipped with integrated small doors blocking the access to the upper floors as part of safety measures for children. There are no handrails on the double heights and along the staircase.

Wellbeing. The black color with different glossy levels of the façade mimics the water and contrasts with the white interior for optimum light reflection. Passive strategies, like cross-ventilation and heating and cooling devices, ensure high levels of thermal comfort. The rooftop deck hosts a garden with several plants. Natural ventilation is provided through the central roof hatch. The use of light colors for the interiors increases the light reflections during dark days. The MDF wooden cladding panels have a thick insulation layer, ensuring high indoor thermal comfort levels.

Usability. It is designed as a compact house: space-saving built-in furniture, storage, and service spaces; a kitchen island with built-in chairs; an open staircase in the living room that subtly breaks the space between the kitchen and living room; and various smart storage spaces. The flexible layout with double heights allows for future transformations and space for extra bedrooms or a small self-contained apartment. The layout is characterized by space optimization with consequent minimum circulation spaces. Exposed beams with no false ceiling provide higher overall floor-to-ceiling heights. Special attention was paid to uniform the slightly different heights between the circulation/access deck and house due to the various weights (and consequent buoyancy and water level) of the different parts of the house and decks. Towing arrangements have ensured its construction in a construction hall located 100 km away from the current site and guarantee ease for future maintenance or relocation.

Management. The wooden façade panels are durable and have a 50-year guarantee (no need for maintenance). The façade pattern prevents rainwater from coming inside or behind the panels.
Integrability. The prefabricated components guarantee the feasibility of integrating elements, machinery, and devices throughout time. Additional space for the integration of a heat pump on the rooftop deck is considered. The open plan in horizontal and vertical distribution allows for future spatial and function adaptability and transformations.

Efficient Use of Resources. Computer-controlled fabrication of elements is used to minimize cutting losses. Surrounding water is used as grey water and even filtered into drinking water. Passive strategies used to optimize indoor comfort and reduce heating and cooling expenses include orientation to maximize sun exposure, a roof hatch in the middle of the house to provide a natural draft on hot days, highly insulated building components for closure elements, and cross ventilation. Fourteen PV panels on the rooftop deck provide energy for the household.

Environmental Regeneration. Landscape integration is achieved by using dark and glossy cladding to echo the tone and reflective quality of the surrounding water. Sawing losses are minimized thanks to the tatami proportions (standard-sized plywood panels and board materials) and prefabricated process, resulting in less material use and, therefore, lower costs. The components are prefabricated 100 km away in a large hall in Hardenberg and then towed to the site. Thanks to prefabricated elements, the house was built in a very short time, reducing the uncertainty related to weather conditions. Furniture and interior components are made from leftover wood and recycled materials. Cladding wood and window frames are made of sustainably harvested hardwood. Surrounding water quality is kept high and used as grey water and even filtered into drinking water. Several strategies foster biodiversity.

Buoyancy - Stability. Balance is ensured through the symmetrical layout and the location of heavy equipment (machinery, bathrooms) in the central middle spine. A maximum number of occupants is provided. The house is kept in position by mooring provisions connected to the distribution docks.

Plant System. Pipes and plant devices are under the distribution docks, provided with trapdoors for inspection.

4.3.1.4. Harnaschpolder, Delft (Netherlands)

Blue 21, ZVA – Den Haag, Bartels and Vedder
2013-2015

The floating houses are part of a redevelopment project of a flood-prone area near Delft, combining housing (on-land and floating) and water retention interventions and a new biking and hiking route along the ecological zone. The floating houses are in a polder, a relatively low-lying piece of land, permanently drained, surrounded by one or more flood defenses, where the water level is artificially regulated. The bathymetry ranges between 1-2m, and the soil beneath the water is quite muddy. Six floating houses were built as part of an experimental project to evaluate whether the design methodology worked. The houses were developed as part of a Collective-Private Initiative (CPI): a group of citizens bought the water plots and developed the project together with the Municipality of Delft and the developers (Balance d'Eau) guided by Blue 21 (former DeltaSync). The role of the Blue21 team was to start up the project in close collaboration with the municipality and the future citizens. In this project, they provided various services, including technical advice, project management, cost estimation, citizen guidance, and architectural sketches and preliminary designs.

Safety. The lightweight metal frame structure is fixed to a pontoon of glass fiber-reinforced composite cellars. The stairs to access the decks have no handrails. Windows located on the ground floor, which is partly underwater, have a vasistas opening system for everyday use to avoid the entrance of water and undesired insect and animals. The windows can be entirely openable in an emergency, especially in case of fire.

Wellbeing. Both privacy and natural light maximization are guaranteed by wide openings on all floors, protected by a hill on the land in front of the houses to provide visual shelter and privacy from the road. The other sides of the houses face the water. Privacy and shelter are also guaranteed through the layout design: the living floor is connected around the terraces and is designed as one flowing space at a level of near alignment with the water. Sleeping rooms are raised to the floor above for optimal privacy. Outdoor spaces were located on the opposite corners of the property to align with key views of the surrounding lake and park. The housing units are structured on a split level. As a result, the experience of the surrounding water is different in each room, and the view of the water is constantly changing. The living space is just above the water level, which ensures optimum contact with the water (contributing to biophilia). Thermal comfort is provided by very high insulation façade components (Rc +7.0) compared to minimum standards required by national regulations, with consequent low energy consumption, and by insulated glazing to avoid heat dispersion in winter. Floor radiant heating contributes to optimizing indoor thermal comfort. A combination of external and internal sun protection shielding contributes to avoiding overheating in summer. A good proportion between footprint and volume stabilizes the structure, reducing motion. Moreover, the building has a very low point of gravity, which results in a high level of motion comfort without much movement in case of strong winds. Regular oiling of the junctions (through spraying) is carried out to avoid noises when the structure adjusts to water fluctuations. When the weather is nice, the façade can be opened, and the living space is enlarged by the floating terrace directly adjacent to it.

Usability. The buildings are made with prefabricated components built and assembled in the yard close to the water plots, which was used as a temporary construction site, as at the time of the construction, that area hadn’t been developed yet. Access to the buildings is guaranteed through a ramp that has mobile junctions, and that is designed to adapt its inclination up to a 2m fluctuation in water levels.

Management. Bathymetry is very low, and the soil is quite muddy. Therefore, the Municipality of Delft is responsible for regular maintenance of the seabed level (digging operations to restore the suitable level for the freeboard not to touch the seabed). In case of heavy rain and rising water levels, it is necessary to pump out water from the canal, and the Municipality of Delft is responsible for it. Using prefabricated sandwich insulated panels for the façade ensures easy and fast repair and replacement of damaged parts.

Integrability. It is complex to adjust the design in a second moment in terms of layout and placement of heavy-fix furniture (bathrooms, pool, plant system) as the structure is designed to balance according to the calculated weight. The calculation variable loads must be considered already in the design phase.

Efficient Use of Resources. PV panels installed can produce sufficient energy for each household in terms of electricity and hot water. Yet, the houses are connected to the grid in case of emergency. The sewage system and water supply are also connected to the grid. All design principles are tested beforehand through a simulation and calculation program.

Environmental Regeneration. To reduce the long-term impact of the structures on the water habitat – in terms of reduced penetration of light in water, decreased available area for air-water interactions, current and wind changes due to wind tunneling effect between houses – several environmental studies were carried out before and after the houses were built. In-situ TROLL 9500 Sensors were placed to assess nitrate and Ammonium ISE Rugged Dissolved Oxygen and to check changes in temperature, pressure, and conductivity parameters. An HD underwater Video Camera was used to monitor changes in biodiversity and assess whether the floating body could provide surfaces that organisms could use to attach themselves to. The number and type of fish and aquatic organisms are indicators of the ecological state of the water body, which proved to have no significant changes in biodiversity once the structures were there. Water quality measures were also carried out before and after the houses were built.

Buoyancy - Stability. The structures have a very low center of gravity, which reduces the influence of wind to a minimum. The addition of outdoor platforms contributes to further stabilizing the overall structure.

Plant System. The service areas are safely placed in a central core.

4.3.1.5. Harlem Shuffle, Haarlem (Netherlands)

vanOmmeren-architects (+ ABC arkenbouw)
2017- 2019

Haarlem Shuffle is also known as an energy-positive floating villa as it was designed to be energy-sufficient and produce more energy than it consumes, thanks to the integration of active and passive solutions. It is located in the Spaarne River, close to the historic center of Haarlem, between the Rustenburgerbrug and the Langebrug. Stretching over two levels, it offers the occupants privacy while capitalizing on natural light and views across the river. The design plays with the perception of the dynamics around the Spaarne, the relationship with Haarlem, and the bright open living spaces. The aim was to establish different relationships and experiences with the surrounding water. Floor-to-ceiling windows and a glass wall have been designed alongside the interior stairwell and open void to allow natural light to filter down to the lower level of the house.

Safety. A lightweight, slim aluminum roof and structure is set on a concrete pontoon. The house has a remot-control system for locking/unlocking the front door. No gas connection is on board, as the house relies entirely on electricity.

Wellbeing. Thermal comfort is guaranteed by highly insulated double-glazed windows and wooden façade panels and an underfloor radiant heating and cooling system. External shading systems avoid overheating in summer. The materials used for the interior contribute to reducing noise transmission, contributing to acoustic comfort. Extensive floor-to-ceiling glazing characterizes bright open living spaces: the large void near the southwest windows enables light to reach the lower music and sleeping spaces. On the waterside, the large windows in the façade offer an unobstructed view over the Spaarne. The void on the waterside connects the area below and above the waterline, resulting in a height of more than five meters with an unobstructed view of the river.

Usability. Access to the house is at the same level as the nearby shore, guaranteeing circulation and accessibility to all users. A remote system controls access. The layout and double heights allow for a certain degree of spatial adaptability and flexibility. Towing arrangements will enable it to be relocated elsewhere for maintenance or functional reasons.

Management. Building components are not prefabricated and are based on non-dry construction processes. This implies a long construction process and represents an obstacle to easy and fast repair or replacement of components.

Integrability. The technical room on level -1 has enough space and is designed for integrating new machinery or equipment.

Efficient Use of Resources. Fifty solar panels (for a total of 60 m^2) are installed on the roof almost horizontally to avoid disrupting the ark's sleek appearance. The panels generate more than enough electricity for heating, cooling, and domestic use. Two air-water heat pumps exploit the water from the surrounding water to generate heat. In addition to active strategies, several passive strategies are implemented: thermal inertia, adequate insulation layers for closures, and external shading systems. Water-saving hydraulic elements allow for the reduction of water consumption.

Environment Regeneration. Local materials are used for building components. Using renewable energy sources contributes to CO_2 reduction in the operational phase of the building.

Buoyancy - Stability. The buoyant body is moored to the land and kept in position.

Plant System. A technical room on level -1 hosts all the plant systems (including heat pumps), allowing for easy periodic control.

4.3.1.6. Urban Riggers, Copenhagen (Denmark)

Bjarke and Ingels Group
2014-2016

Urban Rigger provides a solution for the growing demand for affordable student housing within the center of Copenhagen. The city's harbor represents an optimal location since it is an underused and underdeveloped area at the heart of the city. Bjarke Ingels Group developed an extremely flexible and cost-effective building structure using upcycled standard shipping containers. By stacking nine container units in a circle, 12 studio residences are created and frame a central winter garden used as a common gathering space. The building could be easily replicated in other harbor cities where affordable housing is needed, but space on land is lacking. Currently, six complexes (each made up of 6 containers stacked three on top of the others) are organized in a line along the shore, providing 72 housing units.

Safety. Regulations require containers to be structurally resistant in accordance with ISO 1496. Descending systems provide easy access from the water to the central dock and vice versa. Handrails along all walkways and terraces ensure user safety. Fender devices protect the floating foundation bodies and decks from eventual collision with other structures or vessels.

Wellbeing. Passive strategies include an internal courtyard designed as a wintergarden (greenhouse glass closes the gaps) to minimize thermal exposure during winter; cross ventilation to guarantee good air quality and reduce overheating in summer; green roof. Active strategies include a heat recovery ventilation unit, a hydronic floor heating system, and heat pumps to maintain ideal indoor thermal comfort. In addition to residential functions, the complex hosts other amenities, including a kayak landing and a bathing platform, representing essential meeting places for the inhabitants. The arrangement of the containers into a triangular composition allowed to minimize the footprint of the pontoon while opening views to the water. Each housing unit (or studio) is provided with outward views towards the sea.

Usability. Space flexibility is provided in terms of layout composition. Future expansion potential is guaranteed by using a modular base unit (container), a regular aggregation pattern, and dry connections between units. The standard dimensions of a shipping container ensure that urban rigger units can be transported by road, water, or air to anywhere in the world at a meager cost. By slightly detaching the corners of the containers, a hexagonal courtyard with open corners creates a connection between neighboring communities (complex of 9 containers) and allows for further expansion. Multilevel connections are provided thanks to the overlapping of the different entities. Bike parking areas are located inside the inner courtyard. A flexible bridge ramp also allows access to the complex in case of water level fluctuations.

Management. The standard dimensions of the shipping container make it easy to transport the housing units to docks where maintenance activities can be easily carried out.

Integrability. The modular base (container), possible layout arrangements, and the technical connection solutions amongst units allow further expansion.

Efficient Use of Resources. Hydro-source heating represents an efficient, economical, and sustainable solution that uses the surrounding water as a free and clean heating source. PV panels ensure the operation of the 13KW heat pump with very little electricity needed. A heat recovery ventilation unit removes stale air and supplies constant fresh air while keeping associated heat loss to a minimum with up to 95% heat recovery. Overall, 75% of the energy required for heating and hot water is extracted from the sea. Almost 15% of energy consumption is saved with radiant floor heating.

Environmental Regeneration. The use of active and passive strategies, together with the ease of transportation, strongly contribute to reducing the overall CO_2 footprint of the building in its construction and operation phase. In addition to utilizing upcycled shipping containers, the design employs many environmentally sustainable solutions. Green roofs foster biodiversity and contribute to improving surrounding air quality. Most materials are produced locally.

Buoyancy - Stability. The buoyant concrete foundation is secured to the shore through metal tie rods.

Plant System. Most plant system equipment is in the basement, inside the concrete hull.

4.3.1.7. Seattle floating home (United States of America)

Vandeventer + Carlander Architects
Construction: 2016

Seattle has a long history of floating houses around the bay and in the numerous lakes that characterize its landscape. The floating house designed by Vandeventer + Carlander Architects is currently docked at Roanoke Reef Marina in Eastlake, providing convenient access to the city and the surrounding neighborhood. Tides can reach 5 meters in height. Bathymetry ranges between 5 to 10 meters. Given a limited water footprint, the extremely flexible layout is distributed on two floors, maximizing exposure to views and light. Two opposite corners have been carved out of the house volume to accommodate outdoor spaces.

Safety. The elevation steel structure is connected to the concrete pontoon. A platform running along the lower level provides direct access to the water (equipped with descending devices).

Wellbeing. The location and treatment of glazing promote passive heating and cooling while maximizing the entrance of natural light. Fixed and operable (according to orientation) horizontal teak slats and overhangs provide varying degrees of privacy and sun protection. The openings' position and dimensions (full height) aim to provide quality views of the surrounding water. A translucent channel glass cladding lightens up the entryway with abundant natural light. A rooftop deck offers quality views. To take advantage of Seattle's limited sunshine, users can use outdoor terraces in the east during morning hours and in the west in the evening.

Usability. Built-in furniture (cabinet, kitchen, storage space, workspaces). A covered parking area and additional off-site storage space are provided on the nearby land. The access is gated. The platform running along the lower level allows mooring a small boat. Folding glass doors merge the boundaries between outdoor and indoor space, allowing for a certain degree of spatial flexibility. Accessibility from one floor to another is possible only by using the external circular stair or the interior one.

Integrability. No information is available.

Management. Exterior materials were chosen for longevity and ease of maintenance: the white façade ceramic panels are durable and only require a periodic hose washing for cleaning; teak screens act as a rain screen, protecting the façade behind them. Since the building components are prefabricated and built in a construction dock and only assembled on-site through dry construction processes, replacement of specific parts is easy, quick, and cost-effective.

Efficient Use of Resources. An efficient hydronic in-floor heating system is integrated with an energy-efficient heat pump. The fresh air ventilation system uses an energy-saving heat exchanger. Passive strategies, like insulated treated glazing, increase the overall energy performance of the building.

Environment Regeneration. Dry construction processes allow for the reuse of the building materials (i.e., steel structure, teak slats). The implementation of passive strategies contributes to reducing CO_2 emissions.

Buoyancy - Stability. The floating concrete sub-structure (7,5 x 10,5 m) is anchored to two mooring poles on the front side facing the shore. A sliding connection allows for vertical movement of the house to changing water levels and avoids horizontal movement.

Plant System. Mechanical and storage space is provided within the concrete foundation (-1 level). A waste tank for wastewater is integrated into the building.

4.3.1.8. Floating homes in Nassauhaven (Netherlands)

Public Domain Architects
2019

The Nassauhaven is a narrow strip of water in Feijenoord in Rotterdam, where the height difference between the extremes of the high and low tide ranges from 1,5 to 2 meters. It was originally an industrial area for companies that had to be located on waterways and needed a railway connection. In the second half of the 20^{th} century, many companies left the area, and the Nassauhaven turned into an unused harbor basin. In 2019, Public Domain Architects started a pilot project to develop a neighborhood of eighteen floating houses designed to be future-proof, sustainable, and comfortable. Nassauhaven was promoted as the city's first floating residential area. The project is also called 'the floating street' with its homes arranged in a neat row.

Safety. The houses are built out of a steel frame secured to the floating pontoon and are designed to withstand strong winds, currents, and waves. They are built with fire-resistant materials and have a variety of safety features, such as smoke detectors and sprinkler systems. The electrical systems meet safety standards. The houses are all connected by a system of floating walkways, making it easy for residents to get around in an emergency. The private terraces and decks at the water level are not protected by railings. The access ramps and the full-height windows of the upper floor are protected by metal or glass railings. Each housing unit is equipped with onboard safety equipment. The wooden flooring for outdoor decks is milled and made skid-proof. Outdoor artificial illumination is provided. The buildings are in a well-protected harbor area, away from vessel routes. Fender devices protect the floating foundation bodies and decks from eventual collision with other structures or vessels.

Wellbeing. The buildings are financially categorized as houses (real estate or immovable property) and must, therefore, comply with on-land building standards for comfort: well-insulated façade panels; cross ventilation to ensure fresh air circulation and prevent moisture buildup; large windows to maximize natural light; acoustic insulation in internal and external partitions; radiant floor heating system; outdoor spaces on each floor.

Usability. Adaptable ramp bridges connecting the shore to each house have a certain degree of flexibility to adjust to water fluctuations (tides) up to 2m. The ramp slides onto the house entrance deck to allow a certain degree of horizontal movement. Towing arrangements are provided. Storage space is integrated under each common staircase that provides access to two housing units. The houses are designed to be accessible to people with disabilities. Some houses have smart home features like automated lighting, heating, and security systems.

Management. All floating houses were prefabricated offsite and then transported to their final location. All connections are mechanical, allowing easy disablement in the future or if maintenance is needed. The transport came from the shipyard in Rotterdam-Oost, on the other side of the Nieuwe Maas, and required considerable navigation skills. The climate-resilient wooden façade has a long durability, does not leach out, and doesn't require additional treatment. The concrete pontoons are very durable and relatively easy to install and maintain. EPDM rubber used as a waterproof membrane to protect the roofs is ideal for prefabrication construction and is installed without using open flame, an important aspect of offsite construction.

Integrability. All connections between elements have a certain degree of adaptability. There are various types of building shells, which can be further completed depending on the desires and requirements of the prospective owners. For those who want the ultimate building freedom, there is the option to buy a building shell as is and complete it autonomously, to their liking and pace. The photovoltaic system has a base set of solar panels that can be extended further.

Efficient Use of Resources. Photovoltaic panels provide electricity. A biomass installation generates heat, and a water purification system provides the community with water. As a result, they are energy-neutral and require no connection to sewers. Some houses are equipped with rainwater harvesting systems that collect rainwater and reuse it for non-potable water needs. Moreover, the buildings are designed to be energy efficient, with features such as high-quality insulation, energy-efficient appliances and lighting, and insulated window fixtures.

Environment Regeneration. EPDM is highly durable, resilient, and compatible with photovoltaic roofs. It is an inert material, which thus does not release pollutants into the rainwater that runs off the roofs. In the regeneration process of the area, the straight and hard banks of the Nassau harbor were transformed into a nature-friendly bank to experience the tide more intensely and ensure an enhanced variety of animals and plants. The municipality is responsible for regularly monitoring biodiversity indicators and water quality.

The external illumination is directed inwards or downwards, thus avoiding pointing at the surrounding water.

Buoyancy - Stability. The concrete hollow pontoons are moored to the harbor floor with anchors. The pontoon system is designed to allow the house to rise and fall with tides and water fluctuation of up to 2 meters. The houses are all equipped with stabilizers and long retractable poles that extend down to the harbor bed and prevent the structures from rocking or moving in case of currents or wind. Water leak detectors and alarms reduce the risk of sinking.

Plant System. Water tanks and machinery space are provided within the concrete buoyant base. All plant system machinery, pipes, and devices are watertight to prevent damage from flooding or water leaks and made of corrosion-resistant materials.

4.3.1.9. Pvrok, Střelecký Island (Czech Republik)

Scoolpt
2020

Pvrok is a 3D-printed 43 m² house that can be made within 48 hours. The structure highlights the possibilities of large-scale additive manufacturing and the future of construction. The house was designed to rest on any foundation base. When on water, it was fixed on a steel barge, previously used for cargo transportation on water located on the Vltava River near the Střelecký Island in Prague. The plot of water was rented for 6 months on the occasion of the exhibition, and then the superstructure was moved to a new site in Bohemia where it was set on land. The house includes a bathroom with a toilet, a living room with a kitchen, and a bedroom. It is partly self-sufficient with eco-technologies like recuperation, re-circulation shower, green roof, and reservoirs for drinking, utility, and sewage water. The digital fabrication process used to print the concrete-based material prevents heat bridges and ensures high insulation levels thanks to the great accuracy achieved through parametric design.

Safety. The structure consists of a concrete mixture enriched with nano-polypropylene fibres, plasticizers, and a setting accelerator (17 tons, print speed: 15 cm per second). The overall structure consists of an external self-supporting wavy wall and an internal load-bearing part reinforced with ribs. The printed shell has three times greater strength than concrete and can withstand a significant impact (it is characterized by a resistance to static pressure of up to a 50-ton load). The concrete hardens after 24 hours to the standard firmness of the foundations, acquiring a value of 65 MPa in 28 days. After the construction dried, steel bars with a liquid concrete mixture were installed into these spaces to reinforce the walls against deformation. Onboard safety equipment is provided.

Wellbeing. The thickness of the printed shell ranged from 50 to 60 mm, and the thickness of the whole wall ranged from approximately 350 to 450 mm, guaranteeing a high level of thermal and sound insulation. The perimetral partitions are parametrically designed to avoid heat bridges and guarantee insulation while investing the least material possible. A green roof contributes to the roof insulation and thus to indoor thermal comfort. Big circular porthole windows and a large circular skylight ensure adequate natural lighting in indoor conditions. Graceful curves and organic shapes contribute to a sense of tranquillity.

Usability. The construction process using digital fabrication allows for great flexibility in customizing shape and volume. The house is equipped with remote control capabilities. The house comes in three parts, so it could be easily transported from its manufacturing location (150 km away) and relocated from its current location when and if needed. The boat-like footprint is particularly suitable for transportation on water because of its aerodynamic shape. The interior walls are kept straight to allow furniture integration. Access to the house is provided through a very short-length bridge connected directly to the dockside.

Management. The concrete life expectancy is over 100 years. Since straight walls or walls with a big radius in plane view tend to deform, the external walls are double-curved, and the interior ones are straight. The concrete structure is sprayed with a hydrophobic mixture of paint to make it more water-resistant.

Integrability. The plant system is planned to easily integrate renewable energy production systems, which are currently not there yet.

Efficient Use of Resources. The house can be built within 48 hours, saving up to 50% of all construction costs and reducing CO_2 emissions and waste. Effective and exact distribution of material with robotic fabrication allows for the minimization of waste and leftovers. The house is partially self-sufficient: eco-technologies like a rainwater collection system and reuse for household activities, re-circulation showers (that save up to 90% of the water), a green roof for improving insulation, underfloor heating recuperation system, drinking water, and sewage. It is designed to be connected to the grid for sewage, water, and electricity.

Environmental Regeneration. The additive manufacturing constructon process generates up to 20% less CO_2 emissions. The green roof fosters biodiversity and contributes to air quality. Sound insulation towards the outside is provided to limit disturbance in the surrounding environment. Local materials are used: oak for the interior and lighting devices from local glassworks.

Buoyancy - Stability. The floating substructure is a steel pontoon, previously used as a bulk barge (flat-bottomed boat) designed to transport bulk cargo, such as rocks, sand, or other mineral based. The barge can withstand loads up to 50 tons.

Plant System. Reservoirs for utility, drinking water, and sewage. are provided. Three water tanks are integrated: black, grey, and white water, as well as a tank for collecting rainwater surplus.

4.3.1.10. Maldive floating city prototype (Maldives)

Waterstudio.NL
2023

The Maldive floating prototype is the first island of the Maldive Floating City masterplan developed by Waterstudio.NL, a mixed-used community of several thousands of floating housing units and facilities. It is the first floating city with thousands of houses with full governmental support, based on a legal framework and title deeds for the owners. It also offers the unique possibility of obtaining a residence permit by purchasing a house and inviting the international community to live there (semi) permanently. The units are built from a modular system to ensure quality, standardization, certification, short construction time, cost control, and efficient maintenance.

Safety. On-land building regulation standards are met for safety requirements.

Wellbeing. The design was partly developed through a community-based development to create a sense of identity and cohesion. Standard thermal comfort requirements for on-land buildings are met. Particular attention is paid to ensuring visual comfort and quality views from the unit, ensuring the rear side opens to the sea. Green areas are located in between the housing units.

Usability. Access from Male is provided through boat terminals (jetties), which are connected to the walkways leading to each group of housing units.

Management. The building components are prefabricated and thus easy to replace or maintain.

Integrability. The floating foundations are designed to easily connect to new ones in the event of future expansion. All utility systems are integrated.

Efficient Use of Resources. The housing unit is connected to a smart grid where each unit shares and uses the surplus of available green/blue energy. Each unit has a controlled organic waste treatment and disposal system connected with the other units. Blackwater is treated into an anaerobic digestor. Grey water is filtered in treatment plants located in the platform's foundation. Water desalination plants ensure drinking and domestic water. Energy is produced through PV and deep sea cooling systems through a heat exchanger.

Environmental Regeneration. Blue habitats protect and stimulate coral growth: artificial coral banks will be attached to the underside of the buildings to stimulate coral to grow naturally. The layout and footprint of the units are designed to avoid excessive shading on the water, guaranteeing sunlight to reach the seabed without impacting underwater life.

Buoyancy - Stability. The submerged and protected coral reef of the lagoon will provide a natural wave (reduction) breaker that, in combination with the interrelated grid of floating structures, provides comfort and safety for the residents. The mooring system combines piles and cables to provide adequate stability.

Plant System. The utilities (water, electricity, sewage systems) are hosted in the hull of the floating sub-structures and integrated into the jetties (walkways) that connect the units. The utilities will be connected to a service island surrounding the city in the future, designed to host the smart grid main power and utility equipment.

4.3.2. Synthesis of outcomes

The case study research highlighted the challenges and opportunities of floating residential buildings. Interesting aspects about economic and legal issues emerged, as well as the importance of location in defining specific requirements.
Compared to on-land new development, floating buildings have higher construction costs. Floating structures require specialized engineering and construction techniques, and the predisposition of all the utilities and urbanization infrastructure necessary for its effective use can drive up costs. In the case of the IJburg district, for instance, floating buildings were not the only viable solution for the area's development due to the relatively high construction costs. The floating houses were conceived as a pilot project realized as part of the larger residential development of IJburg. Given its high-tech, sustainable features, Schoonship also represents a luxury district that does not provide a solution for affordable housing developments.
Moreover, the microgrid implemented in Schoonship required an experimental exemption from the current energy laws. This is actively encouraged in the Netherlands, and the local Enterprise Agency was assigned to grant the exemptions. Similarly, using wastewater treatment required the community to invent new technical, organizational, financial, and legal terms, which was time-consuming and costly. This district is an innovative and sustainable solution, but it is not affordable for everyone. This calls for the need to apply alternative ownership and financial models to provide more people with access to sustainable solutions.
Several projects experienced other legal and consequent economic

complications. In the Harnashpolder district, for instance, banks were either unwilling to give mortgages or offered a very high interest rate because of the higher risks involved in building on water. The utility company did not want to be responsible for the connection on the floating structure. Partly for this reason, the building permits took a very long time to be issued. Moreover, to test innovative technologies, the houses are not compliant with the NTA *Netherlands Standards for Floating Buildings*. However, the highly sustainable solutions implemented in Schoonship still require some fine-tuning. During site visits, the residents have complained about the complex and time-consuming issue of cleaning the filters of the recirculating showers, highlighting the possibility of adopting strategies to recirculate water directly at the dwelling or community scale.

As emerged from the Urban Riggers in Copenhagen, finding a sustainable answer to today's urbanization challenge means exploring the undiscovered resources in our cities, such as the hydrographic network or disused harbour areas. Placing buildings on water instead of on land can contribute to solving pressing housing challenges in many European cities, where the most fragile classes face difficulties in finding affordable and permanent housing. Another critical issue is maintenance. Several projects witness degradation problems mainly related to corrosion and biological colonization. Corrosion represents a threat to the structural stability of the building, leading to serious structural failures if not detected and addressed on time. Unlike corrosion, biological colonization does not affect the buildings in a dangerous way. This explains why many case studies do not meet the relevant requirement. Biodeterioration (acids produced by microorganisms that damage building materials, such as stone, concrete, and wood) can lead to cracking and spalling. Some microorganisms can produce allergens and toxins that can harm human health and contribute to moisture levels. These phenomena must, therefore, be seriously monitored. Nevertheless, if biological colonization is adequately controlled and limited to certain areas of the buildings in relation to the surrounding natural environment, it can have several positive effects on the ecosystem. For instance, microorganisms can clean up contaminated sites (bioremediation). Bacteria can be used to break down oil spills, and fungi can be used to break down toxic chemicals. Microorganisms can also be used to control pests and diseases. For example, some fungi can produce toxins that kill insects. Biological colonization is present in Schoonship, IJburg, and Harnashpolder. It creates no issues at all, proving that if the buildings are inspected regularly, the downsides of biological colonization can be kept under control and avoided.

Harnaschpolder case study has highlighted how maintenance does not refer only to the building components but also to the site. The site bathymetry and bed soil are critical for the under-keel clearance of the sub-structure. In Harnaschpolder, regular maintenance of the seabed level is needed to prevent the floating bodies from touching the ground and getting damaged, with consequent considerable management costs. This highlights the importance of selecting an adequate location for floating buildings in terms of bathymetry and soil typology.

For what concerns the plant system, several compelling solutions have emerged. Heat trace tape can prevent pipes from freezing in cold climates. The pipe and plant system can be designed with redundancy in mind so that if one component fails, the system will continue operating. Moreover, float switches could be installed in the plant system to detect flooding and shut down the system in case of a water leak.

The residential case studies have underlined how accessibility in private houses is consistently underestimated, especially compared to public facilities, which must comply with universal design standards in most cases.

All case studies have highlighted how the boundaries between the building and context are blurred and how location plays a crucial role in helping buildings meet the requirements. Broadening the view to the context in which the building is set is essential for meeting the requirements related to environmental regeneration. In parallel with the realization of the first floating homes in Nassauhaven, Rotterdam City is developing a tidal park in the same area. The new park is conceived as an experiment for the future development of eco-friendly city shores. This highlights the importance of considering the entire context in which the floating building is located.

Direct observation during site visits in some of the described case studies has highlighted how surrounding water quality is extremely important and not always preserved. In the case of IJburg, for instance, despite protection measures (i.e., close thresholds between flooring elements or protection railings), several domestic objects float in the water around the houses because of wind and accidental movements. Presumably, protection measures are insufficient or not adequately designed for the specific location and microclimate.

Finally, apart from the projects located in the Netherlands, all the others are in countries without specific regulations or codes for floating buildings. Nevertheless, most seem to comply as much as possible with on-land building rules. Even the projects in the Netherlands have had to resort to exemptions from current building laws to experiment with innovative and sustainable solutions.

Substructures are mainly out of concrete monolithic tubs, given the limited dimensions of the housing units, with exceptions in glass fibre reinforced composite. The superstructure is mainly made of timber or steel frames. The 3D-printed building is made of a concrete mixture enriched with nano-polypropylene fibres, and the Urban Riggers are made from recycled metal containers.

IJBURG FLOATING HOUSES

1

Lake Ijsselmeer, Amsterdam, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Architectenbureau Marlies Rohmer**

CLIENT: **Ontwikkelings-combinatie Waterbuurt West**

DATE: **2001-2012**

BUDGET: **980 €/m²**

IJburg is part of the floating district Waterbuurt West, located immediately behind the Enneüs Heerma Bridge, an essential connection between IJburg and the rest of Amsterdam developed to solve the significant housing shortage. Floating Ijburg is composed of an archipelago of 7 connected jetties to which 4-25 houses are moored. It was developed using an innovative public-private partnership. The floating buildings are legally and financially classified as immovable properties and, therefore, comply with land-based housing regulations regarding dimension standards, comfort levels, and safety measures. The strictly geometrical structure of the triangular allotment is defined by the diagonal slicing of the basin by suspended power lines. This rigid structure is made more flexible by varying distances between the dwellings and their orientation, providing changing views of the surrounding water and a sense of individual identity to each unit. The floating homes are supported by concrete tubs submerged in the water to a depth of half a story. A lightweight supporting steel construction is built on top that can be filled with glazing and brightly colored plastic panels, giving each resident a degree of choice and flexibility.

SITE FEATURES

- Typology: Lake
- Batimetry: 3-4 m
- Water fluctuation: 60 cm
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
70 m² (per unit)
10 652 m² (total)

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

- [x] **Ecosystem preservation/regeneration**
Involvement of environmental experts in the planning/design process to ensure the ecological balance of Lake Ijmeer and the Nature Reserve.
- [x] **Resource circularity**
Passive strategies for heat gain and cooling. Most building components are prefabricated and easy to disassemble.
- [ ] **Affordable and renewable energy efficiency**
- [x] **High levels of comfort and wellbeing**
All comfort requirements meet building regulation standards (thermal, acoustic, and visual comfort). Particular attention is paid to biophilia and motion comfort.
- [x] **Economic feasibility**
Prefabricated components to speed construction time and costs; low maintenance.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	⧄ 1.2.1.	■ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	■ 1.3.2	■ 1.4.2.
■ 1.1.3.	□ 1.2.3.		■ 1.4.3.
	◩ 1.2.4.		■ 1.4.4.
	◩ 1.2.5.		■ 1.4.5.
	◩ 1.2.6.		■ 1.4.6.
			◩ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	⧄ 2.3.3.	
	◩ 2.2.4.	⧄ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	■ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	■ 2.7.2.	◩ 2.8.2.
■ 2.5.3.	■ 2.6.3.	■ 2.7.3.	■ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■ 3.1.1.	◩ 3.2.1.	□ 3.3.1.
◩ 3.1.2.	◩ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGE-

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
◩ 4.1.2.	■ 4.2.2.	◩ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	⧄ 4.2.7.	
	□ 4.2.8.	
	■ 4.2.9.	
	□ 4.2.10	

5. INTEGRABILITY

■ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	◩ 6.4.1.
□ 6.1.2.	◩ 6.2.2.	■ 6.3.2.	□ 6.4.2.
■ 6.1.3.	■ 6.2.3.		
	□ 6.2.4.		
	■ 6.2.5.		
	■ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

□ 7.1.1.	■ 7.2.1.	◩ 7.3.1.	□ 7.4.1.
■ 7.1.2.	□ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	◩ 7.4.3.
		□ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
□ 8.1.2.	◩ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
□ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	◩ 9.2.1.
◩ 9.1.2.	■ 9.2.2.
◩ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
□ 9.1.6.	

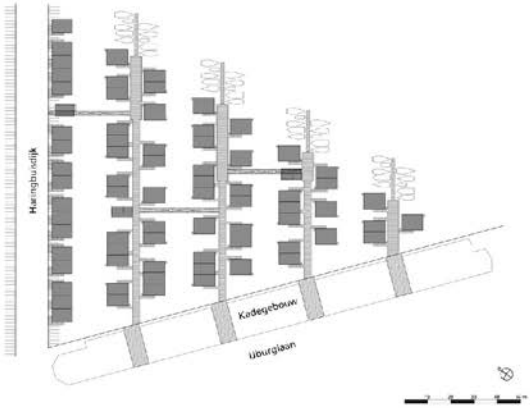
CONSTRUCTION COMPONENTS

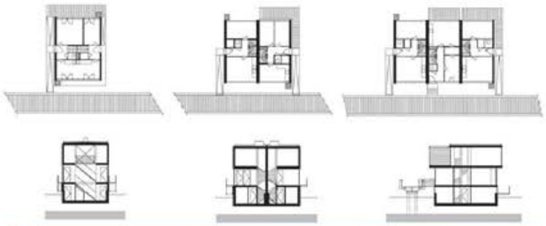
BUOYANT FOUNDATION
Monolithic concrete tub (poured)

LOAD BEARING STRUCTURE
Timber beams and pillars + concrete

CLADDING
Wide glazed openings and wooden slats

FIGURES (© Marlies Rohmer)





SCHOONSHIP

● Buiksloterham, Amsterdam, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Space & Matter, Waterstudio, Metabolic, et al.**
CLIENT: **OVvE Schoonship**

DATE: **2008 - 2021**

BUDGET: **Confidential**

Schoonship is a large-scale floating (nearly) self-sufficient, energy-neutral circular residential district arising in the Johan van Hasselkanaal, a branch of the IJ-canal in Amsterdam. It includes 30 water plots, 46 households, and over 144 residents. The Schoonschip community acquired the plot to build on and then developed the project through the CPO approach (CPO stands for Collectief Particulier Opdrachtgeverschap, or collective private commissioning). Together with a team of experts (Watertstudio.NL and Metabolic) and future residents, Space&Matter developed the urban plan, designed codes for the plots, and designed the smart jetties that provide the infrastructure for the whole development. The sustainability masterplan and codes set out the principles for regenerative design: orientation optimization, energy storage provision, amount of photovoltaics, materials, and other technologies. For instance, each unit had to provide the same contribution to biodiversity, energy generation, water storage, and green roofing. If one resident would like more terrace, a green roof, or more photovoltaic, they would have to exchange it with their neighbors to keep the overall proportion.

SITE FEATURES

- Typology: Canal (Johan van Hasseltkanal)
- Batimetry: 2-4 m
- Water fluctuation: 2 m
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | **MULTI-UNIT** | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL
TOURISM | PRODUCTION | GREEN
CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
150 m², 180 m², 210 m², 225 m², 270 m², 378 m²

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Bio-based, recycled materials; vacuum flush toilets and recirculaiting showers to limit water consumption; biodigestor for waste

Resource circularity
It is an energy-neutral circular district with decentralized and renewable solutions to water, energy, and waste systems.

Affordable and renewable energy efficiency
Electricity is generated from PV panels, hot water is heated with solar thermal panels and heating is provided by submerged heat exchangers. A smart grid, optimizes supply and demand between

High levels of comfort and wellbeing
Maximum Energy Performance Certificate achieved through active and passive strategies; community based process; community identity.

Economic feasibility
Prefabricated components to spped construction time and costs and guarantee low or easy maintenance.

REQUIREMENT COMPLIANCE

1. SAFETY

- ■ 1.1.1.
- ■ 1.1.2.
- ■ 1.1.3.
- ◪ 1.2.1.
- ■ 1.2.2.
- □ 1.2.3.
- ■ 1.2.4.
- ■ 1.2.5.
- ■ 1.2.6.
- □ 1.3.1
- □ 1.3.2
- ■ 1.4.1.
- ■ 1.4.2.
- ■ 1.4.3.
- ■ 1.4.4.
- ■ 1.4.5.
- ■ 1.4.6.
- ◪ 1.4.7.

2. WELLBEING

- ■ 2.1.1.
- ■ 2.1.2.
- ■ 2.1.3.
- ■ 2.2.1.
- ■ 2.2.2.
- □ 2.2.3.
- ■ 2.2.4.
- ■ 2.3.1.
- ■ 2.3.2.
- ◪ 2.3.3.
- ◪ 2.3.4.
- ■ 2.4.1.
- ■ 2.5.1.
- ■ 2.5.2.
- ■ 2.5.3.
- ■ 2.6.1.
- ■ 2.6.2.
- ■ 2.6.3.
- ■ 2.7.1.
- ■ 2.7.2.
- ◪ 2.7.3.
- ■ 2.8.1.
- ◪ 2.8.2.
- ■ 2.8.3.
- □ 2.8.4.
- ■ 2.8.5.

3. USABILITY

- ■ 3.1.1.
- ◪ 3.1.2.
- ■ 3.1.3.
- ◪ 3.2.1.
- ◪ 3.2.2.
- ◪ 3.2.3.
- ■ 3.2.4.
- ◪ 3.3.1.
- ■ 3.3.2.

4. MANAGE-

- ■ 4.1.1.
- ◪ 4.1.2.
- ■ 4.1.3.
- ■ 4.2.1.
- ■ 4.2.2.
- ◪ 4.2.3.
- ◪ 4.2.4.
- ■ 4.2.5.
- ■ 4.2.6.
- ◪ 4.2.7.
- ■ 4.2.8.
- ■ 4.2.9.
- □ 4.2.10
- ◪ 4.3.1.
- ◪ 4.3.2.

5. INTEGRABILITY

- ■ 5.1.1.
- ■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

- ■ 6.1.1.
- ◪ 6.1.2.
- ◪ 6.1.3.
- ■ 6.2.1.
- ◪ 6.2.2.
- ■ 6.2.3.
- ■ 6.2.4.
- ■ 6.2.5.
- ■ 6.2.6.
- ◪ 6.2.7.
- ■ 6.3.1.
- ■ 6.3.2.
- ■ 6.4.1.
- ■ 6.4.2.

7. RATIONAL USE OF RESOURCES

- ■ 7.1.1.
- ■ 7.1.2.
- ■ 7.2.1.
- ■ 7.2.2.
- ◪ 7.3.1.
- ■ 7.3.2.
- ■ 7.3.3.
- ■ 7.3.4.
- ■ 7.4.1.
- □ 7.4.2.
- ■ 7.4.3.

8. BUOYANCY AND STABILITY

- ■ 8.1.1.
- □ 8.1.2.
- ■ 8.1.3.
- □ 8.1.4.
- ◪ 8.2.1.
- ◪ 8.2.2.
- ■ 8.3.1.
- ■ 8.3.2.
- ■ 8.3.3.

9. PLANT SYSTEM

- ■ 9.1.1.
- ◪ 9.1.2.
- ◪ 9.1.3.
- ■ 9.1.4.
- ■ 9.1.5.
- ■ 9.1.6.
- ◪ 9.2.1.
- ■ 9.2.2.

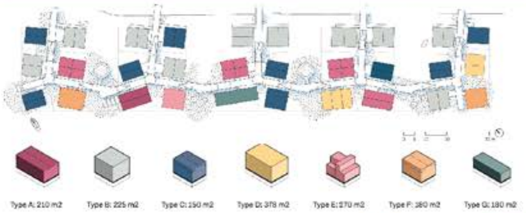
CONSTRUCTION COMPONENTS

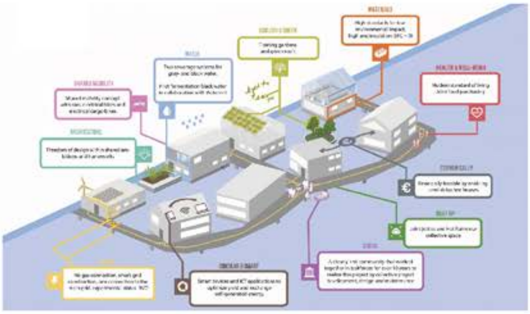
BUOYANT FOUNDATION
Monolithic concrete pontoons

LOAD BEARING STRUCTURE
Timber frame

CLADDING
wooden slats (horizontal or vertical) or concrete prefab panels

FIGURES (© Space&Matter, © Livia Calcagni)





TATAMI HOUSE

River Spaarne, Amsterdam, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Julius Taminiau Architects**

CLIENT: **Julius Taminiau**

DATE: **2017-2018**

BUDGET: **Confidential**

ADVISORS: **Bartels & Vedder, Oranje Arkenbouw**

Tatami House is part of a floating village of 200-300 affordable floating homes located on a canalized river near the old Olympic stadium in Amsterdam. Julius Taminiau designs it for himself. It is a compact house distributed on three floors, the ground floor 1.5 m below water level. Internal proportions and the entire grid are based on the traditional Japanese tatami ratio and layout, which is similar to those of plywood panels and the maximum span of the timber beams. This layout allows for reducing the use of space to the minimum with significant advantages in terms of budget, meeting the low budget availability. The flexible layout with double heights allows for future transformations and space for extra bedrooms or a small self-contained apartment. The layout is characterized by space optimization and minimum circulation spaces.

SITE FEATURES

- Typology: Canalized river
- Batimetry: 2 m
- Water fluctuation: 60 cm
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
160 m² (per unit)

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

- **Ecosystem preservation/regeneration**
  Recycled materials. for building components; strategies to increase biodiversity (plants, rooftop garden); surrounding water quality monitoring.
- **Resource circularity**
  Surrounding water used as grey water and filtered into drinking water; passive strategies (solar chimney, cross ventilation); computer controlled fabrication.
- **Affordable and renewable energy efficiency**
  Photovoltaic system (14 panels) installed on the roof to provide electricity.
- **High levels of comfort and wellbeing**
  High levels of thermal comfort through passive strategies and heating and cooling devices; biophilia and visual quality through sight of water and plants.
- **Economic feasibility**
  Computer controlled fabrication of elements is used to minimize cutting losses and minimize cost; recycled materials; low maintenance costs.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	▨ 1.2.1.	□ 1.3.1	□ 1.4.1.
■ 1.1.2.	■ 1.2.2.	◩ 1.3.2	□ 1.4.2.
■ 1.1.3.	□ 1.2.3.	.	□ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	■ 1.2.5.		▨ 1.4.5.
	■ 1.2.6.		▨ 1.4.6.
			◩ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	▨ 2.3.3.	
	□ 2.2.4.	▨ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	◩ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	□ 2.7.2.	◩ 2.8.2.
■ 2.5.3.	■ 2.6.3.	◩ 2.7.3.	■ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■ 3.1.1.	■ 3.2.1.	■ 3.3.1.
■ 3.1.2.	■ 3.2.2.	■ 3.3.2.
■ 3.1.3.	◩ 3.2.3.	
	■ 3.2.4.	

4. MANAGE-

■ 4.1.1.	■ 4.2.1.	◩ 4.3.1.
◩ 4.1.2.	■ 4.2.2.	◩ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	▨ 4.2.7.	
	□ 4.2.8.	
	◩ 4.2.9.	
	□ 4.2.10	

5. INTEGRABILITY

■ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	■ 6.4.1.
■ 6.1.2.	◩ 6.2.2.	■ 6.3.2.	◩ 6.4.2.
◩ 6.1.3.	■ 6.2.3.		
	◩ 6.2.4.		
	□ 6.2.5.		
	■ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■ 7.1.1.	■ 7.2.1.	■ 7.3.1.	■ 7.4.1.
■ 7.1.2.	□ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
□ 8.1.2.	◩ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
□ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	◩ 9.2.1.
◩ 9.1.2.	■ 9.2.2.
◩ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
□ 9.1.6.	

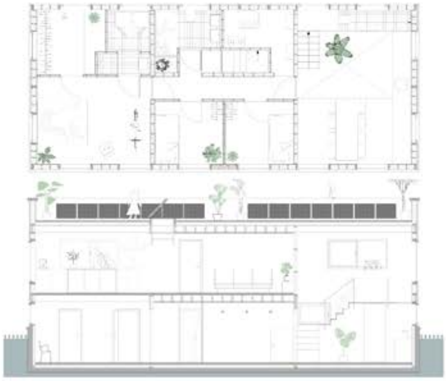
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Monolithic concrete box

LOAD BEARING STRUCTURE
Timber frame (metasequoia)

CLADDING
MDF wooden panels with 50 year warranty

FIGURES (© Julius Taminiau Architects)



HARNASCHPOLDER ECO-HOMES

● Hof van Delftpark, Delft, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Blue21, ZVA (developed by Balance d'eau)**

CLIENT: **Municipality of Delft**

DATE: **2013-2015**

BUDGET: **532 €/m²**

ADVISORS: **Bartels & Vedder**

The six floating houses are part of a redevelopment project of a flood-prone area near Delft, combining housing (on-land and floating) and water retention interventions and a new biking and hiking route along the ecological zone. Six floating houses were built as part of an experimental project to evaluate whether the design methodology worked. The houses were built as part of a Collective-Private Initiative (CPI): a group of citizens bought the water plots and developed the project together with the Municipality of Delft and the developers (Balance d'Eau) guided by Blue 21 (former DeltaSync). The role of the Blue21 team was to start up the project in close collaboration with the municipality and the future citizens. In this project, they provided various services, including technical advice, project management, cost estimation, citizen guidance, architectural sketches, and preliminary designs. The design paid particular attention to reducing the impact on the surrounding environment by constantly monitoring water quality and biodiversity before and after the buildings were built.

SITE FEATURES

- Typology: Canal
- Batimetry: 1-2 m
- Water fluctuation: 2 m
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
100-200 m² (per unit)

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Pre and post-occupancy water quality monitoring; underwater biodiversity monitoring; attention paid to avoid reduced penetration of light in water.

Resource circularity
Passive strategies for heat gain and cooling; solar energy.

Affordable and renewable energy efficiency
PV panels installed are able to produce more or less enough energy for each household in terms of electricity and hot water.

High levels of comfort and wellbeing
Particular attention is paid to: a good balance between privacy, natural light maximization and quality views; thermal comfort;

Economic feasibility
CPi Initiative in collaboration with Municipality who is in charge of maintenance of the area and of the water level.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1. ■ 1.1.2. ■ 1.1.3.
▨ 1.2.1. ■ 1.2.2. ◩ 1.2.3. ■ 1.2.4. ■ 1.2.5. ■ 1.2.6.
■ 1.3.1 ■ 1.3.2 .
□ 1.4.1. ■ 1.4.2. □ 1.4.3. ■ 1.4.4. ■ 1.4.5. ■ 1.4.6. ◩ 1.4.7.

2. WELLBEING

■ 2.1.1. ■ 2.1.2. ■ 2.1.3.
■ 2.2.1. ■ 2.2.2. □ 2.2.3. ■ 2.2.4.
■ 2.3.1. ■ 2.3.2. ▨ 2.3.3. ▨ 2.3.4.
■ 2.4.1.
■ 2.5.1. ■ 2.5.2. ■ 2.5.3.
■ 2.6.1. ■ 2.6.2. ■ 2.6.3.
■ 2.7.1. ■ 2.7.2. ■ 2.7.3.
■ 2.8.1. ◩ 2.8.2. ■ 2.8.3. ■ 2.8.4. ■ 2.8.5.

3. USABILITY

□ 3.1.1. □ 3.1.2. ■ 3.1.3.
◩ 3.2.1. ■ 3.2.2. ■ 3.2.3. ■ 3.2.4.
◩ 3.3.1. ■ 3.3.2.

4. MANAGEMENT

■ 4.1.1. ■ 4.1.2. ■ 4.1.3.
■ 4.2.1. ■ 4.2.2. ◩ 4.2.3. ◩ 4.2.4. ■ 4.2.5. ■ 4.2.6. ▨ 4.2.7. □ 4.2.8. ■ 4.2.9. □ 4.2.10
■ 4.3.1. ◩ 4.3.2.

5. INTEGRABILITY

◩ 5.1.1. ■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1. ◩ 6.1.2. ◩ 6.1.3.
■ 6.2.1. ■ 6.2.2. ◩ 6.2.3. ◩ 6.2.4. ■ 6.2.5. ■ 6.2.6. ■ 6.2.7.
■ 6.3.1. ■ 6.3.2.
◩ 6.4.1. □ 6.4.2.

7. RATIONAL USE OF RESOURCES

◩ 7.1.1. ■ 7.1.2.
▨ 7.2.1. □ 7.2.2.
◩ 7.3.1. □ 7.3.2. □ 7.3.3. ■ 7.3.4.
■ 7.4.1. □ 7.4.2. ◩ 7.4.3.

8. BUOYANCY AND STABILITY

■ 8.1.1. ◩ 8.1.2. ■ 8.1.3. □ 8.1.4.
◩ 8.2.1. ◩ 8.2.2.
■ 8.3.1. ■ 8.3.2. □ 8.3.3.

9. PLANT SYSTEM

■ 9.1.1. ◩ 9.1.2. ◩ 9.1.3. ■ 9.1.4. ■ 9.1.5. □ 9.1.6.
◩ 9.2.1. ■ 9.2.2.

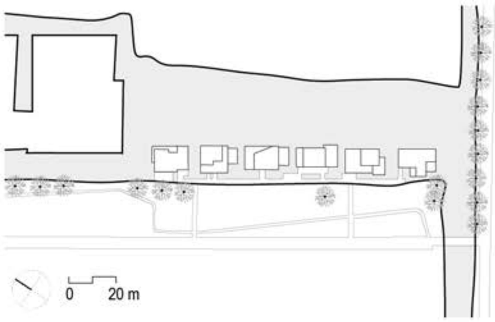
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Glassfiber-reinforced composite basement cellars (9x12m)

LOAD BEARING STRUCTURE
Lightweight steel frame

CLADDING
Prefabricated sandwich insulated panels and glazed surfaces

FIGURES (© Balance d'eau, ©Livia Calcagni)



HAARLEM SHUFFLE

5

● Spaarne river, Haarlem, Netherlands

IDENTIFICATION DATA

ARCHITECT: **vanOmmeren-architects**

CLIENT: **Private (De Blauwe Wimpel)**

DATE: **2019**

BUDGET: **Confidential**

ADVISORS: **RHEINZINK, ABC arkenbouw, Feri Masi, ABC Arkenbouw**

Haarlem Shuffle is also known as the Energy-Positive Floating Villa as it was designed to be not only energy self-sufficient but to produce more energy than it consumes, thanks to the integration of active and passive solutions. It is located in the Spaarne River, close to the historic center of Haarlem, between the Rustenburger-brug and the Langebrug.
Stretching over two levels, it is designed to offer the occupants privacy while also capitalizing on natural light and views across the river. The design plays with the perception of the dynamics around the Spaarne, the relationship with Haarlem, and the bright open living spaces. The aim was to establish different relationships with living near the water. Floor-to-ceiling windows and a glass wall have been designed alongside the interior stairwell and open void to allow natural light to filter down to the lower level.

SITE FEATURES

- Typology: River
- Batimetry: 4-5 m
- Water fluctuation: 1,5 m (tidal range)
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | **MULTI-UNIT** | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL | TOURISM | PRODUCTION | GREEN | CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
110 m² (indoor)
+ 10 m² (outdoor)

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

■ **Ecosystem preservation/regeneration**
Water-saving hydraulic elements allow to reduce water consumption; local materials to integrate in the landscape.

■ **Resource circularity**
Several passive strategies are used: thermal inertia, shading device, cross ventilation, large insulated glazing.

■ **Affordable and renewable energy efficiency**
Fifty solar panels generate electricty for heating, cooling and domestic use; two air-water heat pumps exploit the river water to

■ **High levels of comfort and wellbeing**
Particular attention is paid to thermal comfort, acoustic comfort and providing quality views and natural lighting.

☐ **Economic feasibility**

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.
■ 1.1.2.
■ 1.1.3.

▨ 1.2.1.
■ 1.2.2.
□ 1.2.3.
◩ 1.2.4.
■ 1.2.5.
■ 1.2.6.

□ 1.3.1
◩ 1.3.2

□ 1.4.1.
■ 1.4.2.
□ 1.4.3.
■ 1.4.4.
■ 1.4.5.
■ 1.4.6.
■ 1.4.7.

2. WELLBEING

■ 2.1.1.
■ 2.1.2.
■ 2.1.3.

■ 2.2.1.
■ 2.2.2.
□ 2.2.3.
■ 2.2.4.

■ 2.3.1.
■ 2.3.2.
▨ 2.3.3.
▨ 2.3.4.

■ 2.4.1.

■ 2.5.1.
■ 2.5.2.
■ 2.5.3.

■ 2.6.1.
■ 2.6.2.
■ 2.6.3.

■ 2.7.1.
■ 2.7.2.
□ 2.7.3.

□ 2.8.1.
◩ 2.8.2.
■ 2.8.3.
□ 2.8.4.
■ 2.8.5.

3. USABILITY

■ 3.1.1.
■ 3.1.2.
■ 3.1.3.

□ 3.2.1.
■ 3.2.2.
□ 3.2.3.
■ 3.2.4.

◩ 3.3.1.
■ 3.3.2.

4. MANAGE-

□ 4.1.1.
▨ 4.1.2.
□ 4.1.3.

◩ 4.2.1.
□ 4.2.2.
◩ 4.2.3.
◩ 4.2.4.
■ 4.2.5.
■ 4.2.6.
▨ 4.2.7.
□ 4.2.8.
■ 4.2.9.
□ 4.2.10

□ 4.3.1.
□ 4.3.2.

5. INTEGRABILITY

□ 5.1.1.

■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

□ 6.1.1.
◩ 6.1.2.
◩ 6.1.3.

■ 6.2.1.
◩ 6.2.2.
◩ 6.2.3.
□ 6.2.4.
◩ 6.2.5.
■ 6.2.6.
◩ 6.2.7.

■ 6.3.1.
■ 6.3.2.

■ 6.4.1.
□ 6.4.2.

7. RATIONAL USE OF RESOURCES

□ 7.1.1.
□ 7.1.2.

□ 7.2.1.
■ 7.2.2.

□ 7.3.1.
□ 7.3.2.
□ 7.3.3.
■ 7.3.4.

■ 7.4.1.
■ 7.4.2.
■ 7.4.3.

8. BUOYANCY AND STABILITY

■ 8.1.1.
□ 8.1.2.
■ 8.1.3.
□ 8.1.4.

◩ 8.2.1.
◩ 8.2.2.

■ 8.3.1.
■ 8.3.2.
■ 8.3.3.

9. PLANT SYSTEM

■ 9.1.1.
■ 9.1.2.
■ 9.1.3.
■ 9.1.4.
■ 9.1.5.
■ 9.1.6.

◩ 9.2.1.
■ 9.2.2.

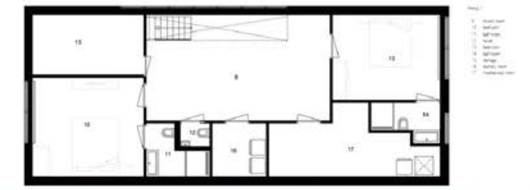
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Monolithic concrete base

LOAD BEARING STRUCTURE
Concrete and wood vertical structutre + aluminium roof

CLADDING
Padauk wood slats

FIGURES (© Van Ommeren Associates)



URBAN RIGGERS

Harbor in Refshalevejlt, Copenhagen, Denmark

IDENTIFICATION DATA

ARCHITECT: **Bjarke Ingels Group (BIG)**

CLIENT: **Udvikling Danmark A/s**

DATE: **2014 - 2016**

BUDGET: **Confidential**

Urban Rigger provides a solution for the growing demand for affordable student housing within the center of Copenhagen. The city's harbor represents an optimal location since it is an underused and underdeveloped area at the heart of the city. It is an extremely flexible, cost-effective building structure of upcycled standard shipping containers. Nine container units in a circle create 12 studio residences that frame a central winter garden used as a common space. The building could be easily replicated in other harbor cities where affordable housing is needed but without land space. Currently, six complexes are disposed in a line along the shore, providing 72 housing units. Future expansion potential is guaranteed by using a modular base unit, a regular aggregation pattern, and dry connections between units. The standard container system, which has been developed to allow easy and low-cost transportation by road, water, or air, guarantees the units' high degree of flexibility and mobility. Several passive and active strategies strongly contribute to ensuring high indoor comfort levels. The three apartments on the ground floor are 30 m² big and with a balcony, while the nine apartments on the 1st floor are 23 m² studio apartments.

SITE FEATURES

- Typology: Harbor
- Batimetry: 8-10 m
- Water fluctuation: 1,5 m
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT — **MULTI-UNIT** — DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL — LEISURE RECREATIONAL — TERTIARY DIRECTIONAL

TOURISM — PRODUCTION — GREEN

CULTURAL EDUCATIONAL — COMMERCIAL — CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
680 m² (total)

GEOMETRICAL LAYOUT
2 superimposed staggered triangles

MAIN OBJECTIVES

- **Ecosystem preservation/regeneration**
  Green roofs foster biodiversity and contribute to improving surrounding air quality; recycled building components.
- **Resource circularity**
  A heat recovery ventilation unit removes stale air and supplies constant fresh air.
- **Affordable and renewable energy efficiency**
  75% of the energy required for heating (radiant floor) and hot water is extracted from the sea; PV panels ensuire the operation of the heat pumps.
- **High levels of comfort and well-being**
  Internal wintergarden as community space; cross ventilation; green roof; hydronic floor heating system; heat recovery ventilation unit; quality views.
- **Economic feasibility**
  Recycled low-cost containers available everywhere and easy to transport to dry docks where maintenance activities can be carried out.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1. ■ 1.1.2. ■ 1.1.3.
■ 1.2.1. ■ 1.2.2. ◩ 1.2.3. ■ 1.2.4. ■ 1.2.5. ■ 1.2.6.
■ 1.3.1 ■ 1.3.2
■ 1.4.1. ■ 1.4.2. ■ 1.4.3. ■ 1.4.4. ■ 1.4.5. ■ 1.4.6. ◩ 1.4.7.

2. WELLBEING

■ 2.1.1. ■ 2.1.2. ■ 2.1.3.
■ 2.2.1. ■ 2.2.2. □ 2.2.3. ■ 2.2.4.
■ 2.3.1. ■ 2.3.2. ◩ 2.3.3. ◩ 2.3.4.
■ 2.4.1.
■ 2.5.1. ■ 2.5.2. ■ 2.5.3.
■ 2.6.1. ■ 2.6.2. ■ 2.6.3.
■ 2.7.1. ■ 2.7.2. ■ 2.7.3.
■ 2.8.1. ◩ 2.8.2. ■ 2.8.3. □ 2.8.4. ■ 2.8.5.

3. USABILITY

■ 3.1.1. □ 3.1.2. ■ 3.1.3.
■ 3.2.1. ■ 3.2.2. ■ 3.2.3. ■ 3.2.4.
◩ 3.3.1. ■ 3.3.2.

4. MANAGE-

■ 4.1.1. ■ 4.1.2. ■ 4.1.3.
■ 4.2.1. ◩ 4.2.2. ◩ 4.2.3. ◩ 4.2.4. ■ 4.2.5. ■ 4.2.6. ◩ 4.2.7. □ 4.2.8. ■ 4.2.9. ◩ 4.2.10
■ 4.3.1. ◩ 4.3.2.

5. INTEGRABILITY

■ 5.1.1. ■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1. ■ 6.1.2. ◩ 6.1.3.
■ 6.2.1. ◩ 6.2.2. ◩ 6.2.3. ■ 6.2.4. ◩ 6.2.5. ■ 6.2.6. ◩ 6.2.7.
◩ 6.3.1. ◩ 6.3.2.
■ 6.4.1. ■ 6.4.2.

7. RATIONAL USE OF RESOURCES

■ 7.1.1. ■ 7.1.2.
□ 7.2.1. □ 7.2.2.
◩ 7.3.1. □ 7.3.2. □ 7.3.3. □ 7.3.4.
■ 7.4.1. ■ 7.4.2. ■ 7.4.3.

8. BUOYANCY AND STABILITY

■ 8.1.1. □ 8.1.2. ■ 8.1.3. □ 8.1.4.
◩ 8.2.1. ◩ 8.2.2.
■ 8.3.1. ■ 8.3.2. ■ 8.3.3.

9. PLANT SYSTEM

■ 9.1.1. ■ 9.1.2. ■ 9.1.3. ■ 9.1.4. ■ 9.1.5. ◩ 9.1.6.
◩ 9.2.1. ■ 9.2.2.

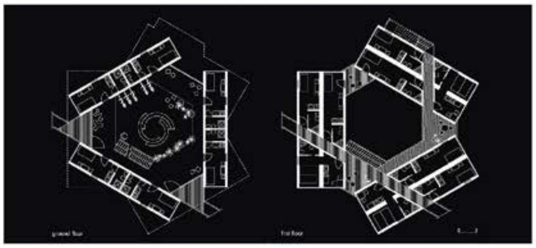
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Monolithic concrete tub

LOAD BEARING STRUCTURE
Metal container

CLADDING
Metal container

FIGURES (© Bjarke Ingels Group)



SEATTLE FLOATING HOME

7

Roanoke Reef Marina in Eastlake, Seattle, USA

IDENTIFICATION DATA

ARCHITECT: **Vandeventer + Carlander Architects**

CLIENT: **Private family**

DATE: **2016**

BUDGET: **Confidential**

Seattle has a long history of floating homes around the bay and in the numerous lakes that characterize its landscape. The floating house designed by Vandeventer + Carlander Architects is located in Lake Union, in the heart of the city, in an outboard slip on a dock with views towards Gas Works Park. Twenty floating homes are moored to the Roanoke Reef Marina dock, considered a luxury waterside community. The house is located amongst a series of floating homes moored to a dock. To preserve the residents' privacy, the architects installed a wooden slatted sunscreen on the upper floor's southern facade and a translucent facade on the side facing the land.
Given a limited water footprint, the highly flexible layout is distributed on two floors, maximizing exposure to views and light. Two opposite corners have been carved out of the home's volume to accommodate outdoor spaces. The living spaces are on the upper floor, taking advantage of the view, while the bedrooms are on the lower, float level.
Access to the house is through a broad exterior deck that runs the length of the float and leads to the front entry while providing access to boat moorage adjacent to the float.

SITE FEATURES

- Typology: Lake
- Batimetry: 5-10 m
- Water fluctuation: 5 m (tidal range)
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | **MULTI-UNIT** | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
497 m²

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

- ■ **Ecosystem preservation/regeneration**
  Dry construction processes for easy dis-assemble and low environmental impact; passive strategies to minimize CO_2.
- ■ **Resource circularity**
  Energy saving heat exchanger integrated in the ventilation system; solar passive strategies.
- □ **Affordable and renewable energy efficiency**
- ■ **High levels of comfort and wellbeing**
  Passive cooling and heating; natural light maximization; quality views both from indoors and from rooftop deck; efficient hydronic heating system.
- ■ **Economic feasibility**
  Prefabricated components to speed construction time and costs; exterior materials were chosen for longevity and ease of maintenance.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1. ■ 1.1.2. ■ 1.1.3.
◩ 1.2.1. ■ 1.2.2. □ 1.2.3. ◩ 1.2.4. ■ 1.2.5. ■ 1.2.6.
□ 1.3.1 ■ 1.3.2.
□ 1.4.1. ■ 1.4.2. □ 1.4.3. ■ 1.4.4. ■ 1.4.5. ■ 1.4.6. ■ 1.4.7.

2. WELLBEING

■ 2.1.1. ■ 2.1.2. ■ 2.1.3.
■ 2.2.1. ■ 2.2.2. □ 2.2.3. ■ 2.2.4.
■ 2.3.1. ■ 2.3.2. ◩ 2.3.3. ◩ 2.3.4.
■ 2.4.1.
■ 2.5.1. ■ 2.5.2. ■ 2.5.3.
■ 2.6.1. ■ 2.6.2. ■ 2.6.3.
■ 2.7.1. □ 2.7.2. □ 2.7.3.
■ 2.8.1. ◩ 2.8.2. ■ 2.8.3. □ 2.8.4. ■ 2.8.5.

3. USABILITY

■ 3.1.1. □ 3.1.2. ■ 3.1.3.
■ 3.2.1. ◩ 3.2.2. ■ 3.2.3. ■ 3.2.4.
■ 3.3.1. ■ 3.3.2.

4. MANAGE-

■ 4.1.1. ■ 4.1.2. ■ 4.1.3.
■ 4.2.1. ■ 4.2.2. ◩ 4.2.3. ◩ 4.2.4. ■ 4.2.5. ■ 4.2.6. ◩ 4.2.7. □ 4.2.8. ■ 4.2.9. □ 4.2.10
■ 4.3.1. ◩ 4.3.2.

5. INTEGRABILITY

■ 5.1.1. ■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1. ◩ 6.1.2. ◩ 6.1.3.
■ 6.2.1. ◩ 6.2.2. ◩ 6.2.3. □ 6.2.4. □ 6.2.5. ■ 6.2.6. ◩ 6.2.7.
◩ 6.3.1. ■ 6.3.2.
■ 6.4.1. □ 6.4.2.

7. RATIONAL USE OF RESOURCES

□ 7.1.1. ■ 7.1.2.
□ 7.2.1. □ 7.2.2.
□ 7.3.1. □ 7.3.2. □ 7.3.3. ■ 7.3.4.
■ 7.4.1. □ 7.4.2. ◩ 7.4.3.

8. BUOYANCY AND STABILITY

■ 8.1.1. ■ 8.1.2. ■ 8.1.3. □ 8.1.4.
◩ 8.2.1. ◩ 8.2.2.
■ 8.3.1. ■ 8.3.2. ■ 8.3.3.

9. PLANT SYSTEM

■ 9.1.1. ■ 9.1.2. ■ 9.1.3. ■ 9.1.4. ■ 9.1.5. □ 9.1.6.
◩ 9.2.1. ■ 9.2.2.

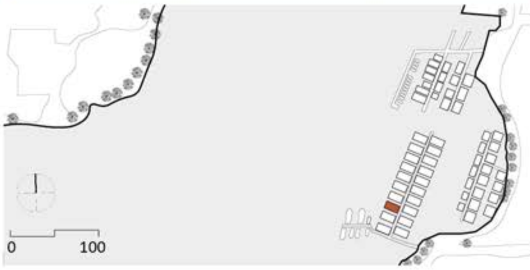
CONSTRUCTION COMPONENTS

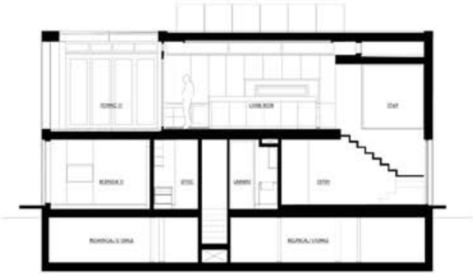
BUOYANT FOUNDATION
Concrete floats (7x13 m each)

LOAD BEARING STRUCTURE
Steel frame

CLADDING
Translucent channel glass cladding (horizontal teak slats for shading) + ceramic panels

FIGURES (©Benjamin Benschneider)





NASSAUHAVEN FLOATING HOUSES

8

● Nassauhaven, Rotterdam, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Public Domain Architects**

CLIENT: **City Council of Rotterdam, private owners**

DATE: **2019**

BUDGET: **Confidential**

The Nassauhaven, in the Feijenoord district in Rotterdam, was originally an industrial area for companies that had to be located on waterways and needed a railway connection. In the second half of the 20th century, many companies left the area, and the Nassauhaven turned into an unused harbor basin. In 2019, Public Do-main Architects started a pilot project to develop a neighbor-hood of 18 floating houses designed to be future-proof, sustain-able, and comfortable. Nassauhaven was promoted as the city's first floating residential area. With its homes arranged in a neat row, the project is known as the "floating street." There are various types of building shells, which can be further completed depending on the desires and requirements of the prospective owners. For those who want the ultimate building freedom, there is the option to buy a building shell as is and complete it autonomously, to their preference and pace. The new floating homes have been designed to be energy-neutral. All building materials have been selected for their sustainability, robustness, and aesthetic character. Another notable aspect is that banks categorize these harbor lofts as houses (real estate or property) and thus meet on-land building regulations.

SITE FEATURES

- Typology: Canal
- Batimetry: 3-4 m
- Water fluctuation: 2 m
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | **MULTI-UNIT** | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL | TOURISM | PRODUCTION | GREEN | CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS: m^2

GEOMETRICAL LAYOUT rectangular

MAIN OBJECTIVES

Ecosystem preservation/regeneration
The straight and hard banks of the Nassau harbor were transformed into a nature-friendly bank. The Municipality is responsible for regular monitoring of the biodiversity indicators.

Resource circularity
Rainwater harvesting and reuse; water purification system; passive solar strategies; waste treatment system.

Affordable and renewable energy efficiency
PV panels to generate electricity; biomass installation to generate heat; energy efficiency appliances.

High levels of comfort and wellbeing
Insulated façade panels; cross ventilation for fresh air circulation and prevent moisture buildup; large windows to maximize natural light; acoustic insulation outdoor spaces on each floor.

Economic feasibility
Prefabricated components to speed construction time and costs; durable materials and low maintenance.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	■ 1.2.1.	■ 1.3.1	◩ 1.4.1.
■ 1.1.2.	■ 1.2.2.	◩ 1.3.2	■ 1.4.2.
■ 1.1.3.	□ 1.2.3.	.	■ 1.4.3.
	◩ 1.2.4.		■ 1.4.4.
	■ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	◩ 2.3.3.	
	■ 2.2.4.	◩ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	■ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	◩ 2.7.2.	◩ 2.8.2.
■ 2.5.3.	■ 2.6.3.	□ 2.7.3.	■ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■ 3.1.1.	■ 3.2.1.	◩ 3.3.1.
□ 3.1.2.	◩ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGE-

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
◩ 4.1.2.	■ 4.2.2.	◩ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	◩ 4.2.7.	
	□ 4.2.8.	
	■ 4.2.9.	
	□ 4.2.10	

5. INTEGRABILITY

■ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	■ 6.4.1.
◩ 6.1.2.	■ 6.2.2.	■ 6.3.2.	□ 6.4.2.
■ 6.1.3.	■ 6.2.3.		
	■ 6.2.4.		
	◩ 6.2.5.		
	■ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

□ 7.1.1.	■ 7.2.1.	□ 7.3.1.	■ 7.4.1.
■ 7.1.2.	□ 7.2.2.	■ 7.3.2.	□ 7.4.2.
		■ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
□ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
□ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	◩ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
◩ 9.1.6.	

CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Concrete hollow pontoon

LOAD BEARING STRUCTURE
Steel frame

CLADDING
Wooden horizontal and vertical slat panels

FIGURES (©Public Domain Architecten, © Livia

PVROK

Vltava River, Prague, Czech Republik

IDENTIFICATION DATA

ARCHITECT: **Scoolpt**

FUNDING: **Stavební spořitelna České spořitelny**

DATE: **2020**

BUDGET: **3 700 €/m²** (only superstructure)

Pvrok is a 3D-printed 43-square-meter house that can be made within 48 hours. The structure highlights the possibilities of large-scale additive manufacturing and the future of construction. The house was designed to rest on any foundation base. When on water, it was fixed on a steel barge, previously used for cargo transportation on water located on the Vltava River near the Střelecký Island in Prague. The plot of water was rented for six months on the occasion of the exhibition, and then the superstructure was moved to a new site in Bohemia, where it was set on land.

The house includes a bathroom with a toilet, a living room with a kitchen, and a bedroom. It is partly self-sufficient with eco-technologies like recuperation, a re-circulation shower, a green roof, and reservoirs for drinking, utility, and sewage water.

The digital fabrication process used to print the concrete-based material prevents heat bridges and ensures high insulation levels thanks to the high accuracy achieved through parametric design.

SITE FEATURES

- Typology: River
- Batimetry: 3-5 m
- Water fluctuation: no fluctuation
- Climate: Cfb - Oceanic climate with humid continental (Dfb) influences

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
43 m²

GEOMETRICAL LAYOUT
elliptical structure on rectangular pontoon

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Green roof fosters biodiversity and better air quality; sound insulation limits disturbance on the surrounding environment; 3D printing produces less CO_2.

Resource circularity
Rainwater collection system and reuse, re-circulation showers, utility and sewage water system, underfloor heating recuperation system.

Affordable and renewable energy efficiency

High levels of comfort and well-being
The structure is parametrically designed to maximize thermal comfort and sound insulation.

Economic feasibility
Digital fabrication and additive manufacturing process allows accuracy and limits material use, waste and construction time. Life expectancy is over 100 years.

REQUIREMENT COMPLIANCE

1. SAFETY

■■■■■
■■□□□

■ 1.1.1.	▨ 1.2.1.	□ 1.3.1	◩ 1.4.1.
■ 1.1.2.	■ 1.2.2.	◩ 1.3.2	□ 1.4.2.
■ 1.1.3.	□ 1.2.3.	.	■ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	■ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			□ 1.4.7.

2. WELLBEING

■■■■■
■□□□□

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	▨ 2.3.3.	
	◩ 2.2.4.	▨ 2.3.4.	
◩ 2.5.1.	◩ 2.6.1.	■ 2.7.1.	■ 2.8.1.
■ 2.5.2.	◩ 2.6.2.	□ 2.7.2.	◩ 2.8.2.
■ 2.5.3.	◩ 2.6.3.	□ 2.7.3.	■ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■■■■■
■■□□□

■ 3.1.1.	□ 3.2.1.	■ 3.3.1.
◩ 3.1.2.	◩ 3.2.2.	■ 3.3.2.
◩ 3.1.3.	◩ 3.2.3.	
	■ 3.2.4.	

4. MANAGE-

■■■■■
■□□□□

■ 4.1.1.	■ 4.2.1.	◩ 4.3.1.
■ 4.1.2.	◩ 4.2.2.	◩ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	▨ 4.2.7.	
	□ 4.2.8.	
	■ 4.2.9.	
	□ 4.2.10	

5. INTEGRABILITY

■■■■■
■■□□□

◩ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■■■■■
■■□□□

□ 6.1.1.	■ 6.2.1.	■ 6.3.1.	■ 6.4.1.
◩ 6.1.2.	◩ 6.2.2.	■ 6.3.2.	■ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	■ 6.2.4.		
	◩ 6.2.5.		
	■ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■■■■□
□□□□□

□ 7.1.1.	■ 7.2.1.	■ 7.3.1.	□ 7.4.1.
□ 7.1.2.	■ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■■■■■
■■■■□

■ 8.1.1.	■ 8.2.1.	■ 8.3.1.
□ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
■ 8.1.4.		

9. PLANT SYSTEM

■■■■■
■■□□□

■ 9.1.1.	◩ 9.2.1.
◩ 9.1.2.	■ 9.2.2.
◩ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
▨ 9.1.6.	

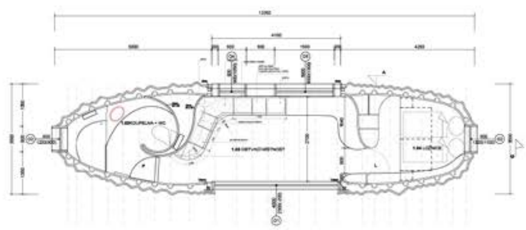
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Steel pontoon 20x10 m (originally for cargo)

LOAD BEARING STRUCTURE
*Concrete mixture enriched with nano-polypropylene fibers, plasticizers and a setting accelerator

CLADDING
Concrete mixture*

FIGURES (©Scoolpt)



MALDIVE FLOATING CITY - Prototype

10

● Male Lagoon (Maldive)

IDENTIFICATION DATA

ARCHITECT: **Waterstudio.NL**

CLIENT: **Government of Maldives + Dutch Docklands**

DATE: **2023**

BUDGET: **Confidential**

The Maldive floating prototype is the first island of the Maldive Floating City masterplan developed by Water-studio.NL, a mixed-used community of several thousand floating housing units and facilities.
It was the first floating city with thousands of houses with full governmental support based on a legal framework and title deeds for the owners. It also offers the unique possibility of obtaining a residence permit by purchasing a house and inviting the international community to live here (semi) permanently.
The units are built from a modular system to ensure quality, standardization, certification, short construction time, cost control, and efficient maintenance.

SITE FEATURES

- Typology: **Lagoon**
- Batimetry: **1-31 m**
- Water fluctuation: **50 cm**
- Climate: **Am - Tropical monsoon climate**

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
? m²

GEOMETRICAL LAYOUT
rectangular on brain coral shaped grid

MAIN OBJECTIVES

- **Ecosystem preservation/regeneration**
Blue habitats projecting and stimulating coral growth;footprint of each unit and overall layout is designed to allow sunlight to reach the seabed.
- **Resource circularity**
Solar power for electricity; water heat exchanger for cooling; water desalination system; organic waste treatment through UV filter and anaerobic digester.
- **Affordable and renewable energy efficiency**
PV system and heat exchanger to use sea water for cooling.
- **High levels of comfort and well-being**
On land building standards. Particular attention is paid to motion and visual comfort.
- **Economic feasibility**
cost-effective contruction (prefabricated components); low operating cost (energy production and smart grid).

REQUIREMENT COMPLIANCE

1. SAFETY

- ■ 1.1.1.
- ■ 1.1.2.
- ■ 1.1.3.
- ▨ 1.2.1.
- ■ 1.2.2.
- □ 1.2.3.
- ◪ 1.2.4.
- ■ 1.2.5.
- ■ 1.2.6.
- □ 1.3.1
- ◪ 1.3.2
- □ 1.4.1.
- ◪ 1.4.2.
- □ 1.4.3.
- ■ 1.4.4.
- ■ 1.4.5.
- ■ 1.4.6.
- ■ 1.4.7.

2. WELLBEING

- ■ 2.1.1.
- ■ 2.1.2.
- ■ 2.1.3.
- ■ 2.2.1.
- ■ 2.2.2.
- □ 2.2.3.
- ■ 2.2.4.
- ■ 2.3.1.
- ■ 2.3.2.
- ▨ 2.3.3.
- ▨ 2.3.4.
- ■ 2.4.1.
- ■ 2.5.1.
- ■ 2.5.2.
- ■ 2.5.3.
- ■ 2.6.1.
- ■ 2.6.2.
- ■ 2.6.3.
- ■ 2.7.1.
- ◪ 2.7.2.
- □ 2.7.3.
- ■ 2.8.1.
- ◪ 2.8.2.
- ■ 2.8.3.
- □ 2.8.4.
- ■ 2.8.5.

3. USABILITY

- ◪ 3.1.1.
- ◪ 3.1.2.
- ■ 3.1.3.
- ■ 3.2.1.
- ■ 3.2.2.
- ■ 3.2.3.
- ■ 3.2.4.
- ▨ 3.3.1.
- ■ 3.3.2.

4. MANAGE-

- ■ 4.1.1.
- □ 4.1.2.
- ■ 4.1.3.
- ■ 4.2.1.
- ■ 4.2.2.
- ◪ 4.2.3.
- ◪ 4.2.4.
- ■ 4.2.5.
- ■ 4.2.6.
- ▨ 4.2.7.
- ■ 4.2.8.
- ■ 4.2.9.
- □ 4.2.10
- ■ 4.3.1.
- ◪ 4.3.2.

5. INTEGRABILITY

- ■ 5.1.1.
- ■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

- ■ 6.1.1.
- ◪ 6.1.2.
- ■ 6.1.3.
- ■ 6.2.1.
- ◪ 6.2.2.
- ◪ 6.2.3.
- ■ 6.2.4.
- ■ 6.2.5.
- ■ 6.2.6.
- ◪ 6.2.7.
- ■ 6.3.1.
- ◪ 6.3.2.
- ■ 6.4.1.
- ■ 6.4.2.

7. RATIONAL USE OF RESOURCES

- ▨ 7.1.1.
- ■ 7.1.2.
- ■ 7.2.1.
- □ 7.2.2.
- ◪ 7.3.1.
- ■ 7.3.2.
- ■ 7.3.3.
- ■ 7.3.4.
- ■ 7.4.1.
- ■ 7.4.2.
- ◪ 7.4.3.

8. BUOYANCY AND STABILITY

- ■ 8.1.1.
- ■ 8.1.2.
- ■ 8.1.3.
- ■ 8.1.4.
- ◪ 8.2.1.
- ◪ 8.2.2.
- ■ 8.3.1.
- ■ 8.3.2.
- ■ 8.3.3.

9. PLANT SYSTEM

- ■ 9.1.1.
- ■ 9.1.2.
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- ■ 9.1.4.
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CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Prefabricated concrete floats

LOAD BEARING STRUCTURE
Cross Laminated Timber (CLT)

CLADDING
Wooden slats

FIGURES (© Waterstudio.NL)

4.4. Contemporary floating non-residential buildings

The non-residential case studies distributed on the political map (Figure 3) include 10 buildings hosting public or private functions including infrastructure, commercial, cultural-education, food production, leisure, tertiary and green:

11. GCA Floating Office, Rotterdam (Netherlands)
12. Floating Pavillion, Rotterdam (Netherlands)
13. Floating Farm, Rotterdam (Netherlands)
14. Mansa Floating Hub - MFS IV, bay of Mindelo (Cape Verde)
15. Jellyfish barge, Florence (Italy)
16. Meripaviljonki Sea Restaurant, Helsinki (Finland)
17. Theater L'Île Ô, Lyon (France)
18. Ferry Terminal, Terengganu (Malesia)
19. Joyous floating sauna, Oslo (Norway)
20. Brockholes Visitor Centre, Lancashire (United Kingdom).

The other five include tourism related functions with a particular focus on hospitality in the sense of temporary living facilities:

21. Marina Azzurra Resort, Lignano Sabbiadoro (Italy)
22. DD16, Moscow (Russia)
23. Ar-che (Germany)
24. Anthénea, Dora (Quatar)
25. Botel 2.0, Porto Ceresio (Italy)

4.4.1. Nonresidential projects

4.4.1.1. Floating Office, Rotterdam (The Netherlands)

Powerhouse Company
2015-2021

The Floating Office Rotterdam is a three-story mixed-use building that accommodates the Global Center on Adaptation headquarters, Powerhouse Company studio and RED company studio, a restaurant, and a swimming pool. It is located in the Rijnhaven and is subject to a tide of about 2 meters high four times per day. The building is conceived as a pilot project for the regeneration of the area, led by the Municipality of Rotterdam. Powerhouse Company planned the building to be as environmentally friendly as possible to reflect the climate-adaptive values of the Global Center on Adaptation and to be completely off-grid (self-sufficient).

Safety. The structure consists of prefabricated timber frames that were screwed together on-site. The structural grid is 6 m x 6m. The pontoon concrete hulls are interconnected with center pins and the deck on top of the basement. During the night, the access is closed by a gate. Railings do not protect the lower deck as it is only 30 cm above water. The lower deck has descending systems to facilitate access to and from the water. A fire safety alarm is integrated inside.

Wellbeing. The triple-glazed surface (3 m x 6 m wide) inserted between the wooden frame ensures water (river) views without compromising thermal comfort, energy consumption, and costs. The glazed windows are integrated with an internal shading system. The overhanging roof also provides shading for indoor spaces and shade and rain protection in outdoor spaces. The green roof (sedum) fosters biodiversity and contributes to increasing thermal insulation. Active design principles were followed in the layout: the mensa and relaxing area is on the ground floor, and the working area is on the upper floor to encourage workers to move around using the central staircase. Several plants are distributed indoors and outdoors, and constant eye contact with water is ensured from every space inside to take advantage of the biophilia effect for the occupants. Control points for regulating heating and cooling enable users to adjust indoor comfort conditions according to their needs. Despite the 2 meter water fluctuations occurring four times a day, the perception of movement is only visual since the floating substructure is highly stable. Some other architectural strategies have been used to reduce the perception of movement, such as the lack of hanging lamps to avoid the sight of swinging elements.

Usability. The ground floor is accessible to the public through ramps that adjust to water fluctuations of up to 2 meters. The building has a central elevator and is, therefore, completely barrier-free. The timber frames are designed with vertical and horizontal elements of the same width, length, and height to be utterly exchangeable. The modular base grid (6 m x 6 m) and the modular structural components (which are simple and demountable) allow the building to adapt to different purposes and changes in the future by being rearranged in a different layout and volume.

Management. The building needed to be constructed offsite at three separate locations and was then assembled and towed through the bridge leading to the Rijnhaven. The bridge height and width determined the maximum dimensions of the building. This constraint led to a horizontal and long design. The prefabricated components (glazed cladding, wooden deck) are easy to remove and replace in case of damage, thanks to the large balconies surrounding each floor. Real-time control of the heating and cooling system allows to reduce energy consumption.

Integrability. Dimensional integrability is guaranteed by the 6 meter grid and modular timber components. Moreover, the concrete void pontoon provides enough space for any other machinery or storage facility integration.

Efficient Use of Resources. The office is entirely off-grid (self-sufficient) thanks to solar panels (870 m^2) that provide the building with its source of electricity (154 MKW electricity per year) and a heat-exchange system that uses the temperature of the harbor water to cool the interior in summer and warm it in winter. The green roof is integrated with a rainwater collection system. A waste management system recycles wastewater and organic waste. Radiant floor heating contributes to the optimization of the overall building energy performance.

Environmental Regeneration. The building is made of prefabricated components, easy to disassemble, and connected through dry construction processes. The real-time control of the heating and cooling (temperature is automatically brought to 24°C) contributes to limit energy consumption, thus reducing $C0_2$ emissions.

Buoyancy - Stability. The prefabricated concrete hulls have bolted connections and are made using pre-tensioning technologies. The working spaces are along the lateral longitudinal areas, and the central axis is dedicated to the distribution and circulation, contributing to keeping the overall balance. Moreover, the heavy fixed furniture and components (staircase and bathrooms) were positioned to counterbalance one another. Occupancy must be monitored according to the variable load calculation: a maximum number of people admitted onboard is defined. Towing arrangements are provided. Two poles planted in the canal bed ensure the stable asset and position of the office, allowing vertical movement in case of high and low tides.

Plant System. The inner part of the pontoon is used for storage and technical spaces. The pontoon concrete barges contain a pipe system that functions as a heat exchanger.

4.4.1.2. Floating Pavilion, Rotterdam (The Netherlands)

Blue21
2010

Rotterdam's Floating Pavilion plays an important role as a showcase of building on water, allowing the city to give space to experiments and knowledge exchange on floating constructions. The Pavilion consists of three domes, the largest of which has a radius of 12 meters. It is designed as a multi-purpose space, hosting a lobby and exhibition space in the bigger dome and a smaller auditorium in another dome. It is partly self-sustaining as it is conceived to be movable from one location to another. The location has varied over time. It has been open to the public since 2010 in Rijnhaven, an area characterized by moderate waves and well-served by public transport from water and land. In 2022, it was relocated in front of the Rotterdam University of Applied Sciences (RDM) campus to serve as a laboratory for university students.

Safety. The façade is composed of modular hexagonal forms, made of steel, and covered with ETFE foil, a very light material that does not burden the foundation yet is sufficiently strong to withstand wind pressure.

Wellbeing. The interior is light, spacious, and well-insulated, thanks to the modular hexagonal steel dome covered with ETFE foil. The foil is double-layered and filled with air that keeps the warmth inside during the winter and preserves the inner temperature at 21 degrees during the summer. Solar transmission is regulated by applying reflective painting on the foil. Under-floor heating and efficient heat exchangers are used to heat and cool the rooms. Vital parts of the building, such as the auditorium, are situated within an insulated inner shell. In this room, Phase Change Materials (PCM) provide a latent heat store: the energy is absorbed by the material changing from one phase to another. All layers of the sound-deadening polyurethane system are applied in liquid form. Thus, there was no need for installing a rubber mat, which allowed for an easier and quicker installation. Additionally, to increase the room's acoustics, MasterTop 1327 D also offers the needed crack-bridging properties. The Pavilion features a demand-driven climate system: at every moment, the climate conditioning is carefully matched to the function and number of people in each space. A vegetation wall covers the interior dome containing restrooms and storage space, regulating humidity, and improving air quality and acoustic insulation.

Usability. The floating foundation enables the structure to be built on water and shipped to its planned destination.

Management. There are separate climate zones with specific heating and cooling requirements and systems. A demand-driven indoor climate system can constantly adjust indoor temperature and ventilation according to the use and occupancy of space, limiting the overall consumption of the building. Rotterdam University of Applied Sciences currently carries out the management.

Integrability. The entire structure is designed to easily integrate the passage, housing and fixing of the components of the plant systems within the non-plant engineering building elements, as most building components are prefabricated.

Efficient Use of Resources. The Pavilion also purifies its toilet water using a three-tank IBA system consisting of three different purification processes in three separate tanks: physical, chemical, and biological purification. Drinking water is also purified and reused as rinse water as much as possible. Whatever is left can safely be discharged into surface water. The exposition space is passively heated by the sun and by cross-ventilation. Large parts of the top and bottom of the domes are mechanically openable to create a stack effect, which provides a refreshing breeze without the need for mechanical ventilation, preventing overheating in summer. To prevent too much exposure to the sun, the cushions on the façade differ in transparency: they are less transparent in the higher layers and more transparent in the lower ones. The auditorium has vacuum-tube solar collectors placed on the ceiling that work as an adiabatic evaporative cooling system, transforming the sun's heat via an intelligent air-treatment cabinet into cool air. When water is added to the warm air, vapor is generated, and the air is cooled down. PV panels are installed on some of the hexagons to generate electricity. Despite being partly self-sufficient, it needs exterior connections to supply electricity and drinking water.

Environmental Regeneration. Drones are installed underwater to monitor the effects on the marine underwater habitat. Efficient heat exchangers (FiWiHex- units) are used. The radiant floor heating is a low-temperature heating system that uses radiation instead of convection of heat and cold. Led lighting is used for increasing energy efficiency.

Buoyancy - Stability. The foundation is a recently patented structure of expanded polystyrene (EPS) combined with a grid of concrete beams. This construction method was developed and patented by Dura Vermeer and Unidek.

Plant System. The plant system and equipment are integrated under the floor and in the floating pontoon.

4.4.1.3. Floating Farm, Rotterdam (The Netherlands)

Goldsmith Studio + Bartels and Vedder + Alcomtec
2015-2020

The Floating Farm is a compact and efficiently stacked urban farm (more than 40 cows) with a strong public and educational character located in the harbor of the M4H development zone of Rotterdam. The building combines technical installations, storage, production, and processing of dairy products. The goal was to bring back agriculture in the city's center, producing and processing on-site and delivering products across the city while minimizing resource depletion and environmental impact. The farm has three floors. Three connected concrete pontoons house the production of fruits (ingredients for yogurt), rain and wastewater recycling, and additional installations. The floor on the water level combines milk and yogurt processing, feeding system, manure handling, and retail; the upper floor host the covered cow garden supported by a manure cleaning robot and a milking robot along with various elements regarding animal welfare. The functional distinction among different floors is reflected in the external cladding, which starts as concrete (hull), turns into translucent polycarbonate for the intermediate floor, and becomes entirely open at the cow's garden level.

Safety. The structure is made of a lightweight triple-stacked metal frame.

Wellbeing. The translucent polycarbonate cladding surrounds the working areas, providing adequate comfort for users while ensuring natural light maximization. The cow garden has mobile windshields to protect cows and workers from rough and strong wind. The presence of machinery and technical equipment contributes to overheating the indoor environment, making it useless to provide additional heating systems.

Usability. The farm is characterized by scalability and customization, as it can be tailored and made with various products and adapted to several scales. Direct access from the land is provided through two metal bridges leading one to the intermediate floor and the other to the cow garden. An interior connection between the upper and intermediate floors is not provided. The two galleries around the cow garden – vertically connected via two steel bridges – string together to create an educational route where visitors can gain insight into the various activities without interfering with the farm process.

Management. The building is connected to the grid in case of emergency, but it is planned to be entirely self-sufficient. The building components are mainly prefabricated and can be easily replaced or repaired.

Efficient Use of Resources. It is designed according to a circularity concept to employ leftover goods produced by the city, such as grass from public parks and food waste, to feed animals and return fresh milk to the city. Cow manure is reused through a highly sustainable closed loop to produce fertilizer for public spaces within the city. An adjacent solar farm of PV panels produces electricity, and a combined heat and power (CHP) plant recovers wasted thermal energy for heating. A bio-digestor divides the manure into liquids – that is purified and used for irrigating the hydroponic cultivations – and dry components transformed into organic fertilizer. The roof structure is integrated with a rain collection system directly connected to the basement, where the water storage tanks are located. The water is filtered and reused for the cows.

Environmental Regeneration. The circular approach finds a new effective use for leftover products and reduces food transportation costs and pollution by keeping food production and consumption tightly linked. There are no systems to prevent any material from falling into the water. If the materials – falling or being transported by wind into the water – are not organic or natural, it may represent a problem for the quality of the surrounding water. The Municipality of Rotterdam carries out regular controls of the water quality.

Integrability. The modularity behind the concept is one of the strategic advantages for future integrations, transformations, or expansions. A hydroponic cultivation system is currently being planned to be integrated into the submerged concrete hull.

Buoyancy - Stability. The three prefab concrete cellars are connected by bolted and (semi) flexible connections. Pre-tensioning technologies are used to provide sufficient resistance. All heavy structural and technical components are in the submerged part of the building, while all significant and transparent functions are situated in a lightweight structure. Two poles anchored to the canal bed keep the structure in place, allowing only for vertical movements up to 2 meters.

Plant System. The rain and wastewater recycling plant systems and additional installations are in the concrete pontoons and are easily accessible for inspection and maintenance.

4.4.1.4. Mansa Floating Hub - MFS IV, bay of Mindelo (Cape Verde)

Kunlé Adeyemi (NLÉ)
2021

Floating Music Hub, Mindelo (MFS™IV) (or Mansa Floating Hub) is a cultural and creative platform located in the bay of Mindelo, on the island of São Vicente, Cape Verde, West Africa. It is based on NLÉ floating solution called Makoko Floating system (MFS). MFS is a lightweight, prefabricated, modular timber structure that can be easily assembled and disassembled. Three platforms hosting a multipurpose live performance hall, a recording studio, and a food and beverage bar are arranged around an isolated triangular floating plaza that serves as an open public space. It is an improved and industrialized (fifth) iteration of the MFS system.

Safety. The structure consists of timber A-frames braced by horizontal and diagonal crosspieces. Metal railings protect the pier and the public plaza to prevent users from falling into the water.

Wellbeing. Colorful polycarbonate on the vertical façades lighten up the indoor environment. A system of external curtains improves the shading of the polycarbonate façades. The ventilated roof, natural cross-ventilation, and louvers for shade ensure indoor thermal comfort conditions. Opaque façade panels consist of insulated panels with an external concrete layer and an interior layer of plywood and maintain comfortable temperatures inside.

Usability. It is designed to be flat-packed and relocated if needed. It is connected to the mainland through a ramp and floating pier.

Management. The prefabricated system is easy to assemble and disassemble. Bolted metal connections are used to join the timber elements to one another and the timber frames to the pontoon base. The triangular-shaped pitched roof is covered in tiles to protect the structures and reduce maintenance needs.

Integrability. The MFS is designed to easily integrate solar panels to provide a renewable energy supply and an organic waste recycling system.

Efficient Use of Resources. Rainwater collection storage is integrated into the floating barrels.

Environmental Regeneration. The timber for the structure is locally sourced.

Buoyancy - Stability. The system floats on recycled plastic barrels. The three buildings are anchored to poles fixed to the seabed: 6 poles are used for the bigger structure, 3 for the medium-sized one, and only 2 for the smaller one. The equilateral triangle is an ideal shape for increasing stability and balance on water due to its relatively low center of gravity.

Plant System. No information is available.

4.4.1.5. Jellyfish barge, Florence (Italy)

PNAT + Studio Mobile
2014

Jellyfish Barge is a modular floating greenhouse designed to be entirely self-sufficient in energy and water. It is an affordable, transportable, and replicable solution to grow food within cities using the extended hydrographic network as a cultivation surface. It combines a food production facility with a vital public space, providing both areas for economic activity and social interaction. It produces 1000-1500 edible plants each month, grown in a highly efficient hydroponic system. With no impact on existing land, water, and energy, it expands the capacity of the urban environment to provide food, social relationships, and urban quality. The installation comprises four modules (each of 70 m²) and one zip connection module. The connection module is the shared space for leisure, didactic, or market activities. The Jellyfish Barge imitates the transpiration process of plants and can produce fresh water from salty, brackish, or polluted water only by exploiting the sun's energy. It proves how low-cost technologies and simple available materials are not in contrast with highly efficient and sustainable solutions. It is a replicable solution that could be easily adapted to different conditions elsewhere and different functions, such as an intensive production facility, an extension of bars and restaurants, or a community garden. The prototype has been located in the Navicelli Canal in Pisa and the Nuova Darsena in Milan. However, it has been conceived for many different waterfront cities worldwide, from post-industrial cities characterized by many abandoned docks to areas in dire need of regeneration, social innovation, and inclusion.

Safety. The structure is made of timber truss beams along the rays of the octagon with horizontal timber beams with a bracing function. The ETFE membrane is fire-resistant and self-extinguishing.

Wellbeing. The ETFE membrane cladding provides the adequate thermal conditions required in the greenhouse. Light is let in and equally distributed thanks to the design of adequate distances between vertical cultures. Air quality is strongly affected by the presence of plants that absorb pollutants and CO_2. The interior layout guarantees ease of maneuver and circulation and the working activities related to crop cultivation.

Usability. The prototype is replicable and easily adaptable to different conditions elsewhere and is provided with towing arrangements. In attrition, since it is prefabricated, it can be easily disassembled. It was designed to be small, specifically for installation in places with a limited supply of materials. The modules are easily customizable and mobile: a farmer could travel between towns down the river or between pick-up points for delivery of fresh products. Access to the structure is provided on one of the octagon's sides (where there are no distillation devices).

Management. All the systems are automated and remotely controlled to increase the ease of use. Data are extracted to predict the future behavior of plants and consumption of systems to improve the overall performance of the prototype constantly. The cladding in the ETFE membrane is highly resistant to atmospheric agents and temperature variations. Moreover, it is self-cleaning thanks to its chemical properties.

Integrability. The structure's modularity and zip connection module allow for potentially infinite further expansion: multiple platforms can be joined together, creating a larger organism. The octagonal shape of the floating platform allows for combining different modules by connecting them with square floating bases. The prototype is designed for the integration of mini-wind turbines and wave generators according to the most efficient system for the location it is set in.

Efficient Use of Resources. Water useed for irrigation is either rainwater or extracted from the water body where the greenhouse floats, whether salt, brackish, or polluted waters. The water management system produces fresh water through solar distillation. The solar stills are located on seven sides of the barge. The water vapor created thanks to the distillation process is sucked into a tank chilled by the seawater on which the barge floats. As distilled water is not the most appropriate for cultivation, 15 % of seawater is added back to improve the crops' mineral content and nutritional value. All the energy demand (desalination process, lighting, irrigation pumps, and fans) is fulfilled by sun power, with PV panels integrated into the roof and wind power. All systems are automated and remotely controlled to increase the ease of use and collect data to improve the system.

Environmental Regeneration. It provides new growing soil without resorting to deforestation or land consumption. Recycled polyethylene drums for the floating pontoons have a standard size and can be easily found worldwide, reducing transportation efforts and, thus, CO_2 emissions. The presence of plants improves the air quality. The barge is mainly made from recycled material. Hydroponic cultivation uses 70% less water than traditional agriculture techniques.

Buoyancy - Stability. Recycled empty polyethylene drums make up the floating pontoon.

Plant System. Tanks containing the vapor that gradually transforms into water are inside the drums that constitute the pontoon.

4.4.1.6. Meripaviljonki Sea Restaurant, Helsinki (Finland)

Simo Freese Architects
2015

The floating restaurant Meripavilionki is Helsinki's first floating building open to the public. The building is located in the Eläintarhanlahti Bay, in Helsinki, characterized by a bathymetry of up to 2 meters and strong winds (7,2 m/s). It is conceived as a modern extension of the Workers House in Helsinki's center. The waterfront site is widely visible and loaded with historical significance. The panoramic restaurant offers 200 seats overlooking the Eläintarhanlahti Bay. The copper and glass façade and the inward-sloping water roof strongly characterize the building. The restaurant includes a dining area, restrooms, a kitchen, a bar, technical and storage rooms, and an outdoor terrace.

Safety. The glass structural façade incorporates outer stiffening glass beams. The steel structure and anchoring method of the pontoons ensures the overall structural integrity of the building. The hall's floor is about a meter above the water's surface. Railings protect walkways accessible to the public. The outdoor terrace is surrounded by glass railings, and the access bridge by metal railings.

Wellbeing. Floor-to-ceiling windows that make up the glass façade maximize natural light and offer quality views of the cityscape and the seascape. The long curving glass façade provides the maximum number of window seats with a sea view. The ventilated roof contributes to adequate indoor comfort and the envelope's energy performance. Glazed surfaces are exposed to the south to maximize passive heat gain. Openable windows are distributed to ensure cross-ventilation. Curved space free from corners is fluid and ensures ease of maneuver and circulation. The outdoor terrace is sheltered with canopies.

Usability. The connection to the mainland is made with flexible joints: the building is reached via a bridge, the angle of inclination of which changes according to the height of the seawater. Access to the restaurant is also by boat through the boat pier connected to the building. There are two different entrances for the guests and the technical staff. Storage space and most furniture are integrated within the interior partition walls to optimize space distribution. Towing devices allow the facility to be relocated elsewhere.

Management. The copper used for the façade is durable and requires minimal maintenance, as it oxidizes naturally. All materials exposed to outdoor weather resist humid and extremely cold climates.

Integrability. No information available.

Efficient Use of Resources. Several passive strategies are implemented to increase the building's energy performance: double-layer glass façade that is south-oriented, ventilated roof, cross ventilation, and shading devices.

Environmental Regeneration. The use of copper and glass for the façade is intended to reflect the surrounding water and integrate within the landscape.

Buoyancy - Stability. A rectangular, swinging arm connects the raft to two giant tripod anchor piles, ensuring no detectable movement for guests onboard. This anchoring system can accommodate a 2.5 meter variation in sea level.

Plant System. Technical rooms are in the basement. The pontoon below the raft contains all the HVAC installations. These are connected to land-side infrastructure below the entrance bridge, which can adapt to water fluctuations.

4.4.1.7. Theater L'Île Ô, Lyon (France)

Waterstudio.NL
2023

Theater L'Île Ô is Europe's first floating theater and offers a hybrid cultural space permanently moored on the river Rhône in the city center of Lyon, next to the Gallieni bridge. The theater superstructure has been erected on a wharf within Lyon's industrial area. A playful design is achieved by aggregating six prismatic white volumes articulated on three levels housing two performance halls (with 78 and 244 seats), a dining area, artistic workshops, an event area, and a covered panoramic rooftop of 140 m^2.

Safety. The superstructure is made from Cross-Laminated Timber (CLT), creating a strong and rigid structure that is simultaneously lightweight. Railings protect the access bridge. In terms of fire safety, it complies with on-land building local regulations.

Wellbeing. The thermal comfort and air quality are ensured by a simple device of natural ventilation controlled manually by the users, an adequately insulated façade, and an optimized temperature regulation system. The acoustic design used bamboo waves emerging from the walls and ceiling of the halls to ensure high acoustic performance. A class-leading AV system is installed to guarantee sound quality. Specific attention was paid to avoid obstructing sight lines from any of the seats in the performance halls. The interior is covered in wood to provide additional comfort, warm color tones, and unique shapes, creating an immersive and welcoming atmosphere.

Usability. Interior space is designed to allow access and circulation to all users. An elevator connects the different floors. The three aluminum bridges provide access from the bank to the theatre. Interior spaces (excluding the performance halls) are designed to be versatile modular spaces.

Management. The concrete hull was built on dry land in the Edouard Herriot harbor and then positioned on the Rhone. The concrete base provides durability to the entire structure. A waterproof membrane is applied on five sides of the structure to protect the theatre from water infiltration. The outer cladding is made of highly resistant and durable lacquered steel sheets. The floating concrete hull was constructed on solid ground and was lowered into the water using a crane. Subsequently, a significant portion of the superstructure was integrated. Then, it was transported to its designated location, where the upper section was affixed to ensure it could pass beneath bridges.

Integrability. No information is available.

Efficient Use of Resources. The stage equipment benefits from an innovative system of water-powered machines that allow for the movement of the stage rigging using water from the river. Natural ventilation occurs through a double-wall system, with air circulating between the two layers of the façade, driven by temperature differentials (cold air above the water and warm air above the theater). This system allows to avoid the use of air conditioning systems.

Environmental Regeneration. Sustainable materials are used. The wood used for the structure comes from local forests in France and Switzerland.

Buoyancy - Stability. A reinforced concrete hull of 550 tons is made of four hull beams (suspender beams) that are concreted together with the base and the entire side wall of the hull. The hull received six continuous reinforced concrete bulkheads for stiffening. The three access bridges contribute to keeping the building about 9 meters away from the quay.

Plant System. The theater is linked to onshore infrastructure for its energy, sewage, and water requirements.

4.4.1.8. Ferry Terminal, Terengganu (Malesia)

Bartels and Vedder
2019

This floating Ferry Terminal is situated in the largest artificial reservoir in Southeast Asia, Tasik Kenyir (or Kenyir Lake), and is conceived as the gateway to exploring the many attractions within the lake. The Kenyir Lake is characterized by large water level fluctuations (more than 15 meters within a year and 1 meter within 24 hours during Monsoon). With a footprint of over 5000 m², the terminal comprises six pavilion buildings, hosting a waiting area, ticket office, VIP area, banquet hall, and two food and beverages outlets with a dining area. The main pavilion hosting the waiting area has a seating capacity of 500 passengers.

Safety. The elevation structure is an aggregation of steel geodesic domes: a hemispherical thin-shell structure based on a geodesic polyhedron. The triangular elements of the dome are structurally rigid and distribute the structural stress throughout the structure, making it able to withstand very heavy loads.

Wellbeing. The six domes have a glazed base along the perimeter, followed by PVC-coated polyester fabric, and several glazed modules on the top. The openings positioned both at the bottom and at the top foster natural ventilation. The PVC-polyester fabric ensures high levels of thermal comfort, and being translucent, it allows natural light into the terminal while providing shade from the sun.

Usability. It is reachable from the mainland through a 70-meter-long bridge. The terminal is designed to be accessible to all users.

Management. The building was manufactured off-site and delivered in components to the site on a cost and time-effective base. The off-site construction was completed in a controlled environment, ensuring higher accuracy and quality. The PVC-coated polyester fabric used for cladding is lightweight, durable, and resistant to water, wind, and UV radiation.

Integrability. The modular floating concrete and EPS grid could be easily extended since the elements can be built off-site in a factory and then shipped to the location to be connected to the other ones.

Efficient Use of Resources. Passive strategies – including maximizing heat gain through the façade cladding materials and natural ventilation by using the stack effect – reduce the overall energy consumption for heating and cooling. A flooring heating system is installed during manufacturing within the concrete pontoon.

Environmental Regeneration. The prefab floating elements were produced 100 km from Kuala Lumpur and shipped 400 km to reach the final site. The floating pontoon system is demountable and reusable and requires no concrete pouring at the site. The dry joints (no use of grout) ensure a short construction period.

Buoyancy - Stability. The pontoon is made of prefab modular concrete slabs with a specially engineered rebar structure and couplings (HOLCON® patent) placed upon EPS bodies. The floating-HOLCON® consists of two concrete planes remotely connected through reinforcement bars, all connected to each other to create a very large modular floating structure. The structure is strengthened by a 3D truss system integrated into the prefab concrete elements. Using traditional mooring piles would have been extremely expensive and not aesthetically pleasing during the dry season (18m high poles sticking out of the water). For this reason, 100 units of tailor-made mooring systems were designed.

Plant System. Over 1000 meter of cables and pipes for electricity, running water, and data lines are securely protected from the public and installed underneath the floor in a purpose-built void within the modular components, easily accessible for upgrading or maintenance. The space between the concrete slabs accommodates technical installation and equipment.

4.4.1.9. Bademaschinen floating sauna, Oslo (Norway)

ACT! Architecture + Borhaven Arkitekter
2021

The floating sauna is set in the Oslo Fjord, overlooking the Oslo Opera House and Munch Museum in Oslo Harbor, and is reached from the quay that runs along the Akershus fortress. It is inspired by the classic Norwegian sea bath houses (*Sjøbadehus*). It consists of two saunas (capable of accommodating up to 16 people each), two towers with changing rooms, a diving spot, and access from

Langkaia. The different elements form a small square where a fire is lit in the winter. The supporting structure and roof are in red royal-treated spruce, and the external walls consist of reused teak windows where the glass panes have been replaced with oiled plywood.

Safety. The timber structure is made stronger by diagonal thin steel rods where bracing with wooden panels is impossible. Railings protect all the staircases. Descending devices allow easy access from the water to the deck. Onboard safety equipment is accessible on the central deck.

Wellbeing. All the spaces have been insulated with blown-in wood fiber insulation. The central square is conceived as a social meeting place, and hosts live music and other events. The different environments are arranged in a pinwheel layout to give the saunas and the outdoor areas the desired orientation towards the city and the fjord.

Usability. Access is provided through the Langkaia pier via a platform on its upper level. The whole complex is not accessible for all users because the access from land is from the upper level, and the saunas are located on the lower level.

Management. The decking and roof are made of hot-oil-treated spruce to give the timber high stability and durability in humid environments. The complex was created and manufactured in an associative process with the help of volunteers from the Oslo Badstuforening Sauna Association, and the construction took just eight months. The structure was built and assembled on land using existing components and then transferred to water.

Integrability. No information is available.

Efficient Use of Resources. Most building components are made from existing leftover material.

Environmental Regeneration. Most components are made of reused materials: the exterior walls consist of recycled teak windows taken from the Grande nursing home in Drøbak, where glass panels have been replaced with oiled plywood; the staircases and railings are made from repurposed metal bars; reclaimed brass pieces were used as doorknobs in the changing rooms. The vibrant red and yellow color palette draws upon the colors of the nearby Akershus Fortress. The oil treatment given to the decking and roof is environmentally friendly.

Buoyancy - Stability. A unique concrete hull provides the buoyancy of the whole complex.

Plant System. No information is available.

4.4.1.10. Brockholes Visitor Centre, Lancashire (United Kingdom)

Adamkhan Arkitekter
2008-2012

The Brockholes Visitor Centre is on a lake within an area of national environmental importance at Brockholes Wetland and Woodland Nature Reserve in Preston. The concrete pontoon floats on top of very shallow waters: there are no more than 30 cm between the draft of the pontoon and the lakebed. The area is particularly prone to flooding: water fluctuations reach 4 m over a year because of flooding. It has been formed over ten years from a former gravel quarry, with various habitats added to existing woodlands and water. The Visitor Centre consists of a cluster of five single-story buildings hosting a conference center, a restaurant, a shop, a gallery, an activity room, and restrooms. The cluster of floating thatched, pyramidal-shaped buildings evokes a prehistoric lakeside settlement and old farm buildings. The sequence of volumes of different heights and shapes creates routes and small squared places of transit and leisure.

Safety. The splaying V-shaped glulam portal frames are up to 10 m long and joined with steel flitch plates due to their complex geometry and high connection forces. The steep timber components are configured diagonally to support and brace the structure together with a stressed skin of insulated cladding panels. A fire consultant (WSP) was contacted to ensure the overall safety of the complex.

Wellbeing. The timber Structural Insulated Panels (SIP) skin provides racking resistance while ensuring high insulation and air tightness. The roof structure comprises rigid plastic foam between strand board panels to boost the thermal insulation of the roof. Acoustic insulation is provided by spraying the underside of the SIPs with recycled newspaper insulation. The complex's buildings are arranged around a series of courtyards, which provide both a sense of enclosure and openness to views, one of which is planted with a little orchard. Central openable skylight openings provide light to the indoor spaces. Unfolding external awnings and metal structures provide shelter and shade outside. The deck floats at the water level, providing constant intimacy with the water and the surrounding reeds and wildlife. Full-height windows around three sides allow daylight to enter and offer unrestricted views of the surrounding wetlands.

Usability. Access is through articulating bridges which adjust to the variations in water level. The height of light fixtures off the ground meets BREEAM criteria. The interior heights are quite generous, thanks to the structural solution. The building is adaptable to different purposes as it can potentially house various functions thanks to the essential neutrality of the indoor and outdoor spaces.

Management. The oak shakes of which the roofs are made are in their natural untreated state, durable, and nearly maintenance-free.

Integrability. No information is available.

Efficient Use of Resources. Façade components have high levels of thermal insulation and building airtightness. The hollow pyramidal shape of each pavilion acts as a thermal chimney, making mechanical ventilation or air-conditioning unnecessary. Fresh air is drawn through the windows and vents at the bottom and let out through the opening skylights at the top. This passive stack effect is fostered by sunlight warming the air through the skylights.

Environmental Regeneration. It was awarded the new BREEAM Outstanding rating for sustainability at the interim stage, mainly because it aimed for zero-carbon in use and production. Highly performative, locally sourced, recycled, or recyclable natural materials with low embodied energy have been used: locally sourced timber, recycled materials, and low-VOC paints. The glulam frames were made with precision-engineered systems to reduce on-site time and eliminate waste. The buildings are clad in oak shingles, rough tiles formed from tree stumps that would otherwise have been discarded. Internally, recycled newspaper insulation is used as it is an excellent low-cost and sustainable acoustic dampening. Moreover, the sourcing and durability of the materials used, potential for recycling, off-site prefabrication, and the distance to the site were all considered within the design. The buildings were prefabricated mainly off-site, ensuring waste reduction and limiting wildlife disturbance.

Buoyancy - Stability. The pontoon was made by casting concrete around large polystyrene void formers, forming a solid yet buoyant raft foundation for the buildings. The pontoon was built in a dry dock on a cavity drain membrane to ensure that it would float when water was let back in. The pontoon is kept anchored in place by four steel piles embedded in the lakebed, which provide strong anchorage despite the relatively weak rock under the lakebed and allow it to rise in flood conditions. The shallow lake was deepened to allow sufficient underwater volume for buoyancy and to allow workboat access.

Plant System. Plant system equipment is integrated into the partition walls and in a dedicated room in one of the units.

4.4.2. Tourism - temporary living projects

4.4.2.1. Marina Azzurra Resort, Lignano Sabbiadoro (Italy)

Frappa Edilizia
2018-2019
Marina Azzurra Resort is an innovative tourist complex consisting of eighty-eight floating houses in Lignano Sabbiadoro, on the left bank of the Tagliamento River. Some houses are inside a quiet dock;

others are moored along the riverbank. The houses are registered and certified as boats and are completed by common areas dedicated to leisure, swimming pools, kiosks, car parks, and cycle/pedestrian paths. Twenty-nine houses are located inside a quiet dock, and the other fifty-nine are moored along the riverbank. The houseboats are on two levels and have a maximum capacity of six people. The sloping roof, which turns into a façade, recalls the vernacular local houses of the lagoon fisherman. The use of latest generation technologies and modern control systems ensures maximum energy efficiency and smart and sustainable management of the house's design, construction, management, and maintenance process. Each house has a living room, two bedrooms, a bathroom, a storage space, an outdoor terrace of 6,50 m² on the main deck (lower floor), a dining room, a kitchenette, and another outdoor terrace of 12 m² on the upper deck.

Safety. Fire prevention equipment is distributed along the pier, providing access to each housing unit, and each housing unit is equipped with a fire alarm system. Railings protect all floating walkways and bridges. A descending device allows safe and easy access to the surrounding water. Each housing unit is provided with on-board safety equipment. The external flooring of the main deck and of the upper terrace is covered with an anti-skid material. Walkways are provided with lighting devices to ensure user safety during nighttime.

Wellbeing. The windows have a thermal transmittance value of 1,2 W/m^2K to guarantee adequate thermal comfort. The houses are placed at adequate distances from one another to ensure views toward the river and adequate ventilation. Housing units are equipped with air conditioning and heating systems.

Usability. The housing unit is provided with a helm that facilitates maneuvers during their placement on-site and in the event of relocation. Most furniture is integrated within the house structure. A distribution pier along the shore provides access to each house, from which bridges lead to the single housing units. At some points, the distribution piers open up to host boat docking spots.

Management. The houses are made entirely of prefabricated components that are easy to replace or maintain. The fiberglass cladding is covered in a glossy finish that prevents wear.

Integrability. All houses are arranged to integrate an engine easily.

Efficient Use of Resources. No information is available.

Environmental Regeneration. The sloping roof, which turns into a façade, resembles the vernacular local houses of the lagoon fisherman, known as *casoni*, while their bright colors recall the houses in Burano island, near Venice.

Buoyancy - Stability. The houseboats rest on fiberglass foundations and are moored along the riverbank to the poles that support the pier. They are tourist leisure facilities used only seasonally.

Plant System. The house is connected to the land grid it relies on, which concerns energy, sewage, and water.

4.4.2.2. AR-CHE Aqua Floathome, Geierswalde Lake (Germany)

WilDesign + Wilde Metallbau GmbH + AUTARTEC consortium (Brandenburgische Technische Universitaet BTU + Institute of Floating Architecture IfSB)
2009

The German reunification marked the end of the open-cast mining industry in the Lower Lusatia region, bringing forth a new lake landscape that fundamentally changed the face of the region. With the vision of the IBA (Internationale Bauausstellungen) for floating architecture, the mining holes were flooded to become artificial lakes. The two-floor Ar-che Aqua Floathome is the first of twenty modular floating houses in the Lusatian Lake District. Today's Lake Geierswald used to be a lignite mine from 1955 to 1972. The remaining pit hole was flooded in 2004, creating the artificial lake with an average depth of 7 meters with water fluctuations between 10 to 20 cm due to changes in precipitations and evaporation. It is home to a variety of flora and fauna and is a popular destination for swimming, boating, fishing, hiking, and camping.
The houses are designed to offer sustainable vacation lakeside luxury apartments. Three façades are almost entirely of glass to provide a stunning view of the lake. The fourth façade features a curved roof to protect the house from harsh winds and weather. The house is not water-locked, as underwater cables allow the inhabitants to enjoy fresh water, plumbing, electricity, and internet conveniences. The self-supporting structure allows complete freedom in terms of interior layout.

Safety. A self-supporting lightweight modular aluminum and steel frame (Steeltec37) supports a curved roof. The deck is covered in anti-skid wooden boards to avoid the risk of users slipping. Railings protect the private terraces on the water level and the upper terrace, while the common pier is left unprotected but equipped with descending systems and safety equipment. The parts of the piers that are not protected are also meant for boats to dock and, therefore, are equipped with fenders.

Wellbeing. The curved roof protects the home from the prevailing wind and weather, while the three other façades enjoy many windows to take in natural daylight and views. The aluminum and steel frame provides a high-performance façade that works to connect the interior with the exterior in an energy-efficient way. Louvered aluminum screens shield the interior from glare and overheating. The homes feature an innovative air-vapor barrier membrane and quality thermal insulation, contributing to the high-performance envelope. The spacious sun deck guarantees an optimal view of the lake at a height of 7 m.

Usability. Flexible floor plan and layout transformations are possible thanks to the self-supporting steel frame, which does not require interior partition walls. Access is provided by land and water, thanks to the integration of a boat dock. A common pier connected to smaller piers reaching each housing unit provides access from the lake shore. Internally, houses are distributed on two floors and are therefore not entirely accessible, limiting circulation for all users.

Management. A double coating is added over steel (a top coating with a clear lacquer and a powder coating over aluminum) to increase its durability and limit maintenance.

Integrability. The modularity of the construction provides excellent flexibility and freedom for future integrations or transformations.

Efficient Use of Resources. A variety of energy-efficient strategies are employed to reduce overall energy use. Steel and glass materials make it possible to convert the walls into large heat and sound-insulated glass surfaces with significant savings in construction materials. Solar panels are integrated into the curved roof when the orientation is optimal for maximizing solar radiation.

Environment Regeneration. The housing units have a low energy footprint thanks to their efficient insulation and renewable energy systems. The artificial lighting for outdoor spaces is oriented upwards and is meant to avoid disturbing the surrounding natural environment.

Buoyancy - Stability. The steel pontoon is made of different elements to ensure watertight compartmentation. It is anchored to the lakebed through mooring piles (two for each housing unit).

Plant System. Machinery and part of the plant system are integrated under the staircase. Underwater cables allow connection for electricity, internet, and fresh water.

4.4.2.3. DD16, Moscow (Russia)

BIO-architects (+ Fabbrica DublDom)
2016

The DD16 is a prototype of a modular compact house that was designed for installation in remote places and extreme conditions. The house consists of two lightweight yet resistant modules in laminated wood with milled ports protected by an exterior finishing in aluminum sheets. The building is designed to be easily transported and relocated elsewhere. Despite the extremely small dimensions, the house provides all comforts and is almost entirely self sufficient. The house is designed to be affordable: it is made from relatively inexpensive materials and can be built quickly and easily. The DD16 is a modular compact house prototype designed for installation in remote places and extreme conditions. In 2016, it was installed in a lake near Moscow.

Safety. The structural frame is made of laminated timber (LVL) with milled ports. The ports helped to decrease the weight and cold bridges and gaps. The structural timber frame is coated with oxidation-neutral phenol-formaldehyde resin, which guarantees slow carbonization and thus meets fire-resistance building regulations. The house is provided with onboard safety equipment.

Wellbeing. Spray polyurethane foam (PPU) is used as an insulation, the rigidity of which helped to decrease the weight of inner finishing materials. The milling ports reduce the cold bridges since all the holes are filled with insulation. Thanks to energy-efficient spraying, the double-glazed windows were made two-layer while maintaining the thermal characteristics of a three-layer double-glazed window. The volume is kept compact with no protruding parts to maximize the overall energy efficiency of the building. Large glazing facing south maximizes heating and lighting. Due to the large glazing and the great amount of light, the space inside visually increases. Stained glass glazing is made with a mirror effect to ensure privacy for the residents while reflecting the natural environment. The wind turns the house to different sides, and the picture outside changes constantly.

Usability. Hidden niches are used for storage. Some furniture can be transformed or folded. The free space in the furniture is also used for storage (e.g., the bed has drawers and a niche for large items). Modular pontoons are made together with a frame that can be dissembled to be transported inside the house and set on water. Beam releases allow attaching the house to the crane or helicopter so one person can easily do all the rigging work in any weather conditions. The house can be easily relocated elsewhere through disassembling since all its components are prefabricated and assembled through mechanical connections: for fastening the rigging slings, the main load-bearing beams are released, and a simple grip carries out the hooking.

Management. The aluminum composite sheet claddings are resistant to harsh weather conditions. The entire structure is designed for factory production, prompt installation on site, and quickly moving the house from place to place. Installation and, eventually, future transportation is primarily conceived through helicopter. Therefore, weight plays a crucial role and has guided the design of the structural elements, building components and furniture.

Integrability. Modular design and grid allow easy and quick extensions and dimensional integrability.

Efficient Use of Resources. Photovoltaic panels are used to generate electricity. Water from the lake is filtered and used for domestic purposes. A bio-toilet filters the wastewater and transforms human waste into compost. Passive strategies strongly contribute to the building's overall energy efficiency. According to where it is supposed to be located, it can be integrated with other renewable energy systems, exploiting water properties (water thermal heat and water movement).

Environment Regeneration. The aluminum façade and the stained glass reflect the surrounding landscape. Building components are made of natural elements that are easy to reuse and recycle.

Buoyancy - Stability. The pontoons are made of concrete modular semi-cylindrical blocks held together by a horizontal metal grid on top of them. The low center of gravity increases the stability of the structure. The weight of every detail is considered so it can be used in very harsh conditions.

Plant System. All technological devices (collector group, electrical panel) are hidden in the niches of the frame.

4.4.2.4. Anthénea eco-suite, Doha (Quatar)

Jean-Michel Ducancelle (+ Jacques-Antoine Cesbron)
2019 (2022 in Doha)

It is a luxury floating circular-shaped capsule powered by solar energy and equipped with high-end facilities. The eco-luxury pod is meant to be nomadic, but the first one in use was in the Marina of Doha, Qatar. It features a kitchenette, a living area, a bedroom, a circular tub filled with fresh or seawater, and a solarium area on the upper floor overlooking the sea. It is available for charter and designed to be delivered to any location.

Safety. The suite is equipped with onboard safety equipment. Descending devices provide access to and from the water. The deck is covered in anti-skid wooden boards. A predictive maintenance system integrated into the pod sends an alert in case of an emergency.

Wellbeing. It provides a 360° view from the inside of the capsule as a glazed strip surrounds it. Transparent panels positioned in the lower part of the capsule provide a view of the underwater marine habitat. The motorized roof is powered directly by the sun. The onboard smart system automatically adjusts and maintains shade according to the sun's position, and the automated smart open roof orients itself depending on the force of the wind to ensure perfect safety and comfort conditions.

Usability. Its circular shape is optimal for transportation. Several towing arrangements are located along the perimeter of the floating base. The lower deck houses storage space for food, water, and other supplies.

Management. The crew of the Athenea regularly inspects and maintains all of the plant systems and technical machinery to ensure that they are operating properly. The pod is designed to be transferred for short distances: it is provided with towing arrangements and has an aerodynamic and stable volume.

Integrability. No information is available.

Efficient Use of Resources. It is powered by five PV panels positioned on the upper level of the dome. The circular shape is designed to take advantage of the sun's rays and maximize energy production. All waste is treated on board.

Environmental Regeneration. A home automation system reduces energy consumption to a minimum. The anchorage through sand screws does not cause damage or impact on the ecosystem and underwater environment. Most of the materials used are recyclable. The plant systems and technical machinery are carefully arranged to minimize noise and vibration. The lower deck is also well-insulated to keep it cool in the summer and warm in the winter.

Buoyancy - Stability. Its circular, compact shape is designed to withstand all weather and sea conditions by the surface tension principle. The capsule is anchored to the seabed through sand screws and can be moored to any dock through ropes.

Plant System. The plant installations are located on the lower deck, accessible through a hatch in the living room. The pod is equipped with an emergency power battery pack.

4.4.2.5. Botel Diffuso dei Laghi 2.0

Il Laboratorio Sa (Gaetano Gucciardo, Roberta Turra)
2018

Botel 2.0 is conceived as a diffuse hotel on the Lugano Lake in Porto Ceresio. Only one unit has been designed for the moment, but the development involves the construction of three new units connected by a common central square. The accommodation offer can be contextualized within the experiential tourism sector, particularly in the biophilic one. The unit is closed-cycle, off-grid, and has no emissions into the atmosphere or water. It is powered by photovoltaics and micro-wind turbines and is provided with phyto-depuration and evapotranspiration systems for water management and reuse. It can be located anywhere, and the design follows the principle of total reversibility. The unit is meant to host up to four people. Particular attention was paid to the LCA of the building in the design phase. Although the housing unit is registered as a navigation unit – since there is no other way to obtain legal permits or authorizations – it meets the comfort and safety standards for buildings on land. The housing unit has a home automation management (stand-alone) system to optimize consumption and comfort.

Safety. A timber frame provides the structural integrity of the one-story unit. Railings surround the deck and the aluminum access ramp.

Wellbeing. The thermal insulating capabilities of the floating platform are ensured by using layered composite PVC, reducing the need for additional internal insulation layers. The OSB sandwich panels used for external walls contain an interior 12 cm thick insulation to ensure thermal comfort. The roof is of corrugated aluminum insulated sandwich panels with different inclinations. Large, insulated windows provide adequate indoor natural lighting while reducing heat loss.

Usability. The whole building is designed to be entirely removable as it is not connected to the on-land electric, water, and sewage grid. Access occurs through a ramp bridge directly from the port dock.

Management. The external cladding is made of larch wood treated with a superficial burning and subsequent brushing to crystallize the soft parts of the wood, reducing the need for regular maintenance. The floating pontoon in an extruded PVC layer has a twenty-year warranty. A home automation system manages the utilities. The building components (timber frame, insulation, and OSB panels) have been assembled in a drydock construction site. All the components were brought to the final location and assembled into the aluminum structure in a temporary site near the water. Once the larix exterior cladding and the windows were mounted, the structure was launched on the water.

Integrability. The unit has been designed with the provision of special arrangements to host the connection with other units or a floating square, as planned for the near future.

Efficient Use of Resources. It is not connected to the on-land electric grid thanks to an integrated photovoltaic system and two micro wind turbines (horizontal and vertical axis wind generators) installed on the rooftop. The building is provided also with a closed-cycle water purification system: phyto-purification filtration and elimination of the bacterial load are carried out before reintroducing the water into circulation. For this purpose, a phyto-depuration garden is integrated on one side of the structure. Water from the lake is extracted for domestic and sanitary use. The sewage undergoes an initial anaerobic digestion process and is then released into the evapotranspiration system. The automated domotic system warns users when they exceed consumption limits, reducing energy consumption and costs and raising awareness of their consumption trends.

Environmental Regeneration. It has zero emissions. The materials used are few and locally sourced. Their natural colors contribute to integrating the building into the environment. Particular attention was paid to the building's life cycle assessment. The PVC used for the buoyant base is recycled and recyclable. PV panels have been positioned horizontally on the roof to be as much hidden as possible to avoid landscape disturbance.

Buoyancy - Stability. The floating system comprises composite PVC sheets with differentiated load-bearing capacity and a collaborating aluminum frame system. The anchor piles were driven from the ground with a mobile crane and hydraulic vibro-driver. Special pastes were used to avoid galvanic currents at the connection points between the metal structures.

Plant System. The electrical and special systems include horizontal and vertical wiring channeled into a technical compartment containing the control panels of the production plants and the storage batteries. The hydraulic and purification systems are positioned on the technical walkway. A home automated application monitors and controls the hydraulic and purification system. Moreover, the cables and tubes are designed for dis-assemblage, with a view to reversibility, transferability, and mobility.

4.4.3. Synthesis of outcomes

The debate onthe juridical and financial status of floating houses is ongoing in several countries. Depending on this status, they are regarded as boats or houses. In the Netherlands, the Council of State made clear that floating houses have the juridical status of a house if there is an intention to stay in a specific location and the construction is connected to the ground (waterbed) with a mooring construction (Vermande, 2009). The juridical status of the house has consequences for mortgages, insurance, and building permits. Currently, commercial banks and mortgage firms in the Netherlands sell mortgages and insurance for floating houses. This has contributed to market demand and trust among potential house buyers. In the Netherlands, floating houses require an ordinary building permit and should fulfill standards in the construction legislation. In other countries, like Finland, Norway, France, or Italy, that do not have a specific code for floating buildings. Hence, obtaining a building permit to build on water is highly complex and requires a long time. For this reason, most structures are classified as houseboats, boats, or barges.

Regardless of location, public buildings must comply with much more stringent regulations than private ones regarding user accessibility and fire safety. Public and private floating facilities open to the public (i.e., restaurants, museums, pavilions, theatres, cultural centers) follow land-based regulations. Unlike residential floating units or touristic accommodations, they are usually registered and classified as houseboats. For instance, the Botel 2.0 is registered as a navigation unit since there is no other way to obtain legal permits or authorizations for building on a water plot. Nevertheless, it meets the spatial, safety, and comfort requirements that regulate land-based residential buildings. Anthenea, on the contrary, is built and delivered with boat certification Category C for 'sheltered waters' and does not meet land-based building rules. The difficulties encountered in buying a plot of water or obtaining construction permits to build on water strongly affect and increase the overall realization time of the projects. The construction process of the Meripaviljonki Sea Restaurant took up to ten years, mostly due to the bureaucracy regarding the permit for construction.

When analyzing actual built projects, onboard user manuals are intended more as rules for the safe and correct use of the building, including information like the maximum number of occupants that the building can host given the load adaptability capacity or the emergency procedures; this is the case for the Floating Office in Rotterdam. The Botel 2.0 is equipped with onboard instructions to help users who only live there for short stays become aware of their energy and water consumption.

Climbing and holding devices are not provided if other measures like special parapets along the perimeter avoid the danger of falling into the water. As proved by several case studies, tourist leisure accommodations or housing units allow easy access to water for recreational purposes rather than safety reasons.

The requirement 9.2.1. Thermal variation resistance of pipelines is correctly observed only in case studies located in areas with a risk of water freezing or simply reaching a temperature close to zero (frost resistance), such as IJburg, Oslo sauna, or DD16.

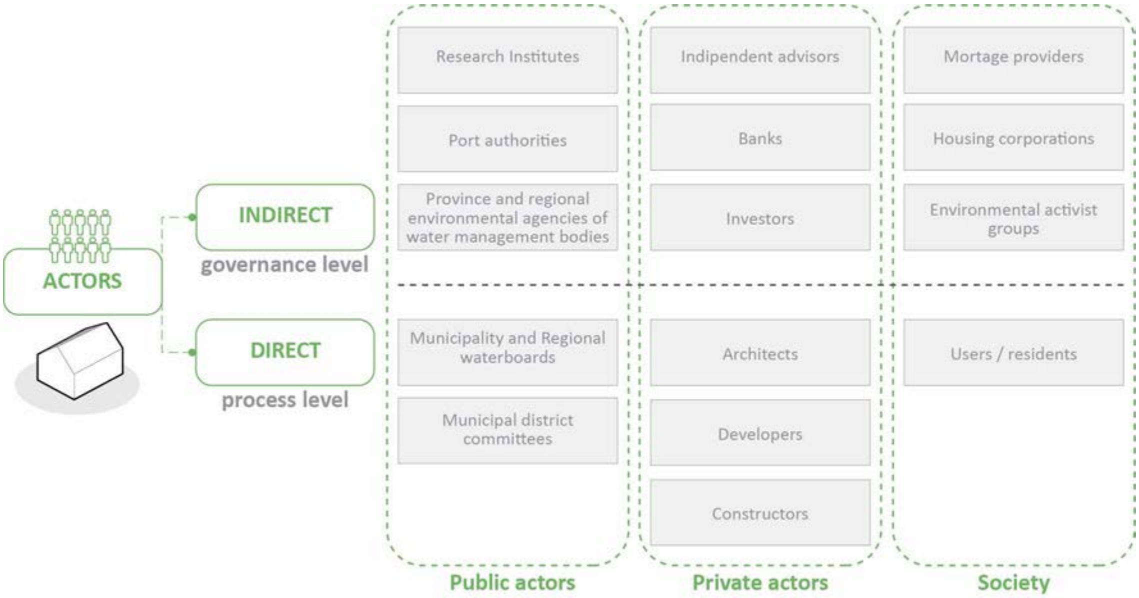
A score of 0 or 0.5 was assigned to Landscape preservation when the floating building is inserted in an unbuilt landscape. However, a score of 1 is assigned if consideration is given to the integration in the context, as in Brokeholes Visitor Center, which reproduces the area's vernacular architecture with local natural materials. Where particular attention was paid to ecological regeneration of the entire context, as in Nassauhaven and Harnschpolder, the requirement was also rated 1.

The Bademaschinen floating sauna in Oslo highlighted how recycling can be time-consuming as one needs to map the material, check the compatibility, store it, transport it, and eventually treat it. Therefore, the requirement 7.1.1. Circular use of materials may be in contrast with requirements 4.1.1. Cost-effective and efficient processing and manufacturing, 4.1.2. Cost-effective and efficient transportation, and 4.1.3. Cost-effective and efficient assembly and construction.

Among the most common materials for the substructure are concrete hulls or concrete cellars or blocks. MFS IV and Jellyfish Barge highlight the potential of using recycled polyethylene barrels as a pontoon system. The tourist accommodation in Marina Azzurra has a fiberglass hull, while the Ar-che floating houses in Germany have a steel hull originating from the shipping industry. Several superstructures are made of different timber frames, confirming the possibility of adopting wooden structures in watery environments.

The case studies have shown the great number of actors involved, directly or indirectly, in floating development (Figure 4). It is possible to identify three main categories: public actors, private actors, and society. The direct actors operate on the process level, and the indirect actors operate on the governance and institutional level. Public actors involve municipal district committees, Municipality and Regional waterboards operating at a process level, and Province and regional environmental agencies of water management bodies at a governance level. Private actors include architects, developers, and constructors at a process level and investors, banks, port authorities, research institutes, and independent advisors indirectly. Society actors involve mainly users and residents but also mortgage providers, housing corporations, and environmental activist groups at an indirect level.

Figure 4. Diagram of direct and indirect actors involved in the design and construction process of floating buildings



FLOATING OFFICE ROTTERDAM (FOR)

11

● Rijnhaven, Rotterdam, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Powerhouse Company**

CLIENT: **Global Center on Adaptation, Municipality of Rotterdam, RED Company**

DATE: **2015 - 2021**

BUDGET: **Confidential**

ADVISOR: **Hercules FC, Bartels & Vedder, Solid Timber, DWA**

The Floating Office Rotterdam is a three-story mixed-use building that accommodates the headquarters of the Global Center on Adaptation, Powerhouse Company studio and RED company studio, a restaurant, and a swimming pool.
The building is conceived as a pilot project for the area's regeneration, led by the Municipality of Rotterdam. Powerhouse Company planned the building to be as environmentally friendly as possible to reflect the climate-adaptive values of the GCA.
It is entirely off-grid (self-sufficient) thanks to solar panels that provide the building with its source of electricity and use the water of the Rijnhaven to cool the building. The building structure is designed in prefabricated wooden frames and can easily be disassembled and reused.

SITE FEATURES

- Typology: Harbor
- Batimetry: 12-18 m
- Water fluctuation: 2 m
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS: 3000 m²

GEOMETRICAL LAYOUT square

MAIN OBJECTIVES

- **Ecosystem preservation/regeneration**
Real time control on heating and cooling contributes to reducing C02 emissions; dry construction process with prefabricated recyclable components.
- **Resource circularity**
Off-grid (self sufficient) thanks to PV panels and heat-exchanger (harbor water); rainwater collection system; waste management system.
- **Affordable and renewable energy efficiency**
Real time control on heating and cooling (building energy performance optimization); radiant floor heating; PV system (154MKW per year).
- **High levels of comfort and wellbeing**
Manual control on indoor temperature; triple-layered glazing and green roof; outdoor quality views; outdoor terraces on all floors; active design strategies.
- **Economic feasibility**
Low exercise costs (off-grid); low maintenance costs; circular economy principles (easy to disassemble and reuse).

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	■ 1.2.1.	□ 1.3.1	□ 1.4.1.
■ 1.1.2.	■ 1.2.2.	■ 1.3.2	■ 1.4.2.
■ 1.1.3.	■ 1.2.3.		□ 1.4.3.
	◩ 1.2.4.		■ 1.4.4.
	■ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	◩ 2.2.3.	◩ 2.3.3.	
	■ 2.2.4.	■ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	■ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	◩ 2.7.2.	◩ 2.8.2.
■ 2.5.3.	■ 2.6.3.	■ 2.7.3.	■ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■ 3.1.1.	■ 3.2.1.	◩ 3.3.1.
■ 3.1.2.	■ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGEMENT

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
■ 4.1.2.	■ 4.2.2.	■ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	■ 4.2.8.	
	■ 4.2.9.	
	◩ 4.2.10	

5. INTEGRABILITY

■ 5.1.1.	◩ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	■ 6.4.1.
◩ 6.1.2.	◩ 6.2.2.	■ 6.3.2.	■ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	■ 6.2.4.		
	□ 6.2.5.		
	■ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■ 7.1.1.	■ 7.2.1.	◩ 7.3.1.	■ 7.4.1.
■ 7.1.2.	◩ 7.2.2.	■ 7.3.2.	■ 7.4.2.
		■ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
■ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
□ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	◩ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
◩ 9.1.6.	

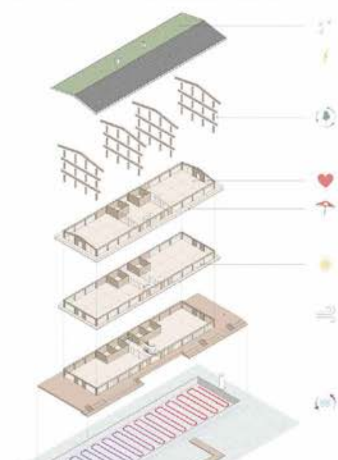
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
15 concrete barges held by tension cables (double reinforcement concrete + steel to avoid ribs)

LOAD BEARING STRUCTURE
Cross Laminated Timber floor slabs and prefab frames

CLADDING
Triple-layered glazed surfaces

FIGURES (© Powerhouse Company)



FLOATING PAVILLION

● Rijnhaven + RDM Dokhaven, Rotterdam, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Blue 21 + Public Domain Architecten**

CLIENT: **Municipality of Rotterdam**

DATE: **2010**

BUDGET: **Confidential**

ADVISOR: **Bartels & Vedder, DWA Installatie-en energieadvies, Advin**

Rotterdam's Floating Pavilion plays an essential role as a showcase of building on water, allowing the city to give space to experiments and knowledge exchange on floating constructions. The pavilion consists of three domes, the largest of which has a radius of 12 meters. It is designed as a multi-purpose space, hosting a lobby and exhibition space in the larger dome and a smaller auditorium in another dome. It is partly self-sustaining as it is conceived to be movable from one location to another.
It has been open to the public since 2010 in Rijnhaven; it was then relocated in 2022 to the Rotterdam University of Applied Sciences (RDM) campus to function as a laboratory for university students.

SITE FEATURES

- Typology: Harbor basin
- Batimetry: 12-18 m
- Water fluctuation: 2 m
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
1000 m² (indoor)
550 m² (outdoor)

GEOMETRICAL LAYOUT
juxtaposition of circles

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Drones are installed underwater to monitor the effects on the marine underwater habitat.

Resource circularity
Wastwater treatment system; passive heating, stack efffect, and cross ventilation; PCM provide latent heat store.

Affordable and renewable energy efficiency
Vacuum-tube solar collectors for adiabatic evaporative cooling; PV panels; demand-driven climate system; heat-pumps extract water for heating/cooling.

High levels of comfort and wellbeing
Demand-driven climate system to regulate thermal comfort; quality views to surrounding water ; green wall improves air quality and regulates humidity.

Economic feasibility
Low operating cost (nearly self-sufficient); low maintenance cost.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1. ■ 1.1.2. ■ 1.1.3.

◩ 1.2.1. ■ 1.2.2. ◩ 1.2.3. ■ 1.2.4. ■ 1.2.5. ■ 1.2.6.

□ 1.3.1 ◩ 1.3.2

■ 1.4.1. □ 1.4.2. □ 1.4.3. ■ 1.4.4. ■ 1.4.5. ■ 1.4.6. □ 1.4.7.

2. WELLBEING

■ 2.1.1. ■ 2.1.2. ■ 2.1.3.

■ 2.2.1. ■ 2.2.2. □ 2.2.3. ■ 2.2.4.

■ 2.3.1. ■ 2.3.2. ■ 2.3.3. ■ 2.3.4.

■ 2.4.1.

■ 2.5.1. ■ 2.5.2. ■ 2.5.3.

■ 2.6.1. ■ 2.6.2. ■ 2.6.3.

■ 2.7.1. □ 2.7.2. □ 2.7.3.

■ 2.8.1. ■ 2.8.2. ■ 2.8.3. □ 2.8.4. ■ 2.8.5.

3. USABILITY

■ 3.1.1. ■ 3.1.2. ◩ 3.1.3.

◩ 3.2.1. ■ 3.2.2. ■ 3.2.3. ■ 3.2.4.

□ 3.3.1. ■ 3.3.2.

4. MANAGEMENT

■ 4.1.1. ◩ 4.1.2. ■ 4.1.3.

■ 4.2.1. ■ 4.2.2. ◩ 4.2.3. ◩ 4.2.4. ■ 4.2.5. ■ 4.2.6. ■ 4.2.7. ■ 4.2.8. ■ 4.2.9. □ 4.2.10

■ 4.3.1. ◩ 4.3.2.

5. INTEGRABILITY

■ 5.1.1.

■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1. ◩ 6.1.2. ■ 6.1.3.

■ 6.2.1. ■ 6.2.2. ■ 6.2.3. □ 6.2.4. ■ 6.2.5. ■ 6.2.6. ■ 6.2.7.

■ 6.3.1. ■ 6.3.2.

■ 6.4.1. ■ 6.4.2.

7. RATIONAL USE OF RESOURCES

◩ 7.1.1. ■ 7.1.2.

■ 7.2.1. □ 7.2.2.

□ 7.3.1. ◩ 7.3.2. ■ 7.3.3. ■ 7.3.4.

■ 7.4.1. ■ 7.4.2. ■ 7.4.3.

8. BUOYANCY AND STABILITY

■ 8.1.1. ■ 8.1.2. ■ 8.1.3. □ 8.1.4.

◩ 8.2.1. ■ 8.2.2.

■ 8.3.1. ■ 8.3.2. ■ 8.3.3.

9. PLANT SYSTEM

■ 9.1.1. ■ 9.1.2. ■ 9.1.3. ■ 9.1.4. ■ 9.1.5. ■ 9.1.6.

◩ 9.2.1. ■ 9.2.2.

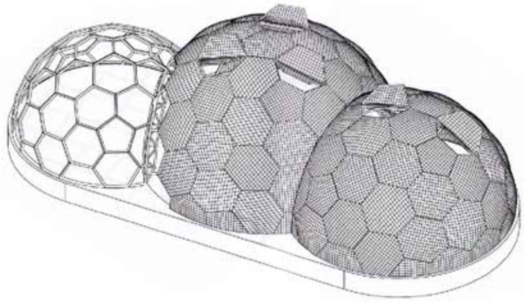
CONSTRUCTION COMPONENTS

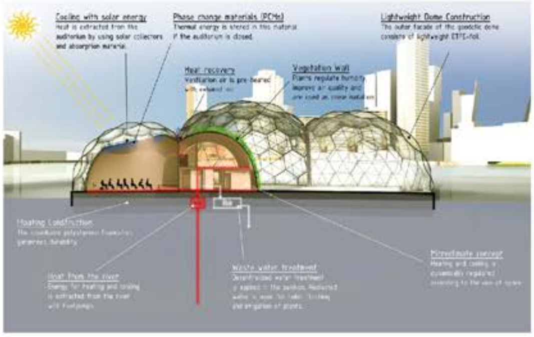
BUOYANT FOUNDATION
EPS blocks that are reinforced with concrete beams

LOAD BEARING STRUCTURE
Modular hexagonal steel frame domes

CLADDING
3-layered ETFE foil inflated cushions

FIGURES (© Blue21)





FLOATING FARM 2.0

Merwehaven, Rotterdam, The Netherlands

IDENTIFICATION DATA

ARCHITECT: **Goldsmith Studio**

CLIENT: **Floating Farm Holding BV**

DATE: **2015 - 2020**

BUDGET: **5000 €/m² (total 10 000 000 €)**

ADVISOR: **Bartels & Vedder, Alcomtec**

The Floating Farm Dairy is a compact and efficiently stacked urban farm (more than 40 cows) with a strong public and educational character. The goal was to bring back agriculture in the center of the city, producing and processing on site and delivering it across the city. The building combines technical installations, storage, production and processing of dairy products. It is distributed on three floors: three connected concrete pontoons house the production of fruits (ingredients for yogurt), rain- and waste-water recycling and additional installations; the floor on the water level combines milk and yogurt processing, feeding system, manure handling and retail; the upper floor host the covered cow garden supported by a manure cleaning robot and a milking robot along with various elements regarding animal welfare.

SITE FEATURES

- Typology: Harbor
- Batimetry: 12-18 m
- Water fluctuation: 2 m
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
484 m² (floor 22x22 m)
2000 m²(floors + cow

GEOMETRICAL LAYOUT
square

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Circular approach: reuse of leftover products, limited food transportation; regular controls of the water quality by the Municipality of Rotterdam.

Resource circularity
Grass and food waste re-used to feed animals; bio-digestor transforms waste in irrigation water and organic fertilizer; rain collection system.

Affordable and renewable energy efficiency
Solar farm of PV panels produces electricity and a combined heat and power (CHP) plant recovers wasted thermal energy for heating.

High levels of comfort and wellbeing
Polycarbonate ensures adequate lighting while guaranteeing thermal comfort; mobile wind shields protect cows and workers from rough and strong wind.

Economic feasibility
Low excercise cost (renewable energy production); low-cost materials.

REQUIREMENT COMPLIANCE

1. SAFETY

1.1.1.	1.2.1.	1.3.1	1.4.1.
1.1.2.	1.2.2.	1.3.2	1.4.2.
1.1.3.	1.2.3.	.	1.4.3.
	1.2.4.		1.4.4.
	1.2.5.		1.4.5.
	1.2.6.		1.4.6.
			1.4.7.

2. WELLBEING

2.1.1.	2.2.1.	2.3.1.	2.4.1.
2.1.2.	2.2.2.	2.3.2.	
2.1.3.	2.2.3.	2.3.3.	
	2.2.4.	2.3.4.	
2.5.1.	2.6.1.	2.7.1.	2.8.1.
2.5.2.	2.6.2.	2.7.2.	2.8.2.
2.5.3.	2.6.3.	2.7.3.	2.8.3.
			2.8.4.
			2.8.5.

3. USABILITY

3.1.1.	3.2.1.	3.3.1.
3.1.2.	3.2.2.	3.3.2.
3.1.3.	3.2.3.	
	3.2.4.	

4. MANAGEMENT

4.1.1.	4.2.1.	4.3.1.
4.1.2.	4.2.2.	4.3.2.
4.1.3.	4.2.3.	
	4.2.4.	
	4.2.5.	
	4.2.6.	
	4.2.7.	
	4.2.8.	
	4.2.9.	
	4.2.10	

5. INTEGRABILITY

5.1.1.	5.2.1.

6. ENVIRONMENTAL REGENERATION

6.1.1.	6.2.1.	6.3.1.	6.4.1.
6.1.2.	6.2.2.	6.3.2.	6.4.2.
6.1.3.	6.2.3.		
	6.2.4.		
	6.2.5.		
	6.2.6.		
	6.2.7.		

7. RATIONAL USE OF RESOURCES

7.1.1.	7.2.1.	7.3.1.	7.4.1.
7.1.2.	7.2.2.	7.3.2.	7.4.2.
		7.3.3.	7.4.3.
		7.3.4.	

8. BUOYANCY AND STABILITY

8.1.1.	8.2.1.	8.3.1.
8.1.2.	8.2.2.	8.3.2.
8.1.3.		8.3.3.
8.1.4.		

9. PLANT SYSTEM

9.1.1.	9.2.1.
9.1.2.	9.2.2.
9.1.3.	
9.1.4.	
9.1.5.	
9.1.6.	

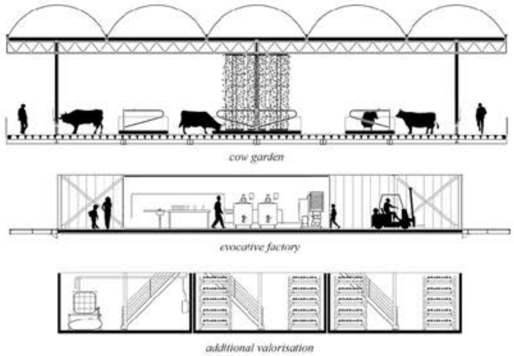
CONSTRUCTION COMPONENTS

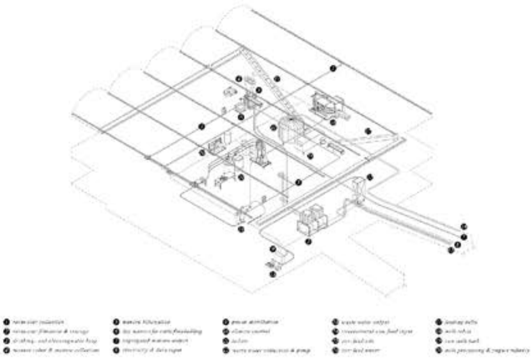
BUOYANT FOUNDATION
Three prefab concrete cellars are connected by bolted connections

LOAD BEARING STRUCTURE
Lightweight triple-stacked metal frame

CLADDING
Concrete (hull) + translucent polycarbonate + open

FIGURES (©Ruben Daio Kleimeer)





MANSA FLOATING HUB - MFS IV

● Mindelo Bay, São Vicente, Cape Verde

IDENTIFICATION DATA

ARCHITECT: **Kunlé Adeyemi (NLÉ)**

CLIENT: **Mansa Floating Hub**

DATE: **2021**

BUDGET: **Confidential**

ADVISORS: **JMP, CFA, SINA, KRJS, AISTER, Dykstra Naval Engineering, AECOM, OCF, Lucas Santos, Editson Viera**

Floating Music Hub, Mindelo (MFS™IV) (known as Mansa Floating Hub) is a cultural and creative platform based on NLÉ floating solution called Makoko Floating system (MFS). MFS is a lightweight, prefabricated, modular timber structure that can be easily assembled and disassembled. The equilateral triangle is an ideal shape for increasing stability and balance on water due to its relatively low center of gravity. It is designed to be flat-packed and relocated if needed.

Three platforms hosting a multipurpose live performance hall, a recording studio, and a food and beverage bar are arranged around an isolated triangular floating plaza that serves as an open public space. It is an improved and industrialized (fifth) iteration of the MFS system. Colorful polycarbonate on the vertical façades lighten up the indoor environment. The system floats on recycled plastic barrels in which a rainwater collection storage is integrated.

SITE FEATURES

- Typology: Bay
- Batimetry: 0 - 20 m
- Water fluctuation: ± 1,5 m
- Climate: BWh - Hot desert

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
779 m²

GEOMETRICAL LAYOUT
Triangular aggregation

MAIN OBJECTIVES

■ **Ecosystem preservation/regeneration**
Locally sourced materials. Designed to be flat packed and relocated with low emision transportation impact.

■ **Resource circularity**
Rain water collection storage integrated in the floating barrels.

□ **Affordable and renewable energy efficiency**

■ **High levels of comfort and wellbeing**
Colorful transparent facade lightens up interiors; cross ventilation and ventilated roof; shading devices; good heat insulation.

■ **Economic feasibility**
Low cost materials and construction process (prefabricated system); low maintenance.

REQUIREMENT COMPLIANCE

1. SAFETY

■■■■■
■□□□□

■ 1.1.1.	□ 1.2.1.	□ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	◩ 1.3.2	□ 1.4.2.
■ 1.1.3.	□ 1.2.3.	.	□ 1.4.3.
	◩ 1.2.4.		□ 1.4.4.
	■ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■■■■■
■■■□□

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	■ 2.3.3.	
	■ 2.2.4.	■ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	◩ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	◩ 2.7.2.	◩ 2.8.2.
■ 2.5.3.	■ 2.6.3.	□ 2.7.3.	⊠ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■■■■■
■■□□□

■ 3.1.1.	■ 3.2.1.	◩ 3.3.1.
□ 3.1.2.	■ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGEMENT

■■■■■
□□□□□

◩ 4.1.1.	■ 4.2.1.	■ 4.3.1.
◩ 4.1.2.	■ 4.2.2.	⊠ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	◩ 4.2.5.	
	■ 4.2.6.	
	⊠ 4.2.7.	
	□ 4.2.8.	
	□ 4.2.9.	
	⊠ 4.2.10	

5. INTEGRABILITY

■■■■■
■■□□□

◩ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■■■■■
□□□□□

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	□ 6.4.1.
■ 6.1.2.	◩ 6.2.2.	◩ 6.3.2.	□ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	□ 6.2.4.		
	◩ 6.2.5.		
	◩ 6.2.6.		
	□ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■■■■□
□□□□□

◩ 7.1.1.	■ 7.2.1.	□ 7.3.1.	□ 7.4.1.
■ 7.1.2.	□ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■■■■■
■■■□□

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
■ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
□ 8.1.4.		

9. PLANT SYSTEM

■■■■■
■■■□□

■ 9.1.1.	◩ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
□ 9.1.6.	

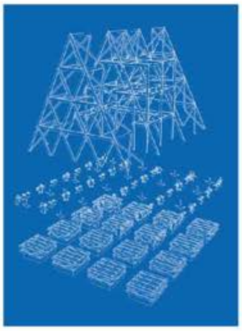
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Recycled plastic barrels

LOAD BEARING STRUCTURE
Timber A-frames braced by horizontal and diagonal crosspieces

CLADDING
Polycarbonate panels

FIGURES (©NLÈ)



JELLYFISH BARGE

● Manvicelli Canal, Pisa, Italy

IDENTIFICATION DATA

ARCHITECT: **PNAT + Studio Mobile**

CLIENT: **Tuscany Region for EXPO 2015**

DATE: **2014**

BUDGET: **10 000 €/m^2** (total 700 000 €/m^2)

ADVISOR: **Stefano Mancuso, UNIFI**

Jellyfish Barge is a modular floating greenhouse designed to be entirely self-sufficient in energy and water. It is an affordable, transportable, and replicable solution to grow food within cities using the extended hydrographic network. It combines a food production facility with a vital public space, providing both areas for economic activity and social interaction. It produces 1000-1500 edible plants grown monthly in a highly efficient hydroponic system. With no impact on existing land, water, and energy, it expands the capacity of the urban environment to provide food, social relationships, and urban quality. The installation comprises four greenhouse modules (70m^2) and one zip connection module. The connection module is the shared space for leisure, didactic, or market activities. The Jellyfish Barge imitates the transpiration process of plants and can produce fresh water from salty, brackish, or polluted water only by exploiting the sun's energy. It proves how low-cost technologies and simple available materials are not in contrast with highly efficient and sustainable solutions.

SITE FEATURES

- Typology: **Canal**
- Batimetry: **3-3,5 m**
- Water fluctuation: **± 40 cm**
- Climate: **Csa - Hot-summer mediterranean climate**

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
70 m^2

GEOMETRICAL LAYOUT
octagonal base

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Recycled materials (polyethylene drums); standard size components to reduce transportation CO_2 emissions; plants contribute to improving air quality.

Resource circularity
Rainwater collectionand reuse for irrigation; water extracted from water body and purified through solar distillation.

Affordable and renewable energy efficiency
PV panels integrated in the roof and small wind turbines generate enough energy for running the activities.

High levels of comfort and wellbeing
Adequate thermal and lighting conditions both for plants and users thanks to the ETFE membrane; good air quality thanks to plants that absorb CO_2.

Economic feasibility
Low cost technologies, affordable production process (modularity, standardization) and materials (available, low cost and recycled); energy self-sufficiency.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.
■ 1.1.2.
■ 1.1.3.

□ 1.2.1.
■ 1.2.2.
□ 1.2.3.
■ 1.2.4.
□ 1.2.5.
◩ 1.2.6.

□ 1.3.1
◩ 1.3.2
.

■ 1.4.1.
□ 1.4.2.
□ 1.4.3.
■ 1.4.4.
■ 1.4.5.
■ 1.4.6.
■ 1.4.7.

2. WELLBEING

■ 2.1.1.
■ 2.1.2.
■ 2.1.3.

■ 2.2.1.
■ 2.2.2.
□ 2.2.3.
■ 2.2.4.

◩ 2.3.1.
◩ 2.3.2.
◩ 2.3.3.
◩ 2.3.4.

■ 2.4.1.

■ 2.5.1.
■ 2.5.2.
■ 2.5.3.

■ 2.6.1.
■ 2.6.2.
■ 2.6.3.

■ 2.7.1.
■ 2.7.2.
■ 2.7.3.

■ 2.8.1.
◩ 2.8.2.
■ 2.8.3.
□ 2.8.4.
◩ 2.8.5.

3. USABILITY

■ 3.1.1.
■ 3.1.2.
◩ 3.1.3.

■ 3.2.1.
■ 3.2.2.
■ 3.2.3.
■ 3.2.4.

■ 3.3.1.
■ 3.3.2.

4. MANAGEMENT

■ 4.1.1.
■ 4.1.2.
■ 4.1.3.

■ 4.2.1.
■ 4.2.2.
◩ 4.2.3.
◩ 4.2.4.
■ 4.2.5.
■ 4.2.6.
■ 4.2.7.
■ 4.2.8.
□ 4.2.9.
◩ 4.2.10

■ 4.3.1.
◩ 4.3.2.

5. INTEGRABILITY

■ 5.1.1.

■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.
◩ 6.1.2.
■ 6.1.3.

■ 6.2.1.
◩ 6.2.2.
◩ 6.2.3.
■ 6.2.4.
◩ 6.2.5.
■ 6.2.6.
◩ 6.2.7.

■ 6.3.1.
■ 6.3.2.

■ 6.4.1.
■ 6.4.2.

7. RATIONAL USE OF RESOURCES

■ 7.1.1.
■ 7.1.2.

■ 7.2.1.
■ 7.2.2.

◩ 7.3.1.
□ 7.3.2.
■ 7.3.3.
◩ 7.3.4.

■ 7.4.1.
■ 7.4.2.
■ 7.4.3.

8. BUOYANCY AND STABILITY

■ 8.1.1.
■ 8.1.2.
■ 8.1.3.
□ 8.1.4.

◩ 8.2.1.
■ 8.2.2.

■ 8.3.1.
■ 8.3.2.
■ 8.3.3.

9. PLANT SYSTEM

■ 9.1.1.
■ 9.1.2.
■ 9.1.3.
■ 9.1.4.
■ 9.1.5.
◩ 9.1.6.

◩ 9.2.1.
■ 9.2.2.

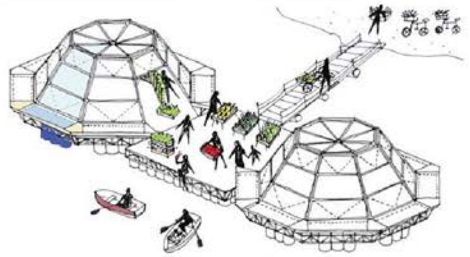
CONSTRUCTION COMPONENTS

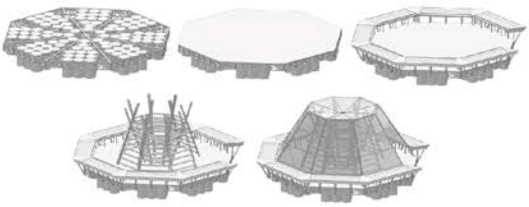
BUOYANT FOUNDATION
96 recycled empty polyethylene drums

LOAD BEARING STRUCTURE
Timber reticular beams along the octagonal perimeter and the pyramid radiuses with horizontal bracing beams

CLADDING
ETFE membrane

FIGURES (©PNAT)





MERIPAVILJONKI SEA RESTAURANT

● Eläintarhanlahti bay, Helsinki, Finland

IDENTIFICATION DATA

ARCHITECT: **Simo Freese Architects**

CLIENT: **Restaurant Kolmio group / Heimo Keskinen**

DATE: **2015 - 2019**

BUDGET: **Confidential**

ADVISOR: **Eva Knif, Anu Halme** (interior design), **Insinööritoimisto Leo Maaskola Oy, Henrik Finne** (HVAC), **A-Insinöörit Oy** (structure)

The floating restaurant Meripaviljonki, known as "Sea Pavilion," is Helsinki's first floating building to be opened to the public. It is conceived as a modern extension of the famous Workers House in the center of Helsinki. The waterfront site is widely visible around the bay and has historical significance.
The panoramic restaurant offers 200 seats overlooking the Eläintarhanlahti Bay. The restaurant includes a dining area, restrooms, a kitchens, a bar, technical and storage rooms, and an outdoor terrace. The architecture concept arises from the visitor experience: a long curving glass facade provides maximum window seats with a view of the sea.
The structural elements of steel are covered by one-fourth of copper, and the rest of the panels are in glass. The glazing has a mirror effect, which returns the image of the surrounding environment. The entrance to the building is either from the land pier or by boat from its own dock.

SITE FEATURES

- Typology: Bay
- Batimetry: 2 m
- Water fluctuation: ± 20 cm
- Climate: Dfb - Warm summer humid continental

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL
TOURISM | PRODUCTION | GREEN
CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
520 m²

GEOMETRICAL LAYOUT
free curved shape

MAIN OBJECTIVES

■ **Ecosystem preservation/regeneration**
The use of copper and glass for the façade is intended to reflect the surrounding water and integrate within the landscape.

■ **Resource circularity**
Passive strategies to increase the building's energy performance (double layer glass facade oriented south; ventilated roof; cross ventilation)

□ **Affordable and renewable energy efficiency**

■ **High levels of comfort and wellbeing**
Good thermal and lighting conditions thanks to the insulated glass facade which provides quality views; cross ventilation; outdoor terrace; ease of circulation.

■ **Economic feasibility**
Low operation costs (energy efficiency of building); low maintenance costs (durable materials).

REQUIREMENT COMPLIANCE

1. SAFETY

1.1.1. 1.1.2. 1.1.3.

1.2.1. 1.2.2. 1.2.3. 1.2.4. 1.2.5. 1.2.6.

1.3.1 1.3.2

1.4.1. 1.4.2. 1.4.3. 1.4.4. 1.4.5. 1.4.6. 1.4.7.

2. WELLBEING

2.1.1. 2.1.2. 2.1.3.

2.2.1. 2.2.2. 2.2.3. 2.2.4.

2.3.1. 2.3.2. 2.3.3. 2.3.4.

2.4.1.

2.5.1. 2.5.2. 2.5.3.

2.6.1. 2.6.2. 2.6.3.

2.7.1. 2.7.2. 2.7.3.

2.8.1. 2.8.2. 2.8.3. 2.8.4. 2.8.5.

3. USABILITY

3.1.1. 3.1.2. 3.1.3.

3.2.1. 3.2.2. 3.2.3. 3.2.4.

3.3.1. 3.3.2.

4. MANAGEMENT

4.1.1. 4.1.2. 4.1.3.

4.2.1. 4.2.2. 4.2.3. 4.2.4. 4.2.5. 4.2.6. 4.2.7. 4.2.8. 4.2.9. 4.2.10

4.3.1. 4.3.2.

5. INTEGRABILITY

5.1.1.

5.2.1.

6. ENVIRONMENTAL REGENERATION

6.1.1. 6.1.2. 6.1.3.

6.2.1. 6.2.2. 6.2.3. 6.2.4. 6.2.5. 6.2.6. 6.2.7.

6.3.1. 6.3.2.

6.4.1. 6.4.2.

7. RATIONAL USE OF RESOURCES

7.1.1. 7.1.2.

7.2.1. 7.2.2.

7.3.1. 7.3.2. 7.3.3. 7.3.4.

7.4.1. 7.4.2. 7.4.3.

8. BUOYANCY AND STABILITY

8.1.1. 8.1.2. 8.1.3. 8.1.4.

8.2.1. 8.2.2.

8.3.1. 8.3.2. 8.3.3.

9. PLANT SYSTEM

9.1.1. 9.1.2. 9.1.3. 9.1.4. 9.1.5. 9.1.6.

9.2.1. 9.2.2.

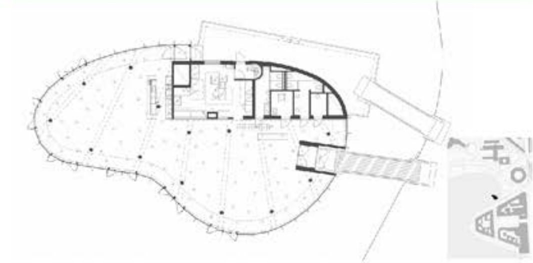
CONSTRUCTION COMPONENTS

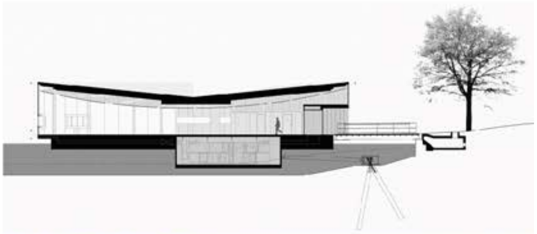
BUOYANT FOUNDATION
Concrete cast pontoon

LOAD BEARING STRUCTURE
Steel frame + stiffening glass beams + concrete slabs

CLADDING
Copper (1/4) + glass (3/4)

FIGURES (©AVP-Ilmakuvaus, ©EskoTuomisto, ©SimoFreese)





THEATER L'ÎLE Ô

17

Port Edouard-Herriot, Rhône, Lyon, France

IDENTIFICATION DATA

ARCHITECT: **Waterstudio.NL**

ADVISORS: **Studio DAP** (acoustic design + site monitor-

CLIENT: **PataDôme d'Irigny theatre, Voies Navigables de France (VNF), City and Metropolis of Lyon, Ministry of Culture**

DATE: **2022 2023**

BUDGET: **Confidential**

It is Europe's first floating theater and offers a hybrid cultural space permanently moored on the river Rhône in the city center of Lyon. The playful design and aggregation of six prismatic white volumes is articulated on three levels housing two performance halls (with 78 and 244 seats), dining area, artistic workshops, event area and a covered panoramic rooftop of 140 m². Given its major function, particular attention was paid to the acoustic comfort and sound quality. It is completeley accessible and circulation is ensured for all users (elevator).
Interior spaces (excluding the performance halls) are designed to be versatile modular spaces in order to be able to host a variety of complementary functions. A low-tech manually controlled ventilation system allows to avoid the use of air condioning

SITE FEATURES

- Typology: Harbor
- Batimetry: 1-16 m
- Water fluctuation: ± 1,1 m
- Climate: Cfa - Humid subtropical climate

SCALE

SINGLE UNIT

MULTI-UNIT

DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL

LEISURE RECREATIONAL

TERTIARY DIRECTIONAL

TOURISM

PRODUCTION

GREEN

CULTURAL EDUCATIONAL

COMMERCIAL

CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
1200 m²

GEOMETRICAL LAYOUT
Aggregation of cubes

MAIN OBJECTIVES

■ **Ecosystem preservation/regeneration**
Site monitoring prior to design; sustainable materials sourced locally.

■ **Resource circularity**
Water from the river is used to power the machines that allow the stage movement; passive strategies using sun, orientation and wind.

□ **Affordable and renewable energy efficiency**

■ **High levels of comfort and well-being**
Acoustic simulation studies; thermal comfort controlled by natural ventilation and by anoptimized temperature regulation system; quality sight lines from indoors.

■ **Economic feasibility**
Low operation cost (building energy performance; water-powered theatre machines.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	■ 1.2.1.	□ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	■ 1.3.2	■ 1.4.2.
■ 1.1.3.	■ 1.2.3.	.	■ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	□ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	■ 2.2.3.	■ 2.3.3.	
	■ 2.2.4.	■ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	□ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	◩ 2.7.2.	⧄ 2.8.2.
■ 2.5.3.	■ 2.6.3.	□ 2.7.3.	■ 2.8.3.
			⧄ 2.8.4.
			■ 2.8.5.

3. USABILITY

■ 3.1.1.	□ 3.2.1.	■ 3.3.1.
■ 3.1.2.	■ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGEMENT

◩ 4.1.1.	■ 4.2.1.	■ 4.3.1.
◩ 4.1.2.	■ 4.2.2.	◩ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	□ 4.2.8.	
	■ 4.2.9.	
	◩ 4.2.10	

5. INTEGRABILITY

□ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

◩ 6.1.1.	■ 6.2.1.	■ 6.3.1.	◩ 6.4.1.
◩ 6.1.2.	◩ 6.2.2.	■ 6.3.2.	□ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	□ 6.2.4.		
	◩ 6.2.5.		
	◩ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

◩ 7.1.1.	□ 7.2.1.	□ 7.3.1.	□ 7.4.1.
◩ 7.1.2.	□ 7.2.2.	□ 7.3.2.	■ 7.4.2.
		□ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
■ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
⧄ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	◩ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
⧄ 9.1.6.	

CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Reinforced concrete hull made by four hull beams (suspender beams)

LOAD BEARING STRUCTURE
Cross-Laminated Timber (CLT) structure

CLADDING
Lacquered steel sheets

FIGURES (©Waterstudio.NL)

FERRY TERMINAL

● Tasik Kenyir, Terengganu, Malesia

IDENTIFICATION DATA

ARCHITECT: **Bartels and Vedder**

ADVISORS: **Studio DAP** (acoustic design + site monitor-

CLIENT: **Cornerstone Asia**

DATE: **2019**

BUDGET: **Confidential**

This floating ferry terminal is situated in the largest artificial reservoir in Southeast Asia, Tasik Kenyir (or Kenyir Lake), and is conceived as the gateway to exploring the many attractions within the lake. With a footprint of over 5000 m², the terminal comprises six pavilion buildings connected by bridges. The main pavilion hosting the waiting area has a seating capacity of 500 passengers. The other pavilions house a ticket office, VIP area, banquet hall, and two food and beverage outlets with a dining area. The significant water level fluctuations of more than 15 meters within a year and 1 meter within 24 hours during the Monsoon required the design and engineering of a special patent for the floating sub-structure made of a concrete framing floor system on top of EPS bodies connected, creating a very large floating base. Traditional mooring piles would have been extremely expensive and not aesthetically pleasing during the dry season. For this reason, 100 units of tailor-made mooring systems were designed.

SITE FEATURES

- Typology: Harbor
- Batimetry: 1-16 m
- Water fluctuation: ± 1,1 m
- Climate: Cfa - Humid subtropical climate

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
5000 m²

GEOMETRICAL LAYOUT
Aggregation of domes

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Prefabricated building components madeof locally sourced materials.

Resource circularity
Passive strategies including maximizing heat gain through the façade cladding materials and natural ventilation by using the stack effect.

Affordable and renewable energy efficiency
Passive strategies ensure high building energy perfromance.

High levels of comfort and well-being
The PVC-polyester fabric ensures high levels of thermal comfort while allowing natural light into the terminal and providing shade from the sun.

Economic feasibility
Low maint cost (building energy performance); low maintenance cost (durable, and resistant).

REQUIREMENT COMPLIANCE

1. SAFETY

■■■■■
■■■□□

■ 1.1.1.	■ 1.2.1.	□ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	■ 1.3.2	□ 1.4.2.
■ 1.1.3.	■ 1.2.3.		■ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	□ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■■■■■
■■■□□

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	■ 2.2.3.	◩ 2.3.3.	
	■ 2.2.4.	◩ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	□ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	□ 2.7.2.	■ 2.8.2.
■ 2.5.3.	■ 2.6.3.	□ 2.7.3.	⧄ 2.8.3.
			⧄ 2.8.4.
			■ 2.8.5.

3. USABILITY

■■■■■
■■■■□

■ 3.1.1.	■ 3.2.1.	◩ 3.3.1.
■ 3.1.2.	■ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGEMENT

■■■■■
■■■□□

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
◩ 4.1.2.	■ 4.2.2.	■ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	⧄ 4.2.8.	
	■ 4.2.9.	
	◩ 4.2.10	

5. INTEGRABILITY

■■■■■
■■■■■

■ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■■■■■
■□□□□

■ 6.1.1.	■ 6.2.1.	◩ 6.3.1.	■ 6.4.1.
⧄ 6.1.2.	◩ 6.2.2.	◩ 6.3.2.	□ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	□ 6.2.4.		
	◩ 6.2.5.		
	■ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■■■■□
□□□□□

◩ 7.1.1.	□ 7.2.1.	■ 7.3.1.	□ 7.4.1.
■ 7.1.2.	□ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■■■■■
■■■□□

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
■ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
⧄ 8.1.4.		

9. PLANT SYSTEM

■■■■■
■■■□□

■ 9.1.1.	◩ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
⧄ 9.1.6.	

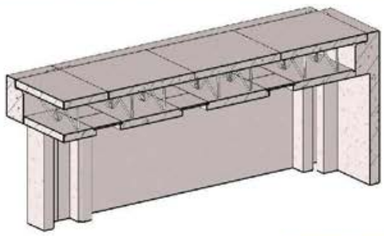
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Reinforced concrete hull made by four hull beams (suspender

LOAD BEARING STRUCTURE
Cross-Laminated Timber (CLT) structure

CLADDING
Lacquered steel sheets

FIGURES (©Bartels and Vedder)



BADEMASCHINEN FLOATING SAUNA

Oslo harbor, Norway

IDENTIFICATION DATA

ARCHITECT: **ACT! Architecture**

CLIENT: **Oslo Badstuforening**

DATE: **2021**

BUDGET: **Confidential**

ADVISOR: **Borhaven Arkitekter, Fjord Ingeniører**

The floating sauna, inspired by the classic Norwegian sea bath houses (Sjøbadehus), consists of two saunas (capable of accommodating up to 16 people each), two towers with changing rooms, a diving spot, and access from Langkaia. The different elements form a small square where a fire is lit in the winter. The castle-like layout and the color scheme of red and yellow are a nod to the proximity to the Akershus fortress. Instead, other elements pay homage to the canon of postmodernist architecture.
The supporting structure and roof are in red royal-treated spruce, and the external walls consist of reused teak windows where the glass panes have been replaced with oiled plywood.
The sauna was built partially by volunteers, and the process from ideation to completion was only eight months.
The Oslo Sauna Association, a non-profit formed in 2016 by anarchists and diplomats from the Ministry of Foreign Affairs ice bathing club, runs the sauna.

SITE FEATURES

- Typology: Harbor
- Batimetry: 6 - 10 m
- Water fluctuation: ± 50 cm
- Climate: Dfb - Warm-summer humid continental climate

SCALE

SINGLE UNIT — MULTI-UNIT — DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL — LEISURE RECREATIONAL — TERTIARY DIRECTIONAL

TOURISM — PRODUCTION — GREEN

CULTURAL EDUCATIONAL — COMMERCIAL — CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
90 m²

GEOMETRICAL LAYOUT
Aggregation of squares and rectangles

MAIN OBJECTIVES

- ■ **Ecosystem preservation/regeneration**
  Most components are made of re-used materials.Oil treatment given to decking and roof is environmentally friendly. Colors take inspiration from nearby fortress.
- ■ **Resource circularity**
  Most components are made of re-used materials.
- □ **Affordable and renewable energy efficiency**
- ■ **High levels of comfort and well-being**
  Good wood fiber insulation ensures different levels of thermal comfort; central square ias a social meeting place; layout according to quality view sights. environments are arranged in a pin-wheel layout in order to give the saunas and the outdoor areas the desired orientation towards the city and the fjord.
- ■ **Economic feasibility**
  Low construction cost (left-over and low cost materials, partially built by volunteers); the whole process (ideation to construction) took only eight months.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	▨ 1.2.1.	□ 1.3.1	◩ 1.4.1.
■ 1.1.2.	■ 1.2.2.	◩ 1.3.2	■ 1.4.2.
■ 1.1.3.	□ 1.2.3.	.	■ 1.4.3.
	◩ 1.2.4.		■ 1.4.4.
	□ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			◩ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	◩ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	◩ 2.3.2.	
■ 2.1.3.	▨ 2.2.3.	▨ 2.3.3.	
	■ 2.2.4.	▨ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	■ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	■ 2.7.2.	■ 2.8.2.
■ 2.5.3.	■ 2.6.3.	■ 2.7.3.	▨ 2.8.3.
			▨ 2.8.4.
			■ 2.8.5.

3. USABILITY

□ 3.1.1.	◩ 3.2.1.	■ 3.3.1.
□ 3.1.2.	◩ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGE-

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
▨ 4.1.2.	■ 4.2.2.	■ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	□ 4.2.8.	
	■ 4.2.9.	
	▨ 4.2.10	

5. INTEGRABILITY

■ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	◩ 6.4.1.
■ 6.1.2.	◩ 6.2.2.	■ 6.3.2.	□ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	□ 6.2.4.		
	◩ 6.2.5.		
	□ 6.2.6.		
	▨ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■ 7.1.1.	□ 7.2.1.	■ 7.3.1.	□ 7.4.1.
■ 7.1.2.	□ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
□ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
▨ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	■ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
▨ 9.1.6.	

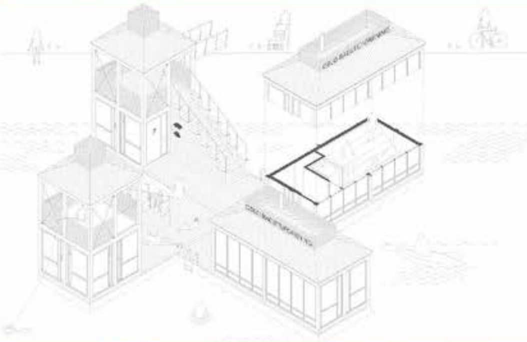
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Concrete hull

LOAD BEARING STRUCTURE
Timber structure braced with thin steel rods

CLADDING
Oiled lywood in recycled window frames

FIGURES (©Rebecca Zeller)



BROCKHOLES VISITOR CENTRE

● Brockholes Wetland, Lancashire, United Kingdom

IDENTIFICATION DATA

ARCHITECT: **Adamkhan Arkitekter**

CLIENT: **Lancashire Wildlife Trust**

DATE: **2008 - 2012**

BUDGET: **3 570 €/m²** (total 5 000 000€)

ADVISOR: **Price & Myers, Jonathan Cook Landscape Architects, Jackson Coles, Max Fordham**

The Brockholes Visitor Centre consists of a cluster of 5 single-story buildings hosting a conference center, a restaurant, a shop, a gallery, an activity room, and restrooms. The shallow lake in the wetlands was deepened to allow sufficient underwater volume for buoyancy and to allow workboat access. The cluster of floating thatched, pyramidal-shaped buildings evokes the vernacular farm villages of the Tigres-Euphrates Marsh Arabs.
A single 65m x 42m floating structural pontoon supports a series of buildings and linked courtyards. The sequence of volumes of different heights and shapes creates routes and small squared places of transit and leisure. The building is BREEAM Outstanding accredited thanks to the wide range of environmentally sustainable features (sustainable and locally sourced materials, renewable energy sources, rainwater collection, and wastewater treatment).

SITE FEATURES

- Typology: Wetland
- Batimetry: 30 cm under the structure
- Water fluctuation: ± 4 m
- Climate: Cfb - Temperate oceanic climate

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
1400 m²

GEOMETRICAL LAYOUT
Rectangular base

MAIN OBJECTIVES

- **Ecosystem preservation/regeneration**
  Sustainable low-embodied energy materials; precision engineered construction process to reduce waste; off-site prefabrication to avoid wildlife disturbance.
- **Resource circularity**
  Waste treatment system; Rainwater collection and reuse; passive strategies exploiting sun and wind.
- **Affordable and renewable energy efficiency**
  High building energy perfromance thanks to passive strategies (stack effect, thermal insulation and air tightness of cladding), heat pump and PV panels.
- **High levels of comfort and well-being**
  The skin (SIPs) along with sprayed recycled newspaper insulation contributes to a high level of insulation and air tightness acoustic damping.
- **Economic feasibility**
  Low-cost materials (thermal and acustic inulation); precision engineered construction process.

REQUIREMENT COMPLIANCE

1. SAFETY

1.1.1.	1.2.1.	1.3.1	1.4.1.
1.1.2.	1.2.2.	1.3.2	1.4.2.
1.1.3.	1.2.3.		1.4.3.
	1.2.4.		1.4.4.
	1.2.5.		1.4.5.
	1.2.6.		1.4.6.
			1.4.7.

2. WELLBEING

2.1.1.	2.2.1.	2.3.1.	2.4.1.
2.1.2.	2.2.2.	2.3.2.	
2.1.3.	2.2.3.	2.3.3.	
	2.2.4.	2.3.4.	
2.5.1.	2.6.1.	2.7.1.	2.8.1.
2.5.2.	2.6.2.	2.7.2.	2.8.2.
2.5.3.	2.6.3.	2.7.3.	2.8.3.
			2.8.4.
			2.8.5.

3. USABILITY

3.1.1.	3.2.1.	3.3.1.
3.1.2.	3.2.2.	3.3.2.
3.1.3.	3.2.3.	
	3.2.4.	

4. MANAGEMENT

4.1.1.	4.2.1.	4.3.1.
4.1.2.	4.2.2.	4.3.2.
4.1.3.	4.2.3.	
	4.2.4.	
	4.2.5.	
	4.2.6.	
	4.2.7.	
	4.2.8.	
	4.2.9.	
	4.2.10	

5. INTEGRABILITY

5.1.1.	5.2.1.

6. ENVIRONMENTAL REGENERATION

6.1.1.	6.2.1.	6.3.1.	6.4.1.
6.1.2.	6.2.2.	6.3.2.	6.4.2.
6.1.3.	6.2.3.		
	6.2.4.		
	6.2.5.		
	6.2.6.		
	6.2.7.		

7. RATIONAL USE OF RESOURCES

7.1.1.	7.2.1.	7.3.1.	7.4.1.
7.1.2.	7.2.2.	7.3.2.	7.4.2.
		7.3.3.	7.4.3.
		7.3.4.	

8. BUOYANCY AND STABILITY

8.1.1.	8.2.1.	8.3.1.
8.1.2.	8.2.2.	8.3.2.
8.1.3.		8.3.3.
8.1.4.		

9. PLANT SYSTEM

9.1.1.	9.2.1.
9.1.2.	9.2.2.
9.1.3.	
9.1.4.	
9.1.5.	
9.1.6.	

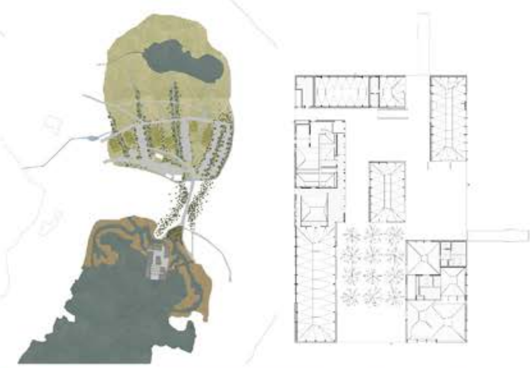
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Concrete cast around large polystyrene void blocks

LOAD BEARING STRUCTURE
V-shaped glulam portal frames (braced with diagonal timber

CLADDING
Timber Structural Insulated Panels (SIP)

FIGURES (©Ioana Marinescu, ©Adam Khan)



MARINA AZZURRA RESORT

● Tagliamento River, Lignano Sabbiadoro,Udine, Italy

IDENTIFICATION DATA

ARCHITECT: **Frappa edilizia**

CLIENT: **Europa Group Srl**

DATE: **2018 - 2019**

BUDGET: **Confidential**

Marina Azzurra Resort is an innovative tourist complex consisting of 88 floating houses in Lignano Sabbiadoro, on the left bank of the Tagliamento River. The houses are registered and certified as boats and are completed by common areas dedicated to leisure, swimming pools, kiosks, car parks, and cycle/pedestrian paths. Twenty-nine houses are inside a quiet dock; the other 59 are moored along the river bank. The houseboats are on two levels and have a maximum capacity of 6 people. The sloping roof, which turns into a façade, recalls the vernacular local houses of the lagoon fisherman, known as " casoni".
The use of the latest-generation technologies and modern control systems ensures maximum energy efficiency and smart and sustainable management of the house's design, construction, management, and maintenance process.
Each house has a living room, two bedrooms, a bathroom, a storage space, an outdoor terrace of 6,50 m² on the main deck (lower floor), a dining room, a kitchenette, and another outdoor terrace of 12 m² on the upper deck.

SITE FEATURES

- Typology: River and Lagoon
- Batimetry: 2 -3 m
- Water fluctuation: ± 30-40 cm
- Climate: Cfa - Humid subtropical climate

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
65 m²

GEOMETRICAL LAYOUT
Rectangular base

MAIN OBJECTIVES

■ **Ecosystem preservation/regeneration**
The sloping roof integrates in the landscape (similar to vernacular local lagoon fisherman houses); assembled on dry dock without disturbing natural life.

☐ **Resource circularity**

☐ **Affordable and renewable energy efficiency**

■ **High levels of comfort and wellbeing**
Thermal comfort is guaranteedthrough adequate insulation and windows as ell as mechanichal cooling and heating; quality views towards the river and delta.

■ **Economic feasibility**
Prefabricated components. The large number of standardized houses largely reduces the cost of the single housing unit.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	■ 1.2.1.	□ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	■ 1.3.2	■ 1.4.2.
■ 1.1.3.	■ 1.2.3.	.	■ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	□ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■ 2.1.1.	◩ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	⧄ 2.3.3.	
	■ 2.2.4.	⧄ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	■ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	□ 2.7.2.	■ 2.8.2.
■ 2.5.3.	■ 2.6.3.	□ 2.7.3.	■ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■ 3.1.1.	□ 3.2.1.	■ 3.3.1.
□ 3.1.2.	□ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGEMENT

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
⧄ 4.1.2.	■ 4.2.2.	◩ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	□ 4.2.8.	
	■ 4.2.9.	
	⧄ 4.2.10	

5. INTEGRABILITY

□ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	□ 6.4.1.
⧄ 6.1.2.	◩ 6.2.2.	□ 6.3.2.	□ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	□ 6.2.4.		
	◩ 6.2.5.		
	◩ 6.2.6.		
	■ 6.2.7.		

7. RATIONAL USE OF RESOURCES

◩ 7.1.1.	□ 7.2.1.	◩ 7.3.1.	□ 7.4.1.
■ 7.1.2.	□ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	◩ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
■ 8.1.2.	◩ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
⧄ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	◩ 9.2.1.
■ 9.1.2.	⧄ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
□ 9.1.6.	

CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Fibreglass pontoon

LOAD BEARING STRUCTURE
Steel frame

CLADDING
Sloping roof facades in plastic straw + fiberglass panels on short sides

FIGURES (©Frappaedilizia, ©Marina Azzurra)

AR-CHE FLOATING HOMES

● Geierswalder Lake, Lusatia, Germany

IDENTIFICATION DATA

ARCHITECT: **WilDesign**

CONTRACTOR: **Thomas Wilde**

DATE: **2009**

BUDGET: **3 570 €/m²** (total 5 000 000€)

ADVISOR: **AUTARTEC consortium (Brandenburgische Technische Universitaet BTU + Institute of Floating Architecture IfSB)**

The German reunification marked the end of the open-cast mining industry in the Lower Lusatia region, bringing forth a new lake landscape that fundamentally changed the face of the region. With the IBA (Internationale Bauausstellungen) vision for floating architecture, the mining holes were flooded to become artificial lakes.

The two-story Ar-che Aqua Floathome is the first of twenty modular floating houses in the Lusatian Lake District. Three façades are almost entirely glazed to provide a stunning lake view. The fourth façade features a curved roof to protect the house from harsh winds and weather.

The house is not entirely water-locked, as underwater cables allow inhabitants to enjoy fresh water, plumbing, electricity, and Internet conveniences. The self-supporting structure allows complete freedom in terms of interior layout.

SITE FEATURES

- Typology: Lake
- Batimetry: 20 m
- Water fluctuation: 10 - 20 cm
- Climate: Continental climate - Warm summer (or Hemiboreal climate)

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
80 - 220 m²

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Efficient insulation and renewable energy systems. Outdoor artificial lighting is oriented upwards to avoid disturbing the surrounding natural environment.

Resource circularity
A variety of energy efficient strategies are employed to reduce overall energy use.

Affordable and renewable energy efficiency
Solar panels are integrated on the roof when the orientation is optimal for maximizing solar radiation; energy efficient strategies to limit energy use.

High levels of comfort and wellbeing
Volume and orientation are designed to protect the house from wind and harsh weather. High levels of thermal, acustic and visual comfort are ensured.

Economic feasibility
Low maintenance is required; prefabricated and easily available building components.

REQUIREMENT COMPLIANCE

1. SAFETY

■■■■■
■■■■□

■ 1.1.1.	⧄ 1.2.1.	■ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	■ 1.3.2	■ 1.4.2.
■ 1.1.3.	□ 1.2.3.	.	■ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	■ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		◩ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■■■■■
■■■□□

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	⧄ 2.3.3.	
	■ 2.2.4.	⧄ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	◩ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	□ 2.7.2.	■ 2.8.2.
■ 2.5.3.	■ 2.6.3.	◩ 2.7.3.	■ 2.8.3.
			□ 2.8.4.
			■ 2.8.5.

3. USABILITY

■■■■■
■■■□□

■ 3.1.1.	◩ 3.2.1.	■ 3.3.1.
□ 3.1.2.	■ 3.2.2.	■ 3.3.2.
◩ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGEMENT

■■■■■
■■□□□

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
⧄ 4.1.2.	■ 4.2.2.	◩ 4.3.2.
■ 4.1.3.	◩ 4.2.3.	
	◩ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	⧄ 4.2.8.	
	■ 4.2.9.	
	⧄ 4.2.10	

5. INTEGRABILITY

■■■■■
■■■■■

■ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■■■■■
■□□□□

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	■ 6.4.1.
⧄ 6.1.2.	◩ 6.2.2.	■ 6.3.2.	□ 6.4.2.
■ 6.1.3.	◩ 6.2.3.		
	□ 6.2.4.		
	◩ 6.2.5.		
	◩ 6.2.6.		
	◩ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■■■■□
□□□□□

◩ 7.1.1.	□ 7.2.1.	◩ 7.3.1.	◩ 7.4.1.
■ 7.1.2.	□ 7.2.2.	□ 7.3.2.	□ 7.4.2.
		□ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■■■■■
■■■□□

■ 8.1.1.	◩ 8.2.1.	■ 8.3.1.
■ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
⧄ 8.1.4.		

9. PLANT SYSTEM

■■■■■
■■■■□

■ 9.1.1.	◩ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
◩ 9.1.6.	

CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Steel pontoon

LOAD BEARING STRUCTURE
Self-supporting modular aluminum and steel frame and roof

CLADDING
Glazed facades (three sides) and steel envelope and roof

FIGURES (©RainerWeisflog, ©NadaQuenzel, ©Steeltec37)

DD16

● Moscow, Russia

IDENTIFICATION DATA

ARCHITECT: **BIO-architects**

CLIENT: **Private owner**

DATE: **2016**

BUDGET: **Confidential**

ADVISOR: **Fabbrica DublDom, ECOVOLT, ElastoKAM, Nuprotec, ULTRALAM**

The DD16 is a prototype of a modular compact house that was designed for installation in remote places and extreme conditions. One of the main design challenges was to reduce weight as much as possible without having to lose strength. Therefore, the weight of every detail is taken into account. The house consists of 2 lightweight yet resistant prefabricated modules in laminated timber with milled ports to reduce the overall weight and protected by an exterior finishing in aluminum sheets. The building is designed to be easily transported and relocated elsewhere. Despite the very small dimensions, the house provides all comforts and is almost entirely self-sufficient: large glazing and a significant amount of light visually increase the space; some furniture can be transformed or folded; the wind turns the house, and the view constantly changes. The house is designed to be affordable. It is made from relatively inexpensive materials. It is prefabricated and it can be promptly installed on site and is easily and quickly movable from place to place.

SITE FEATURES

- Typology: Lake
- Batimetry: 3-6 m
- Water fluctuation: 10-20 cm
- Climate: Dfb - Warm-summer humid continental climate

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
16 m² (indoor)
7 m² (outdoor)

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

Ecosystem preservation/regeneration
The glass facade as well as the aluminum cladding reflect the natural environment. Building components are made of materials that are easy to reuse.

Resource circularity
Solar power for electricity; water from the lake for domestic use; ecological bio-toilet.

Affordable and renewable energy efficiency
Compact volume without protrusions, triple-glazed large glazing facing south, solar energy for heating and lighting, high performance insulation.

High levels of comfort and wellbeing
View to water; ventilation; presence of green for biofilia and bioclimatic effect; thick layer of insulation to meet Passivhaus standards; triple-glazed windows.

Economic feasibility
The house is designed to be affordable: it is made from relatively inexpensive materials and can be built quickly and easily.

REQUIREMENT COMPLIANCE

1. SAFETY

■■■■■ ■■□□□

- ■ 1.1.1.
- ■ 1.1.2.
- ■ 1.1.3.
- □ 1.2.1.
- ■ 1.2.2.
- □ 1.2.3.
- ■ 1.2.4.
- □ 1.2.5.
- □ 1.2.6.
- □ 1.3.1
- ■ 1.3.2
- □ 1.4.1.
- ■ 1.4.2.
- ■ 1.4.3.
- ■ 1.4.4.
- ■ 1.4.5.
- ■ 1.4.6.
- ■ 1.4.7.

2. WELLBEING

■■■■■ ■□□□□

- ■ 2.1.1.
- ■ 2.1.2.
- ■ 2.1.3.
- ■ 2.2.1.
- ■ 2.2.2.
- □ 2.2.3.
- □ 2.2.4.
- ■ 2.3.1.
- ■ 2.3.2.
- ▨ 2.3.3.
- □ 2.3.4.
- ■ 2.4.1.
- □ 2.5.1.
- ▨ 2.5.2.
- ■ 2.5.3.
- ■ 2.6.1.
- ■ 2.6.2.
- ■ 2.6.3.
- ■ 2.7.1.
- □ 2.7.2.
- □ 2.7.3.
- ■ 2.8.1.
- ■ 2.8.2.
- ▨ 2.8.3.
- ▨ 2.8.4.
- ■ 2.8.5.

3. USABILITY

■■■■■ ■■□□□

- □ 3.1.1.
- □ 3.1.2.
- □ 3.1.3.
- ■ 3.2.1.
- ■ 3.2.2.
- ■ 3.2.3.
- ■ 3.2.4.
- ■ 3.3.1.
- ■ 3.3.2.

4. MANAGEMENT

■■■■■ ■■■□□

- ■ 4.1.1.
- ■ 4.1.2.
- ■ 4.1.3.
- ■ 4.2.1.
- ■ 4.2.2.
- ▨ 4.2.3.
- ■ 4.2.4.
- ■ 4.2.5.
- ■ 4.2.6.
- ■ 4.2.7.
- □ 4.2.8.
- ■ 4.2.9.
- ▨ 4.2.10
- ■ 4.3.1.
- ■ 4.3.2.

5. INTEGRABILITY

■■■■■ ■■■■■

- ■ 5.1.1.
- ■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■■■■■ ■□□□□

- ■ 6.1.1.
- ▨ 6.1.2.
- ■ 6.1.3.
- ■ 6.2.1.
- ▨ 6.2.2.
- ▨ 6.2.3.
- □ 6.2.4.
- ▨ 6.2.5.
- ▨ 6.2.6.
- ■ 6.2.7.
- ■ 6.3.1.
- ■ 6.3.2.
- ■ 6.4.1.
- □ 6.4.2.

7. RATIONAL USE OF RESOURCES

■■■■■ ■■■■□

- ■ 7.1.1.
- ■ 7.1.2.
- ■ 7.2.1.
- ▨ 7.2.2.
- ■ 7.3.1.
- ■ 7.3.2.
- ■ 7.3.3.
- ■ 7.3.4.
- ■ 7.4.1.
- ▨ 7.4.2.
- ■ 7.4.3.

8. BUOYANCY AND STABILITY

■■■■■ ■■■□□

- ■ 8.1.1.
- ■ 8.1.2.
- ■ 8.1.3.
- ▨ 8.1.4.
- ■ 8.2.1.
- ■ 8.2.2.
- ■ 8.3.1.
- ■ 8.3.2.
- □ 8.3.3.

9. PLANT SYSTEM

■■■■■ ■■■■■

- ■ 9.1.1.
- ■ 9.1.2.
- ■ 9.1.3.
- ■ 9.1.4.
- ■ 9.1.5.
- ■ 9.1.6.
- ■ 9.2.1.
- ■ 9.2.2.

CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
concrete modular semi cylindrical blocks on which a steel horizontal grid is based

LOAD BEARING STRUCTURE
Highly resisteant laminated veneer lumber (LVL) with milled ports

CLADDING
Aluminum sandwich panel (polyurethane foam insulation)

FIGURES (© BIO-architects)

ANTHÉNEA

Marina of Doha, Qatar

IDENTIFICATION DATA

ARCHITECT: **Jean-Michel Ducancelle + Jacques-Antoine Cesbron**
CLIENT: **Anthenea SAS + Triple Trend Design House**

DATE: **2019** (2022 in Doha)

BUDGET: **14 1000 €/m²**

It is a luxury floating circular-shaped capsule equipped with high-end facilities. It features a kitchenette, a living area, a bedroom, a circular tub filled with fresh or seawater, and a solarium area on the upper floor overlooking the sea. Anthenea is built and delivered with boat certification Category C for "sheltered water". Its spherical shape is based on the principle of 'surface tension,' which is the optimal form for resistance to extreme conditions in the water.
It is designed to be energy-independent. It is powered by five south-facing rooftop solar panels and silent electric engines. It is equipped with its own water and waste treatment systems. It features an energy sensor dome that meets the electrical and hot water needs.
The pod is designed to easily expand in a network of connected pods hosting several function needs, ranging from an event space to a spa room.

SITE FEATURES

- Typology: Bay
- Batimetry: 0-4 m
- Water fluctuation: 60 m
- Climate: BWh - Hot desert climate

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
36 m² (indoor)

GEOMETRICAL LAYOUT
circular

MAIN OBJECTIVES

- **Ecosystem preservation/regeneration**
It is made entirely of recyclable materials; the sand-screw anchoring system doesn't damage the underwater ecosystem; silent plant system machinery.

- **Resource circularity**
It is powered by solar energy; all waste is treated on board.

- **Affordable and renewable energy efficiency**
The PV panels are installed on a motorized dome to take advantage of the sun rays; a home automation system reduces energy consumption.

- **High levels of comfort and well-being**
360° view from the inside of the capsule; transparent panels for underwater view; smart motorized roof for shading and wind protection.

- **Economic feasibility**

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	■ 1.2.1.	□ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	◪ 1.3.2	■ 1.4.2.
■ 1.1.3.	□ 1.2.3.	.	■ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	□ 1.2.5.		■ 1.4.5.
	□ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	◪ 2.3.3.	
	■ 2.2.4.	◪ 2.3.4.	
◪ 2.5.1.	■ 2.6.1.	■ 2.7.1.	■ 2.8.1.
◪ 2.5.2.	■ 2.6.2.	□ 2.7.2.	■ 2.8.2.
■ 2.5.3.	■ 2.6.3.	□ 2.7.3.	■ 2.8.3.
			◪ 2.8.4.
			■ 2.8.5.

3. USABILITY

□ 3.1.1.	□ 3.2.1.	■ 3.3.1.
□ 3.1.2.	◪ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGEMENT

□ 4.1.1.	■ 4.2.1.	■ 4.3.1.
■ 4.1.2.	◪ 4.2.2.	◪ 4.3.2.
■ 4.1.3.	◪ 4.2.3.	
	◪ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	■ 4.2.8.	
	■ 4.2.9.	
	◪ 4.2.10	

5. INTEGRABILITY

□ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	■ 6.4.1.
□ 6.1.2.	■ 6.2.2.	□ 6.3.2.	□ 6.4.2.
■ 6.1.3.	■ 6.2.3.		
	□ 6.2.4.		
	■ 6.2.5.		
	◪ 6.2.6.		
	■ 6.2.7.		

7. RATIONAL USE OF RESOURCES

□ 7.1.1.	□ 7.2.1.	◪ 7.3.1.	■ 7.4.1.
■ 7.1.2.	□ 7.2.2.	■ 7.3.2.	□ 7.4.2.
		■ 7.3.3.	◪ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◪ 8.2.1.	■ 8.3.1.
□ 8.1.2.	■ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
■ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	■ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
■ 9.1.6.	

CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
Polycarbonate exterior hull

LOAD BEARING STRUCTURE
Fiberglass structure

CLADDING
Fiberglass structure

FIGURES (© Anthénea)

BOTEL 2.0

Porto Ceresio, Lugano Lake, Varese, Italy

IDENTIFICATION DATA

ARCHITECT: **Gaetano Gucciardo (Il Laboratorio SA)**

CLIENT: **Botel Diffuso dei Laghi srl**

DATE: **2018**

BUDGET: **2500 €/m^2**

Botel 2.0 is conceived as a diffuse hotel on the Lugano Lake in Porto Ceresio. Only one unit has been designed for the moment, but the development involves the construction of 3 new units connected by a central square. The accommodation offer can be contextualized within the sector of experiential tourism and, more particularly, in the biophilic one. The unit is closed-cycle, off-grid, and has no atmospheric or water emissions. It is powered by photovoltaics and micro-wind turbines and is provided with phyto-depuration and evapotraspiration systems for water management and reuse. It can be located anywhere, and the design follows the principle of total reversibility. Particular attention was paid to the LCA of the building in the design phase. Although the housing unit is registered as a navigation unit - since there is no other way to obtain legal permits or authorizations - it meets the comfort and safety standards for buildings on land. The housing unit is equipped with a home automation management (stand-alone) system to optimize consumption and comfort. Each house has a living room, two bedrooms, a bathroom, a storage space, an outdoor terrace of 6,50 m^2 on the main deck, a dining room, a kitchenette, and another outdoor terrace of 12 m^2 on the upper deck.

SITE FEATURES

- Typology: Lake
- Batimetry: 3-6 m
- Water fluctuation: 140 cm
- Climate: Cfb - Oceanic climate - Marine west coast

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
60 m^2 (per unit)

GEOMETRICAL LAYOUT
rectangular

MAIN OBJECTIVES

Ecosystem preservation/regeneration
Zero emissions; Locally sourced, recycled or recyclable materials; natural colors contribute to integrating the building in the environment.; hidden PV panels.

Resource circularity
Energy self sufficient (solar and wind energy producion); closed-cycle water purification system; sewage management system.

Affordable and renewable energy efficiency
It is not connected to the on land electric grid thanks to photovoltaic panels and two micro wind turbins; efficiency is moniotred by a domotic system.

High levels of comfort and well-being
High thermal comfort standard (compliant with on land building regulations); outdoor spaces to interact with nature; garden for phytodepuration.

Economic feasibility
No energy consumption; prefabricated low cost building components; low maintenance costs.

REQUIREMENT COMPLIANCE

1. SAFETY

■ 1.1.1.	□ 1.2.1.	■ 1.3.1	■ 1.4.1.
■ 1.1.2.	■ 1.2.2.	■ 1.3.2	■ 1.4.2.
■ 1.1.3.	□ 1.2.3.		■ 1.4.3.
	■ 1.2.4.		■ 1.4.4.
	□ 1.2.5.		■ 1.4.5.
	■ 1.2.6.		■ 1.4.6.
			■ 1.4.7.

2. WELLBEING

■ 2.1.1.	■ 2.2.1.	■ 2.3.1.	■ 2.4.1.
■ 2.1.2.	■ 2.2.2.	■ 2.3.2.	
■ 2.1.3.	□ 2.2.3.	◪ 2.3.3.	
	■ 2.2.4.	◪ 2.3.4.	
■ 2.5.1.	■ 2.6.1.	■ 2.7.1.	■ 2.8.1.
■ 2.5.2.	■ 2.6.2.	□ 2.7.2.	■ 2.8.2.
■ 2.5.3.	■ 2.6.3.	■ 2.7.3.	■ 2.8.3.
			◪ 2.8.4.
			■ 2.8.5.

3. USABILITY

■ 3.1.1.	■ 3.2.1.	◪ 3.3.1.
■ 3.1.2.	◪ 3.2.2.	■ 3.3.2.
■ 3.1.3.	■ 3.2.3.	
	■ 3.2.4.	

4. MANAGE-

■ 4.1.1.	■ 4.2.1.	■ 4.3.1.
◪ 4.1.2.	■ 4.2.2.	■ 4.3.2.
■ 4.1.3.	■ 4.2.3.	
	■ 4.2.4.	
	■ 4.2.5.	
	■ 4.2.6.	
	■ 4.2.7.	
	■ 4.2.8.	
	■ 4.2.9.	
	■ 4.2.10	

5. INTEGRABILITY

■ 5.1.1.	■ 5.2.1.

6. ENVIRONMENTAL REGENERATION

■ 6.1.1.	■ 6.2.1.	■ 6.3.1.	■ 6.4.1.
■ 6.1.2.	◪ 6.2.2.	■ 6.3.2.	◪ 6.4.2.
■ 6.1.3.	■ 6.2.3.		
	◪ 6.2.4.		
	◪ 6.2.5.		
	■ 6.2.6.		
	◪ 6.2.7.		

7. RATIONAL USE OF RESOURCES

■ 7.1.1.	■ 7.2.1.	◪ 7.3.1.	■ 7.4.1.
■ 7.1.2.	□ 7.2.2.	■ 7.3.2.	□ 7.4.2.
		■ 7.3.3.	■ 7.4.3.
		■ 7.3.4.	

8. BUOYANCY AND STABILITY

■ 8.1.1.	◪ 8.2.1.	■ 8.3.1.
■ 8.1.2.	◪ 8.2.2.	■ 8.3.2.
■ 8.1.3.		■ 8.3.3.
□ 8.1.4.		

9. PLANT SYSTEM

■ 9.1.1.	◪ 9.2.1.
■ 9.1.2.	■ 9.2.2.
■ 9.1.3.	
■ 9.1.4.	
■ 9.1.5.	
■ 9.1.6.	

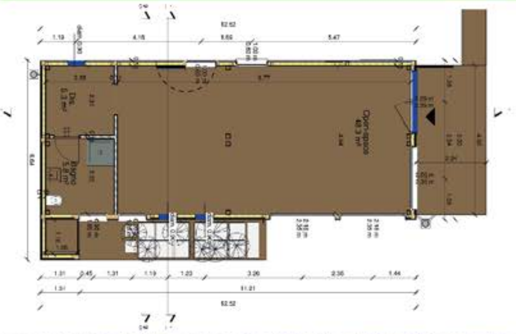
CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
composite PVC sheets with differentiated load-bearing capacity + collaborating aluminum horizontal grid

LOAD BEARING STRUCTURE
Timber frame

CLADDING
OSB insulated sandwich panels for facade and corrugated sheet panels for roof

FIGURES (© Gaetano Gucciardo)



4.5. Multi-criteria evaluation matrix

A multi-criteria matrix (MCM) is a decision-making tool that helps to evaluate and compare multiple alternatives based on a set of criteria. On the x axis of the MCM are the performance requirements and on the Y axis the case studies. As explained in the methodology, the MCM has a two-fold objective:

1. the identification of best practices amongst case studies according to their compliance to the requirements;
2. the identification of a priority weight amongst requirements according to their fulfilment in the practice field (case studies).

Unlike MCM are conventionally used – alternatives to be evaluated and the criteria with which to evaluate – in this case it can be used and read in both directions. No weight is assigned to each requirement, since the MCM is meant to extract the different weights. This means that each requirement (criterion) is rated the same and assigned a common weight of 1.

The cells have been left blank if the answer is not known as no information is available. The value 0.5 is inserted in cases in which the requirement is partially met or if the requirement is presumably met but not intentionally. Some projects include buildings directly connected to land and therefore with no walkways, nor safety platforms, for instance. In this case it has been decided to assign score 1 to not make them result with a lower score. In fact, the safety platform could be considered the land, and the walkways are not there so they do not require illumination for instance.

4.5.1. MCM Results: best practices and considerations on case studies

According to the evaluation of the case studies (alternatives) based on the requirements (criteria), all case studies address more than 60% of the requirements (Figure 5).

The graph in Figure 5 shows the degree of compliance of the 25 case studies (alternatives) with the design requirements (criteria). The

overall score is expressed as a percentage of the optimal compliance level which corresponds to 100%. Higher scores indicate better compliance. Overall, the graph suggests that there is a good level of compliance with design requirements across all typologies. The highest compliance score is 84 %, achieved by case studies n°11, Floating Office Rotterdam (non-residential), and n°25, Botel 2.0 (touristic accommodation). Overall, the compliance scores of the case studies are relatively high, with an average score of 73.6 %, confirming the case studies can be conceived as best practices.
In average, the non-residential typologies have the highest average score (77.8%), followed by the touristic accommodation typologies (74.2%) and then the residential typologies (72.3 %). This suggests that non-residential and touristic accommodation buildings may be more likely to be designed in compliance with requirements than residential buildings. One possible explanation for this is that non-residential and touristic accommodation buildings are often either public or open to public, hence subject to stricter design requirements than residential buildings, especially in terms of

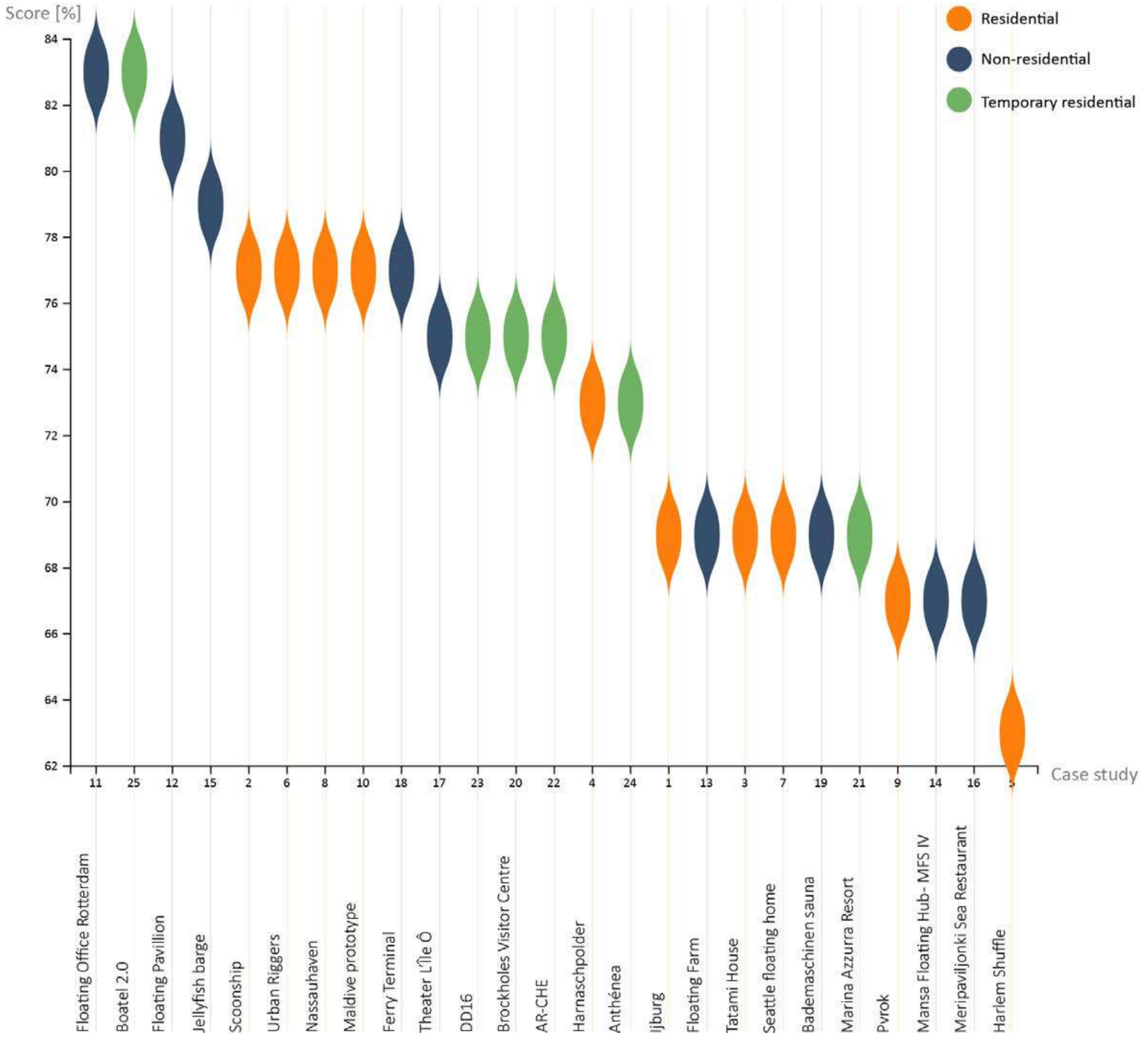


Figure 5. The graph shows the degree of compliance of the 25 case studies (alternatives) with the design requirements (criteria).

safety, accessibility, and sustainable-related criteria. However, it is important to note that this is just a small sample of case studies, and more research would be needed to draw any firm conclusions about the relationship between typology and compliance with design requirements.

The residential buildings which are part of a district or multi-unit clusters have higher scores than single-housing units. A possible explanation is that districts or clusters of buildings have the possibility of sharing certain systems greatly reducing operating costs. Residential buildings that are part of larger developments (districts or cluster of buildings) tend to have higher scores than single-housing units. This could be due to several factors, including the possibility of relying on shared systems (district heating and cooling systems, waste treatment and water management, renewable energy production and energy grid) which can reduce operating costs and therefore make them more compliant with energy efficiency and circularity requirements. Another contributing factor is economy of scale: larger developments can often benefit from economies of scale, which can lead to lower construction costs and therefore higher scores for construction processes and management. There could be some potential drawbacks to living in a district or multi-unit housing development, such as a lack of privacy. However, this requirement, for instance is always carefully considered by designers, as shown by the case study analysis.

4.5.2. MCM Results: priority order among requirements

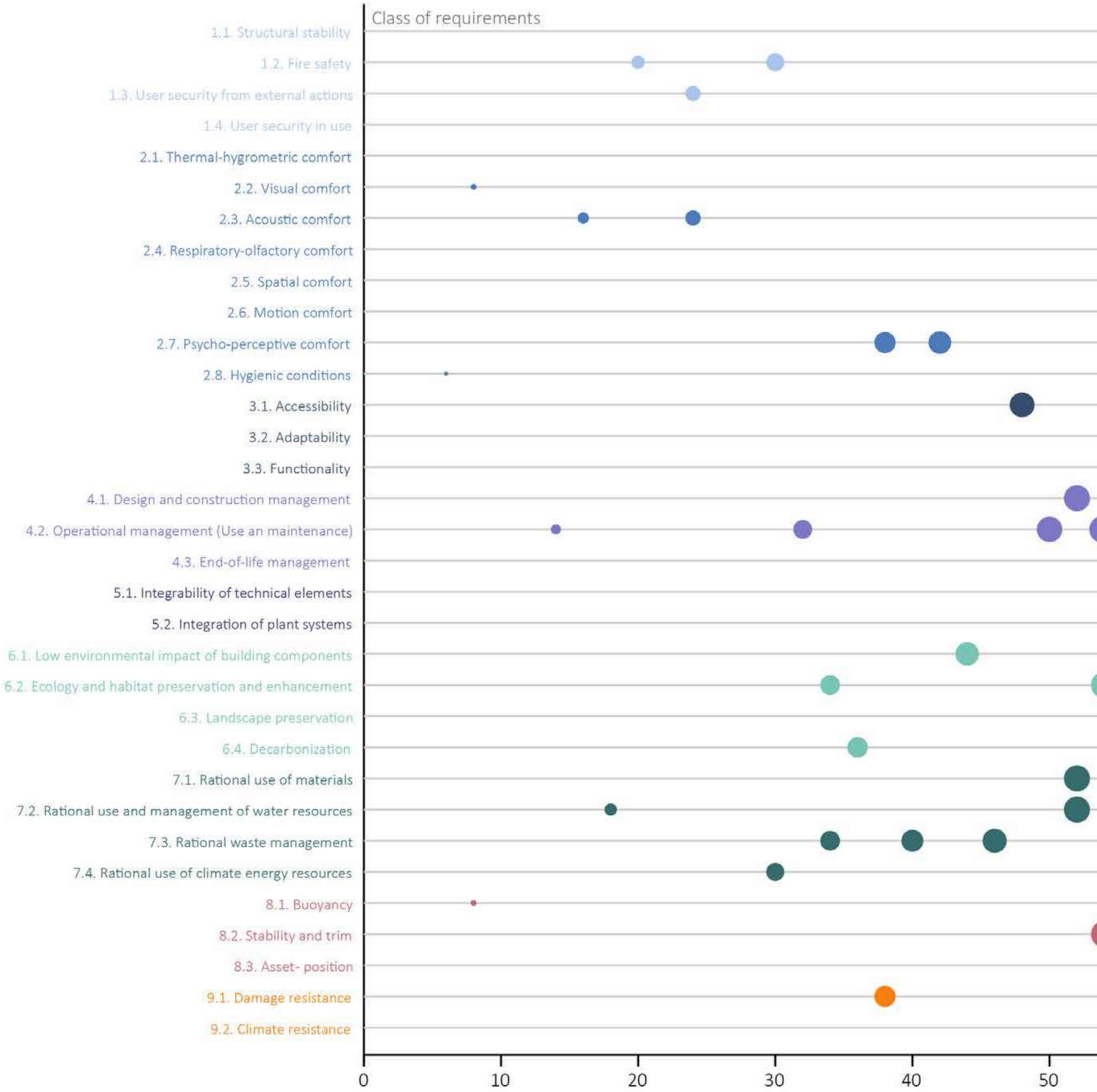
The bee-swarm plot diagram in Figure 6 displays the distribution of items (classes of requirements) over a continuous dimension (score). Each (line) is represented with a dot placed on the horizontal axis, which increases in dimension based on its fulfillment. The vertical dimension is used to avoid overlaps among circles, showing their distribution. The color coding provides additional categorical information on the class of demand to which the classes of requirement refer. The diagram reports part of the information in the multi-criteria matrix (Appendix E). The only requirements met by all case studies (100%) are the following:

- 1.1.1. Mechanical resistance to static actions
- 1.1.2. Mechanical resistance to dynamic actions
- 1.1.3. Structural continuity with sub-structure
- 1.2.2. Structural fire integrity
- 2.1.1. Indoor temperature level and control
- 2.1.2. Indoor humidity level and control
- 2.1.3. Ventilation control
- 2.2.2. Artificial illumination level and control
- 2.5.3. Occupancy rate
- 3.3.2. Ease of use and maneuver
- 4.2.6. Hygroscopicity
- 8.1.1. Freeboard
- 8.1.3. Watertight integrity

- 8.3.1. Mooring arrangements
- 8.3.2. Anchoring provisions and arrangements
- 9.1.1. Maintainability-repairability
- 9.1.4. Pipeline watertight integrity

These requirements refer mainly to the classes of demand of safety, wellbeing, and buoyancy. Concerning the safety class, structural stability and fire safety are observed by all designers in their projects, given the mandatory nature of those requirements in all disciplinary fields, from architecture to offshore engineering. Wellbeing is addressed by all requirements only for the most conventional requirements like thermal, acoustic, and visual comfort. One explanation is that these requirements are precisely prescribed by on-land building regulations and, therefore, followed by designers when building on water. Motion comfort is met by almost all case studies (98%), while the other ones referring to psycho-perceptive comfort are far less addressed in practice. Biophilia, active design, or behavioural or community engagement (requirements 2.7.1., 2.7.2., 2.7.3.) are generally not considered a priority in design. They account respectively for 86%, 42%, and 38%.
Regarding the plant system, on the whole, damage prevention measures are taken into consideration by 90% of the projects. In particular, the maintainability and repairability of the plant system (9.1.1.) and pipeline watertight integrity (9.1.4.) are addressed by all case studies, as they ensure the correct functioning of the building.
Other essential requirements, accounting for 96%, are 1.4.4. Overtopping reduction (clearance above water), 1.4.5. Non-slip resistance, 3.2.4. Mobility (towing arrangements), 4.2.5. Atmospheric agents resistance (exposed materials and components) 5.2.1. Plant system integration, 6.2.1. Avoid interference with protected areas, and 9.2.2. Adaptability of pipe-lines to water fluctuations. Requirements like 1.4.4. Overtopping reduction (that prevents the threat of waves or tides washing over the deck) and 1.4.5. Non-slip resistance (of the walking surfaces in contact with water) are observed by many projects because they are part of the safety class of demand despite being specifically related to the water environment. Requirement 3.2.4. Mobility (towing arrangements) is undoubtedly crucial for the building's maintenance, repair, and relocation. Therefore, it is not surprising that most case studies are equipped with towing arrangements.
Requirements like 4.2.5. Atmospheric agents resistance (of exposed materials and components) and 9.2.2. Adaptability of pipelines to water fluctuations are extremely important for floating buildings as the first ensures their long-term durability, and the latter their daily survival and adaptation to the changing site conditions. Adaptable pipelines are essential for ensuring the constant operation of the building's plant systems under all weather and climate conditions. Most case studies reasonably observe requirement 5.2.1. Plant system integration, as it guarantees the overall efficiency of the building. Protected areas are regulated by specific regulations, which overrule building codes. Therefore, any construction must

Figure 6. Bee-swarm plot diagram displaying the distribution of items (classes of requirements) over a continuous dimension (score).




73 %
77 %
78 %
71 %
86 %
68 %
54 %
77 %
84 %
60
70
80
90
100
score
Score [%]
6.0
100.0
Class of demand
Safety
Wellbeing
Usability
Management
Integrability
Environmental regeneration
Rational use of resources
Buoyancy
Plant system

comply with the protected areas' regulations. Since the case studies are located in countries where regulations that protect these areas are in force, this requirement could be removed as it is implicit. However, since the framework could be applied anywhere, keeping the requirement as a reminder in the PDSF may be necessary.

Requirement 8.3.3. Under keel clearance is revealed to be highly observed by designers (92% of case studies). This requirement, as argued in Chapter 3.3.4, is crucial as it is connected to several aspects, including safety, environmental impact, and mobility. It prevents the building from grounding, minimizes the impact of the building on the seabed and marine life, and allows it to manoeuvre the building easily and safely in shallow waters.

The requirements of the Environment regeneration class are accomplished by 68% on average. Only slightly more than one-third of the case studies address requirement 6.2.4. Foster biodiversity. Between fifty and sixty percent of the case studies meet the requirements 6.2.2. Avoid impingement, entrainment, entanglement, and impairment of biostructure and aquatic vegetation, 6.2.5. Avoid unnecessary reduction/obstruction and facilitate incoming sunlight in water, and 6.2.7. Reduce underwater noise sources (hydroacoustic energy). More attention is paid to requirement 6.2.6. Reduce light pollution and avoid underwater illumination at night, which is met by one-eighth of the case studies.

Rational use of resources, as depicted in the graph in the figure, is the least observed class of demand. Requirement 7.1.1. and 7.2.1. are met by only half of the case studies, while 7.3.3. by slightly more than one-third. It is interesting to highlight how 64% of the projects use renewable energy resources (requirement 7.4.1.), while only 30% use marine renewable energy (requirement 7.4.2.). The only requirements observed by most case studies (86%) are 7.4.3. Use of bioclimatic passive solutions and 7.3.4. Safe waste storage and disposal.

Only 26% of the case studies have an on-board user manual (requirement 4.2.10. On-board user manual). This requirement comes from the NTA 8111 rules in force in the Netherlands. Therefore, most projects realized after 2008 in the Netherlands should fulfil it. However, the NTA 8111 requires to provide the user of the floating structure with a manual containing the load limitations, with no reference to how to operate the floating building safely and efficiently, how to maintain the floating building properly, and how to respond to emergencies. For this reason, in most cases, the score assigned is 0.5, as the requirement is only partially met. Case study 25 is the only project that includes a user manual that explicitly mentions how to optimize the energy efficiency of the building and ensure safety.

Among the other requirements that are worth noting is requirement 1.3.1. Collision risk reduction arrangements, is only met by 24% of case studies. This requirement comes from maritime regulations and refers to moving objects. The case studies that meet this requirement are equipped with fender devices mainly to allow easy boat docking rather than to protect the floating foundation bodies and decks from eventual collision with other structures or vessels. This is mainly due to two reasons. On one hand, most floating buildings are located in areas with low levels of boat traffic and thus lower risk of collision. On the other, the buildings are kept apart by mooring systems that limit the horizontal movements of the structures. Aside from this, several projects do not comply with any specific water-related regulation besides conventional architectural codes that reasonably do not include anti-collision arrangements.

Requirements 2.2.3. Emergency and signal lighting and 8.1.4. Sink risk prevention indicators are addressed in only 8% of the projects. According to building codes, the first is mandatory only for public buildings. This is the most likely explanation for it not being met by most case studies. The case studies that are public and meant for public use are only three: the Theater L'Île Ô, the Ferry Terminal, and the Brockholes Visitor Centre. As no information is available for the visitor centre regarding this requirement, it is only met with certainty by two case studies (8%). Emergency and signal lighting and sink risk prevention indicators can be expensive to install and maintain. This can make them a less attractive option for some developers, especially those working on limited-budget projects and residential or private buildings that are not obliged to comply with these requirements according to on-land building regulations. Sink prevention indicators (like bilge level sensors, tilt sensors, and water ingress detection systems) come from the shipping field. They could be extremely useful to ensure the safety of occupants and the structure by providing early warning and, thus, sufficient time to evacuate and take other precautionary measures. However, they are not considered by designers, as most projects comply with on-land-based building regulations that do not include this requirement as the buildings do not encounter this risk.

The least observed requirement is 2.8.4. Pest and dangerous animal prevention. A possible explanation is that it contrasts (mutual exclusion) with several other requirements like 2.7.1. Biophilia, 6.2.4. Foster biodiversity, or even 6.1.3. Toxic emission control of materials. Some designers and developers may prioritize sustainability and ecological design principles, leading to less emphasis on traditional pest and animal control methods. They may seek alternative approaches that minimize environmental impact. Another reason could be that most of the sites where the case studies are located are sheltered waters, close to urban areas with low wildlife. Therefore, the need for protection measures to prevent dangerous animals is relatively low. However, this does not mean that the requirement is not worth being part of the framework, as there could be several locations where water can attract insects and dangerous pests.

4.6. Integrations from practice

Some significant aspects have emerged because of the case study analysis and the multi-criteria evaluation. Overall, the case study analysis has confirmed the framework's requirements, leading to its validation within practice. As it provided only minor, non-substantial integrations, providing a third updated version of the PDSF has been deemed unnecessary. Hereafter are outlined the noteworthy results of the case study analysis that have led to slight adjustments of the PDSF 2.0.
Despite being mentioned by very few regulations (UNI 8289; CLC SOR/2010-120), requirement 3.3.1. Furniture integrability is often observed in projects (more than two-thirds of the case studies). The case study review has confirmed its importance.
The requirement 3.2.2. Functional/spatial flexibility, which had no regulatory system supporting it but only scientific literature, has been proven extremely important as it is fulfilled by 80% of the case studies.
Case study n°25 (Botel 2.0) has an automated domotic system that warns users when they exceed consumption limits. This system could be considered a digital version of the on-board user manual for the information related to the efficient energy operation of the building. This suggests how the on-board user manual (requirement 4.2.10) could work together with real-time monitoring systems (requirement 4.2.8.) and integrated real-time information and alarms.
The requirement 6.4.2. CO_2 absorption design solutions has been further integrated with examples from case studies that use photocatalytic materials and natural materials with embodied carbon properties.
The case studies n° 2 (Schoonship), n°10 (Maldive floating city prototype), n° 11 (Floating Office Rotterdam), n° 12 (Floating Pavilion), n° 15 (Jellyfish barge), and n° 25 (Botel 2.0) have highlighted how, being in a water-based habitat, the requirement 7.2.1. Water collection, treatment, and reuse should also embrace systems that can extract and treat water from the surrounding

environment (sea, lake, river, lagoon, canal). Desalination processes can be used to treat seawater containing a high salt concentration, which must be removed before it can be used for domestic purposes. Lake and river water can contain various bacteria, algae, and chemicals that must be removed by using similar processes used for rainwater treatment (filtration, aeration, and disinfection).

Despite being mentioned only by certification systems and not by regulations, requirement 7.2.2. Limit water consumption is observed in 18% of the case studies. Several projects include water-saving taps equipped with technologies that limit water consumption, recirculating showers, and similar devices. Although this performance requirement is not explicitly addressed in performance-based codes and guidelines, it is considered extremely important within international goals and objectives and thus must be included. In August 2022, the EU Joint Research Centre (JRC) warned that the current drought could be the worst in 500 years and predicted that severe drought would worsen in Europe, potentially reaching 47% of the continent. According to the European Drought Observatory (Toreti et al., 2022), the dry conditions are related to a broad and persistent lack of precipitation combined with a sequence of heat waves.

References

Eurostat (2021) Glossary:Overcrowding rate. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Overcrowding_rate

Dave Cheshire. (2019). Net zero buildings and the rise of the 'prosumer'. Retrieved from https://www.linkedin.com/pulse/net-zero-buildings-rise-prosumer-dave-cheshire/

Toreti, A., Bavera, D., Acosta Navarro, J., Cammalleri, C., de Jager, A., Di Ciollo, C., Hrast Essenfelder, A., Maetens, W., Magni, D., Masante, D., Mazzeschi, M., Niemeyer, S., Spinoni, J., (2022). Drought in Europe August 2022, JRC130493. Luxembourg: Publications Office of the European Union. doi:10.2760/264241

Vermande, H. (2009). Drijvende woningen en de bouwregelgeving, Handreiking voor ontwikkelaars, bouwers en gemeentelijke plantoetsers. Floating Houses and Construction Legislation, Guidelines for Developers, Contractors and Municipalities).–the Netherlands.

PART III

Design Experimentation

CHAPTER 5 Mapping opportunities for floating urban development along Italian waterfronts

ABSTRACT

Italy is particularly well-suited for floating urban development due to its extensive coastline and inland hydrographic network. The main drivers of floating urban development include the increasing threats posed by SLR and flooding to waterfront communities and the shortage of land for urban expansion. Floating urban development can reduce the environmental impact of urban development by minimizing land consumption and pollution. Not all waterfront areas are suitable for urban development on water: water depth needs to be sufficient to accommodate floating pontoons, wave exposure must be limited, proximity to existing infrastructure must be guaranteed. Therefore, the chapter presents the results of a geographical analysis carried out using a geographic information system for mapping the most suitable areas for floating urban expansion. The features of interest include: water depth, wave exposure, proximity to infrastructure, urban density and growth, high vulnerability to sea level rise and to flooding. Finally, the chapter identifies a specific waterfront area with a high potential for floating urban development implementation based on a comprehensive evaluation of the variables mentioned above. The identified area of Isola Sacra in the Lazio region is accurately described and analyzed concerning insisting constraints (archeological, environmental, building), ecological features, hydrography characteristics, climate and microclimate conditions, infrastructure (mobility and proximity facilities), and socioeconomic and urban needs.

Italy, with its extensive coastline and inland hydrographic network and its rich maritime history, is well-positioned to explore the potential of FUD. This chapter delves into the opportunities and considerations for FUD along Italian coastal areas. It begins by examining the drivers behind FUD, including the need to address climate change impacts such as SLR and flood mitigation, optimize land use, and provide a solution for sensitive coastal ecosystems. It then highlights the unique characteristics, challenges, and potentials of specific waterfront areas for FUD and explores and assesses the parameters that determine a higher degree of suitability for FUD. At a large scale, these factors include the co-occurrence of two tendencies, each of which can be expressed using different parameters. The first can be generally defined as the need for more urban space and can take the form of soil consumption, urbanization, or population growth and density. The second tendency refers to the climate-driven water-related risk exposure to either SLR or flood. The hypothesis is that cities that are facing rapid urban expansion and are characterized by high flood risk require large amounts of space to accommodate their population growth and would be areas with high potential for floating developments. Therefore, mapping the Italian territory aims to identify the most suitable locations for implementing floating solutions as an extension of existing waterfront communities, considering expected flood risk and SLR on the one hand and expected population growth or urbanization degree on the other. The methodology and hypothesis have already been validated by Dal Bo Zanon et al. (Dal Bo Zanon et al., 2020) in similar studies in the Netherlands. Upon closer examination and a narrower focus on specific areas, the relevance of other variables gains further prominence. These variables include water depth, wave exposure, proximity to existing infrastructure, local regulations, and ease in acquiring permissions, and concentration of cultural, historical, infrastructural, and social assets. Finally, the chapter identifies a specific waterfront area with a high potential for FUD implementation based on a comprehensive evaluation of the variables mentioned above. The identified area is accurately described and analyzed. Archeological, environmental, and building constraints, ecological and hydrographic characteristics, climate and microclimate conditions, infrastructure, and socioeconomic and urban needs are identified.

5.1 Vulnerability of Italian waterfront cities and settlements

In Europe, about 86 million people (19% of the entire population) are estimated to live within 10 km of the coastline (Carreau & Gallego, 2006). In contrast, most of the Mediterranean population (about 75%) lives in coastal areas. The most critical areas in the Mediterranean include the coasts of Turkey (Anzidei et al., 2011), the northern Adriatic (Antonioli et al., 2007; Lambeck et al., 2011), the Aeolian islands (Anzidei et al., 2017) the coast of central Italy (Aucelli et al., 2017) and eastern Morocco (Snoussi et al., 2008). In Italy, where coasts stretch for more than 7,500 km, the number of people living in coastal areas reaches 70% of the total population[1]. Over 14,000 areas in the EU are at significant risk of flooding, according to a new WISE-Freshwater online viewer launched in October 2023[2]. The map in Figure 1 is taken from the EC Flood Risk Area viewer. The orange color shows the areas of potentially significant flood risk identified by each member state. Italy[3] seems to be extremely vulnerable to flooding not only in coastal areas but also along inland waters[4]. Besides coastal areas, inland waters represent a significant portion of the total land surface in Europe. Italy is the richest country in Southern Europe in terms of water resources[5] counting 69 natural lakes with a surface area greater than 0.5 km^2 each, 183 artificial basins with over 1 km^2 of surface, and 234 watercourses and rivers for a total of 288 026 km^2. According to the European Environment Agency (EEA) dashboard maps[6], that include the Copernicus riparian zone dataset, modelled hydrological parameters, and results from the Mapping the world's free-flowing rivers database (Grill et al., 2019), floodplain areas in Europe account for 428,323 km^2, which correspond to 7.4% of the territory. Such an extension involves a floodplain population of 71,360,542 inhabitants, corresponding to 11.7 % of Europe's population. The same dashboard provides data on each country. Italy has a floodplain area of 28,885 km^2, equal to 9.7% of the national territory and involving 13.3 % of the population. Both percentages are higher than Europe's average. The majority of floodplain types in Italy are very-flat lowlands (12,700 km^2) and flat lowlands (9,600

1. Retrieved from annuario.isprambiente.it

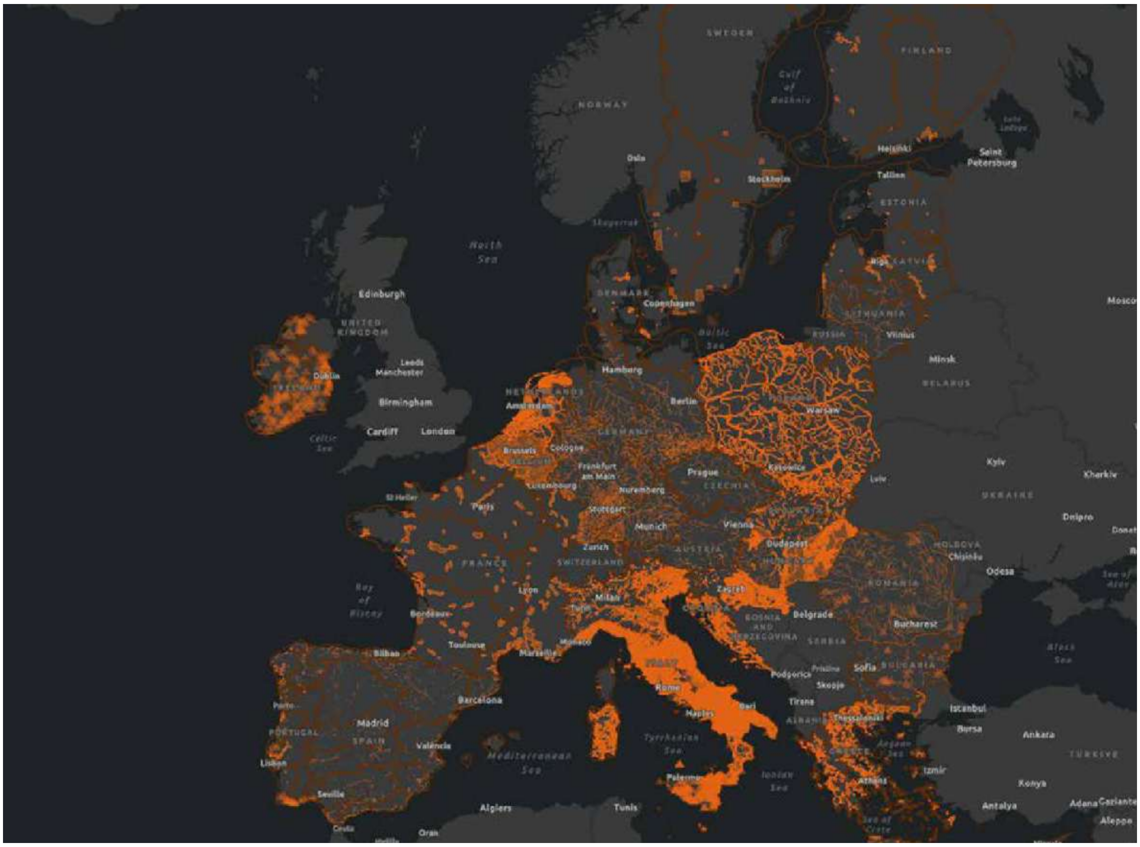
2. EU Member States provides the flood risk information presented in the viewer with support from the Commission and the European Environment Agency under the Floods Directive. Therefore, accurate comparisons between different countries may encounter some bias issues.

3. The Ministry of Environment and ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) have mapped the Italian region.

4. Directive 2000/60/EC (art. 2.10) defines a water body or "body of surface water" as "a discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal, a transitional water or a stretch of coastal water".

5. Retrieved from https://web.archive.org/web/20070120141920/http://www.apat.gov.it/site/it-IT/Temi/Acqua/Risorse_idriche/Acque_dolci/

6. Retrieved from https://portal.discomap.eea.europa.eu/arcgis/apps/dashboards/



km²), accounting together for more than 77% of the floodplain types[7]. Regarding SLR hazard in Italy, Lambeck et al. (2011) provided a sea-level rise projection for 2100, using an extensive database that included the isostatic and tectonic contribution to the IPCC[8], and Rahmstorf (Rahmstorf, 2007) climatic models. Results have shown that by the end of the century, SLR estimated along Italian coasts is between 0.94 and 1.035 meters (conservative model) and between 1.31 and 1.45 meters (on a less conservative basis). To these values, we must add the so-called storm surge, i.e., the coexistence of low pressure, waves, and wind, which varies from area to area, which in particular conditions causes an increase in sea level along the coast of about 1 meter (ENEA 2019).

In the Italian region, rapid urbanization started after the 60s of the 20th century, leading to the uncontrolled expansion of coastal settlements, which today are exposed to increasing coastal hazards[9]. Land consumption, defined as the shift from non-artificial land cover to artificial land cover (Strollo et al., 2020), which is associated with the loss of ecosystem services, is another essential aspect to consider when identifying areas that are more eligible for consideration in applying the shift from land to water for urban purposes. The map in Figure 2, elaborated upon using data provided by ISPRA (ISPRA, 2023), shows the percentage of soil consumed at the communal level. The orange-red areas experienced more than 9% of soil consumption in 2022. Cities like

Figure 1. Map of Areas of Potential Significant Flood Risk in Europe retrieved from EC Flood Risk Area viewer.

7. The European floodplain typologies follow an ecological approach based on environmental factors like altitude and slope, which are known to govern floodplain habitats and biota but are not affected by human alterations.

8. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf

9. Sterr, H., Klein, R.J.T., Reese, S., 2003. Climate Change and Coastal Zones: an Overview of the State-of-the-art on Regional and Local Vulnerability Assessment. Published in: Climate Change and the Mediterranean: Socio-economics of impacts, vulnerability and ad-aptation, 2003. Retrieved from http://www.feem.it/getpage.

Milan, Turin, Naples, Bari, and Palermo have experienced more than 30% of soil consumption, followed by Rome and its surrounding municipalities, Venice, Catania, the Tuscan coast, and the Pianura Padana areas around Modena, Parma, and Bologna, ranging from 15 to 30% of soil consumption. The dark blue circles pinpoint the Urban Morphological Zone (UMZ)[10] potentially at risk of river flooding (1 in 100 years return period), modelled for 2071 - 2100. The data is taken from the EEA database Datasets, which made use of UMZ from Urban Atlas 2012, and LISFLOOD model outputs from JRC[11]. The resultant modelled flood area was intersected with the UMZ extent, and the proportion of potentially flooded UMZ area was calculated for each city by dividing the potentially flooded area by the total UMZ area. It is essential to highlight that the indicator is based on elevation and does not include existing or planned flood protection measures like dams or dikes. In the highlighted areas, the percentage of flooded territory ranges from 0.03% in Sassari (Sardinia) to 45% in Padova. Taking a closer look at the areas that overlap with soil consumption, it is crucial to point out Milan with 13+5 % of the UMZ extent, Florence with 13%, Turin with 9%, Rome with 4,4%, Modena with 10,2%, Forlì with 6,5%, Bologna with 2%, Ravenna with 23%, Bari with 6,1%, and Catania with 16,8%, Pisa with 10,6%.

The violet circles identify the areas facing coastal inundation risk. The map shows the coastal cities exposed to inundation by the SLR of 1 metre (without any coastal flooding defences present). The SLR dataset used for the map was developed by CReSIS[12]. To no surprise, coastal inundation tends to match with river flooding risk projections, as both are exacerbated by climate change. SLR is the primary driver of coastal inundation, while increased precipitation is the leading cause of river flooding. In addition, coastal areas are often located in low-lying areas where rivers also tend to flow, making them more susceptible to flooding. Moreover, most of the areas at risk of coastal inundation are often located at the deltas of rivers, like Rome is on the Tiber River, Venice is immediately above the River Adige delta, and the area below Venice is crossed by the River Po and its delta. Pisa is located on the delta of the River Arno.

Legambiente[13] Vice President (Zanchini & Manigrasso, 2017) published a study on the transformation of over 8,000 kilometers of Italian coastal areas within the last forty years. A numerical analysis of the phenomena was reconstructed by processing images and maps through a careful study of satellite photographs. The investigation revealed that 3,291 km, which correspond to 51% of the Italian coastal landscape, were modified between 1988 and 2012 (Zanchini & Manigrasso, 2017). Industries, ports, and infrastructure occupy 719.4 km, while medium and large city centers occupy 918.3 km. Current satellite images are compared with those dating back to 1988, a few years after the fundamental law on landscape protection known as Galasso Law was approved, ensuring a 300-meter buffer of protected coastal land. Despite the limits imposed by Law 431/1985, an additional 41,000 meters of coastal terrain have been irreversibly transformed since 1985. In general, the transformation

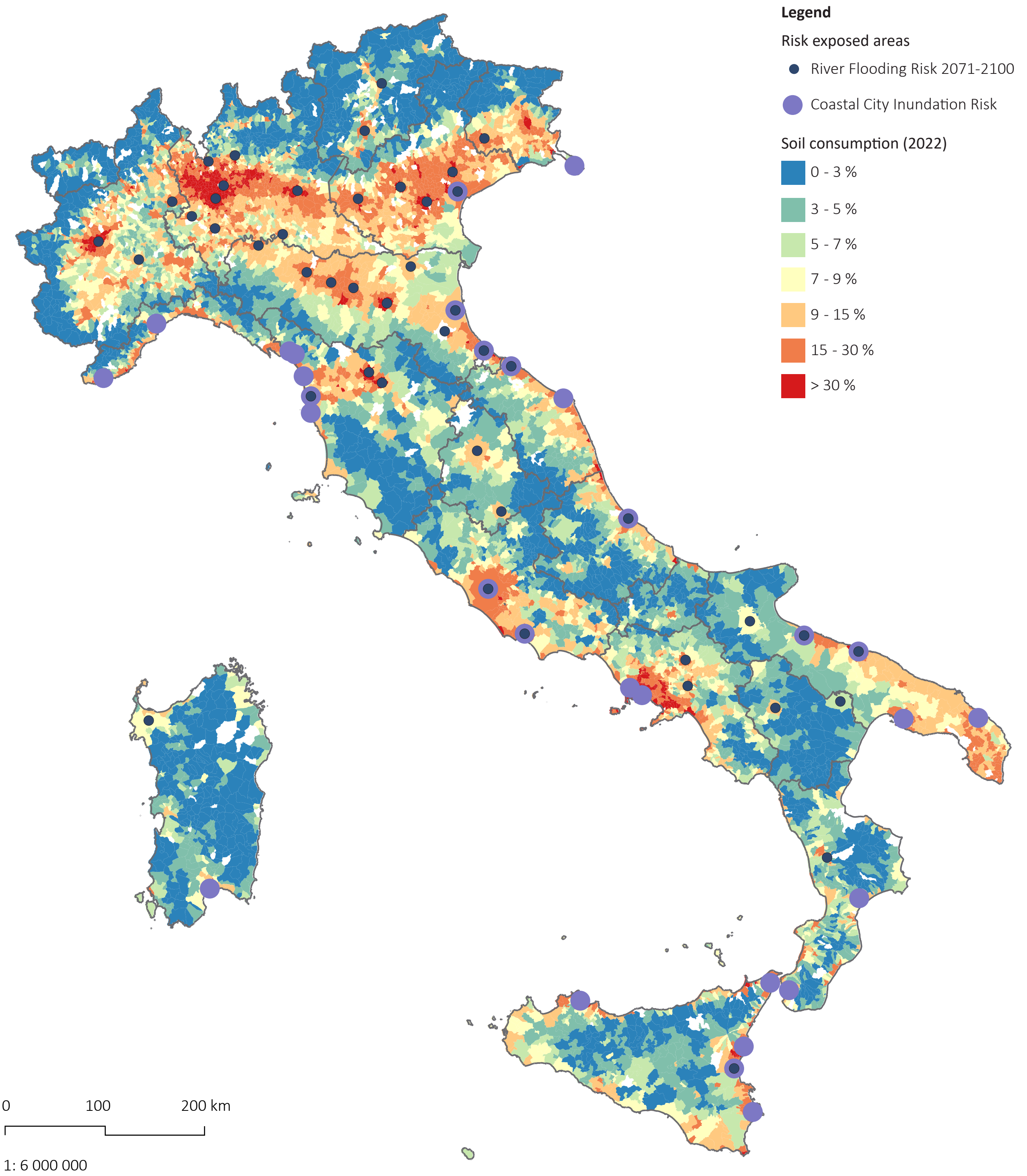
10. UMZ is the reference unit for the city morphology. They are regarded as the best approximation of the real city form and are defined as a set of urban areas laying less than 200 m apart within the core city administrative boundaries (densely built-up urban areas).

11. The discharge return levels were derived for every river pixel for return periods of 100 years. For a time window of 30 years (2071–2100), a Gumbel distribution was fitted to the annual maximum discharges simulated by LISFLOOD in every grid cell of the modelled domain based on 12 models and the A1B scenario.

12. CReSIS (Centre for Remote Sensing of Ice Sheets) 2018, Lawrence, Kansas, USA. Digital Media. http://data.cresis.ku.edu/.

13. Legambiente, founded in 1980, is one of the main Italian environmentalist association.

Figure 2. Soil consumption (2022) related to risk exposure in terms of river flooding and coastal city inundation (2071-2100). Source: Livia Calcagni

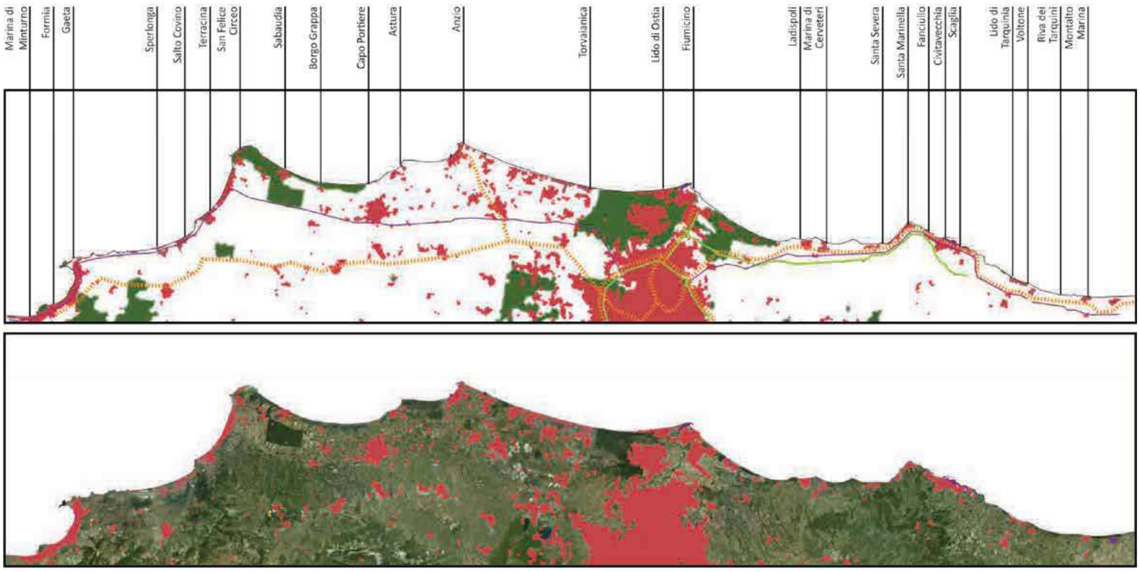


of the coast has taken place at the expense of beaches, dunes, and natural green areas, but above all, at the expense of agricultural land. Calabria, Liguria, Lazio, and Abruzzo have a poor track record, with only one-third of the natural environment preserved, while the rest is contaminated and occupied by ports and buildings. Lazio is one of the most affected regions by land consumption, with more than 63% of the coast transformed. Only 12 kilometers of the coast can still be classified as agricultural landscapes, whereas 109 kilometers of natural environment remain intact because they fall within protected areas. Uncontrolled coastal urban development led to an unsustainable overexploitation of fragile ecosystems, resulting in a total of 302 kilometers of coastline being transformed. These numbers correspond to 13 km per year or 48 meters per day. Architect E. Zanchini, for his study, divides the Italian coastline into five types of urban landscapes: industrial and port areas (more generally infrastructural), high-density urban areas, low-density urban, agricultural, and natural areas. The most serious situation has occurred in Sicily, with 65 kilometers transformed. But the condition in Lazio is also severe, with 41 kilometers of natural and agricultural landscapes erased by concrete, and in Campania with 29 kilometers.
In recent decades, despite protection constraints, land occupation has mainly favored new residential agglomerations (second homes) and tourist activities. In Lazio, however, there are infrastructural interventions such as the new port of Ostia and the expansions carried out in Civitavecchia (Figure 3). There are several projects proposed for new infrastructures involving Fiumicino, Anzio, Formia, San Felice Circeo and Gaeta.

Considering the population's demographic distribution, instead of soil consumption, provides information on the vulnerability of the different areas in terms of the risk of loss of life, property

Figure 3. Coast Consumption 2012. Source: Zanchini, E., & Manigrasso, M. (2017). Vista Mare: La Trasformazione Dei Paesaggi Costieri Italiani. Edizioni Ambiente. p 89

Dense urban landscape (55 km)
Natural landscape (109 km)



damage, and economic disruption. Understanding population distribution is essential for informed urban planning and urban development decisions. The map in Figure 4 depicts the overlapping of population distribution and flood risk. The red gradient shows the population distribution by municipalities: dark red areas have higher demographic numbers. The data is taken from the ISTAT[14] census 01/01/2023. The blue-gradient category returns three levels of flood risk:

a. low-probability hazard (LPH) - 300 years
b. medium-probability hazard (MPH) - 100 years
c. high-probability hazard (HPH) - 20-50 years (or extreme event scenario).

The data behind the potentially floodable areas is produced by ISPRA and is consistent with the Floods Directive 2007/60/EC. The same data are behind the map in Figure 1. Legislative Decree 49/2010, implementing the Floods Directive, establishes that scenarios of high probability or frequent floods are those corresponding to return times between 20 and 50 years (e.g., for the scenario c = Tr ≤ 30 years), while scenarios of medium probability or infrequent floods are those corresponding to return times between 100 and 200 years (e.g., for the scenario b = Tr ≤ 150 years). Those related to return times exceeding 200 years are considered low-probability or extreme event scenarios (e.g., for the scenario a = Tr ≤ 300 years). The extent of the floods should be understood as the entire surface that would be covered with water in the event of a specific scenario (therefore not excluding the riverbed).

The map highlights the areas that are densely populated and, at the same time, face a more significant flood risk. The Po Valley is not so densely populated but is interested by medium-probability hazards for a considerable extent of its territory. In terms of extension, the areas around the Tiber delta in the Municipality of Rome andFiumicino (as shown in the zoom), the northern part of Puglia region (Foggia Province), the city of Catania, and the coastal areas between La Spezia and Livorno are far less impacted. Yet, the risk is higher (high-probability risk). These areas also host a higher number of inhabitants.

Leaving aside urban population in terms of demographic distribution, urban densification in the consolidated city and sprawling phenomena on fringe and rural areas have become a matter of investigation (Bruegmann 2005; Schneider and Woodcock 2008, Strollo 2020). It's even more compelling to compare and overlap flood risk with the urbanization degree, as shown in the map in Figure 5. This correlation is even more critical because if a region's demography is high, it is not necessarily growing. The orange gradient scale returns three degrees of urbanization[15]:

a. cities or densely populated areas
b. small cities and suburbs or intermediate population density areas
c. rural areas or scarcely populated areas.

The blue-gradient areas represent, once again, the flood-risk areas.

14. The Istituto Nazionale di Statistica (ISTAT) is an Italian public research body that deals with general censuses of the population, services and industry, agriculture, sample surveys on families, and general economic surveys at the national level. The data refers to the demographic balance and resident population as of December 31.

15. The classification of municipalities is based on the criteria of geographical contiguity and density and minimum population thresholds of the regular grid with 1 km² cells (EU Reg. 2017/2391). ISTAT, in collaboration with Eurostat, has prepared the Classification based on the 2011 population census for the municipalities that have existed since 1/1/2018. An elaboration is released for the years preceding that year and starting from 2011 to allow diachronic analysis of statistics and indicators at the municipal level.

Figure 4. Map of flood risk in Italy overlapped with population distribution by municipality. Source: re-elaboration by Livia Calcagni using data from ISTAT census 01/01/2023 and ISPRA according to the Floods Directive 2007/60/EC.

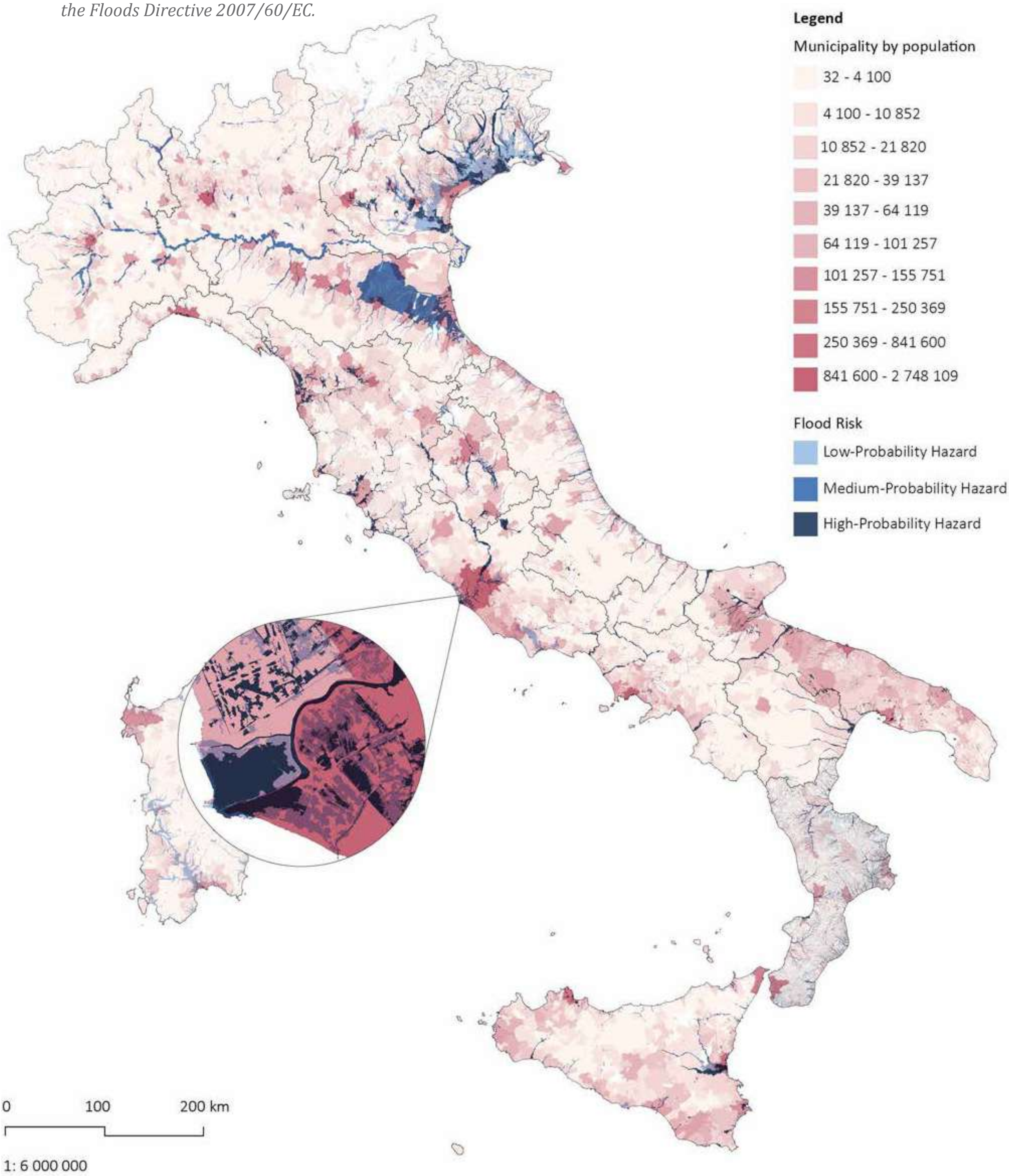
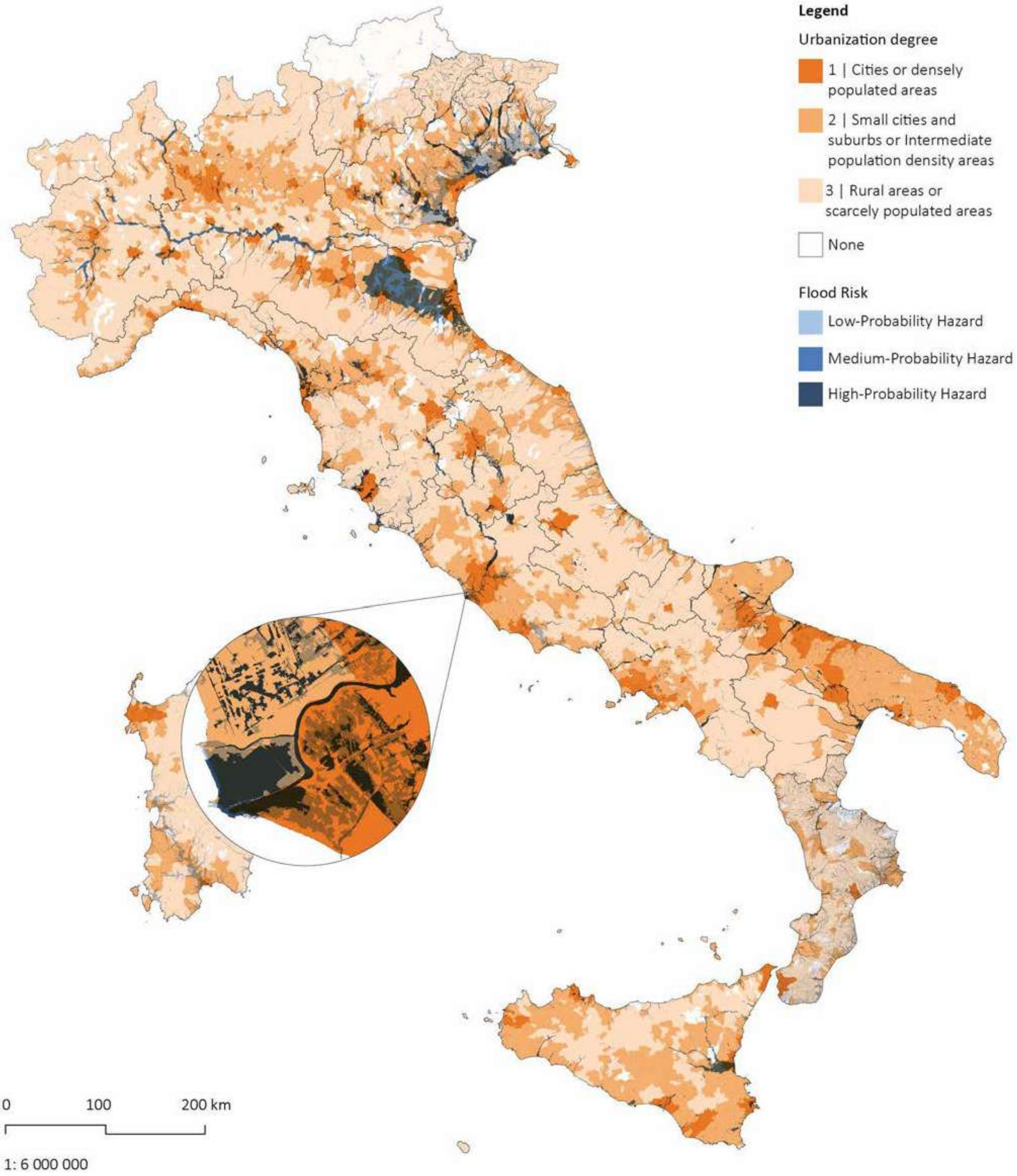


Figure 5. Map of flood risk in Italy overlapped with urbanization degree. Source: re-elaboration by Livia Calcagni using data from ISTAT census 2011 and ISPRA according to the Floods Directive 2007/60/EC.



Compared with the previous map (population by municipality and flood risk), the areas of interest – affected by both phenomena – are almost the same. This implies that the most densely populated municipalities usually have the highest degree of urbanization.

To provide information not only on the co-existence of flood risk and demographic distribution or urbanization degree but also on SLR projections and demographic distribution and urbanization degree, maps in Figure 6 and 7 were elaborated. Therefore, the same map containing information on the degree of urbanization for Italian municipalities was superimposed on the risk of SLR. The map in Figure 6 represents the areas most subject to sea level rise with forecast scenarios for 2100 and their relation to demographic distribution. The map in Figure 7 shows the areas most subject to sea level rise with forecast scenarios for 2100 and their association with urbanization degree.
The forecast data is calculated considering the SSP5-8.5 scenario[16], according to which annual emissions will approximately double by 2050. The parameters considered for SLR projections include the following set-ups inserted in the Coastal Risk screening tool developed by Climate Central[17].

- Sea level rise + annual flood: local sea level projection plus the added height of a local annual flood[18]. The Sea level projection source is the IPCC 2021.
- Current pollution pathway trajectory: SSP5-8.5.
- Mid-range result from sea-level projection range (50th percentile).
- Threatened areas shown include all land below water level.

In both maps, the areas in light blue grid hatch are those predicted to be submerged by water by 2050 according to the SSP5-8.5 scenario, while those marked in blue hatch are expected to be submerged by water by 2100.
Along the northern Adriatic coast, the territory of the lower Po Valley (n°4), right near the mouth of the Po River, is undoubtedly the Italian area that presents a greater risk of being submerged. Forecasts for 2100 show an area extending to over 40 km inland, almost reaching the city of Ferrara. The area affected by the phenomenon involves the provinces of Rimini, Ravenna, Ferrara, Rovigo, and Venice.
Moving south, the area within the Provinces of Foggia and the Province of Barletta (n°6) will be submerged by water already in 2050 and to a greater extent by 2100. The municipalities affected by the phenomenon are Fiumara, Margherita di Savoia, Trinitapoli, Setteposte, Zapponeta, Ippocampo, Scalo dei Saraceni, Scali degli Zingari, and Siponto. The internal areas affected by flooding by 2100 are located more than 4 km from the current coastline.
Shifting to the northern Tyrrhenian coast, the Province of Livorno (n°1) is particularly affected by rising sea levels, especially the area around Marina di Pisa, located at the mouth of the Arno River, Calambrone, and Tirrenia. The internal areas affected by the phenomenon by 2100 are almost 4 km away as the crow flies from the current coastline.

16. According to this scenario, the increase in emissions will cause warming of around 4.4° Celsius above pre-industrial levels by 2100. Shared Socioeconomic Pathways (SSPs) are scenarios of global socioeconomic changes expected up to 2100.

17. Climate Central is an independent group of scientists who research and report on how climate change affects people's lives. It is a policy-neutral nonprofit.

18. An annual flood's height above sea level is exceeded once per year on average. Source for local flood height increments outside the US: Muis et al. (2016). A global reanalysis of storm surges and extreme sea levels. *Nature Communications 7*:11969.

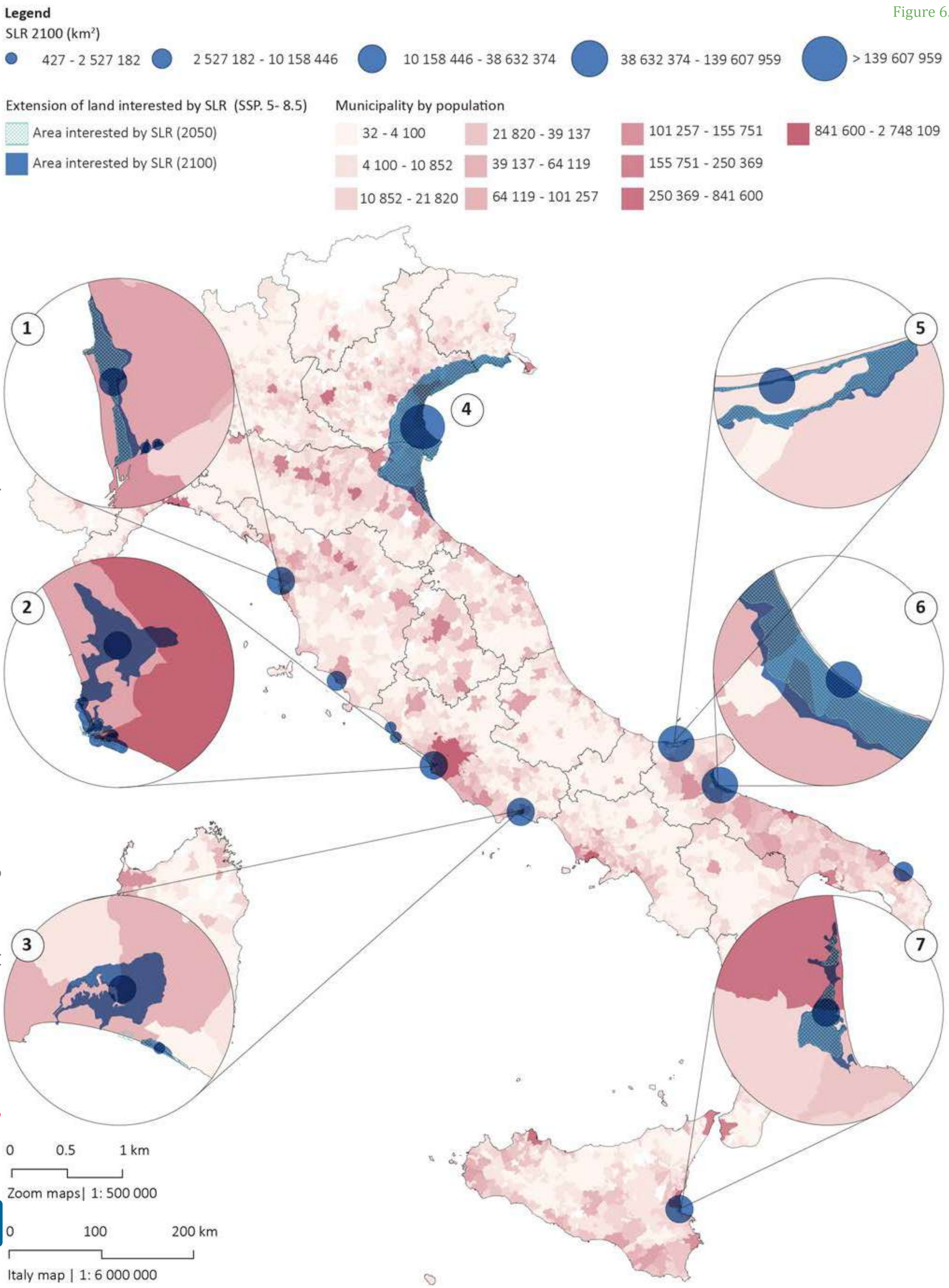
Moving south, predictions of SLR involve the entire hamlet of Isola Sacra and a good part of the area currently used as infrastructure of the Leonardo da Vinci International Airport (Municipality of Fiumicino), portions of Ostia and Piana del Sole (Municipality of Rome), and up to 200 m of areas adjacent to the Tyrrhenian coastline that stretches from Fiumicino towards Civitavecchia in the Province of Rome (n°2). The internal territory affected by the phenomenon by 2100 will reach more than 9 km of inward land from the current coastline.
Further south, the Gulf of Gaeta (n°3) is also affected by the phenomenon, especially the town of Sperlonga and the stretch of land between the coast and the municipality of Fondi.
In Sicily, the most vulnerable area to SLR is located south of the Simeto River's Pineta della Riserva della Foce in the Province of Catania (n°7). It includes the municipality of Vaccarizzo-Delfino and some further southern areas of Catania metropolitan city. The phenomena also affect some parts of the Province of Syracuse, such as Villaggio San Leonardo.

Ultimately, it is crucial to mention the speeding up of the erosion phenomena, especially along the Italian coasts (Manigrasso, 2023). Unauthorized development and inadequacy of mitigation techniques and technology have resulted in increased erosive stress and unsettling landscapes. Over the last two decades the State and the regions have spent an average of around 100 million euros each year for coastal protection interventions. At least 80% of these loans concerned rigid infrastructure like groynes and barriers spread along 1,300 kilometers of beaches. M. Manigrasso highlights how this deep artificialization of the coast, or rather the disruption of the natural coastal dynamics, has triggered erosion. Along with protection measures, advance strategies such as land reclamation or beach nourishment have been implemented. The alteration of the dynamics accelerates the dispersion of the added sediments.

Figure 6. Map of Sea level rise projections by 2100 (SSP.5-8.5) in Italy overlapped with urbanization degree. Source: re-elaboration by Livia Calcagni using data from ISTAT census 2011 and Climate Central Coastal Risk (IPCC 2021, SSP5-8.5).

Figure 7. Map of Sea level rise projections by 2100 (SSP.5-8.5) in Italy overlapped with urbanization degree. Source: re-elaboration by Livia Calcagni using data from ISTAT census 2011 and Climate Central Coastal Risk (IPCC 2021, SSP5-8.5).

Figure 6.


Legend
SLR 2100 (km²)
427 - 2 527 182
2 527 182 - 10 158 446
10 158 446 - 38 632 374
38 632 374 - 139 607 959
> 139 607 959
Extension of land interested by SLR (SSP. 5- 8.5)
Area interested by SLR (2050)
Area interested by SLR (2100)
Municipality by population
32 - 4 100
4 100 - 10 852
10 852 - 21 820
21 820 - 39 137
39 137 - 64 119
64 119 - 101 257
101 257 - 155 751
155 751 - 250 369
250 369 - 841 600
841 600 - 2 748 109
1
2
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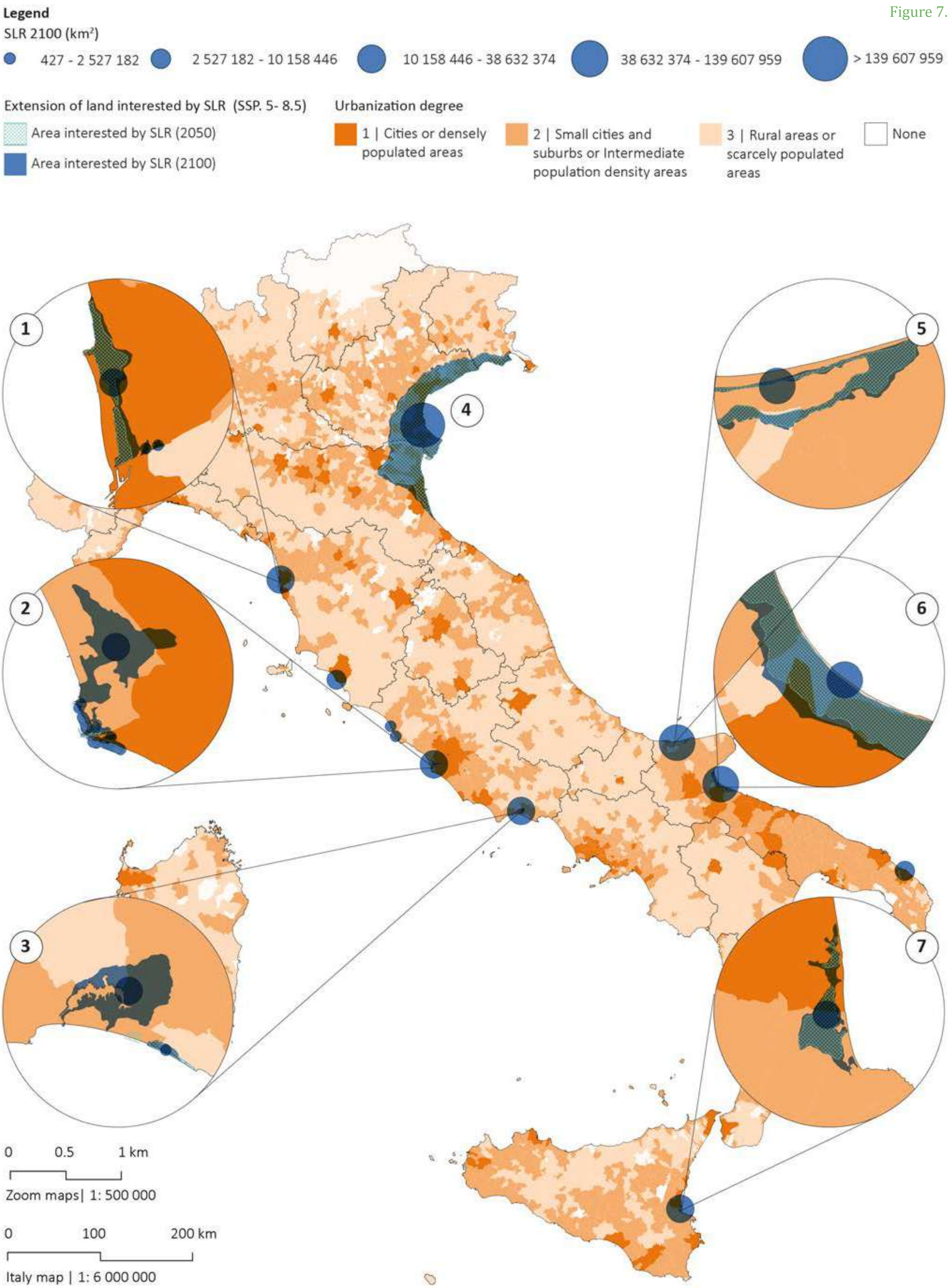
0 0.5 1 km
Zoom maps| 1: 500 000
0 100 200 km
Italy map | 1: 6 000 000

Figure 7.



Legend
SLR 2100 (km²)
427 - 2 527 182
2 527 182 - 10 158 446
10 158 446 - 38 632 374
38 632 374 - 139 607 959
> 139 607 959
Extension of land interested by SLR (SSP. 5- 8.5)
Area interested by SLR (2050)
Area interested by SLR (2100)
Urbanization degree
1 | Cities or densely populated areas
2 | Small cities and suburbs or Intermediate population density areas
3 | Rural areas or scarcely populated areas
None
1
2
3
4
5
6
7
0 0.5 1 km
Zoom maps| 1: 500 000
0 100 200 km
Italy map | 1: 6 000 000

5.2 Tiber river Delta – Case study

19. This does not entail that other areas could be more suitable for FUD.

All things considered, the area of the Tiber delta was identified for the application of the PDSF. It is located at the intersection of the Metropolitan City of Rome (Ostia) and the Municipality of Fiumicino (Figure 8).

It was chosen as a pilot site because of the following criteria[19].

a. High demographic concentration.
b. City or densely populated area.
c. Significant soil consumption.
d. Vulnerable to SLR and coastal inundation.
e. Vulnerable to flood risk: High Probability Hazard.
f. Presence of strategic infrastructure (airport, port).
g. Presence of archeological sites.
h. Flood risk classification.
i. No interference with vessel routes.

In addition to these variables, according to M. Manigrasso's studies, the Lazio coast – of which 220 km out of 290 km have low sandy shores – is highly subject to erosion. It has undergone several hard-work protection and nourishment interventions. In particular, near-shore (Ostia Ponente) and spaced-out (Ostia Centro) submerged barriers have been built along the coastline. Between 1990 and 2015, the erosion along the Ostia coast increased from roughly 50,000 m^2 to 120,000 m^2. Between 2016 and 2018, the situation worsened even more, and erosion in the section of the high-water collector channel facing the outflow to the sea resulted in the entry

Figure 8. Territorial context: Isola Sacra in between the Municipality of Rome and the Municipality of Fiumicino, Province of Rome. Source: Livia Calcagni.

of seawater into the habitat behind, causing severe damage to the ecosystem.

Concerning the presence of strategic infrastructure, the area hosts the Rome - Fiumicino International Airport Leonardo da Vinci, the busiest airport in the country and the 10th busiest airport in Europe, and the tourist port of Rome that extends for approximately one kilometer along the shores of the Tyrrhenian Sea in the coastal hamlet of Ostia. As shown in Figure 3, soil consumption along the entire Lazio coast is extremely alarming. The figures below (Figures 9-13) clearly show the transformations that the area of Isola Sacra and Port of Ostia underwent between 1944 and 2023.

The areas surrounding Isola Sacra host important archaeological sites. The Port of Claudius, built by the emperor in 42 AD and subsequently modified by Trajan in 113 AD, is in the Municipality of Fiumicino. The archaeological park of Ostia Antica, an important commercial hub of Ancient Rome right along the mouth of the Tiber, lies in the municipality of Ostia[20]. In 1925, during the reclamation works on Isola Sacra, the Necropolis of Porto was discovered in the territory of the municipality of Fiumicino. The excavations have brought to light a necropolis with roughly 150 tombs, referring to a period ranging from the 1st to the 4th century AD. The area has a significant historical-archeological identity and cultural heritage that must be preserved. However, several traits of the coastal area close to the mouth of the Tiber and along the coast are not subject to archeological constraints. Figure 14 highlights the areas interested by archeological constraints.

Since Isola Sacra lies on both a coastal and a river stretch (Tiber delta) it is subject to the combined effects linked to the presence of the two hydrographic elements. Isola Sacra is located right on the last stretch of the Tiber, enclosed between two branches where the river bifurcates at Capo due Rami. The main canal called Fiumara Grande, which constitutes the natural course of the river, reaches the sea to the south, while the Fiumicino canal (Fiumara Piccola) reaches the sea to the north. The drains of Leonardo da Vinci Airport and the runoffs of the airport area are located in the Fiumicino canal, at the height of the Portuense road. The wastewater from the Ostia purifier[21] is discharged into the Fiumara Grande, whose banks are reduced to a landing stage in the last stretch.

The Tiber River, winding its way through the heart of Rome, has become increasingly polluted in recent years, with sewage, industrial waste, and urban and agricultural runoff all contributing to its ecological decline. In such an area, floating habitats represent an opportunity to regenerate the ecosystems by using nature-based solutions capable of purifying the waters or increasing biodiversity. The Tiber, with 405 km, is the third longest Italian river after the Po and the Adige and the second after the Po River in terms of width of the hydrographic basin (about 17,000 km^2). The Tiber is also the third Italian river by volume of water, with an average annual flow rate of almost 230 m^3/sec at the mouth. The minimum flow rate measured was approximately 70 m^3/sec while the maximum was 2750 m^3/sec. The Tiber River basin has a sublittoral Apennine-type

20. The data is taken from authoritative sources and updated, in particular from the Geoportal of the Lazio Region accessible to https://geoportale.regione.lazio.it/layers/

21. Source: https://www.arpalazio.it/documents/20124/53499/Corpi+idrici+Roma+2019.pdf

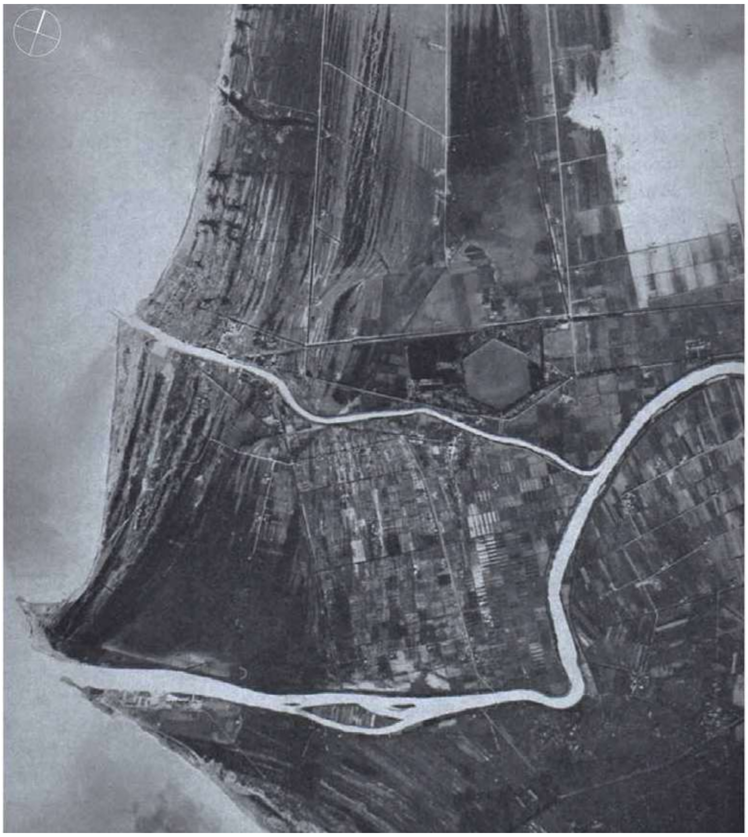


Figure 9. 1944. RAF (Royal Air Force) satellite image of the Tevere Delta.

Figure 10. 2023. Satellite image from Google Earth: Data SIO,NOAA, U.S. Navy, NGA, GEBCO Image © 2023 TerraMetrics

Figure 11. 1990. Ortofoto 1:10.000 Sezione n° 386070 Foce del Tevere. Regione Lazio Assessorato - Urbanistica - Assetto del territorio - Tutela Ambiente

Figure 12. 2002. Ortofoto 1:5000 Sezione n° 386071. Regione Lazio Assessorato - Urbanistica - Assetto del territorio - Tutela Ambiente

Figure 13. 2020. Satellite image from Google Earth: Data SIO,NOAA, U.S. Navy, NGA, GEBCO Image © 2023 TerraMetrics

Figure 14. 2 Archeological protected areas. Source: Geoportale Regione Lazio - Aree archeologiche

22. Grid A of the Risk assessment system classification according to the Tiber River basin.

regime, characterized by two maximum values of precipitation and two minimums, with the summer minimum more accentuated than the winter one and the autumn maximum greater than the spring one. In the absence of glaciers in the basin, the flows are determined almost exclusively by rainfall and are maximum in the autumn-winter semester between October and March (Bellotti, 2018). The delta is part of Grid A[22] where the reference flood assumed in the risk assessment is measured by the Ripetta hydrometer. It marks a hydrometric level corresponding to a peak flow rate of 3,300 m^3/sec. The Isola Sacra area is exposed to R4 risk near the river embankment and R2 risk at less than 300 m distance from the embankment and along the coast (Figure 15)[23].

The flood risk classes, according to the Legislative Decree 49/2010,

Figure 15. Risk classification. Source: Geoportale Regione Lazio, Mappe di rishio del Tevere.

are four (R1-R4) expressed in terms of:

a. indicative number of potentially affected inhabitants;
b. strategic infrastructures and structures (motorways, railways, hospitals, schools, etc.);
c. environmental, historical and cultural assets of significant interest present in the potentially affected area;
d. distribution and type of economic activities in the potentially affected area
e. plants referred to in Annex I of Legislative Decree 59/20052 which could cause accidental pollution in the event of floods and protected areas referred to in Annex 9 to Part III of Legislative Decree 152/2006;
f. other information considered helpful by the district authorities,

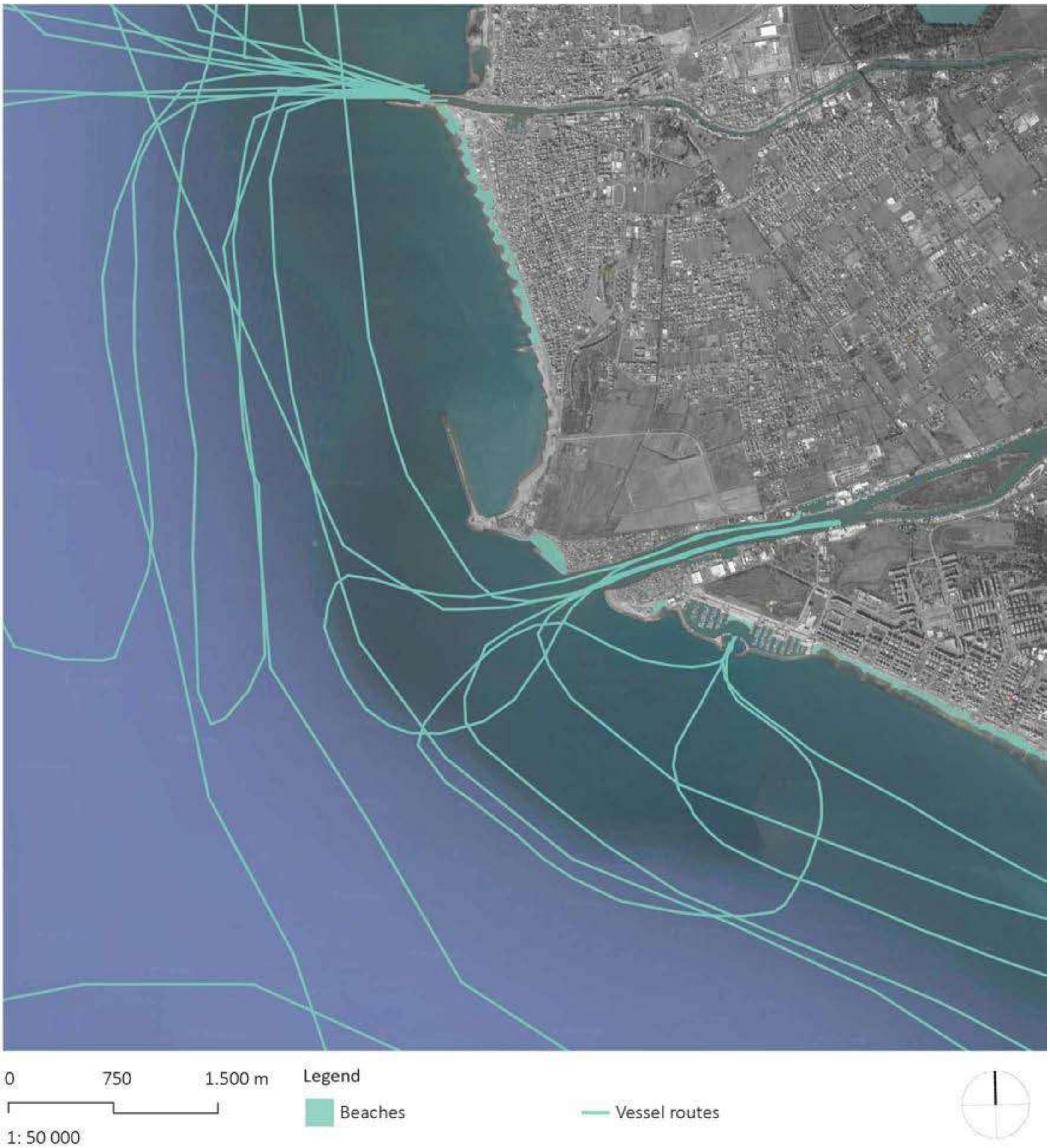
23. Data is taken from the Official document released by Autorità di Bacino del Fiume Tevere in 2005: Ipotesi di regolazione dei deflussi ai fini del governo delle piene nel bacino del Tevere (Direttiva Presidente del Consiglio dei Ministri del 27/02/2004 – Parte II – Le caratteristiche del fenomeno di esondazione).

such as areas subject to floods, with high volumes of solid transport and debris flows, or information on relevant sources of pollution.

The assets exposed to R4 risk fall within the flood zone characterized by the greatest danger, Tr 50, and are characterized by a very high sensitivity. Assets exposed to R2 risk can have a very high or high sensitivity in relation to their intended use but are included within the flood zone between Tr 200 and Tr 500 or in indirect flood areas due to flood with Tr 200 or marginal to the same.

Figure 16. Main shipping routes and bathing areas. Scale 1: 50000. Source: Vesselfinder Portal (https://www.vesselfinder.com/it)

The map in Figure 16 shows the main nautical routes traced by recreational boats, that are mainly used for fishing. The vessels define areas of flows that run parallel to the coast. Most naval routes have their docking and departure point in the Tiber River's smaller



and northernmost tributary, leaving the Isola Sacra area free from maritime flows. The map also features in the aqua green color hatch, the bathing areas located south and north of the river mouth, in morphologically more suitable coastal traits and touched, to a lesser extent, by naval routes.

5.2.1. Historical excursus

The most recent archeological research dated the origins of Ostia to the 4th century BC when the Romans erected a *castrum* at the mouth of the Tiber consisting of a camp and a small residential settlement (330 BC) following the capture of Veio in 396 BC. Ostia Antica developed along the Tiber River. The name Ostia is derived from the Latin *ostium* (entrance, mouth) and refers to the presence of the Tiber's mouth (delta). Urban and building development began with the foundation of the Ostiense Police Headquarters in 266 BC. Ostia became a commercial metropolis connected to Rome by multiple communication routes, the most important of which was the Decumanus Maximus, a natural continuation of the Via Ostiensis.
The increased trade between Ostia and Rome prompted Emperor Claudius to build the Portus Augusti Ostiensis in 42 AD to guarantee a safe dock for ships. The location of the Port drew various concerns since it was not sufficiently protected from the dangers of wave motion and strong southern currents. Because of these factors, Emperor Trajan altered the building of the Port of Ostia. The Fossa di Traiano, an artificial pit corresponding to today's Fiumicino canal, connected the river to the imperial Port. The lengthening of the pit led to the formation of the Isola Sacra, a 12 km^2 at the mouth of the Tiber. At the time, the island covered roughly three-quarters of its current surface, with the remainder increasing from century to century thanks to the addition of alluvial sediments deposited by the Tiber. The project was completed in 113 AD and named Portus Traiani. The homonymous necropolis was discovered near Isola Sacra, where roughly 150 imperial-age burials with well-preserved mosaics and decorative stucco paintings were found. Following the advancement of the coastline and the progressive swamping of the two port basins, the city of Portus depopulated to the advantage of nearby smaller settlements such as the episcopate of Port.
Over the centuries, several popes have ordered the construction of coastal towers along this stretch of the Tyrrhenian coast, such as the Nicolina Tower, built by Nicholas V in 1450 and restored by Pius V in 1567, the Alessandrina Tower and the Clementina tower. Under the pontificate of Pius V successor, Gregory XIII (1572-82), a fishing village began to develop around the Clementina tower. Figure 17 shows how Fiumicino was depicted in 1582 in a contemporary fresco in the Vatican Gallery of Geographical Maps. Between 1823 and 1828, under Pope Leo XIII, the task of creating an urban center adequate to the population's needs was entrusted to one of the major architects of the time, Giuseppe Valadier. The modern town of Fiumicino emerged from Borgo Valadier. From 1880 onwards, with the opening of the railway connecting Fiumicino to Rome, the city

Figure 17. Fresco in the Vatican Gallery of Geographical Maps: Fiumicino and the ruins of Portus in 1582.

experienced rapid economic and demographic development. In the 19th century, the Roman coast was characterized by salt marshes and areas of dense vegetation which prevented stagnant water from flowing towards the sea. The Tiber's violent floods hindered direct land cultivation in the Ostia region and throughout the Roman countryside. Once fertile and cultivated, the swamp of Isola Sacra became a malarial area during the Middle Ages. However, at the end of the 19th century, it was reclaimed by settlers from Ravenna. The first laws for hydraulic rehabilitation of the Roman countryside were proposed by the unitary state in 1878 (Palliccia, 2006). On July 15, 1880, the project for the Tiber's re-arrangement was approved, involving the reclamation of Ostia and Maccarese through various levels of channels. The area was infested with malaria, and the work took more than seven years to be completed. The first years of the 20th century marked the beginning of the urbanization of Ostia: the road network with the modernization of the old Via Ostiense and the works for the Via del Mare, the construction of the Rome-Ostia train and the railway station designed by architect Marcello Piacentini, the first municipal offices, the implementation of drinking water and electricity utilities, the construction of the seaplane base, the inauguration of the Castelfusano pine forest, the modernization works of the Canale dei Pescatori, services to the citizen, the construction of the Lungomare Toscanelli and the ensuing establishment of the first bathing facilities between 1919 and 1933. Both Ostia and Fiumicino lost a consistent part of their infrastructure, buildings, and monuments during World War II, and the post-war reconstruction and recovery was slow. At the end of the 1950s, substantial building investments affected Ostia, and speculative building took over, homogenizing the coastal town to the planned or illegal suburbs of the capital (Creti, 2008). Ostia took over the structure of a suburban neighborhood of Rome: rough urban planning and public housing, often illegal (Di Somma, 2011). This building boom transformed Ostia from a vacation destination to a neighborhood inhabited no longer only by the fishermen but also by the daily commuters working in Rome (Di Somma, 2011).

5.2.2. Urban fabric and urban system

Passo della Sentinella, the mouth of the Tiber River, marks the border between the 10th Municipality of the city of Rome, Lido di Ostia Ponente (33rd district of Rome), and the Isola Sacra district of the Municipality of Fiumicino. The coast represents both the territory's natural boundary and the settlement fabric's morphological edge. It also acts as a barrier separating Ostia's embankment from that of Isola Sacra. It is a highly vulnerable area, yet strategically positioned for the entire metropolitan city of Rome. Despite its haphazard and unplanned urbanization, Isola Sacra is still experiencing urban pressure linked to the construction of new buildings. This is partly because of the few facilities linked to the airport system and related activities.

Furthermore, the floodplain is occupied by naval activities that monopolize the territory and limit a direct view of the sea. The riverfront area is marked by a high flood risk and is characterized by abandonment and often abusiveness. A distinctive characteristic of the area is the significant presence of architectural artifacts, archaeological sites, and parks spread along the coast and at the mouth of the Tiber, which bear witness to its century-old history and cultural identity. The natural landscape is still visible and characterized by plenty of undeveloped land, mostly uncultivated. The prevailing fabric is spontaneous, characterized by a preponderance of residential unauthorized constructions. The area adjacent to the mouth of the Tiber is spontaneous too, mainly residential, but characterized by a comb layout with a prevalence of single-family houses. It took a while for the area to develop because of the irregular and unplanned road infrastructure. Still today, most of the roads remain unpaved. The same spontaneous residential fabric characterizes the embankment on the Ostia side. The territory is dotted with small production settlements with an artisanal or industrial character distinguished by an irregular unitary structure. Several built-up fringe and edge areas are left incomplete and poorly defined. Both sides of the river in this stretch can be defined as distressed urban areas, defined by OECD as situations of underdevelopment in developed contexts. In other words areas of a city that suffer social, economic, cultural, and ecological deprivations within the city, characterized by serious conditions of underdevelopment compared to the city itself and to the national average (OECD, 1998).

The Passo della Sentinella area is a densely built area due to a building expansion that started in the 1970s. Nonetheless, there are no urban-level public services in the area, and there is only one public facility at a local level, specifically the Chapel of Santa Maria del Fiume, classifiable as cult equipment. The area is also poorly served in terms of private activities and facilities (commercial, leisure, tourism). Moreover, within 200 meters from Fiumara Grande, scholastic, administrative, cultural and welfare facilities are absent. Shifting the focus to infrastructure, as can be seen from the map in Figure 18, the project area only has ordinary and secondary roads, and there is no rail infrastructure or public mobility network nearby. There are no cycling lanes nor pedestrian areas. From via del Passo della Sentinella, access to the water is guaranteed only through private piers and is consequently only accessible and usable by who uses the private services along the coast and river banks. In some points along the road, where the buildings stop, access to the water is possible, yet with great difficulty, as there are no roads or paths specially designated for it. Several concrete bridges allow to cross the ditches in the area.

Following amendments and additions, Law No. 1150 of August 17, 1942, brought the Fiumicino master plan into effect. The area adjacent to Passo della Sentinella (Table 12.13 updated D.C:C:

Figure 18. Land mobility system. Scale 1:10 000. Source: Re-elaboration by Livia Calcagni and Adriano Ruggiero using data retrieved from Lazio Region Geoportal, Rome information layers.

2009) hosts port equipment (Sub-area F1a2) and warehouses for shipbuilding, storage, tourism and recreational activities (Sub-area F2f) along the coast overlooking the Tyrrhenian Sea, and several building-maintenance areas for environmental rehabilitation and remediation (Sub-area B1b) along the westernmost stretch of the river mouth. A large portion of the Tiber embankment that spreads eastward is also a Subarea F2f. Close to the residential area along the river bank, there is an urban park (Public green).
Rome's master plan was enacted in 2008[24]. Even though it is home to a decent number of people (spontaneous and informal residences), the area next to the Tiber embankment near the river mouth is classified as local public services and public green spaces (city to be renovated). The latter, together with an area designated primarily for activities (Renovated City) further east, constitutes the objective of an integrated program. The island inside the Tiber and the eastern embankment are part of the Roman Coast State Natural Reserve (Established Parks). These areas are also partly classified as public parks and local public services (Service and Infrastructure System). The southern coast is enclosed by open areas (Historic City).

5.2.3. Anthropic system

A comparative analysis of the demographic data[25] concerning the population of Isola Sacra with that of the municipality of Fiumicino was carried out. Slightly more than 81,000 people live in the Municipality of Fiumicino, compared to 14,500 in the hamlet of Isola Sacra, according to the 2016 census. In the hamlet of Isola Sacra, there are 14,500 inhabitants according to the census of 2016, against the 81,016 inhabitants of the Municipality of Fiumicino[26]. The population density is 1,491.77 inhabitants per km^2, significantly higher than Fiumicino's population density (378.77 inhabitants per km^2). Most of the population (53%) is female, consistent with the other municipalities' data. According to data on current marital status, 45% of the inhabitants are unmarried, corresponding to a slightly higher portion compared to the broader area of Fiumicino. Married people account for 43% of the local population; the remaining 12% includes widows and separated people. An increasing trend in the annual variation of families from 2015 to 2020 contrasts with that of the entire Municipality of Fiumicino or Rome. Roughly 30% of families comprise one person, 25% are made of 2 components, 20% of 3, and the remaining 25% involves family groups of more than four components. Defining a trend more equally distributed compared to the reference municipalities. The age share of the population between 25 and 64 years old with at least a high school qualification or higher degree accounts for 34%, far less than the national average of 64.4% (in 2021). This is one of the leading indicators of a country's level of education since the diploma is considered the level of essential training for participation in the job market with potential for individual growth. Only 5% of the inhabitants of Isola Sacra (between 25-64 years old) have a

24. Approval Resolution of the City Council n.18 of February 12, 2008.

25. Data is gathered from renowned and updated sources, in particular the ISTAT census (http://dati.istat.it/?lang=en; and gis. censusopolazione.istat.it/apps/dashboards/06b7107f6cee43d2872c73817e94e11b) and statistical reports provided by the Municipality of Fiumicino (https://www.comune. fluidino.rm.it/index.php/vivere-fiumicino/dati-statistici-territoriali) and by the Municipality of Rome (https://www.comune.roma. it/web/it/roma-statistica-popolazione.page).
Data related to average income is provided by the Ministry of Economy and Finance, and level of education and rate of occupation are provided by the Geographical Portal *Italia in detail*.

26. Accordng to the 2022 census.

bachelor's or higher degree, a significantly lower value compared to the national average (20.1%) according to the ISTAT report on education levels for 2021. The foreign population residing in Isola Sacra accounts for 8%, which aligns with the other municipalities. The average yearly income – of about 20,000 euros – increased in the years between 2005 and 2015.

5.2.4. Environmental system

5.2.4.1. Hydrography and seabed

The 1970s building boom resulted in the formation of urban centers with high population density on the Tiber's buffer strips, both on the banks of the Municipality of Fiumicino and the Municipality of Ostia. Both sides of the river are regulated by Article 69 of the NTA[27] of the PRG of the Municipality of Rome and the Municipality of Fiumicino. Article 69 provides precise indications that must be observed in protected natural areas, waterways, and relative buffer zones (Figure 19).
The riverbed at the mouth of the Tiber is mostly muddy. By using two different analysis scales (Figure 20a and Figure 20b), it is possible to extrapolate data relating to the depth of the seabed, considering different study areas. In Figure 20a, the contour lines show how the seabed depth increases as one moves away from the coast, reaching a depth of -35 m at a distance of 5 km. At a closer scale (Figure 20b), the depth of the seabed inside the river mouth and in the area adjacent to the sea is highlighted through punctual georeferentiation. The maximum depth is 8 m at the farthest point from the coast, while the average depth inside the river varies between 4 to 5 m, reaching 3 m in the area closest to the river banks.

5.2.4.2. Landscape system

Although the Passo della Sentinella area is entirely built, the territory bordering the Fiumara Grande is predominantly classified as *natural landscape* or *natural landscape of continuity*. The island of Isola Sacra in the river is part of the Roman Litoral Natural State Reserve. It is a protected natural area established by the Ministry of Environment with a ministerial decree on March 29, 1996. The State Natural Reserve extends over more than 16,000 hectares of historical and naturalistic interest, stretched discontinuously along the Lazio coast between Palidoro and Capocotta. It falls partly within the municipality of Fiumicino and partly within Rome and constitutes the largest protected area overlooking the Mediterranean Sea. With Law 394 of December 6, 1991, the Management Plan and the Implementation Regulation of the Roman Litoral Natural State Reserve were adopted. The area of Isola Sacra included in the Natural State Reserve extends itself mainly within the *Coastal Plain* landscape. Phytoclimatically, the protected area is located between the coastal strip of the Mediterranean Region and the Mediterranean Transition Region (Blasi, 1994). The territory's

27. Norme Tecniche e Attuative. Rules that specify the interventions foreseen by a general or detailed urban plan, specifying the quantitative and qualitative indications of the area.

Figure 19. Hydrography and buffer zones. Scale 1:10 000. Source: Re-elaboration by Livia Calcagni and Adriano Ruggiero using data retrieved from Lazio Region Geoportal - Public waters respect.

current land use is clearly distinguished between the flat area for agricultural use and the coast, which, despite being fragmented by extensive urban areas, contains significant examples of naturalistic value. Within the Reserve's boundaries, different environmental systems characterized by different vegetation can be identified, some of which include plant formations of *great naturalistic interest* that can be traced back to the Habitat Directive 92/43/EEC or *botanical emergencies of national or local importance*. The delta system, the coastal wetlands, and the ditches marked by natural, semi-natural, or artificial wetlands characterize the natural landscape of the Roman coast in the Isola Sacra area.

Figure 20a. Seabed bathymetry with contour lines. Source: Re-elaboration by Livia Calcagni and Adriano Ruggiero using data retrieved from ISPRA Ambiente and from the repository of the EU Project Maestrale

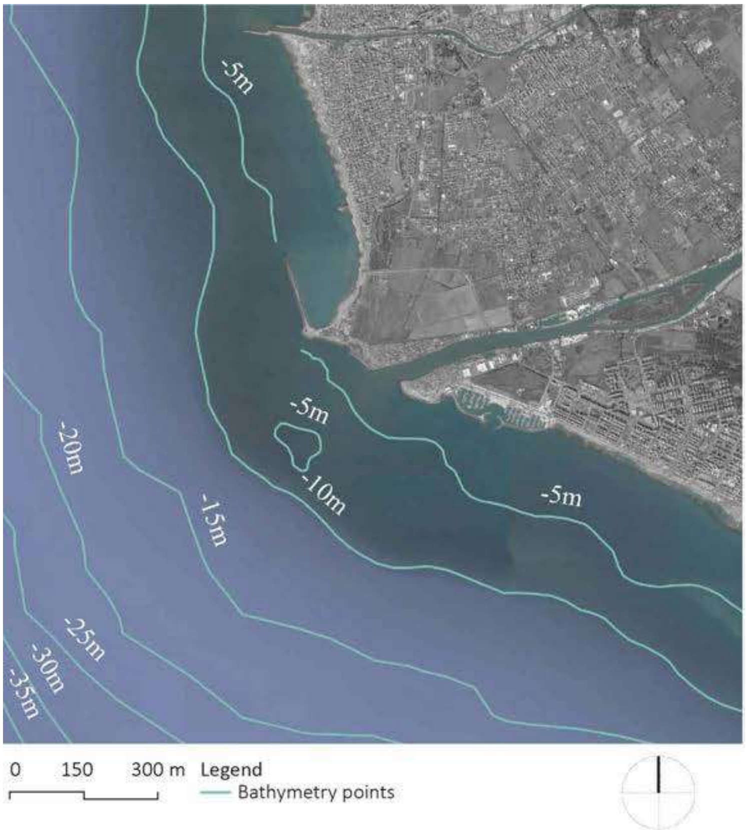
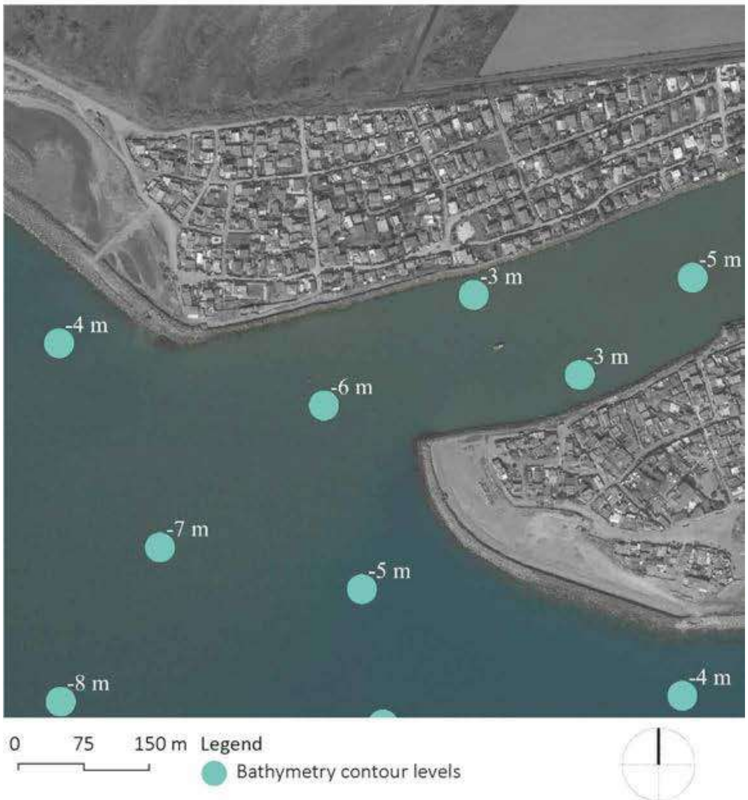


Figure 20b. Seabed and riverbed bathymetry with punctual indication. Source: Re-elaboration by Livia Calcagni and Adriano Ruggiero using data retrieved from ISPRA Ambiente and from the repository of the EU Project Maestrale



5.2.4.3. Natural habitat and protected areas

From a floristic and faunal point of view, the Roman Litoral Natural State Reserve is characterized by a high presence of allochthonous entities, making it one of the main allodiversity hotspots at the regional scale. According to a recent summary report, 117 alien plant species were detected in the Reserve area in 1980, accounting for 33.3% of the 351 species in the entire Lazio Region[28]. A possible explanation for this high rate of alien species could be the significant anthropic pressure that characterizes the Reserve area. The Tiber River is the landscape element that most distinguishes the area, as it constitutes a valuable natural habitat for a variety of autochthonous animal and plant species.

The Regional landscape plan PTPR (*Piano Territoriale Paesaggistico Regionale*) highlights the complex system of coastal habitats that follow one another along the territory. Agricultural areas are adjacent to artificially built areas and highly valuable wetlands. The wetlands have a hydrogeological role as they contribute to attenuating and regulating river floods, a biological function as they represent one of the most important types of habitat for biodiversity conservation, and a chemical and physical one since they are nutrient traps.

Natura 2000 is the main instrument of the EU biodiversity conservation policy. It deals with a coordinated system of areas intended for the conservation of biological diversity in the EU territory. This ecological network spread across the entire EU territory was established by Directive 92/43/EEC *Habitats* to ensure the long-term preservation of threatened or rare natural habitats and species of flora and fauna at the community level.

A large area adjacent to Passo della Sentinella is classified as a *Special Conservation Area* (ZSC), a *Site of Community Importance* (SIC) where conservation measures have been implemented to maintain or restore natural habitats and populations of the species designated by the European Commission. The Decree of the President of the Republic n. 357/1997 implements Directive 92/43/EEC on the conservation of natural and semi-natural habitats, as well as wild flora and fauna. It introduces the Impact Assessment in Italy, which represents the preventive procedure to which any plan or project that may have significant impacts on a Natura 2000 site, individually or in combination with other plans and projects, must be submitted, considering the site's conservation objectives. The Natura 2000 Network includes the SCI IT6030024 - *Isola Sacra* which is strictly contiguous to the Roman Litoral Natural State Reserve and consists of a periodically flooded depression behind the dunes. The SIC offers a variety of habitats of community interest, such as Halophilous and thermo-Atlantic grasslands and orchards (*Sarcocornetea fruticosi*), Wet interdune depressions, Mediterranean flooded pastures (*Juncetalia maritimi*) and other pioneer vegetation in Salicornia and other annual species of muddy and sandy areas. The IT6030024 SIC has a Management Plan[29], depicted in Figure 21 as *Artboard 1 - Constraints*.

The implementation regulations of the Management Plan[30] provide

28. Data retrieved from Piano di Gestione L. 294 6 dicembre 1991, art 17 - Riserva Naturale Statale Litorale Romano - Relazione Generale di Piano e Regolamento (https://www.comune.roma.it/web-resources/cms/documents/Piano_Gestione_RNSLR_Relazione_Generale_PdG__Riserva_Litorale.pdf).

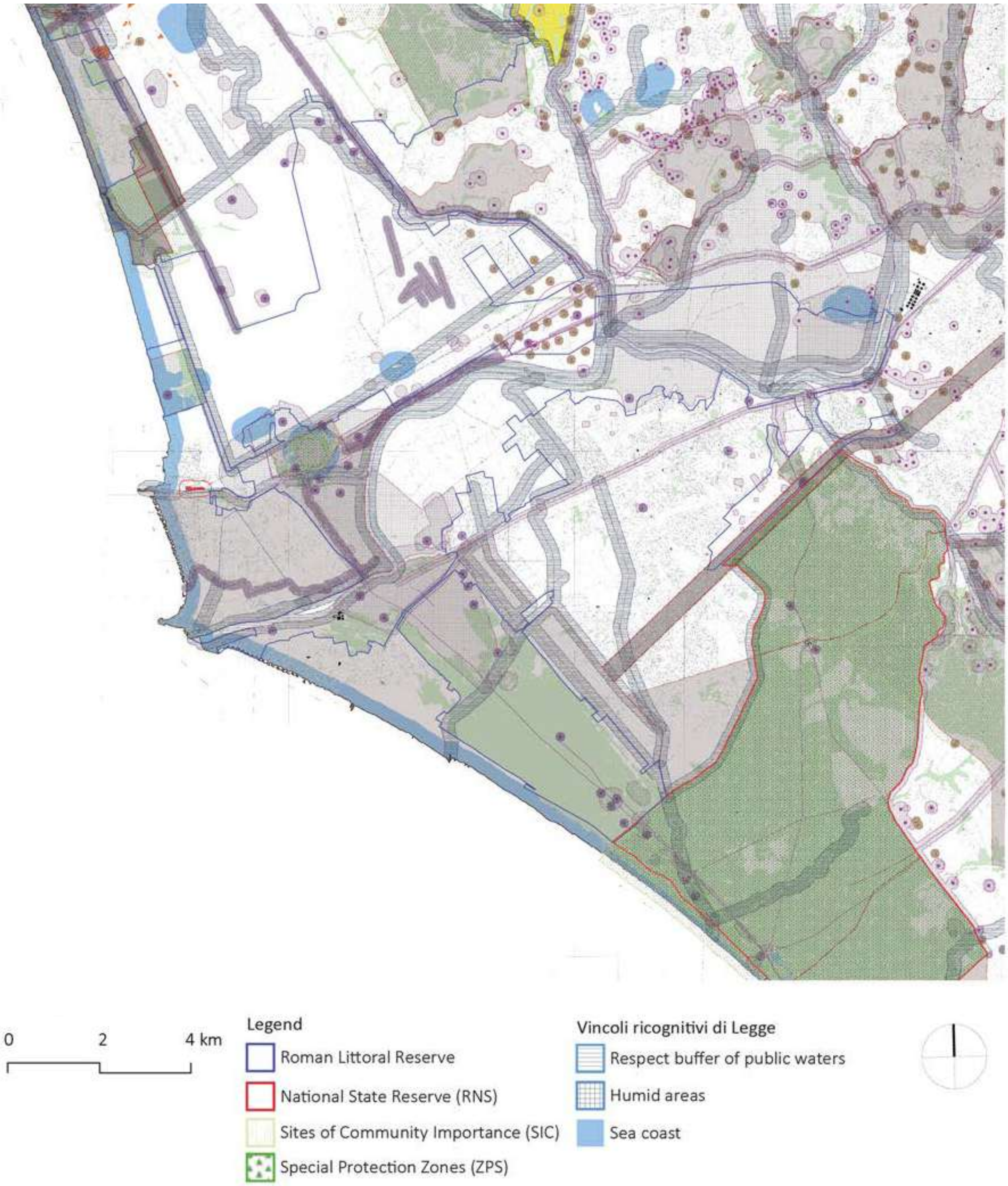
29. Piano di Gestione L.394 6 dicembre 1991, art 17, Riserva Naturale Statale (RNS) Litorale Romano, available for consultation at the Ministry of the Environment and Protection of Land and Sea, the Lazio Region (https://www.parchilazio.it/litoraleromano), and the Municipality Management Bodies, Roma Capitale and Fiumicino.

30. Regolamento attuativo del Piano di Gestione della Riserva Naturale Statale del Litorale Romano - Commissario ad acta Dott. Vito Consoli D.P. R.L. T00468 del 16/12/2015 (accessible: https://www.parchilazio.it/documenti/schede/regolamento_attuativo_rnslr.pdf).

constraints in force in the areas that fall within the Management Plan. Except for seasonal agricultural activities, Article 2 *General rules* prohibits any activity that produces noise levels higher than those compatible with a protected area under the terms of Law 447/95. It allows:

- interventions aimed at the environmental regeneration and conservation of the naturalistic quality of cultural and environmental areas and assets;
- interventions aimed at building or expanding structures to

Figure 21. Artboard 1 - Constraints. Management Plan of the Litorale Romano State Nature Reserve. Source: Lazio Region, Lazio Parks



support environmental and historical-cultural heritage use; these interventions must be compatible with the appearance and vocation of the areas, with prescribed building types that guarantee better performance energy, environmental and architectural quality;

- interventions aimed at the reconstitution of local autochthonous vegetation,
- interventions aimed at preventing fires and any risks to public safety;
- strictly necessary to ensure the conservation of the historical-archaeological monumental heritage;
- interventions required to ensure public and private safety, made where possible with naturalistic engineering techniques and solutions.

Article 4 – Supplementary rules for Type 2 Areas - except specific indications prescribed by type of Area and Management Unit – generally allow:

- transformation and urbanization interventions planned by current urban planning instruments;
- any new building or transformation, even in variations to the current urban planning instruments, if aimed at the institutional objectives of the Natural Reserve;
- creation of public services or sports facilities intended for the benefit of neighbouring inhabited areas, with a low/medium urban load and compatible with the landscape;
- recovery plans, urban restructuring and redevelopment;
- construction of structures and infrastructures serving agricultural activities, as required by Regional Law 38/99 art. 57 and 57bis (PUA) and relating to the settlement area.

Article 7 - Rules for urban-building interventions in the coastal area prohibits the creation of new structures (fixed or temporary) even if aimed at using the beaches, except for works authorized in advance to protect the coast or for public safety. Building renovation is permitted if aimed at seismic adaptation or creating more sustainable structures in terms of consumption of land and other natural and energy resources. All interventions must comply with current regulations regarding sustainable architecture, green buildings, and landscape-environment regeneration.

Article 15 - Rules for urban and building interventions in hydrographic buffer areas prohibits new construction interventions in the hydrographic buffer area but allows the construction of watercourse crossings and docks in compliance with the NTA[30] of PTPR Art. 35 (Protection of public water courses) and of routes for slow mobility (cycle-pedestrian) equipped with walkways.

In short, urban and building interventions in the hydrographic buffer area are currently prohibited. However, they are allowed in coastal areas if aimed at "creating more sustainable structures in terms of consumption of land and other natural and energy resources". This implies that any construction must address these objectives.

However, the construction of a floating building on the Tiber is subject to a set of specific norms and regulations. First, constructing

31. See note 27.

a floating building on the River Tiber would require obtaining building permission from the Municipality of Rome. The building permit is an administrative act that authorizes the execution of construction work, whether permanent or temporary. In the specific case of a floating building, the building permit is necessary because the structure is permanently anchored to the riverbanks and constitutes a new construction. The request for a building permit must be submitted to the Protocol Office of the Municipality of Fiumicino. A state concession from the State Property Office is also required. The state concession is an administrative act that grants access to state property, such as river land. The state concession request must be submitted to the State Property Office and the State Concessions Office. After obtaining the building permit and the governmental concession, the construction of the floating building can commence.

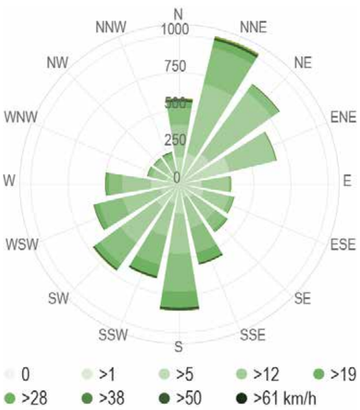
Although urban-building interventions in the hydrographic buffer area are currently forbidden, for the scenarios developed in the Master's Design Lab (Chapter 6) and research purposes, reference will be made to article 7, which is valid for the coastal zone, extending its application to the hydrographic area.

5.2.4.4. Climate and microclimate

Based on Köppen-Geiger climate classification, Isola Sacra has a Csa climate: Hot-summer Mediterranean climate. Therefore, it falls among the temperate climates with dry summers and annual ranges from 15 to 17°C. The wind rose for Isola Sacra (Figure 22) shows that the strongest winds come from NNE and NE, with an average speed between 12 and 19 km/h, which can also exceed 50 km/h between December and January. The wind comes from the north, especially from the end of November to the beginning of March. Between March and April and from late September to late November, the wind comes from S and SW with average speeds between 5 and 19°C and peaks above 50 km/h. The prevailing wind direction is from the West for five months a year, from the end of April to the end of September.

The average maximum daily temperature (solid yellow line in the graph in Figure 23) ranges between 12°C (January and December) to 29°C (August), while the average minimum daily temperature (solid blue line) has a minimum peak of 4°C in February. In June and August, temperatures can reach 35° (for a maximum of 4-5 days per month). August is the hottest month, while January is the coldest. Precipitation (Figure 24) ranges between a minimum of 15 mm in July and a maximum of 102 mm in November. The months from May to August are the driest. Monthly rainfall in the area varies significantly by season. Basing the comfort level on the dew point (as it determines whether the perspiration will evaporate from the skin, thus cooling the body), the lower dew points cause a drier feeling while higher dew points a more humid one. Seasonal variations in perceived humidity are extreme in Fiumicino. The most humid season lasts 3.9 months, from early June to early October,

Figure 22. Wind rose diagram (average wind speed and main directions) of Isola Sacra, Fiumicino. Source: Re-elaboration by Livia Calcagni using data from Meteoblue.



Wind speed (m/s)

Jan	Feb	Mar	Apr	May	Jun
4,25	4,38	4,29	4,16	3,66	3,44

Jul	Aug	Sep	Oct	Nov	Dic
3,40	3,35	3,58	3,93	4,43	4,51

and the comfort level is muggy, oppressive, or at least intolerable 17% of the time. The month with the most muggy days is August, with about 19.3 days[31].

The average surface temperature of the water (Figure 25) undergoes extreme seasonal variations throughout the year. The warmest period of the year lasts 2.8 months, from June 29 to September 22, with an average temperature exceeding 23°C. August is the warmest month, with an average temperature of 25 °C. The period with cooler water lasts for 4.5 months, from December 14 to April 29, with an average temperature of less than 16°C. The coldest month is February, with an average temperature of 14 °C. The data in the climate diagrams are based on model reconstructions of hourly simulations of weather models for more than 30 years (January 1, 1980 - December 31, 2016) and provide reasonable indications of typical climate models and expected conditions[32].

31. The temperature and dew point estimates are registered by two fairly closeclose weather stations: Leonardo da Vinci International Airport (LIRF, 93%, 3.9 km, north, 3 m altitude change); Pratica di Mare Airport (LIRE, 7%, 21 km, southeast, 11 m altitude change).

32. All climate data, including cloud cover, precipitation, wind speed, and direction, were collected from NASA's MERRA-2 Modern-Era Retrospective Analysis

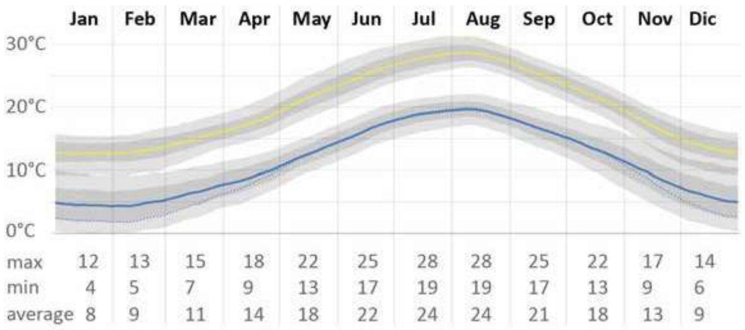


Figure 23. Average, minimum and maximum air temperature per month in Isola Sacra, Fiumicino. Source: Re-elaboration by Livia Calcagni using data from Weather Spark.

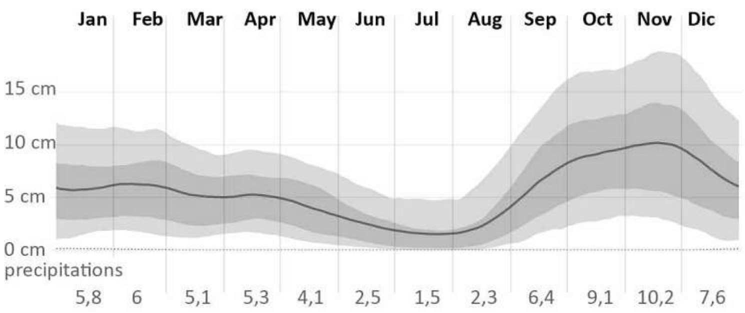


Figure 24. Precipitations per month in Isola Sacra, Fiumicino. Source: Re-elaboration by Livia Calcagni using data from Weather Spark.

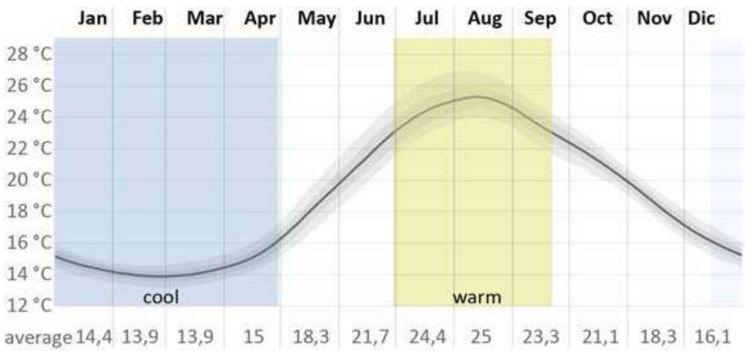


Figure 25. Averagre surface water temperature per month in Isola Sacra, Fiumicino. Source: Re-elaboration by Livia Calcagni using data from Weather Spark.

References

Antonioli, F, Anzidei, M., Auriemma, R., Gaddi, D., Furlani, S., Lambeck, K., Orru, P. E., Solinas, E., Gaspari, A., & Karinja, S. (2007). Sea level change during Holocene from Sardinia and northeastern Adriatic from archaeological and geomorphological data. *Quaternary Science Reviews, 26*, 2435–2458. doi:10.1016/j.quascirev.2007.06.022

Anzidei, M., Antonioli, F., Lambeck, K., Benini, A., Soussi, M., & Lakhdar, R. (2011). New insights on the relative sea level change during Holocene along the coasts of Tunisia and western Libya from archaeological and geomorphological markers. Quaternary International, 232(1–2), 5–12.

Anzidei, M., Bosman, A., Carluccio, R., Casalbore, D., D'Ajello Caracciolo, F., Esposito, A., Nicolosi, I., Pietrantonio, G., Vecchio, A., & Carmisciano, C. (2017). Flooding scenarios due to land subsidence and sea-level rise: a case study for Lipari Island (Italy). *Terra Nova, 29*(1), 44–51. doi: 10.1111/ter.12246

Aucelli, P. P. C., Di Paola, G., Incontri, P., Rizzo, A., Vilardo, G., Benassai, G., Buonocore, B., & Pappone, G. (2017). Coastal inundation risk assessment due to subsidence and sea level rise in a Mediterranean alluvial plain (Volturno coastal plain–southern Italy). *Estuarine, Coastal and Shelf Science, 198*, 597–609. doi: 10.1016/j.ecss.2016.06.017

Bellotti, P. (2018). Regime fluviale del Tevere e variazione del litorale deltizio dal Rinascimento ai nostri giorni. *Suplemento de RIPARIA 1*. Retrieved from https://rodin.uca.es/xmlui/handle/10498/20285.

Blasi, C. (1994). *Fitoclimatologia del lazio.* Univ. La Sapienza: Regione Lazio, Assessorato Agricultura-Foreste, Caccia e Pesca.

Bruegmann, R. (2005). *Sprawl: A Compact History.* Chicago, USA: University of Chicago Press. doi: 10.7208/chicago/9780226076973.001.0001

Carreau, P. R., & Gallego, F. J. (2006). EU25 coastal zone population estimates from the disaggregated population density data 2001. Brussels, Belgium: European Commission, DG Joint Research Centre.

Creti, L. (2008). *Il lido di Ostia Rome. Rome, Italy:* Libreria dello Stato, Istituto Poligrafico e Zecca dello Stato.

Dal Bo Zanon, B., Roeffen, B., Czapiewska, K. M., de Graaf-van Dinther, R. E. (2020). Potential of Floating Urban Development for Coastal Cities: Analysis of Flood Risk and Population Growth. In *Lecture Notes in Civil Engineering. 41*. doi: 10.1007/978-981-13-8743-2_17

Di Somma, A. (2011). Evoluzione urbanistica del waterfront di Ostia. *Portus Plus.* Retrieved from http://retedigital.com/wp-content/themes/rete/pdfs/portus_plus/1_2011/Tem%C3%A1ticas/

La_recalificaci%C3%B3n_de_los_waterfront/05_AndreaDiSomma.pdf

ENEA (2019). Innalzamento del Mar Mediterraneo in Italia. Report ENEA Retrieved from https://www.sindacatobalneari.it/sites/default/files/2019-02/Scheda%20sintesi%20innalzamento%20mar%20Mediterraneo%20.pdf

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., & Crochetiere, H. (2019). Mapping the world's free-flowing rivers. *Nature, 569*(7755), 215–221. doi: 10.1038/s41586-019-1111-9

ISPRA. (2023). Consumo di suolo, dinamiche territoriali e servizi ecosistemici.Retrieved from https://www.snpambiente.it/snpa/consumo-di-suolo-dinamiche-territoriali-e-servizi-ecosistemici-edizione-2023/

Lambeck, K., Antonioli, F., Anzidei, M., Ferranti L., Leoni, G., Scicchitano, G., Silenzi, S. (2011). Sea level change along the Italian coast during the Holocene and projections for the future. *Quaternary International, 232* (1-2) doi: 10.1016/j.quaint.2010.04.026

Manigrasso, M. (2023). Land Consumption and Coastal Erosions in Italy. A Focus about the Lazio Region. In *Waterfront dialectics. Rome and its Region facing climate change impacts* (pp. 71–86). Tab edizioni.

Muis, S., Verlaan, M., Winsemius, H.C., Aerts, J.C.J.H., Ward, P.J. (2016) A global reanalysis of storm surges and extreme sea levels. *Nature Communications,* 7, 11969, doi:10.1038/ncomms11969.

OECD (1998). Integrating distressed urban areas. Organisation for Economic Co-operation and Development.

Palliccia, P. (2006). La battaglia dei ravennati che salvarono Ostia dalle acque. *Storia in Network, 11,* Articolo 5. Retrieved from http://win.storiain.net/arret/num111/artic5.asp

Rahmstorf, S. (2007). A semi-empirical approach to projecting future sea-level rise. *Science, 315*, 368–370. doi: 10.1126/science.1135456

Schneider, A., & Woodcock, C. E. (2008). Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. *Urban Studies, 45*(3), 659–692. doi: 10.1177/0042098007087340

Snoussi, M., Ouchani, T., & Niazi, S. (2008). Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: The case of the Mediterranean eastern zone. E*stuarine, Coastal and Shelf Science, 77*(2), 206–213. doi: 10.1016/j.ecss.2007.09.024

Sterr H, Klein R, Reese S (2003) Climate change and coastal zones: an overview on the state-of-the-art of regional and local vulnerability assessments. In C. Giupponi, M. Shechter (Eds) *Climate change in the Mediterranean.* Cheltenham, UK, pp 245–278.

Strollo, A., Smiraglia, D., Bruno, R., Assennato, F., Congedo, L., De Fioravante, P., Giuliani, C., Marinosci, I., Riitano, N., & Munafò, M. (2020). Land consumption in Italy. *Journal of Maps, 16*(1), 113–123. doi: 10.1080/17445647.2020.1758808

Zanchini, E., & Manigrasso, M. (2017). *Vista mare: la trasformazione dei paesaggi costieri italiani.* Milan: Edizioni Ambiente.

CHAPTER 6 Application and assessment of PDSF on pilot site

ABSTRACT

This chapter discusses the development of several design scenarios on the Delta of the River Tiber near the coastal urban area along Passo della Sentinella in Fiumicino, Italy. The scenarios of floating mixed-used settlements conceived as an extension of the existing urban area on the water are designed by junior architects from the Sapienza University of Rome to provide climate-proof housing solution for a population currently living in the flood-risk area in un-authorized and below-standard houses. The fifteen designers, grouped into five teams of two to four to reproduce a typical architectural working environment, used the framework to develop their scenarios throughout the design process. The proposed design scenarios for floating settlements highlight several key considerations that should be addressed in transitioning from terrestrial to aquatic architecture and urbanism. The scenarios demonstrate a remarkable morphological variety of floating structures and layout aggregations, even though they originate from the same framework. However, there is a tendency to replicate terrestrial design thinking and approaches without critically considering the specific needs of floating settlements. One of the most critical issues is the integration of floating settlements with the surrounding terrestrial environment. The margin, or the water-land boundary, is a crucial interface that should be carefully designed to blur the boundaries between the two realms and address the new needs. The PDSF framework proves to be a valuable tool for guiding and addressing the design criteria for floating settlements. However, the results show that the effectiveness of the framework could be enhanced by incorporating more visual design inputs and a user-friendly interface to help architects transition from terrestrial to aquatic design thinking and make the framework more accessible and easier to navigate.

The pilot project area consists of a plot of water located within the delta of the River Tiber near the coastal area along Passo della Sentinella approximately twenty meters distant from the Fiumicino embankment.

Junior architects[1] enrolled as students in the *Course Technological Design for Urban Regeneration* within the Master Degree *Architecture and Urban Regeneration*[2] at Sapienza University of Rome have been asked to develop regeneration projects of the areas through the design of a floating settlement, meant to host the population living on the flood-risk areas in un-authorized and below standard houses. Indeed, the transition from conventional models towards resilience scenarios requires a strong inter-scalar relationship between interventions at the territorial and urban scale and specific interventions according to integrated downscaling and upscaling actions. In this perspective, urban regeneration is not only conceived as the requalification of existing buildings, micro-recovery interventions, urban acupuncture, and measured building replacement but also as new resilient, sustainable construction capable, above all, of restoring living dignity to those who live in degraded and inadequate housing contexts. For this reason, given that the site is a distressed urban area (as shown by the socioeconomic and urban analyses), it lends itself particularly well to implementing regeneration processes in its broadest sense. Furthermore, the removal of illegal dwellings in the area implies the relocation of current residents. A settlement on the water provides new homes near the places where the local community has lived for the last thirty-forty years without uprooting and relocating them to distant areas. Otherwise, this would be the case since the surroundings are protected natural areas that do not allow the construction of new buildings.

The course topic was precisely the *Environmental and technological design of floating settlements* to host the current residents living in illegal below-standard houses. The task was to design a floating settlement conceived as a basic prototype, expandable and repeatable according to new arising climate or urban needs, exploring the potential of a floating settlement as the extension of the existing urban area. The objective was to explore the utility and effectiveness for designers of using the framework on a real location, to evaluate its role in supporting the design process, and eventually draw conclusions on what could be further improved. The design implied carefully considering the relevant on-land area and creating

1. A Junior Architect is a professional with an architectural bachelor's degree or a similar education who is at the beginning of their career and working under the supervision of a licensed or senior architect.

2. The Course *Progettazione Tecnologica Per La Rigenerazione Urbana* [Course code 29814] is coordinated by Full Prof. Arch. Alessandra Battisti, with the support of tutors Arch. Livia Calcagni, Arch. Marco Antonini, Adriano Ruggiero, Arch. Angela Calvano, and Arch. Andrea Canducci. This exercise was carried out during the summer semester of 2023 (March – July).

meaningful tangible and intangible relations and connections between land and water. The fifteen designers were grouped into five teams of two to four to reproduce a typical architectural working environment. The precise location of the water plot along the embankment is at the discretion of each working group based on the evaluation of the analysis presented in Paragraph 6.2.1. and any further information acquired during the design process (e.g., water access roads, presence, or absence of existing or planned services on land, microclimate, social demand, and other relevant specific needs). The settlement is intended to house about 25-40 inhabitants. In addition to the residential units, it must provide at least two shared facilities (public and private) accessible to the settlement's residents and the local community living in the surrounding area. This implies that not all 2000 m² must be used. More precisely, the following indications concerning the functional program were provided (Figure 1).

Residential units

- More than 6 residential units (a minimum living area of 20 m² must be ensured for the first 4 inhabitants, and additional 10 m² for each of the following ones).
- At least 2 different residential typologies (e.g., studio apartment, two-room apartment, three-room apartment, four-room apartment, co-living, social-housing).
- 1 to 3-story buildings.
- Access to each unit from land and/or water.

Urban planning facilities: equipment of collective interest

- Minimum 4.5 + 2 m^2 per inhabitant.
- Functional typology at the discretion of the designer (e.g., religious, cultural, social, welfare, healthcare, administrative, for public services).
- 1 to 3-story buildings.

Additional facilities

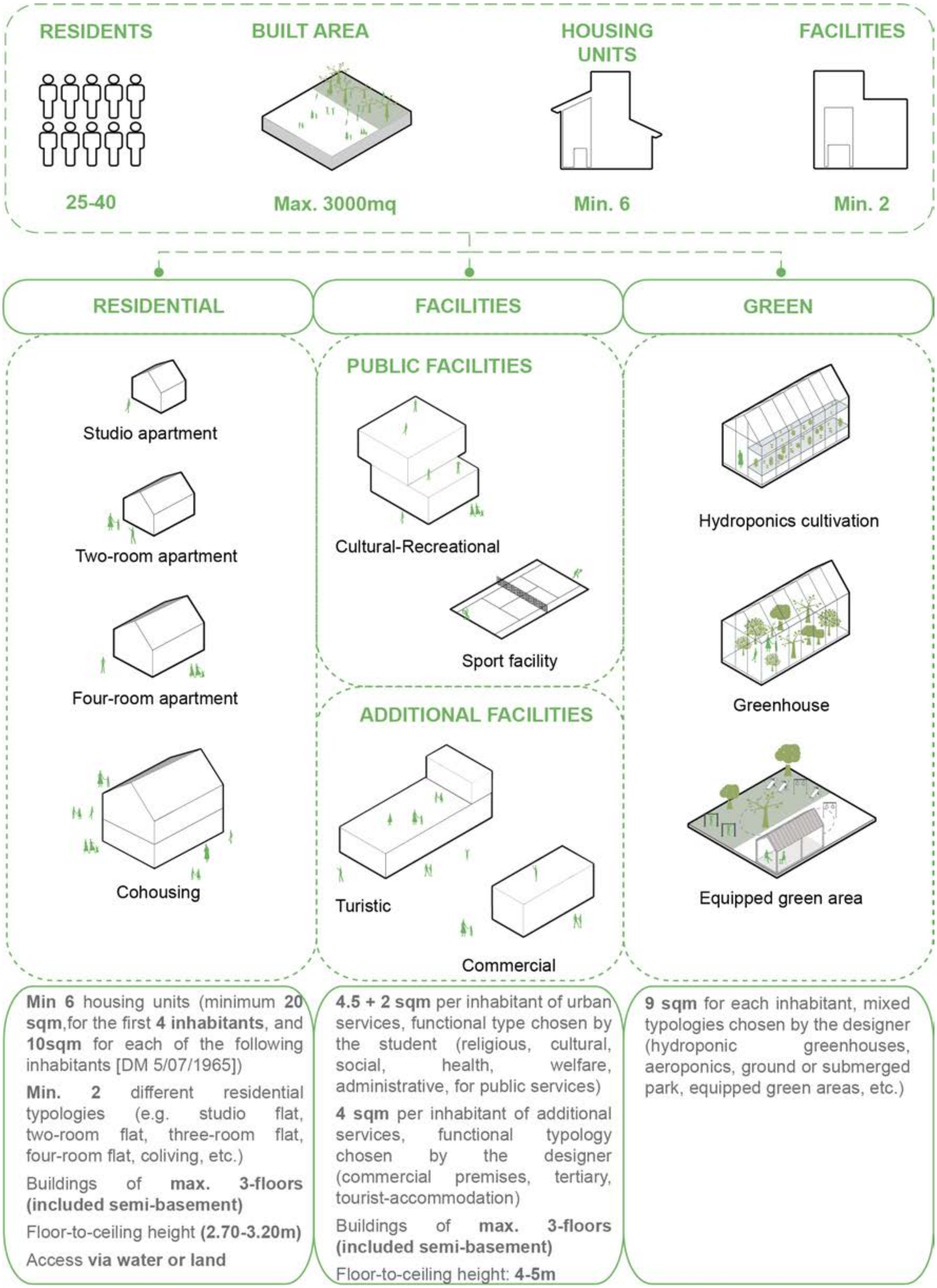
- Minimum 4 m^2 per inhabitant.
- Functional typology at the discretion of the designer (e.g., commercial premises, tertiary, leisure, culture, productive activity, tourist-accommodation, etc.).
- 1 to 3-story buildings.

Public green areas

- Minimum 9 m^2 per inhabitant.
- Functional typology at the discretion of the designer (e.g., hydroponic greenhouses, aeroponics, ground or (semi) submerged park, green equipped areas, etc.).

Designers were asked to take into account dimensional indications, but no morphological recommendations were provided.

Figure 1. Functional program and dimensional indications. Source: Livia Calcagni and Adriano Ruggiero.



6.1 Design scenarios

The design scenarios are described following the same approach used for the case study analysis. As explained in Paragraph 2.1.1.1., the demand-performance approach operates by objectives, which can essentially be conceived as a clarification of the needs of the end user. For this reason, the design objectives are clearly stated at the beginning of each scenario description. The design objectives have been crucial for defining a priority among the classes of demand and have led the designers to advance different choices in the process of decision-making.

6.1.1. Scenario 1

A. Cipollone, M. Saimiei

Design objectives:

- non-repetitive modularity (one basic module, multiple arrangements)
- community living
- circularity.

The settlement is meant for 35 inhabitants and comprises a co-living of 395 m² and private housing units for a total of 195 m². Public facilities include a toy library (95 m²) and a co-working space (95 m²), while commercial activities include a restaurant (120 m²), a bar (45 m²), and a rowing club (120 m²). The settlement results from the linear aggregation of 16 hexagonal modules.

Safety. The dock is raised 0.80 m above water level to avoid overtopping and slip risks. Access is provided in five different points ensuring easy escape in case of emergency. The superstructure is a balloon-frame in laminated fir wood. Fire-safety measures are considered in the design of the upper galleries that serve as emergency exits for the upper floors.

Wellbeing. Active, passive and bioclimatic systems ensure thermal comfort and air quality (bioclimatic greenhouse, motorized shading system integrated in the glazing, integrated air-pre-cooling system through nebulization of water, wind towers). Outdoor private spaces provide quality views to each housing unit.

Usability. Home automation allows the user to adapt the comfort parameters of each different space according to specific needs (number of users, outdoor conditions) and activities. The distribution between buildings occurs along the perimetral sides of the hexagons and access is provided in five different points. The modular floating platforms and their easy aggregation makes the whole system potentially endlessly extendable and replicable.

Integrability. Dry connections and modularity allow future transformations and integrations of components and devices.

Environmental Regeneration. The pontoon in concrete is self-healing and with a finishing in cocciopesto that absorbs CO_2.

Efficient Use of Resources. Passive systems allow to optimize the building energy efficiency: buffer-spaces facing north, bioclimatic wintergarden facing south; ventilation tower; cross-ventilation; trombe wall; ventilated roof system; horizontal shading of windows through overhanging balconies. Different renewable energy sources are used for energy production: oscillating body sensors to generate electrical energy from wave motion; photovoltaic and concentrated photovoltaics; heat pump for radiant flooring system; solar collectors for domestic hot water; micro-wind system; gyroscope for swell with waves up to 3,5 m. Water management is provided: grey water management; rain-water collection system.

Buoyancy - Stability. The concrete pontoon ensures the buoyancy and stability.

Plant System. No design focus.

6.1.2. Scenario 2

E. Farseschi, G. Filippi, A. Latini

Design objectives:

- modularity
- extensibility
- functional mixite and demand adaptability
- energy self-sufficiency and high energy building performance
- food-production
- resource circularity
- community engagement and biophilia.

The project comprises a 136 m² big cohousing building and several housing units: 45 m² studios with a garden, 64,5 m² two-room apartments with a terrace and 90 m² apartments with a garden. The facilities include a bar (25 m²), a restaurant (150 m²), a cultural center (150 m²), and hydroponic greenhouses (28 m²). Outdoor spaces are meant not only for distribution but are also equipped with sports and playground equipment. The primary access from land is via a dock that leads to a central square that distributes to the different buildings. The buildings are hosted on large pentagonal modular floating sub-structures. The aggregation of pentagonal modules on one side forms a large complex polygon with an irregular shape, ensuring (water) voids between them.

Safety. The pontoon modules float 0.50 m above water level. The XLAM panels have a high mechanical and thermal resistance. Transparent balustrades (tempered multi-layered glass) protect the piers and perimetral parts of the walkways and open spaces without limiting the entrance of light indoors or the sight of the surrounding water.

Wellbeing. Each housing unit has an outdoor space. Outdoor space is designed following active design principles and for social aggregation and engagement. The orientation of the housing units is thought to maximize light exposure and cross ventilation. All rooms and spaces are planned following local on-land codes for overcrowding and minimum surfaces and heights, therefor in line with PDSF. Green roofs foster biophilia and increase thermal insulation.

Usability. Access from land is provided through a central pier which leads to the central pentagonal square. The modular system allows easy adaptation to changing demands (spatial and technical flexibility): the settlement can extend in a spontaneous and elastic way, based on the changing needs of the users and of the local community, by limited low-cost interventions.

Management. The assemblage and construction is easy and quick: the floating modular platforms are assembled in a construction yard, they are transported to the site and anchored to the seabed. The buildings are made of prefabricated components and assembled on site on the platforms. XLAM panels allow to reduce CO_2 emissions during the manufacturing phase due to rapid and easy construction and allow for quick and efficient assemblage. Façade components and plant species require low-maintenance. The components are assembled through dry connections and are easy to disassemble for maintenance operations or replacement.

Integrability. The use of a repeatable module measuring 5 x 5 m for the construction of the residences allows for future transformations and integrations. The entire buoyant sub-structure is designed to be easily expanded and replicated. The pentagonal shape ensures a varying aggregation pattern as it is not rigid as a hexagon for instance. The connection system with potential future modules is already provided. The housing units are designed to accommodate several inhabitants according to future predictions of resilient housing demand.

Environmental Regeneration. Green roofs with sedum minimize management requirements and irrigation water usage. The vegetation used is salt-resistant and requires low maintenance and scarce irrigation (e.g., *Cynodon Dactylon*, *Nerium Oleander*, *Lavandula L.*, *Prunus Maritima*).

Efficient Use of Resources. The photovoltaic monocrystalline panels installed on rooftops and façade meet the annual demand for energy consumption. Solar collectors produce 50% of the hot domestic water demand. The hydroponic greenhouse provides the food for the restaurant. A rainwater collection system integrated on rooftops serves for irrigation and domestic use purposes. Grey and black waters are collected and treated. Several bioclimatic passive devices are implemented: wintergardens; bioclimatic patio and loggias, climate-efficient glazing: TIM (transparent insulation materials) glass fixtures with high light transmission values and thermal insulating properties for vertical glazed façade, clear-glass glazing in wintergarden and bioclimatic patios, low-emissivity glass for windows; mobile and fixed shading devices according to orientation and indoor function. The photovoltaic façade panels are made from recycled plastic.

Buoyancy - Stability. The lightened concrete floating blocks filled in recycled plastic foam ensure the overall buoyancy and stability.

Plant System. The water collection tanks are stored in the floating pontoons. The void in the hull provides space for water-collection tanks and grey water treatment operation system.

6.1.3. Scenario 3

C. Battisti, R. Lella, C. Spigolon

Design objectives:

- "a community for all" open to all citizens (not a gated community)
- telematic connectivity
- ecosystem and environmental protection and enhancement
- agri-food community for social re-integration
- energy self-sufficiency
- blue tourism enhancement
- life cycle approach.

As an agri-food community, the project intends to recover and enhance agriculture in a modern way (hydroponic cultivation) and the traditional local fishing activity. The project provides a network of accommodation facilities to enhance blue tourism. The residential units (simplex and duplex) comprise 30% of the settlement buildings. Urban services account for 22%, while additional facilities, including a mussel farming hub, a fish supply chain hub, an agricultural greenhouse, and a market/restaurant, add up to 16% of the total. More than one-third (32%) of the settlement is dedicated to green and blue infrastructure (pool, water square, and rain gardens). The settlement has a asymmetric layout and therefor no hierarchy of spaces. The public spaces are located in the central part.

Safety. The box system structure in ventilated XLAM walls guarantees lightness, fire, and earthquake resistant, and static resistance. The access is open to the general public.

Wellbeing. High thermo-hygrometric comfort is achieved through several bioclimatic passive strategies: design of indoor spaces to promote passive cooling, deciduous trees on the distribution pier to cool summer winds (while allowing light passage in winter) and absorb CO_2; green trellis roofing; low-emissivity glass (coated with a layer of metal oxides to limit heat loss) to contain heat loss on the north façades; bioclimatic greenhouses with clear-glass glazing to promote indoor passive heating; mobile sun screens; ventilated XLAM walls (heat accumulator in winter and hot air dispersion in summer). The visual/perceptive relationship with the water is promoted through highly technological glass windows and their positioning. Public spaces constitute the polarities of the settlement: the socialization places dialogue with the surrounding natural area and with the pre-existing land fabric. The chromatic indoor range is designed according to the areas and the activities.

Usability. The axialities favour access to and from the mainland and infrastructure. Facilities and activities open to all citizens are integrated in the settlement. Flexibility and versatility characterize the designs of modular and interchangeable spaces and of easy-to-disassemble components to allow adaptation to exposure and changing demand over time.

Management. A telematic platform allows to monitor the environmental impact of consumptions and waste production, providing real-time information, flood risk, and other emergencies. A smartphone application connected in real-time to the platform is is meant to raise awareness between inhabitants and citizens.
Dry-assembled prefabricated materials and components are used. The XLAM structure is easy to assemble on site in a quick and accurate way. Production and construction of components is carried out through process engineering

Environmental Regeneration. The dune park around the shore protects the area and is provided with pedestrian and cycle paths. Sound levels and illumination are designed to limit disturbance to the sea life as much as possible. Monitoring of riverbed and of the under keel clearance is ensured to avoid grounding or disturbing the habitat. Mussel cultivation and reuse of waste mussel shells to limit coastal erosion and encourage ecosystem development: shells are collected in biodegradable nets used for the protection of the dune park. Regarding ecosystem development, the creation of green areas in continuity with the coast aim to promote biodiversity. Most components are made of natural and reusable/reused materials and assembled through dry assembly processes. Green and blue infrastructure is used to improve microclimate: green roof, raingardens, water square.

Efficient Use of Resources. A web-app informs users on real-time consumptions. Several solutions to re-use waste are implemented: aerobic composting for recycling organic waste (derived from daily activity, production, sales and catering activities) into secondary agricultural raw materials like fertilizer for crops and green areas; rain gardens for the accumulation, filtering and reintroduction of rainwater into the domestic network through phytoremediation. An integrated photovoltaic system comprses semi-transparent polycrystalline photovoltaic panels placed on the pitched roof of the bioclimatic and hydroponic greenhouse to produce electricity without compromising internal lighting. The river flow is exploited to generate energy through hydraulic turbines (Kaplan turbine). Passive bioclimatic strategies include: solar chimney, bioclimatic atrium, bioclimatic greenhouse, mobile solar screens according to changing needs. Efficient active energy systems include: air-water heat pump for heating and cooling and hot water. A photo-therm technology façade is integrated: the thermophotovoltaic ventilated façade modules produce energy combined with heat recovery, guaranteeing an increase in electrical production and the simultaneous generation of thermal energy.

Buoyancy - Stability. The housing units and facilities and services are based on platforms (sub-structures) made of cylindrical PVC barrels filled with air and inserted into a load-bearing structure in galvanized steel which supports a layer of lightweight concrete covered in wood. The outdoor spaces and decks have a sub-structure in polyethylene blocks of three different sizes which support a layer of lightweight concrete covered in wood. Robustness is ensured by a hot-dip galvanized steel frame. The anchoring system is specifically designed taking inspiration from local naval anchoring systems.

Plant System. No design focus.

6.1.4. Scenario 4

M. Carlon, M. Vergona and A. Vitale

Design objectives:

- community engagement: common indoor and outdoor spaces
- green public areas
- energy community
- circularity of resources
- spatial flexibility

3. The Kaplan turbine is an axial turbine: the flow of water that turns the propeller blades enters and exits in an axial direction with respect to the rotation axis of the impeller. Thanks to the possibility of regulating the angle of incidence of the blades, it has the advantage of providing excellent performance in the presence of small differences in level, but also with large variations in flow rate (from 200 m^3/s upwards).

- accessibility
- functional mixite.

The settlement results from the aggregation of rectangular and square platforms placed along a longitudinal axis parallel to the shore. Non-residential facilities include a cultural hub (72 m²), including labs and educational activity spaces, and a gastronomic hub (106 m²) with cooking labs and a restaurant. The food served in the restaurant is produced in the hydroponic greenhouse. The cohousing (288 m²) includes several shared spaces, such as a laundry room, a kitchen, a living area, and a bioclimatic atrium.

Safety. Railings along the borders protect users from falling into the surrounding water. The connection between super-structure and sub-structure is guaranteed via inverted T-shaped metal plates.

Wellbeing. Biophilic design is implemented through the integration of a water square that resembles a pool, of green in-between buildings, and green roofs. Several bioclimatic passive devices optimize heat gain in winter and cooling in summer: cross-ventilation, bioclimatic atrium, mobile and fixed shading devices according to functions and exposure; TIM glass for windows facing south, east and west; Low-emissive glass for windows facing north. Indoor plants contribute to increasing air quality (formaldehyde, benzene, dust and mold reduction and CO_2 absorption).

Usability. Two docks allow access to the settlement from the shore. There are also a few wharfs where small boats can dock.

Management. 5-layer XLAM structural panels and prefabricated components are assembled with dry connections (joints, bolts, screws, nails, plates and metal profiles), allowing easy and fast replacement in case of damage.

Integrability. Plant systems and technological devices are planned to work together to be more efficient: photovoltaic solar panels are used to generate electricity and power the lighting system, the heat pump that activates the heating and cooling systems; solar thermal collectors are used to generate heat, to produce domestic hot water.

Environmental Regeneration. A roof garden (extensive sedum roofing) is integrated on cohousing and service buildings. A phytoremediation process is used for rainwater treatment. Hydroponic greenhouse for plant cultivation limit water consumption for irrigation.

Efficient Use of Resources. Photovoltaic panels are integrated on the rooftops oriented south. Solat thermal collectors on the rooftops of studio apartment produce hot domestic water. Bioclimatic passive strategies include buffer-space facing north in the cohousing, bioclimatic wintergardens facing south, and a bioclimatic atrium.

Bioclimatic loggias with semi-transparent double-glazing are integrated with photovoltaic cells (allowing the passage of diffused light). A rainwater collection system is installed on the roof of the studio apartments. Waters are treated via horizontal surface flow phyto-purification and reused for hydroponic greenhouses and irrigation of green areas.

Buoyancy - Stability. The pontoon system in concrete blocks with a polystyrene core ensures buoyancy and stability. The anchoring is through chains with no mooring poles.

Plant System. Battery for energy storage.

6.1.5. Scenario 5

M. Battiata, G. Passarelli, V. Shuleuskaya, G. Venerucci

Design objectives:

- target user: population at risk of SLR and flooding
- social regeneration and social mixite
- sustainable tourism promotion
- historical-landscape identity enhancement
- environmental ecosystem protection
- integration of renewable energy resources
- flexibility and replicability.

The settlement develops along a main axis parallel to the coast from which the accesses to the various buildings branch off, each resting on an autonomous sub-structure system. The settlement comprises residential buildings (conventional housing units and cohousing) and a social housing. Facilities include a coworking, a restaurant, a food atelier, an artisan laboratory, a water sports shop, hydroponics cultivation, a library and a laundry. Small piers connect rectangular pontoons, each hosting one super-structure, to the main distribution dock that serves as a public central space.

Safety. Access to land is ensured only by one dock that connects to the main square of the settlement. XLAM structure which guarantees lightness, fire and earthquake resistance, and static resistance.

Wellbeing. The settelment is structured around common inclusive public spaces. Thermal comfort is above local standards. The occupancy rate is calculated according to functions and available space. The ventilated roof avoids humidity and condense issues. A radiant floor heating optimizes comfort and reduces consumptions.

Usability. Cycling lanes along the canals are meant to increase the overall livability and accessibility of the area.

Management. Prefabricated components are assembled on-site. Home automation to manage technological systems, with consequent reduction in operation and management costs.

Figure 2. Scenario 1 developed by Anton Cipollone and Meryam Saimiei.

Figure 3a, 3b. Scenario 2 developed by Emanuele Farneschi, Giacomo Filippi and Alessandro Latini.

Figure 4a, 4b. Scenario 3 developed by Celeste Battisti, Riccardo Lella, Claudia Spigolon.

Figure 5a, 5b. Scenario 4 developed by Margherita Carlon, Marta Vergona, Andreina Vitale.

Figure 6a, 6b. Scenario 5 developed by Matteo Battiata, Giulietta Passarelli, Viktoryia Shuleuskaya, Giorgio Venerucci.

Automated systems include the mobile façade, an air quality control system, and the heating system.

Environmental Regeneration. The entire area (land and water) is regenerated: development of ecological corridors and creation of blue barriers. Sevral devices for monitoring the seabed are arranged to avoid habitat disturbance and grounding risk. Hydroponic farming for plant cultivation is chosen to reduce water consumption. Deciduous trees are planted on the buoys of the wave energy converters to cool summer winds and absorb CO_2.

Efficient Use of Resources. Several active systems are integrated for energy production: wave energy converters (oscillating water columns), biomass combustion plant, and photovoltaic system. Passive systems to increase indoor comfort include: buffer spaces on northern façades equipped with low-emissivity glass; ventilation tower to guarantee air exchanges inside the rooms and exploit the chimney effect triggered by the temperature difference between the top and the lower areas (window height); bioclimatic greenhouse with clear glass for heat accumulation in winter through direct solar radiation and equipped with openings and screens to ensure ventilation in summer; cross ventilation; trombe wall for façades and ventilated roof covering. Ecological systems include: rainwater collection, filtration and reuse, grey water management and reuse for irrigation and flushing purposes.

Buoyancy - Stability. The pontoon system in separated concrete ribbed sub-structures with disposable formwork ensures the stability and buoyancy of the whole settlement.

Plant System. The domotic smart home system allows to monitor and manage the plant systems according to the changing needs and activities.

Figure 2.

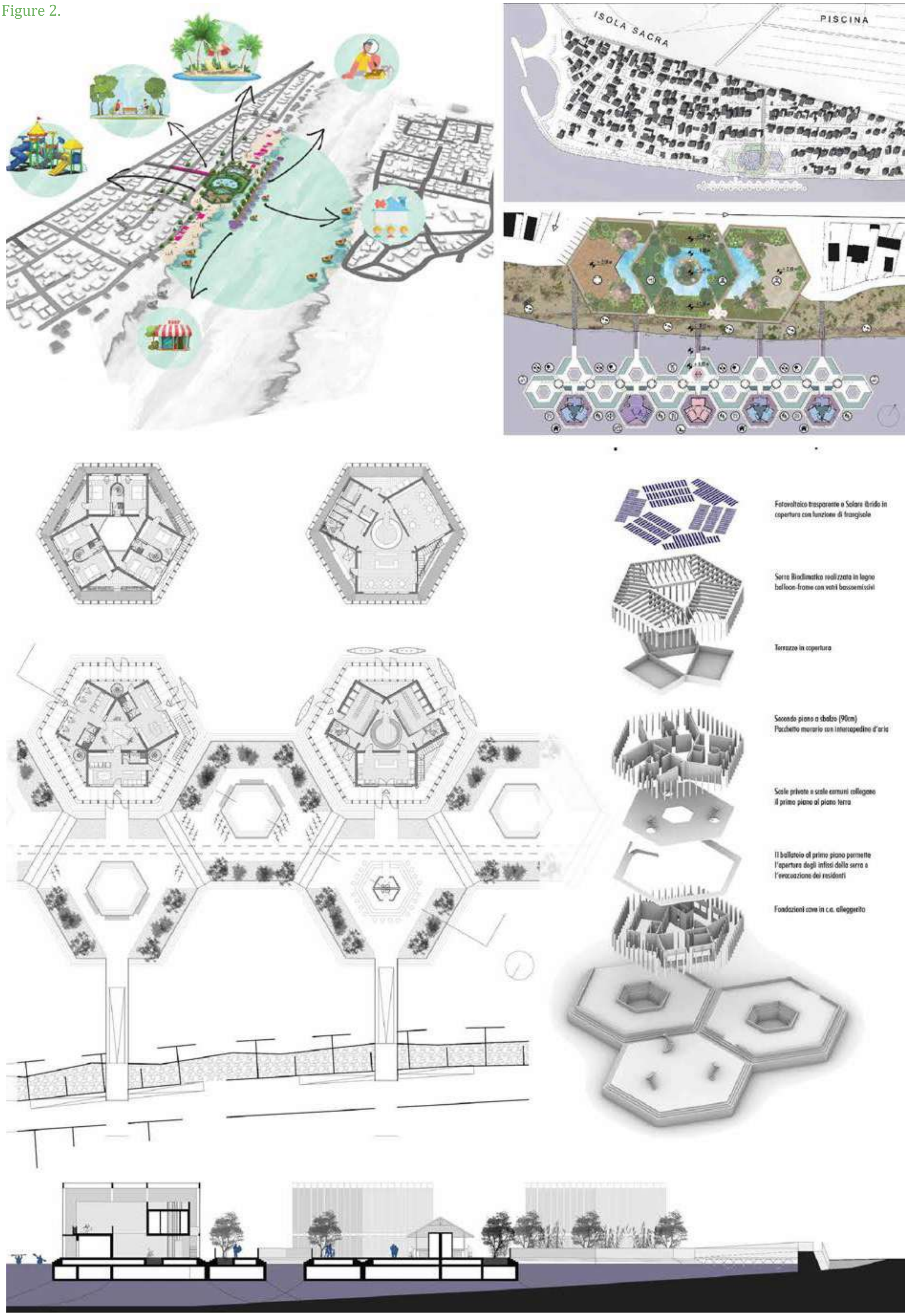

ISOLA SACRA
PISCINA
Fotovoltaico trasparente o Solare ibrido in copertura con funzione di frangisole
Serra Bioclimatica realizzata in legno balloon-frame con vetri bassoemissivi
Terrazze in copertura
Secondo piano a sbalzo (90cm)
Pacchetto murario con intercapedine d'aria
Scale private e scale comuni collegano il primo piano al piano terra
Il ballatoio al primo piano permette l'apertura degli infissi della serra e l'evacuazione dei residenti
Fondazioni cave in c.a. alleggerito

Figure 3a.

Figure 3b.

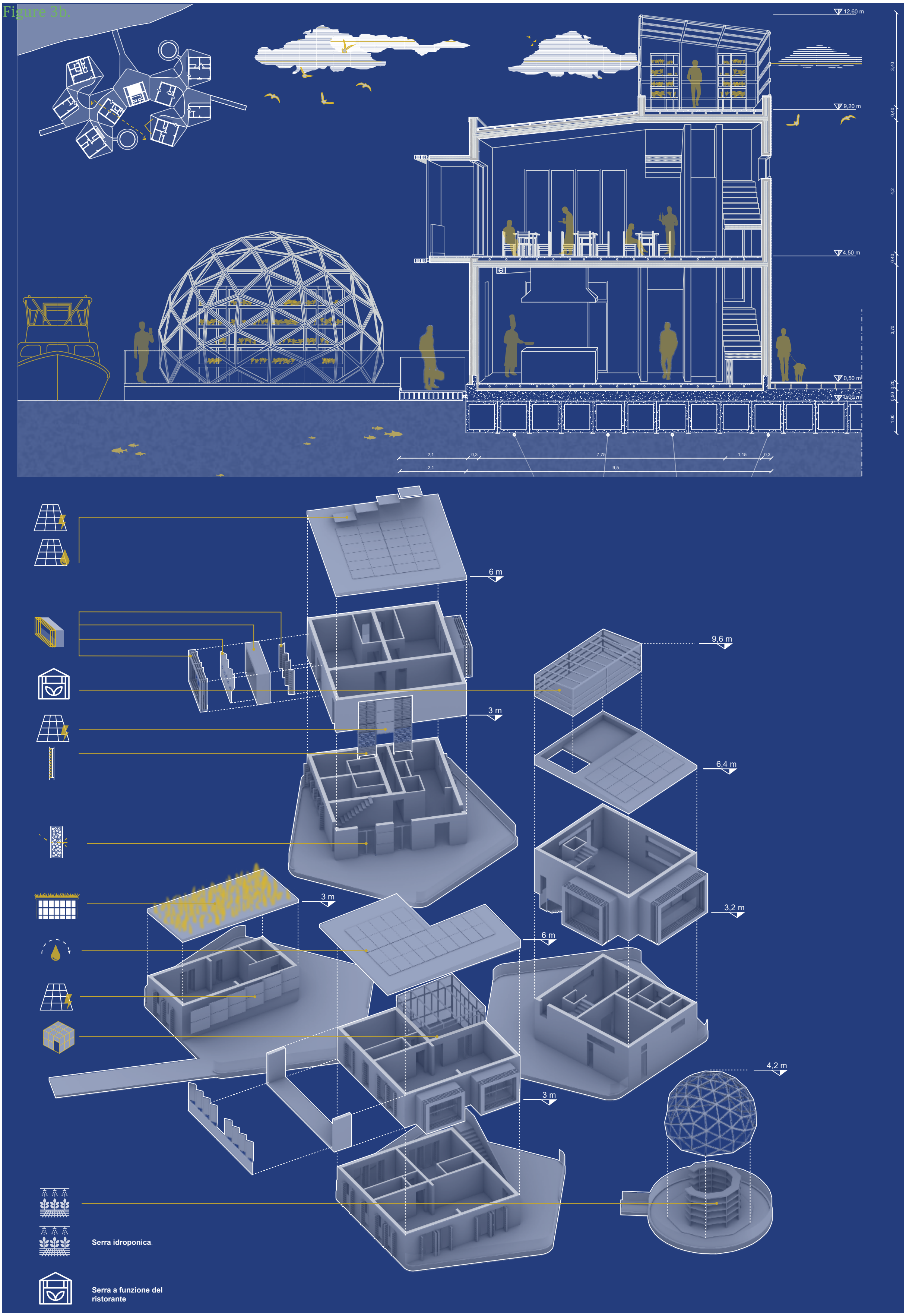

12,60 m
9,20 m
4,50 m
0,50 m
0,00 m
6 m
9,6 m
3 m
6,4 m
3 m
3,2 m
6 m
4,2 m
3 m
Serra idroponica
Serra a funzione del ristorante

Figure 4a.

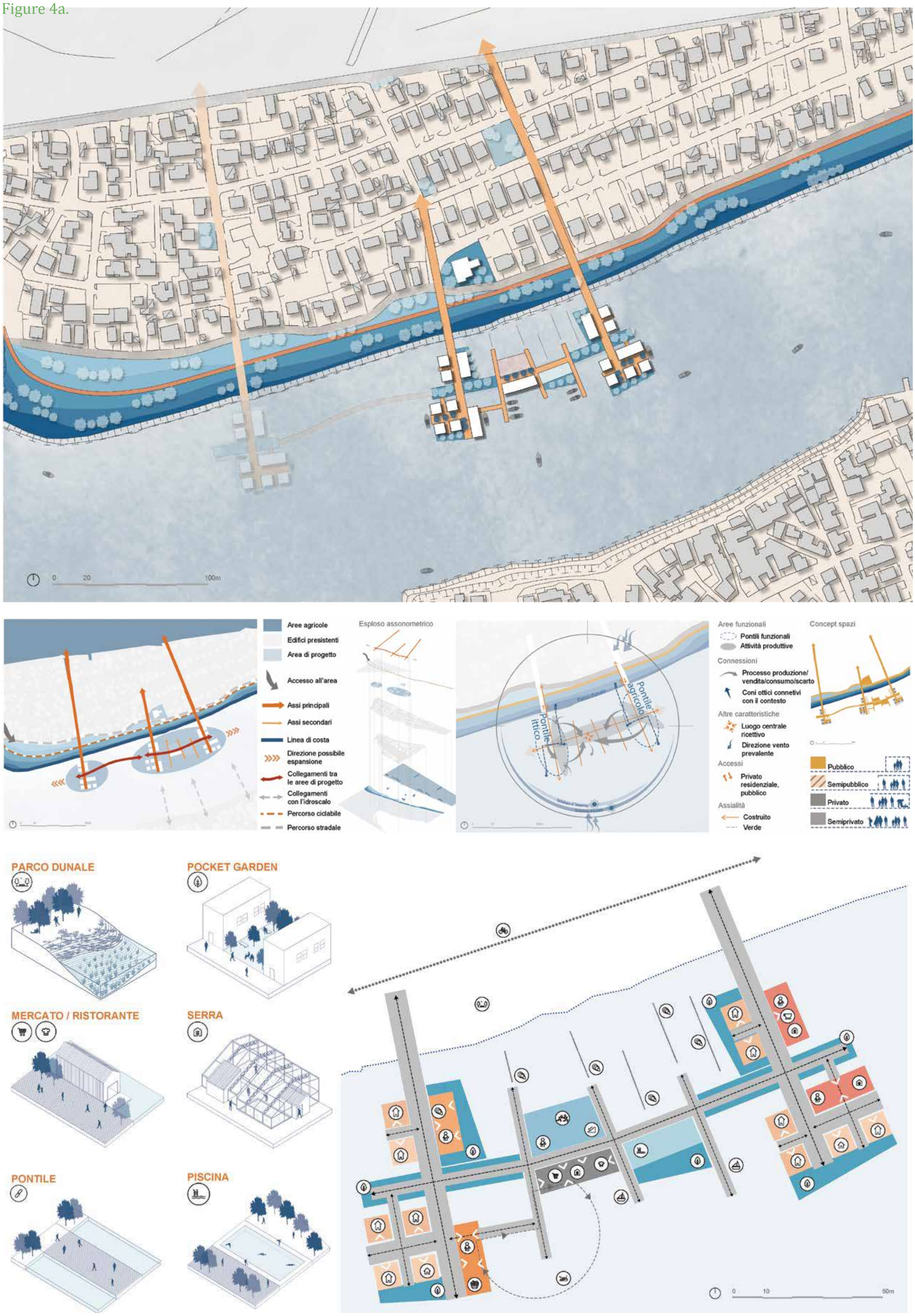
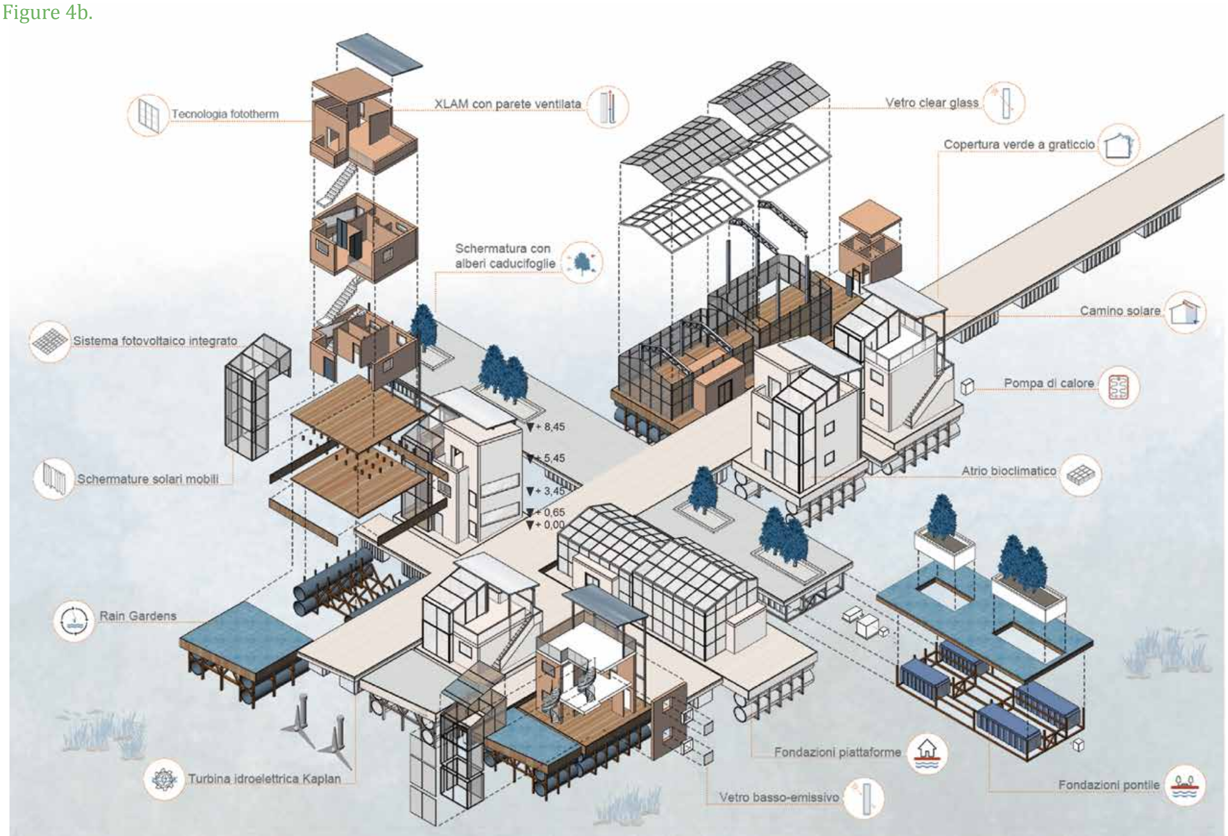
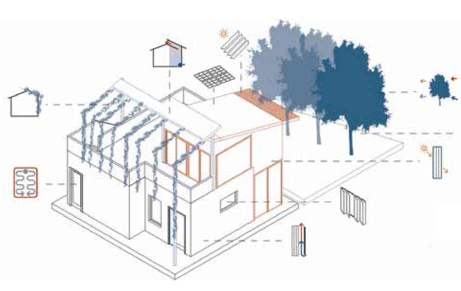

0
20
100m
Aree agricole
Edifici presistenti
Area di progetto
Accesso all'area
Assi principali
Assi secondari
Linea di costa
Direzione possibile espansione
Collegamenti tra le aree di progetto
Collegamenti con l'idroscalo
Percorso ciclabile
Percorso stradale
Esploso assonometrico
Pontile agricolo
Pontile ittico
Aree funzionali
Pontili funzionali
Attività produttive
Connessioni
Processo produzione/ vendita/consumo/scarto
Coni ottici connetivi con il contesto
Altre caratteristiche
Luogo centrale ricettivo
Direzione vento prevalente
Accessi
Privato residenziale, pubblico
Assialità
Costruito
Verde
Concept spazi
Pubblico
Semipubblico
Privato
Semiprivato
PARCO DUNALE
POCKET GARDEN
MERCATO / RISTORANTE
SERRA
PONTILE
PISCINA
0
10
50m

Figure 4b.


Tecnologia fototherm
XLAM con parete ventilata
Vetro clear glass
Copertura verde a graticcio
Schermatura con
alberi caducifoglie
Sistema fotovoltaico integrato
Camino solare
Pompa di calore
Schermature solari mobili
Atrio bioclimatico
+ 8,45
+ 5,45
+ 3,45
+ 0,65
+ 0,00
Rain Gardens
Fondazioni piattaforme
Fondazioni pontile
Turbina idroelettrica Kaplan
Vetro basso-emissivo

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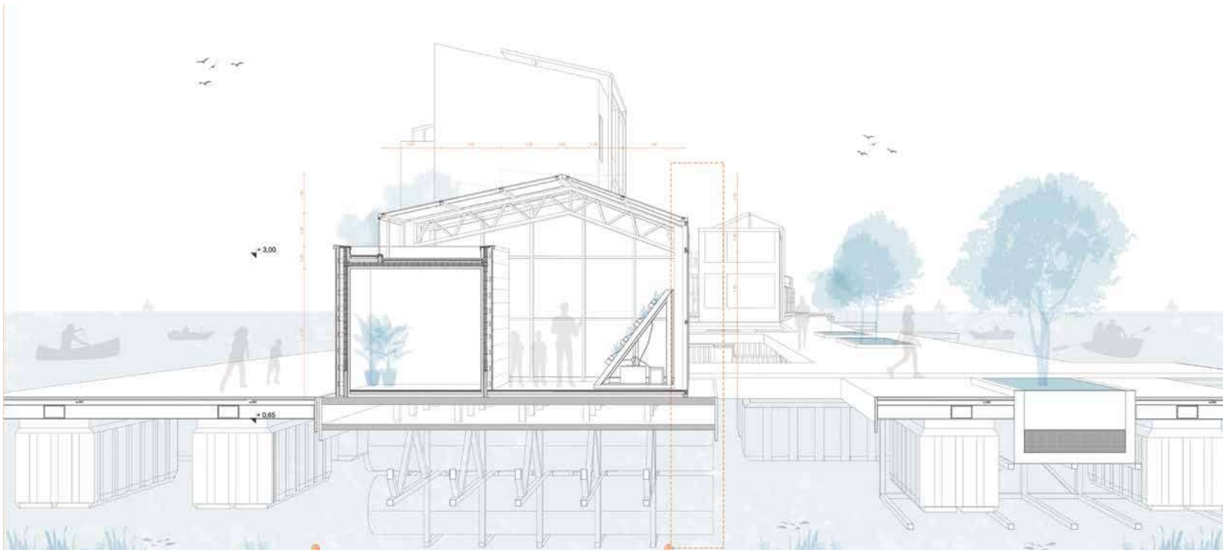


Figure 5a.

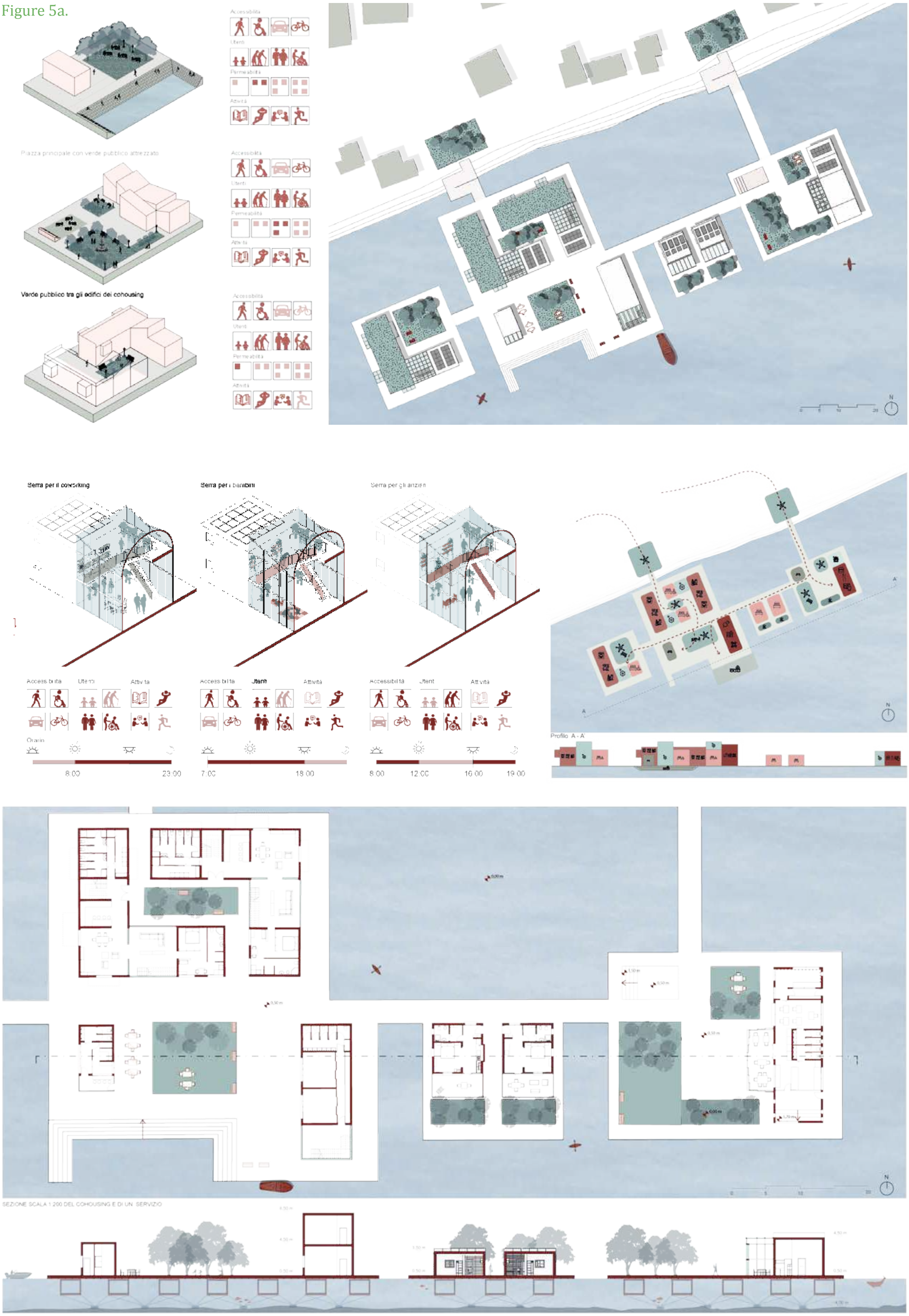

Accessibilità
Utenti
Permeabilità
Attività
Piazza principale con verde pubblico attrezzato
Verde pubblico tra gli edifici dei cohousing
Serra per il coworking
Serra per i bambini
Serra per gli anziani
Orario
8:00
23:00
7:00
18:00
8:00
12:00
16:00
19:00
Profilo A - A'
SEZIONE SCALA 1:200 DEL COHOUSING E DI UN SERVIZIO

Figure 5b.

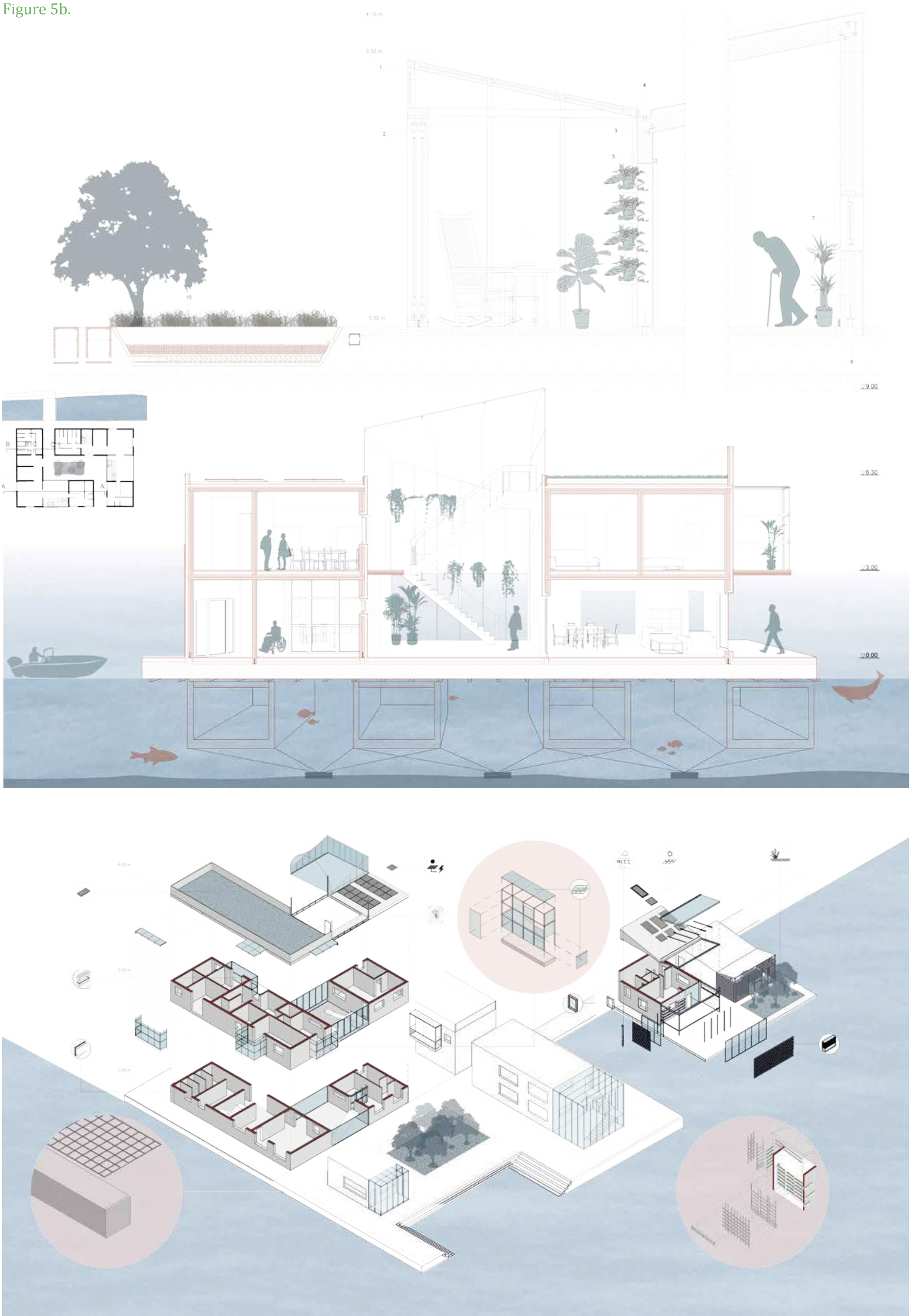


Figure 6a.

1.1 Costruzione di nuovi insediamenti sull'acqua
1.2 Realizzazione di opere di mitigazione
1.3 Ricollocazione della popolazione più a rischio
2.1 Aumentare la mixité sociale
2.2 Favorire il turismo
3.1 Realizzazione di marciapiedi
3.2 Realizzazione di illuminazione pubblica

1.1 Garantire una permeabilità visiva e fisica dei margini
1.2 Riqalificazione del waterfront
2.1 Rivalutazione della cultura della pesca
2.2 Messa a sistema dell'area con i landmark dell'isola di Tor Boacciana del faro
3.1 Sviluppo di corridoi ecologici
3.2 Realizzazione di blue barriers
3.3 Installazione dispositivi per il monitoraggio del fondale marino

1.1 Attrezzare i porti
1.2 Stabilire percorsi sull'acqua di trasporto pubblico locale
1.3 Realizzare pista ciclabile lungo i canali
1.4 Connettere l'area con la rete di trasporto pubblico locale
2.1 Disporre luoghi di aggregazione e aree verdi
2.2 Istituzione di un complesso scolastico
2.3 Realizzazione di un centro di formazione professionale
3.1 Installazione di sistemi fotovoltaici integrati con l'edilizia
3.2 Generare energia dal moto ondoso
3.3 Produzione di energia da biomasse

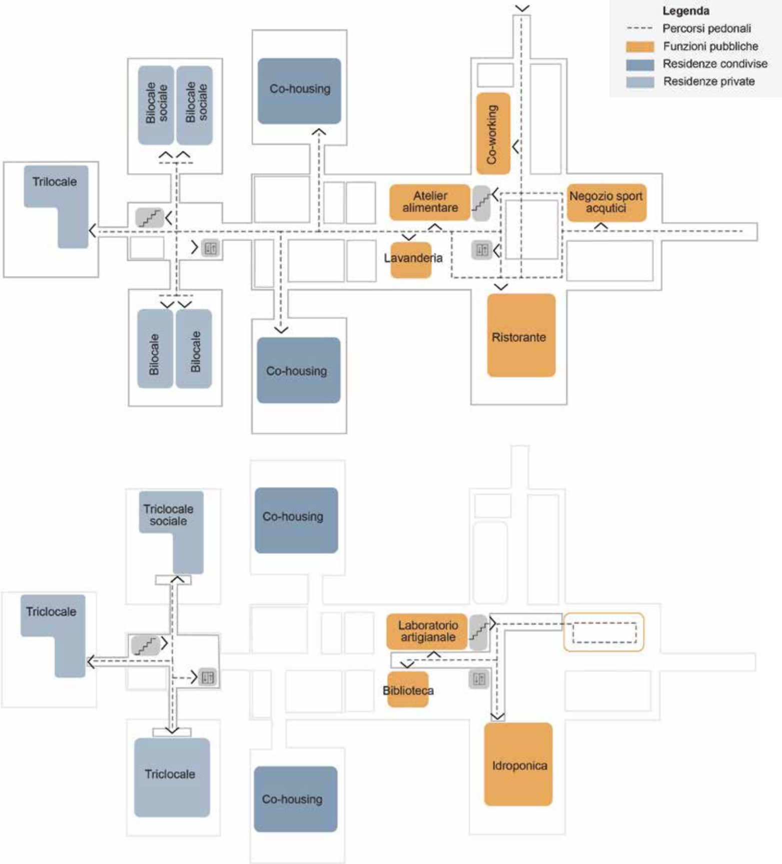


Figure 6b.

6.2 Scenario and framework evaluation

The proposed design scenarios for floating settlements highlight several key considerations that should be addressed in transitioning from terrestrial to aquatic urbanism.

Although the same framework was provided to all designers, a remarkable morphological variety of floating structures and layout aggregations distinguishes the different scenarios. However, there is a tendency to replicate terrestrial designing approaches without critically considering the specific needs of floating settlements. The margin, or the water-land boundary, is critical to design, especially integrating floating settlements with the surrounding terrestrial environment. However, the design scenarios often overlook this critical interface, leading to a disconnection between the two realms. Blurring the boundaries between land and water while addressing new, unusual needs reveals to be one of the most critical issue for designers. This is further exacerbated by the challenges in designing connections between floating settlements and embankments, particularly in addressing height variations between land and floating structures and water fluctuations over time. The design scenarios also demonstrate a lack of attention to the potential of water as a resource beyond energy generation. Water offers opportunities for plastic recovery, natural biodiversity enhancement, biophilic design, quality sight views, and several other aspects that vary according to location. However, these aspects are often neglected in the proposed design scenarios.

The design scenarios and their development highlighted three other highly complex aspects of managing and designing floating settlements: floating foundations, green spaces, and plant systems. Floating foundations require careful consideration of the connection between the super-structure and the sub-structure, anchoring, and mooring systems, as well as sizing. As shown throughout the semester, several designers have the tendency to design a unique, very large floating structure, encountering construction, transportation, and motion comfort issues.

Green spaces are designed as they would be on land, regardless of their weight, role as bioclimatic green infrastructure, contextualized usage, placement, plant selection (resistant to salinity or humidity), and maintenance.

The plant systems design revealed to be another challenging task despite it being broadly addressed in the PDSF. The most complex issues regarded connection with land utilities, such as sewage and water networks.

The PDSF framework proves to be a valuable tool for guiding and addressing the design criteria for floating settlements. However, its effectiveness could be enhanced by incorporating more visual design inputs, such as case studies and reference images, to help architects transition from terrestrial to aquatic design thinking. A user-friendly interface would also make the PDSF more accessible and easier to navigate. Moreover, to maximize the framework's efficacy, a comprehensive presentation of the principles behind the framework, instructions on how to use it, and an explanation of each class of demand and the new (unconventional) requirements could have revealed essential to demonstrate its practical application.

Overall, the design scenarios highlight the need for a mind shift in tackling the challenges posed by floating settlement design. Architects and urban planners must move beyond replicating terrestrial design approaches and embrace the unique opportunities and constraints of the aquatic environment. This requires a deep understanding of water-based communities' physical, ecological, and social dynamics. The morphological variety, margin integration, integrated design thinking, resource utilization, and management of complex systems are critical considerations for successful, sustainable, resilient floating settlements. On the whole, the PDSF framework provides a helpful tool for evaluating and optimizing these aspects, and its effectiveness can be further enhanced by incorporating visual design inputs, a user-friendly interface, and comprehensive training materials.

CHAPTER 7 Proof of concept of a computational design tool

ABSTRACT

This chapter provides a proof of concept for a computational design support system to advance performance-driven reasoning in floating building design. The intent is to simplify testing the platform's functionality and receive valuable feedback from its practical implementation before building a full-scope system. The proposed user interface design platform emphasizes a quality score for each requirement, for each class of requirement, for each class of demand and eventually for the overall design. It also highlights the logical interaction between the different requirements to help identify optimal decisions in the presence of trade-offs between two or more conflicting requirements. The shift from the performance-based design-support framework to a performance-driven computational tool is achieved in three steps. First of all, the performance requirements are converted into quantitative, measurable indicators and introduced in a Grasshopper script to integrate and control the design workflow. A custom user interface to control Grasshopper definitions is designed using the Grasshopper plugin Human UI. It enables designers to interactively explore and evaluate different design options according to the design objectives. Practitioners have tested the tool by applying it to two existing projects. Its practical implementation provides valuable feedback before building a full-scope system and proves its feasibility and usability regardless of location. The results of the practical application of the proof of concept suggest that the design support system is a promising tool not only for supporting the design process but also for evaluating the performance of floating residential buildings, hence working as a certification system. Moreover, the potential for upscaling the design support tool to urban scales opens up new possibilities for sustainable and resilient urban development in waterfront cities.

7.1. Introduction and overall methodology

Over the last decade, there has been a growing recognition of the importance of mathematical, algorithmic, and knowledge-based computational processes in performing portions of design, evaluation, construction and interface design, as they allow the integration of all project parameters affecting the project into a single workflow (Carpo, 2012; Dade-Robertson, 2013; Menges & Ahlquist, 2011). Data-driven and integrated analytical computational methods simplify the production and visualisation of blurred conditions that develop over time and may underpin complex, multi-faceted design processes (Hensel & Sørensen, 2014). Parametric design software, like Grasshopper, enable designers to think in terms of logical problems and commands. Interface design aid plugins provide explicit guidance or assistance in decision-making by offering extensive information, highlighting trade-offs and correlations between elements, and providing active suggestions (Roth et al., 1994). In such an interdisciplinary field, intuitive browser-supported interfaces activate a dialogue between heterogeneous domains, allowing the user to control the entire process comprehensively (Nebuloni & Buratti, 2023) and consider dynamic aspects resulting from interaction with a wide range of parameters (Nebuloni & Rossi, 2018).
This paragraph presents a Proof of Concept (PoC) for how the PDSF could be turned into a comprehensive digital design support tool that enables designers to make informed decisions supporting performance-driven reasoning in floating building design. It is argued that performance-based and performance-driven architectural design differ in that the latter involves computer-aided techniques so that the performance can be used as the criteria to truly drive the design. The PoC marks the shift from a performance-based framework to a performance-driven design support system and consists of the implementation of a demo version of the platform to demonstrate the feasibility and practical potential of the performance-based design framework for practitioners and public technical officers. The scope of the PoC is limited to the design of

floating residential buildings. The intent is to test the platform's functionality and receive valuable feedback from its practical implementation before building a full-scope system.
The main research question is how we can effectively organize, visualize and share a performance-based design-support framework for floating architecture with practitioners and policymakers. Sub-questions include: at what point of the design process could the performance-based design-support framework be integrated? How can a performance-based design framework be turned into a performance-driven digital platform? To what extent does a performance-driven design framework for floating buildings demonstrate feasibility and practical potential in a limited PoC implementation? The PoC implementation also helps to identify the critical aspects that require further refinement or expansion to achieve full-scale functionality and applicability.
From a methodological point of view, the study was structured into four phases (Figure 1):

1. **Translation of performance requirements into quantitative, measurable indicators.** This procedure is carried out for a single class of demand (wellbeing) and all associated requirements. It serves as a paradigmatic example to demonstrate the feasibility of the process that can be repeated for all the other classes. The numerical indicators are identified using recent scientific literature, ISO standards and Eurocodes both for the built environment and the marine industry (shipping and offshore), floating building codes, International protocols and guidelines, and green building certification systems such as LEED, WELL, and BREEAM. The framework and indicators are subjected to validation by scientific experts and practitioners involved in environmental architecture, floating architecture, hydraulic and mechanic marine engineering, and urban ecology.

2. **Definition of a computational algorithm.** The development of this early-stage digital tool entails writing a script in Rhino software and Grasshopper 3D programming language to integrate and control the workflow based on the performance indicators. Rhino allows Grasshopper to process data and generate scores for each requirement and overall results. Rhino helps visualise data structure, correlations, and trade-offs, integrating a local custom user interface. Setting an evaluation model on a design platform enables constant interaction and improvement of the building's design process from an early stage.

3. **Creation of a custom user interface.** An interactive interface is created using the Grasshopper plugin Human UI. The Human UI interface allows to create Grasshopper apps with custom user interfaces for Grasshopper definitions, setting up tabbed views, dynamic sliders, pulldown menus, checkboxes, 3D viewports,

web browsers, and interactive elements that are both functional and aesthetically pleasing. The tabbed view interfaces allow to organise the classes of demand into different sections, making the framework easier to navigate. The dynamic sliders enable the control of the values of Grasshopper parameters in real-time. This facilitates architects and other stakeholders involved in the design process of floating buildings to interactively explore different design options and evaluate them according to their design objectives.

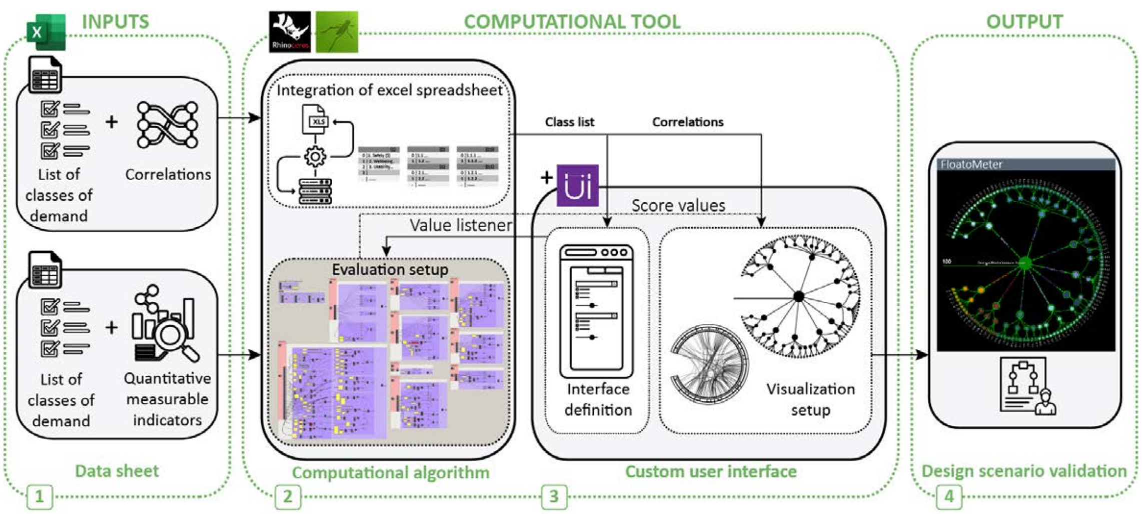
4. **Application and validation of the tool on design scenarios.** The tool is used to evaluate two existing projects. The building for long-term residency is in Europe (Netherlands) while the temporary residential building is in the United States (Miami). The tool provides an evaluation of the performance score of the overall design. The tool's output is shared with the architects involved in the design process of the two projects. They are invited to interact with the tool to identify potential improvements based on the performance score, address the trade-off elements, and eventually revisit the design.

The content of the following sub-chapters has been structured into a paper entitled “A comprehensive computational tool for performance driven reasoning in floating building design and evaluation” that has been submitted and accepted for publication in the open access Journal of Digital Landscape Architecture (JoDLA)[1] following the Conference of Digital Landscape Architecture: Exploring New Trajectories in Computational Urban Landscapes & Ecology (DLA 2024) to be hosted by TU Wien, in Vienna between June 5-7 2024.

A video tutorial of the digital interface is provided in Appendix D to showcase the tool's features and functionalities in a more intuitive and engaging way than text alone.

1. Currently e-ISSN 2511-624X for the Issue JoDLA 9-2024.

Figure 1. Methodological and computational process behind the creation of the dashboard: (1) conversion into quantifiable indicators (inputs from excel spreadsheet data), computational tool development including (2) grasshopper workflow and (3) custom user interface, and (4) design evaluation (output)



7.2. Translation of performance requirements into measurable indicators

...

Given that a requirement, by definition, must be quantifiable with a set of parameters or indicators, and that the term performance implies a measurable result, the first step is meant to demonstrate how each requirement can be assessed and verified through quantifiable parameters. Each performance requirement has been articulated into specific aspects. For instance, the requirement 'Ventilation control' has been broken down into a set of indicators, that include air change per hour (ACPH), Filtration MERV (Minimum Efficiency Reporting Value), Ventilation rate (CMH), Presence of natural ventilation in each room, and air speed in winter and summer. Baselines and targets (and target ranges) are established for each indicator based on scientific literature and the current state

R n°	Requirement	Indicator
2.1.1.	Indoor temperature level and control	Temperature range [T]
2.1.2.	Indoor humidity level and control	Relative humidity [RU]
2.1.3.	Ventilation control	Air change per hour (ACPH)
		Filtration MERV (Minimum Efficiency Reporting value)
		Ventilation rate (CMH)
		Natural ventilation in each room (openable wndows)
		Air speed (winter)
		Air speed (summer)
2.2.1.	Natural illumination level and control	Ratio glazed surface/room surface
2.2.2.	Artificial illumination level and control	Offices and writing (desk) areas, kitchens, auditoriums
		Stairways, distribution and storage space illuminance
		General indoor activity illuminance
		Glare (URG index value)
		Luminance at any angle between 45 and 90 degrees from nad

of building indicators in the jurisdiction or industry (standards, norms, and certification systems). Targets and target ranges represent the desired level of performance that the design aims to achieve, whereas baselines represent the minimum required to comply with norms or quality standards. Some indicators are expressed as a range, like a temperature range indicator for the requirement 'Indoor temperature level and control' (20°C < x < 26°C), or as a threshold value that establishes a condition that must be met for the requirement to be considered satisfied. A threshold value is the 'Ventilation rate', expressed as CMH > 36 m^3/h. Instead, some other indicators consist of conditions that must be met and, therefore, are expressed by a binary indicator that denotes whether a specific requirement is met. The value 1 indicates that the indicator is met, and the 0 implies it is not. This binary condition simplifies the evaluation process and limits the need for subjective interpretations. For instance, one of the indicators of 'Quality views' is the view of natural elements. In this case, the binary format of yes/no answers enables efficient data processing within the tool. These three indicators (target ranges, threshold values, and binary representations) are the most widely used in certification systems that assess the quality of a design because they provide clarity and objectivity, which are critical for ensuring fair and consistent certifications. With each condition represented by a numerical value, the certification system can easily calculate metrics such as the percentage distribution of compliance among classes of demand or the overall design rate. When necessary, conversion factors are developed to translate incompatible measure units into values between 0 and 1. Table 1 shows the relevant indicator for each requirement for the Wellbeing (W) class of demand.

Table 1. Relevant set of indicators for each requirement for the Wellbeing (W) class of demand.

	Value	Unit	Reference
	20 < x < 26	°C	EN 16798-1:2019; UNI TS 11300
	30 < x < 70	%	EN 16798-1:2019; UNI TS 11300
	3 < x < 6		9 FHB (Harvard)
	1 to 16	MERV rating	9 FHB (Harvard)
	> 36	m^3/h	WHO guidelines
	0-1	n° of rooms with natural ventilation/total rooms	DM 5/09/1975 (ITALY); WELL - A07
	0.01-0.1	m/s	EN 12831-1:2017
	0.1-0.2	m/s	EN 12831-1:2017
	> 12,5	%	DM 5/09/1975 (ITALY)
	> 500	lx	EN 12464: 2021
	> 100	lx	EN 12464: 2021
	[illegible]0	lx	EN 12464: 2021
	[illegible]6	URG	WELL - L04; EN 12464: 2021
dir	< 6,0	cd/m^2	WELL - L04

R n°	Requirement	Indicator
		Light control system
2.2.3.	Emergency and signal lighting	Emergency lighting
2.2.4.	Quality views	Unobstructed view
		View of natural elements
2.3.1.	Noise level limits	Average background noise levels in bedrooms
		Average Sound Pressure Level (SPL)
2.3.2.	Indoor acoustic insulation/sound barriers	Maximum Sound Pressure Level (SPL)
2.3.3.	Reverberation time control	Reverberation Time: areas for dining (t)
2.3.4.	Sound reducing surfaces	Use of acoustic materials that absorb and/or block sound to support concentration and reduce reverberation in rooms for dining, working and conferencing and learning
2.4.1.	Absence of unpleasant odors (Ventilation control)	Ventilation rate
2.5.1.	Minimum areas and volume	Living area /inh.
		Living area /inh.
		Living room area
		Single bedroom area
		Double bedroom area
2.5.2.	Minimum heights	Indoor height for living spaces
		Indoor height for service spaces
2.5.3.	Occupancy rate	One room for each single person aged 18 or more
		One room per pair of single people of the same gender between 12 and 17 years of age
		One room for each single person between 12 and 17 years of age and not included in the previous category
		One room per pair of children under 12 years of age
2.6.1.	Vertical acceleration control	Vertical acceleration range (return period 1:1 - yr)
		Vertical Jerk level

Value	Unit	Reference
0-1		Mahdavi, A. (2016). The human factor in sustainable architecture. In Low Energy Low Carbon Architecture (pp. 177-198). CRC Press.; Shaw, R., & Bransford, J. (Eds.). (2017). Perceiving, acting and knowing: Toward an ecological psychology (Vol. 27). Routledge.
0-1		Farley, K. M., & Veitch, J. A. (2001). A room with a view: A review of the effects of windows on work and well-being.;
0-1		Farley, K. M., & Veitch, J. A. (2001). A room with a view: A review of the effects of windows on work and well-being.; Tsunetsugu, Y., Lee, J., Park, B. J., Tyrväinen, L., Kagawa, T., & Miyazaki, Y. (2013). Physiological and psychological effects of viewing urban forest landscapes assessed by multiple measurements. Landscape and Urban Planning, 113, 90-93.
0-1		
< 35	dBA	WELL - S02; WHO guidelines
< 55-40	dBA	WELL - S02
< 65 - 50	dBA	WELL - S02
< 1.0	s (seconds)	WELL - S04
0-1		WELL - S05
> 36	m^3/h	WHO guidelines
> 14 (first 4 inh.) > 10 (from 5th onwards)	m^2 /inh.	DM 5/09/1975 (ITALY)
> 18 (new buildings)	m^2 /inh.	Building Decree [Bouwbesluit] 2012 (NL)
> 11	m^2	Building Decree [Bouwbesluit] 2012 (NL)
> 9	m^2	DM 5/09/1975 (ITALY)
> 14	m^2	DM 5/09/1975 (ITALY)
> 2.70	m	DM 5/09/1975 (ITALY)
> 2.40 [2.20]	m	DM 5/09/1975 (ITALY) [Building Decree [Bouwbesluit] 2012 (NL)]
0-1		European commission EUROSTAT GLOSSARY
0-1		European commission EUROSTAT GLOSSARY
0-1		European commission EUROSTAT GLOSSARY
0-1		European commission EUROSTAT GLOSSARY
0.05 < a RMS < 0.10	m/s^2	Space@Sea (D7.2); ISO 2631-1:1997(E)
< 0.3	m/s^2	ITTC (1999)

R n°	Requirement	Indicator
		Wave frequencies
2.6.2.	Motion control	At least one of the following architectural strategies is observed: - aligning the building's long axis with the predominant wave direction -incorporate Active Stabilization Systems - utilize Passive Damping Systems
		Design Interior Spaces to Minimize Motion Perception - at least one of the following is observed: - exterior view to water (per activity room) - manual natural ventilation (per activity room) - no hanging lamps or objects (per activity room)
		Vibration limits
		Vibration dose value (VDV) - 15h
2.6.3.	Vibration control	ISO Motion Sickness Dose Value (MSDV)
2.7.1.	Biophilia	Indoor biophilic design: occupant access to nature within indoor enviornment
2.7.2.	Behavioral engagement	Indoor biophilic design: view to green/blue areas
		Participatory process
		Social engaging and community spaces
2.7.3.	Active lifestyle design	Behavioural comfort (control on comfort parameters)

Value	Unit	Reference
≠ 0.18-0.25	Hz	DNV GL – OS-C301
0-1		Case study review Ivanovich, E. A., Vasilescu, M. V., & Scurtu, I. C. (2022). Ship stabilization technology a feature used for energy efficiency. In IOP Conference Series: Earth and Environmental Science (Vol. 968, No. 1, p. 012007). IOP Publishing. Comstock, J. P. (1977). Principles of naval architecture. SNAME. Lloyd, A. R. J. M. (1989). Seakeeping: ship behaviour in rough weather. Admiralty Research Establishment, Haslar, Gosport, Publisher Ellis Horwood Ltd, John Wiley & Sons, ISBN: 0 7458 0230 3. Moaleji, R., & Greig, A. R. (2007). On the development of ship anti-roll tanks. Ocean Engineering, 34(1), 103-121.
1-100	%	Reed, J.W., Hansen, R.J. and Vanmarcke, E.H. (1973), "Human response to tall building wind-induced motion" M Schutz, L., Zak, D., & Holmes, J. F. (2014). Pattern of passenger injury and illness on expedition cruise ships to Antarctica. Journal of Travel Medicine, 21(4), 228-234. Koch, A., Cascorbi, I., Westhofen, M., Dafotakis, M., Klapa, S., & Kuhtz-Buschbeck, J. P. (2018). The neurophysiology and treatment of motion sickness. Deutsches Ärzteblatt International, 115(41), 687. Bos, J. E., MacKinnon, S. N., & Patterson, A. (2005). Motion sickness symptoms in a ship motion simulator: effects of inside, outside, and no view. Aviation, space, and environmental medicine, 76(12), 1111-1118. Case study review
< 0.4	m/s^2	SBR-richtlijn B "Hinder voor personen in gebouwen"
0.2	m/s	The Australian Department of Environment and Conservation (2006)
10		Dallinga, R. P., & Bos, J. E. (2010). Cruise ship seakeeping and passenger comfort.
0-1		W GBC; 9 FHB (Harvard)
0-1		W GBC; 9 FHB (Harvard)
0-1		W GBC; WELL - C02
0-1		WELL - C11
0-1		WELL Standards -C02; W GBC; Mahdavi, A. (2016). The human factor in sustainable architecture. In Low Energy Low Carbon Architecture (pp. 177-198). CRC Press.; Shaw, R., & Bransford, J. (Eds.). (2017). Perceiving, acting and knowing: Toward an ecological psychology (Vol. 27). Routledge.

R n°	Requirement	Indicator
		Attractive scarecase design: inclusion of at least two independent strategies from the following list on each floor: Music; Artwork; Designed to have light levels of at least 215 lux when in use; Windows or skylights that provide access to daylight and/or nature views; Natural design elements (e.g., plants, water features, images of nature); Gamification.
		Visible staircases or Wayfinding signage to encourage use of staircase
		Provision of no-cost physical activity areas and/or equipment
		Active furnishings
2.8.1.	Air quality	PM2.5
		PM10
		Benzene
		Formaldehyde
		Toulene
		Volatile organic compound (VOC)
		Carbon monoxide
		Ozone
		Radon
2.8.2.	Microbe and mold control	Air tightness (ACH)
		Vapor pressure deficits (VPD)
		Moisture control: adoption of following strategies: 1. Control liquid water (keep liquid water out of the building envelope) 2. Prevent excessive indoor humidity and water vapor migration by air flow and diffusion in order to limit condensation and moisture absorption into cool materials and surfaces. 3. Select moisture-resistant materials for unavoidably wet locations.
2.8.3.	Drinking water quality	Protection of moisture-sensitive building materials and selection of moisture-resistant materials or finishes in surfaces likely to be exposed to liquid water
		Compliance with World Health Organization. Guidelines for drinking-water quality. 4th ed. Geneva, Switzerland: WHO Press; 2017.
2.8.4.	Pest and dangerous animals prevention	Screened/protected openings (if necessary)
2.8.5.	Dust prevention and management	Filtration efficiency MERV
		Cleanable surfaces
		Low-Dust Materials

Value	Unit	Reference
0-1		WELL - V03
0-1		WELL - V03
0-1		WELL - V08
0-1		WELL - V07
< 15	µg/m^3	WELL- A01
< 50	µg/m^3	WELL- A01
< 10	µg/m^3	WELL- A01
< 50	µg/m^3	WELL- A01
< 300	µg/m^3	WELL- A01
< 500	µg/m^3	WELL- A01
< 10	µg/m^3	WELL- A01
< 100	µg/m^3	WELL- A01
< 0.15	Bq/L	WELL- A01
3 < x < 7	m^3/m^{2}h at 50 Pa	ATTMA standards TSL1 and TSL2
0.7 < x < 1.2	kPa	ASHRAE Standard 55-2017
0-1		EPA 402-F-13053
0-1		WHO Guidelines
0-1		WHO Guidelines
0-1		Case studies; NTA 8111-2011; CDC24/7: Saving Lives, Protecting People – Centers for disease Control and Prevention – Chapter 8 Travel by Air, Land & Sea
1 to 16	MERV rating	ASHRAE
0-1		9 FHB
0-1		9 FHB

7.3. Definition of a computational algorithm and creation of a custom user interface

The Grasshopper script at the core of the digital design support system (DSS) was developed together with urban technologist at Waterstudio and PhD candidate at Delft University of Technology, Sridhar Subramani, under the supervision of Dr.ir. Koen Olthuis, Co-founder of Waterstudio & Dutch Docklands and researcher at Delft University of Technology, Architecture and the Built Environment and Urban Design. It is divided into four parts:

1. **Integration of Microsoft Excel spreadsheet into the Grasshopper file/script.** In this section of the definition, the spreadsheet defining the correlations and trade-offs between all the requirements, including mutual exclusion, mutual influence, one-sided influence (when one requirement affects another one, and consequently the latter is affected by the first one), and correspondence, is accessed within the grasshopper definition. The relationships between requirements are converted into a data tree structure for workflow use. Classes of demands represent a primary tree branch, whereas classes of requirements and requirements are sub-branches of the data tree. The definition of distinct tree paths for each requirement highlights the correlations and displays the data structure for the interface.

2. **Interface definition.** The human UI plugin enables the creation and design of the user interface (UI) platform. The tool opens up with a start screen that prompts the user to choose 'Create Project'. Following, a form pops up to input the project name and location coordinates (Figure 2). In this way, the tool can geolocalize the project on a visual map, input default data (e.g., climate features) in the 'location' tab, and tailor the 'Performance Indicators' sections according to relevant regulations and context features. Once the 'New Project' is created and georeferenced, the interface is structured in four sections (or tabs) (Figure 3).

- '**About**': general information on the tool and instructions on how to use it.

- '**Location**' tab (Figure 4): the user can check and fill in the missing data regarding four fields.
  a. Space: country, surrounding buildings (average height), utility lines (presence and ease of access), distance to construction or shipyard (any workspace), presence of adequate waterways connected to water plot, distance to the nearest seaport.
  b. Water: plot size, (main) orientation, wave height, currents, level fluctuations, nautical activities, water temperature, salinity, biochemical water quality, soil consistency, bathymetry, soil displacement and sedimentation.
  c. Climate: average temperature, annual low extreme, annual high extreme, solar irradiance, mean relative humidity, annual precipitations, number of rainy days per year, average wind speed, and main wind direction.
  d. Environment: air quality, seismic risk, natural protected areas.

  The location-based parameters inform and customize the system, determining the regulations to which the requirements must adhere and adjusting some indicators according to site-specific legal, climate, and environmental conditions. For instance, water conditions in the 'Water' category have a significant impact on the Buoyancy - Stability class of demand.

- '**Performance Indicators**' tab: the interface displays the nine

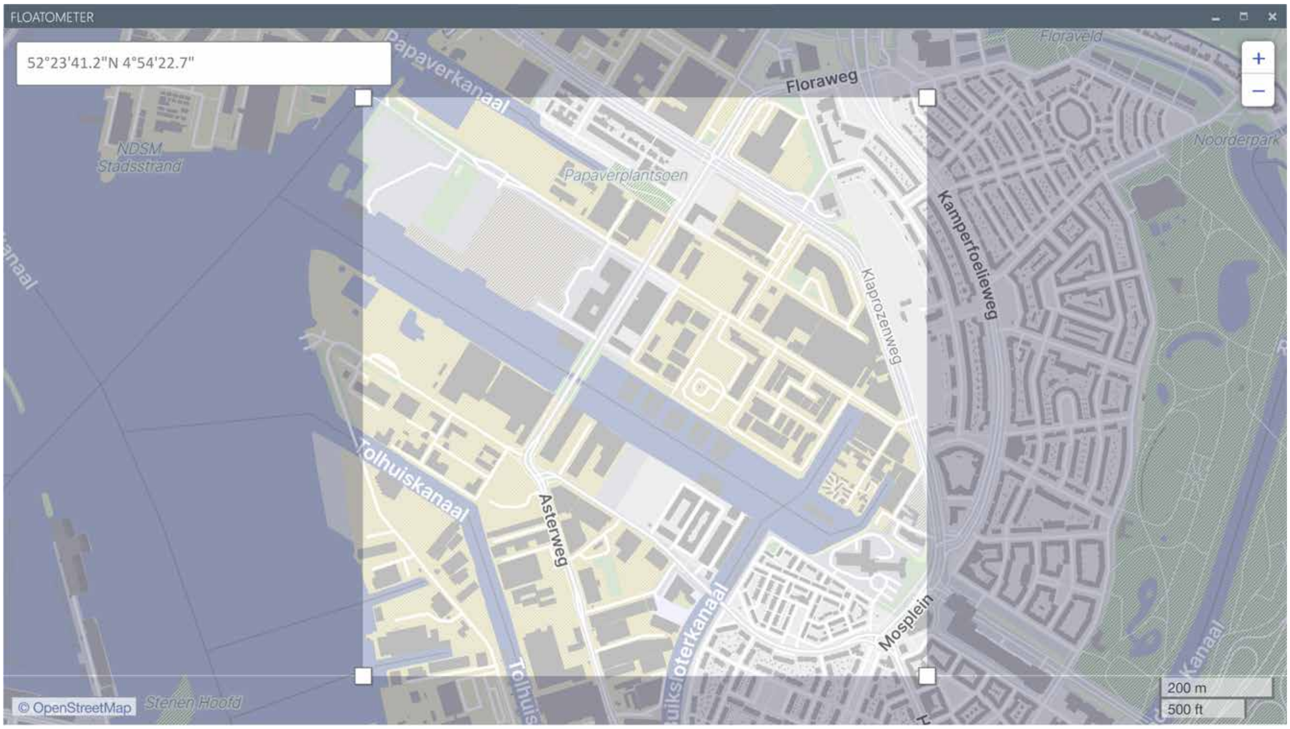
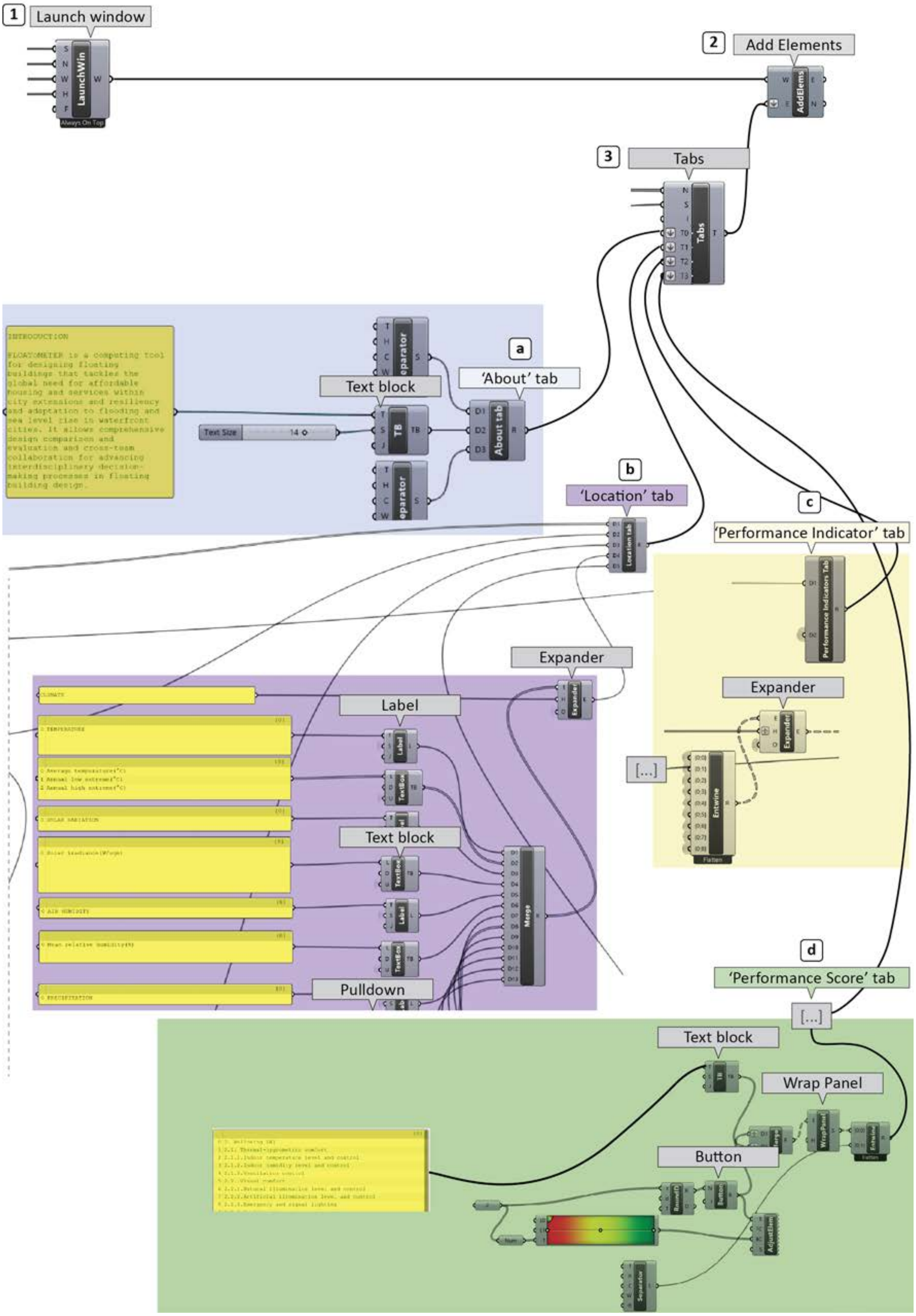
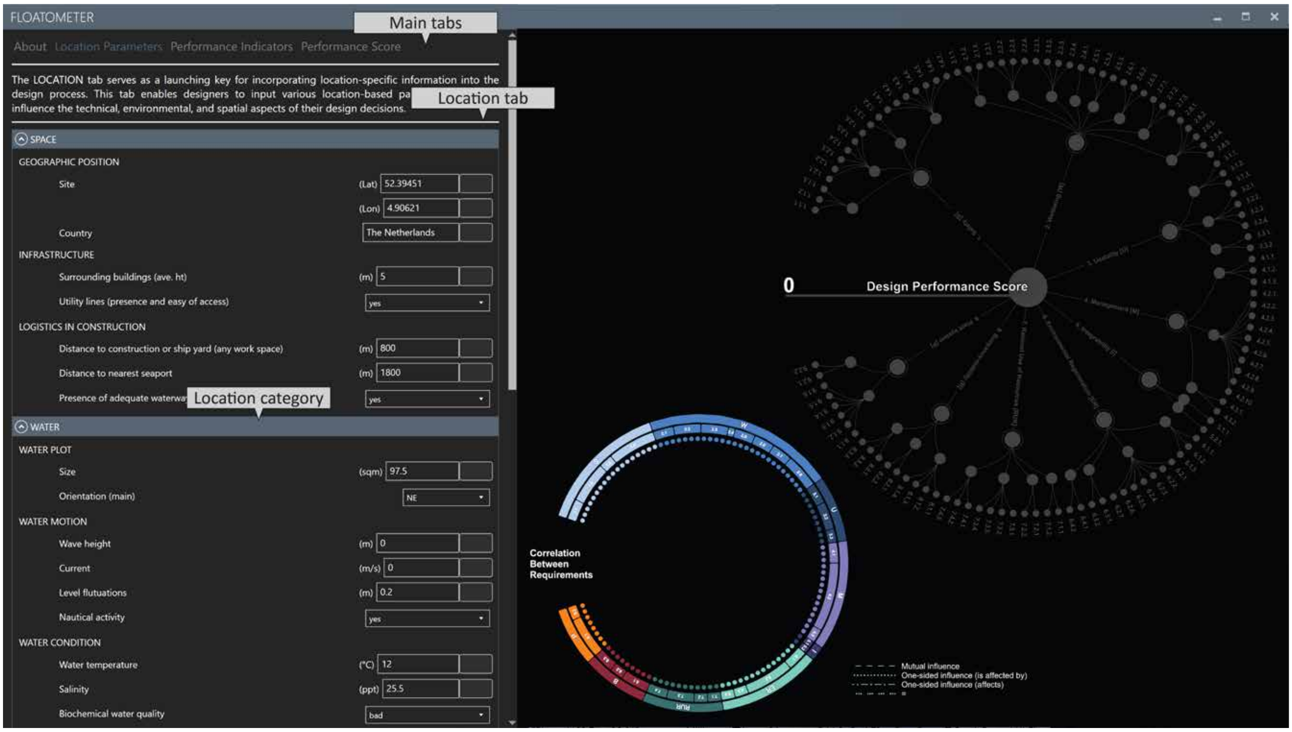


Figure 2. Tool interface: location coordinates input screen. Elaboration by Livia Calcagni and Sridhar Subramani.

Figure 3. Grasshopper workflow for the definition of the four main tabs of the dasboard.





classes of demand with checkboxes for users to select relevant ones for their project. Each class of demand has a dedicated tab with input fields for relevant indicators for each requirement. Units and conversion tools are readily integrated. Each input field collects a values for a measurable variable (indicator) that defines each requirement. The entry variables are represented as range sliders or empty boxes that collect a numeric value with appropriate measure units. Some variables, such as emergency lighting, accept a boolean value via a drop-down checklist. Each input value has a value listener, which feeds the input values into the evaluation system in real time as the user interacts with the tool. As users input data, the circular diagram ('Compliance Tracker') on the top right of the dashboard updates in real-time, showing which baseline requirements are met and which need adjustments. Clicking on a requirement on the checklist opens a pop-up window with justification for non-compliance and suggestions for improvement.

Figure 4. Tool interface: 'Location tab'. Elaboration by Livia Calcagni and Sridhar Subramani.

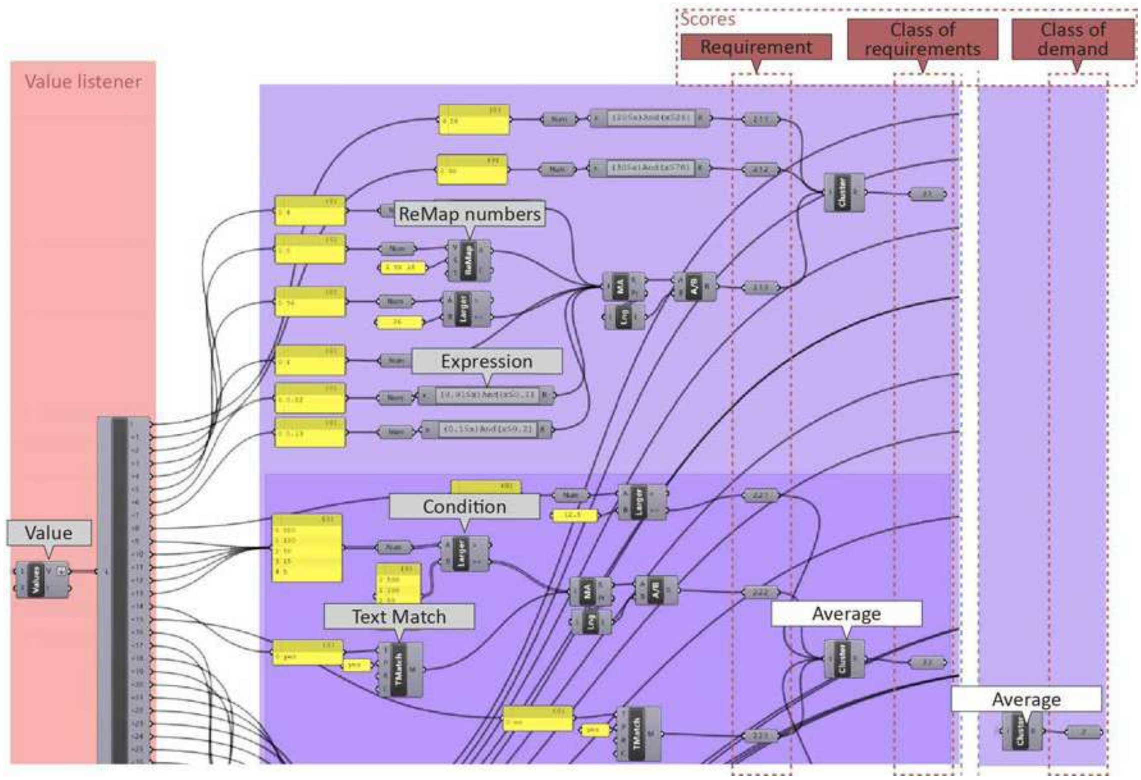
- '**Performance Score**' tab: the scoreboard shows the score for each requirement using intuitive gauges or progress bars (from green to red according to its degree of compliance). The overall performance score is displayed prominently, along with individual scores for each class of requirement and each class of demand.

3. **Evaluation set up** (Figure 5). All entered input values from the user interface are fed into this section of the definition to process the evaluation. The input variables are normalised into

a value range between 1 (optimal) and 0 (inadequate) based on the type of quantifiable or measurable indicators defined for each requirement. This is accomplished by remapping the value range, converting them to boolean values, or checking the conditional value range. The normalisation enables the evaluation of a score for each requirement and the average score for each class of requirements and class of demand, thus also providing a final performance score for the design.

4. **Visualisation set up.** The Rhino® window is used to showcase the data structure of the classes, the performance scores, and correlations. The larger circular diagram ('Compliant Tracker') showcases the data structure, with the circle's colour defining each branch of a class of demand. The connecting lines help to visualise the branches of each class of demands. The colour range of the lines from red to green indicates the score of each requirement from inadequate (red) to ideal (green). By clicking on any requirement on the 'Compliance Tracker' or selecting its checkbox, the system highlights the other requirements that are connected to it. The total performance score, expressed on the central line, spans from 0 to 100 and results from the average of the normalised values. The smaller circle on the bottom left of the dashboard ('Correlation Tracker') shows the correlations between requirements. Different line types display the type of relation mentioned above. When a checkbox is clicked on the interface, the visualization changes to reflect that specific requirement and displays both diagrams.

Figure 5. Grasshopper workflow: excerpt of Evaluation setup for the class of Wellbeing with relevant components highlighted.



7.4. Application and validation of the tool on design scenarios

The emphasis on design increasingly extends to a variety of specific local conditions and processes across spatial and time scales. Each design approach involves multiple dynamic processes, each with its own duration, pace, and timeline and specific geological, climate, environmental, cultural, social, and economic conditions. This strengthens the need for a data-driven design process that must be tailored to each specific case. For this to be possible, it is essential to consider the specifically relevant sets of data, their interrelations, and aspects of evaluation that characterise every context. This entails the need to consider location not as a class of demand within the DSS tool but as a starting condition that will affect the design process and the solutions used to address each class of demand. As a result, the DSS dashboard includes an onboarding section related to the input of location-specific information. As clarified in Chapter 7.3., the 'Location' tab (Figure 4) serves as a launching section for incorporating location-specific information into the design process that will affect the technical, environmental, and spatial aspects of the users' design decisions. The DSS tool must collect sufficient data to personalise the user experience and provide precise ranges and targets according to the specific legal and climate region where the project is located.

The tool was used to evaluate the quality of two built projects to determine its applicability in different contexts, and effectiveness in aiding the improvement of the design. Two projects designed and built by the Dutch firm Waterstudio.NL, were chosen for two main reasons: complete data and documentation (direct access to graphic and textual material) and time efficiency. Creating a new project from scratch would take a significant amount of time and resources that could be better spent on more focused evaluation of the design support tool.

The first project is Schoonship K.13 (Figure 6), a floating house part of the Schoonship floating district in the Johan van Hasseltkanaal in the north of Amsterdam, Netherlands (see Paragraph 4.4.1.2.). The other project, designed for temporary residency, is Arkup

(Figure 7), a luxury, self-sufficient floating villa in Miami, Florida. It is classified as a pleasure boat, so legally, it is a boat, but it is habitable like a house. Figures 8, and 9 refer to Scoonship K.13 and show different screen captures of the evaluation process within the dashboard: Location section, Performance Indicators value insertion, and Performance score and evaluation. Figures 10 refers to the Environmental Regeneration class of demand for Arkup while Figure 11 shows Arkup's Performance tab score. The dashboard with which the designers can interact is on the left, while the circular diagrams on the right display in real time the results for each class, all the selected correlations, and the project's overall performance score.

Although both Schoonship K.13 and Arkup were found to be high-quality projects with overall scores of 69 and 81, the tool demonstrates how they could undergo further improvements. Arkup, unlike Schoonship, has smoke detectors, alarms, sprinklers, fire extinguishers, and several collision risk reduction arrangements, including fenders and a watertight compartmentalised pontoon. These provisions increase Arkup's overall safety score. Schoonship lacks a watertight subdivided pontoon and sink risk prevention indicators (water leak detectors and bilge pumps), but it does have, unlike Arkup, with rubber seals around the mooring poles to

Figure 6. Schoonship K.13 by Waterstudio.NL in Amsterdam, Netherlands. Source: Waterstudio. NL Archive.

Figure 7. Arkup by Waterstudio.NL in Miami, Florida. Source: Waterstudio. NL Archive

reduce squeaking, rubbing, and creaking during vertical movement of the structure due to water level fluctuations. On the other hand, Schoonship, unlike Arkup, employs a variety of passive strategies to improve the building envelope performance and nature-based solutions to foster biodiversity.

The dashboard identifies aspects where both projects could improve in terms of environment regeneration, especially ecology and habitat preservation and enhancement, CO_2 emission and absorption strategies, and landscape preservation, as not all requirements are met in these classes. Furthermore, Arkup and Schoonship K.13 could integrate marine-renewable energy production equipment to meet all energy demands and become entirely self-sufficient. Schoonship K.13 could also integrate a rainwater harvesting system or a purification/desalination unit to increase the household water supply. Both projects could improve within the class rational use of resources by integrating solid waste reduction and diversion through reuse, recycling, composting, and waste-to-energy processes throughout the construction and operational phases. Arkup does not meet most of the spatial comfort requirements, mainly because it is registered as a boat rather than a permanent residential building.

Arkup has a relatively high overall performance score, presumably because of its incredibly high construction cost. Schoonship has lower construction costs but still represents a luxury district that does not provide a solution for affordable housing developments. For this reason, it is essential to integrate economic considerations within the tool to evaluate the overall performance, taking into account construction costs and operational expenses.

Two architects from Waterstudio.NL, who were in charge of the design of the projects, were invited to use the tool to evaluate their project and identify possible improvements. Unstructured interviews were carried out to gather feedback on the functionality and potential of the tool. This least rigid type of interview, with no predetermined set of questions, was chosen to gain a more comprehensive understanding of the interviewee's experiences. The evaluation criteria (requirements) categorised in different disciplinary classes were regarded as well-structured and comprehensive. The interviewed architects suggested that the tool should include a supplementary instruction manual clarifying each parameter. Overall, they highlighted that it is currently more suitable for evaluating the final design rather than for supporting the design process from the very initial phase, as it is hard to fill in all values at an early stage of the design process. They also suggested that public officers could use the tool as a certification/evaluation system to check if projects meet specific requirements and criteria. To perform effectively as a design support tool for practitioners, it should be divided into different sections corresponding to the design phases and integrate a 3D design model. Therefore, to embrace all stages of the design process, the tool could be split into three or more chronological sections that refer to the different design stages. For instance, some detailed requirements pertaining to the projects' final stages should be removed from the first section.

Figure 8. Tool interface for project 2. Schoonship K.13 by Waterstudio.NL in Amsterdam, Netherlands: Performance Indicators tab filled in (Step 2) – Example on class of demand, 2. Wellbeing, Thermo-hygrometric comfort. Elaboration by Livia Calcagni and Sridhar Subramani.

Figure 9. Tool interface for project 2. Schoonship K.13 by Waterstudio.NL in Amsterdam, Netherlands: Performance Score tab filled in (Step 3) – Example on class of demand 7. Rational Use of Resources. Elaboration by Livia Calcagni and Sridhar Subramani.

Figure 10. Tool interface for project 2. Arkup by Waterstudio.NL in Miami, Florida: Performance Indicators tab filled in (Step 2) – Example on Environment Regeneration class of demand. Elaboration by Livia Calcagni and Sridhar Subramani.

Figure 11. Tool interface for project 2. Arkup by Waterstudio.NL in Miami, Florida: Performance Score tab filled in (Step 3) – Example on class of demand 7. Rational Use of Resources. Elaboration by Livia Calcagni and Sridhar Subramani.

Figure 8.

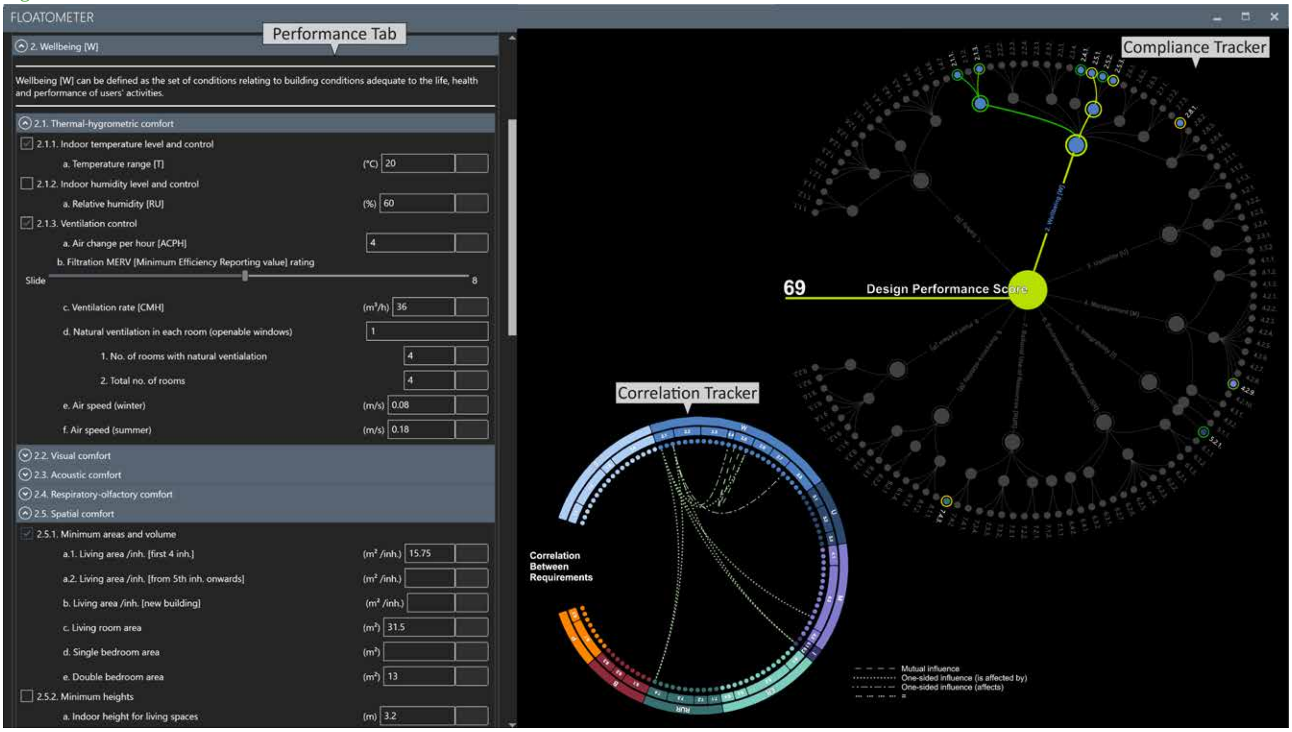


Figure 9.

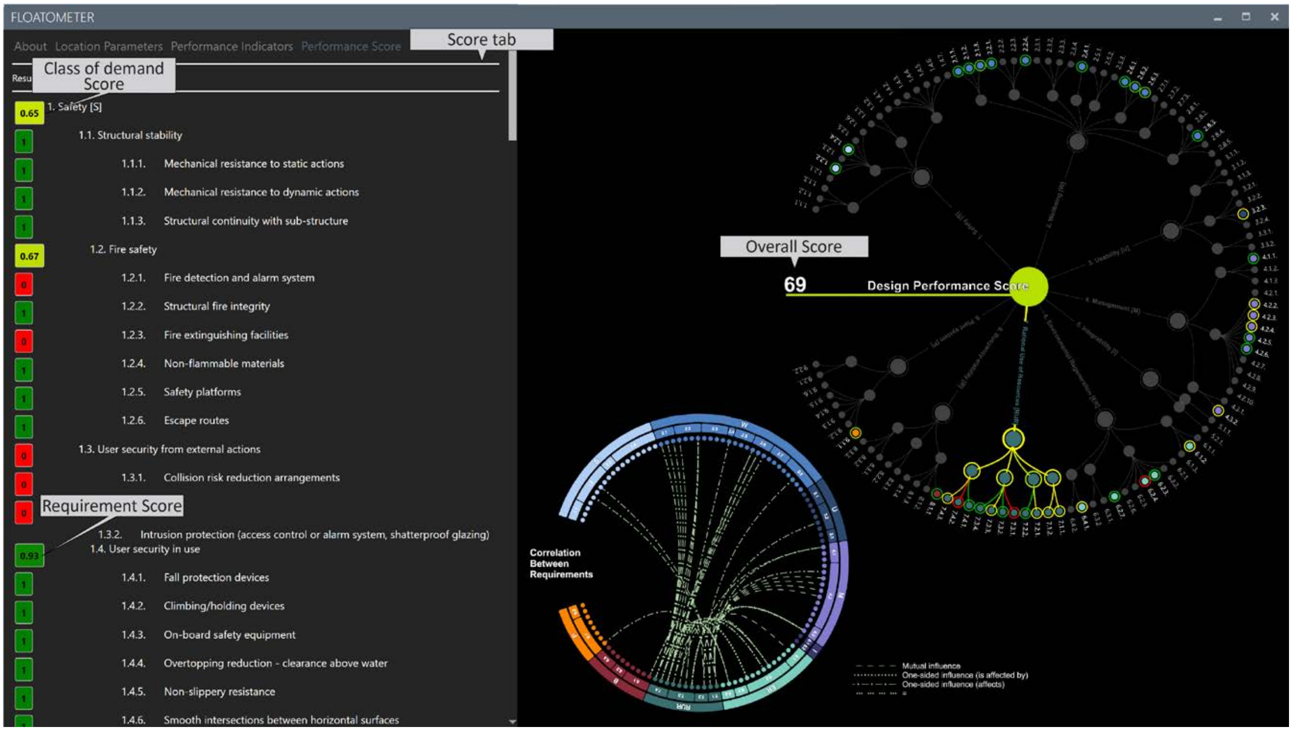


Figure 10.

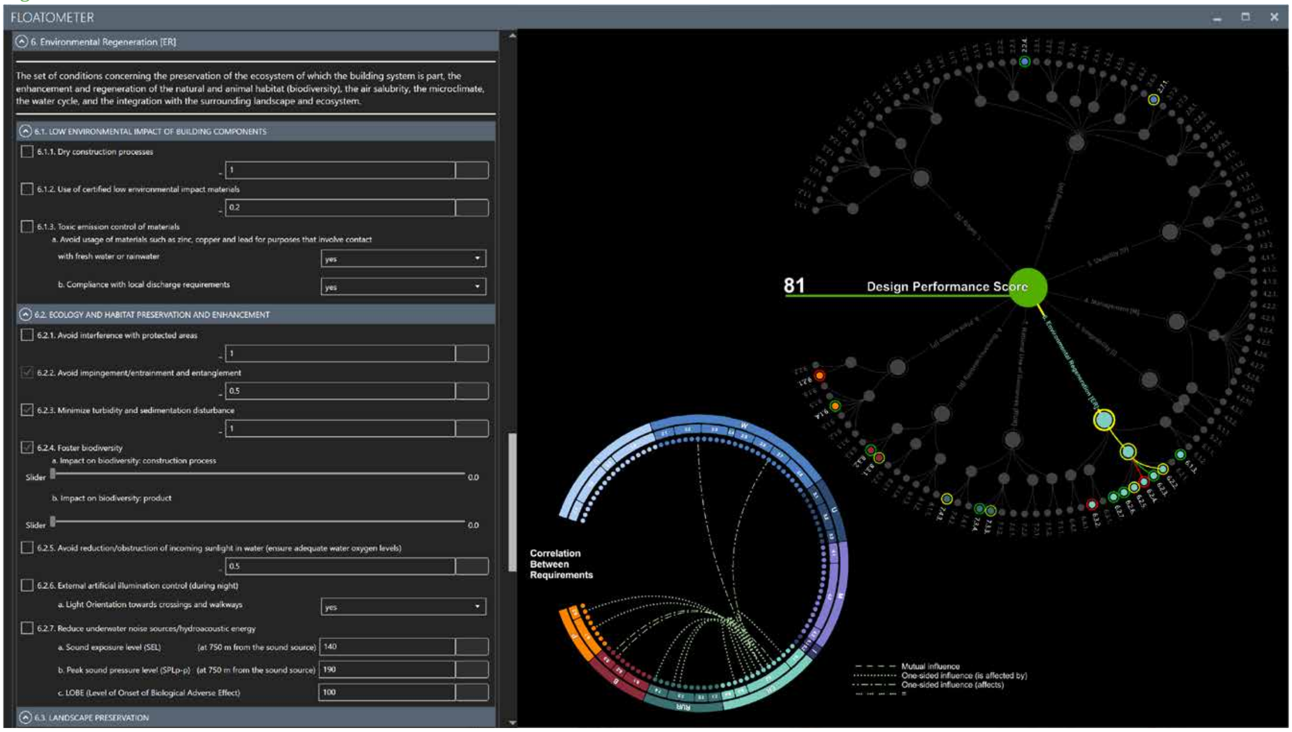
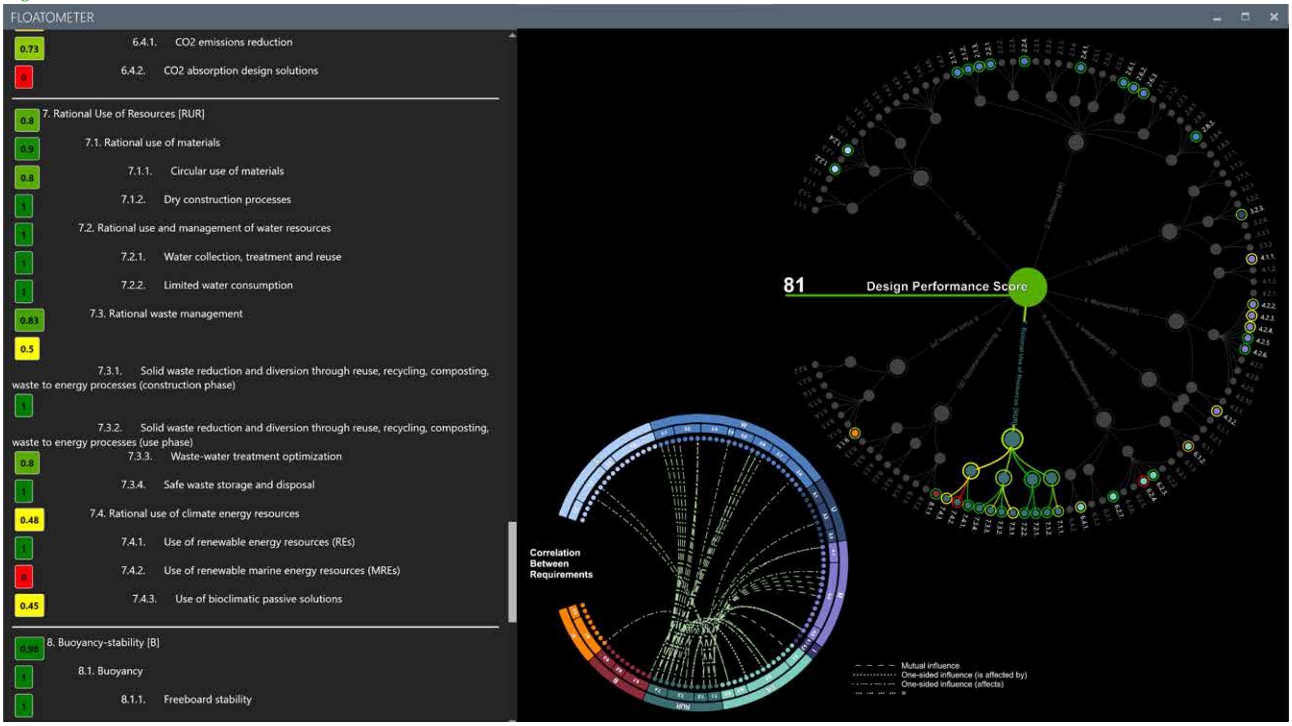


Figure 11.



References

Carpo, M. (2012). *The digital turn in architecture 1992-2012.* John Wiley & Sons.

Dade-Robertson, M. (2013). Architectural user interfaces: Themes, trends and directions in the evolution of architectural design and human computer interaction. *International Journal of Architectural Computing, 11*(1), 1–19. doi: 10.1260/1478-0771.11.1.1

Menges, A., Ahlquist S. (2011). *Computational design thinking: computation design thinking*. John Wiley & Sons.

Hensel, M. U., & Sørensen, S.S. (2014). Intersecting knowledge fields and integrating data-driven computational design en route to performance-oriented and intensely local architectures. *Footprint, 15*, 59-74. doi: 10.7480/footprint.8.2.812

Roth, S. F., Kolojejchick, J., Goldstein, J. (1994). Interactive graphic design using automatic presentation knowledge. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 112–117. doi: 10.1145/191666.191719

Nebuloni, A., Buratti, G. (2023). Design by data. From interfaces to responsive architectures. *Techne, 25*, 93–100. doi: 10.36253/techne-13629

Nebuloni, A., Rossi, A. (2018). *Codice e progetto. Il Computational Design Tra Architettura, Design, Territorio, Rappresentazione, Strumenti, Materiali e Nuove Tecnologie.* Milan: Mimesis Edizioni.

Conclusions

The conclusion draws together the key findings and contributions of the research, organizing them into six overarching themes that serve as springboards for future investigations. These themes, namely the importance of site-specificity, the cross-scale approach towards upscaling, the need for enhancing user experience and attractiveness, the need for a clear legal framework and political will, the notion of performance, and the potential negative aspects of floating urban development, encapsulate the core elements of the research and highlight promising avenues for further exploration and development in the field of floating architecture and floating urban development. By addressing these critical aspects, future studies can advance our understanding of floating architecture and contribute to its practical applications.

The importance of focusing on performance

This thesis fits into the line of scientific thought that uses the concept of performance in its broadest connotation and refers not only to aspects linked to the efficiency of resources and energy consumption but also to structural aspects (Bollinger et al., 2010; Luebkeman & Shea, 2005; Oxman & Oxman, 2010; Pedreschi, 2008; Pugnale, 2010), materials, physical and social wellbeing, and programmatic or operational features (Derix, 2010). As underlined by Professor Turrin (Turrin, 2013), the concept of performance in architecture is outlined as “the capacity of a building to fulfil the architectural requirements, in relation to human needs and environmental factors. The ensemble of human needs and environmental factors is here called context”. In this perspective, the performance requirements, made explicit by codes and regulations, to which architecture is called upon to respond today, place the theme of performance at the centre of the debate as a design focus. Martin Bechthold, Professor at Harvard Graduate School of Design, in his essay Performalism or Performance-based Design (Bechthold, 2013), invites us to eliminate the suffix –ism and consider the performative parameters as normality within the design process and as an ethical obligation of the profession strictly connected to the paradigm of environmental sustainability.

The performance-oriented paradigm, extensively reasoned by Professor Michael Hensel (Hensel, 2010; Hensel, 2013), has introduced a new operational methodology through which the formal generation is guided and informed by performances (material, structural and spatial organization, environment, and energy), which become design input rather than a mere quantitative parameter. This thesis seeks to understand the interrelation between the notion of performance and the complexity of the design act, placing the focus on the design methodology (process) necessary to solve complex interdisciplinary design challenges.

The case study analysis has highlighted how, in some cases, the designers had to resort to exemptions from current building laws to test and experiment with innovative technologies and sustainable solutions. This draws attention to the importance of focusing on performance – on the objectives rather than on the means or on quantitative prescribed parameters – to ensure overall quality and allow freedom for experimentation and innovation.

The importance of site-specificity

The literature review and case studies revealed that the emphasis on design is gradually encompassing a variety of specific local conditions and processes across spatial and time scales. The case studies highlighted how each design approach involves several dynamic processes, each with its specific duration and pace. This site specificity and dynamic nature of each context and project cannot be handled through a one-size-fits all approach which would easily become outdated and inefficient. Data-driven processes provide a solution for tailoring the design process and project to each unique case. Therefore, it is necessary to consider the specifically relevant sets of data, their interrelations, and the criteria and characteristics of evaluation that distinguish every different context. This entails considering location not as a class of demand within the PDSF but as a starting condition that will affect the design process and the means to address each class of demand. Understanding the local context's unique characteristics and physical, ecological, and social dynamics is essential for creating sustainable and resilient floating structures embedded in the environment. Hence, the framework's application must come after an in-depth site analysis. Location influences several aspects, including structural integrity, maintenance, utility, reliability and self-sufficiency, motion comfort, and environmental adaptability.

Meeting guidelines and standards ensures quality and environmental compliance. However, overlooking local specificity can result in inefficient designs that fail to adapt to the unique challenges and opportunities of the site. The PDSF intends to address this challenge by placing itself as one step of the multi-layered design process. Therefore, the PDSF can be framed within the more extensive design process, which begins with the selection or assignment of a place followed by the identification of design objectives. The site, in terms of climate, geological, hydrographic, and socio-economic features, sets several constraints and offers specific opportunities that shape and define the design objectives. The design objectives then guide the user in the decision-making process. The framework comes into play in this phase to support the decision and design-making process. Within this perspective, the requirements are provided as guidelines that the designers can choose whether to meet or not according to their specific design objectives. The baseline standards for structural integrity, safety, environmental impact, and accessibility are usually defined by local regulations and must be met by all floating buildings. However, the way (means) in which the requirements are met is up to the designer (and influenced by local regulations), as the PDSF only provides information on what (objectives) must be met. Once the designers have carried out an in-depth analysis of the site and the local context and have developed preliminary design concepts, they can use the PDSF and adjust it to their specific needs by addressing all requirements, either part of them or simply allocating different importance to each requirement.

Moreover, it is an open, upgradable tool, as evidenced by its constant upgrading throughout this dissertation's different stages of elaboration. Future versions of the PDSF can easily be tailored for specific regions or countries and integrate new requirements. The PDSF is structured to enable easy implementation, integrations, and changes resulting from a feedback loop between the framework and its application. The possibility of constantly upgrading it allows the PDSF to adapt to changing conditions, needs, and scales over time.

The urgency for a clear regulatory framework and political will

As the case studies have demonstrated, technology is not a barrier to the development of floating buildings and cities. Advances in technology enable us to create inhabitable structures in shallow, sheltered waters and deep-sea waters. However, FUD has still not taken off, mainly because of political, legal, and, consequently commercial barriers. Besides the UN, only a few organizations have the economic and political influence and incentive to test and deliver a satellite floating city in the ocean. One of the main reasons renowned architectural offices have yet to challenge themselves with floating structures is that the absence of a clear and solid legal framework does not guarantee their operation. The risk is too high and not worth the challenge. Oceanix and the Maldive floating city are just the last utopian proposals, but they have been forerun by the ideas brought forward in the 70s. This cyclical return of floating city proposals implies that even if the contemporary floating city designs fail, it will not be long before another floating city proposal arises. The turning point stands in the social, political, and commercial will.

The main legal issue related to floating buildings is the intrinsic ambiguity of their status, somewhere in between a real estate property and a vessel. Their hybrid and undefined legal status results in regulatory uncertainty. This status also depends on the design of the floating building in terms of how permanently it is connected to the shore and to the site where it is installed. How a floating building is classified has consequences for its registration and the private, administrative, and fiscal issues that apply to it. For instance, if commercial banks and mortgage firms do not sell mortgages and insurance for floating houses, the market demand and trust among potential house buyers is held back. If it is considered real estate, urban planning, zoning regulations, and taxation are similar to standard buildings, and social benefits related to housing or other typologies may apply. If it is considered a ship, marine law applies. As the case study analysis highlighted, floating buildings usually have double status and double registration in countries far ahead in this process, like the Netherlands. Even in countries with no specific floating building regulations, governments or local authorities are responsible for the regulatory procedures for floating constructions. At least, they have to assign the locations and conditions under which floating and amphibious buildings are allowed in their policies and regulations and generally arrange for access and services.

In most countries, including Finland, Norway, France, or Italy, that do not have a specific code for floating buildings, obtaining a building permit to build on water is highly complex and requires a long time. For this reason, most structures are classified as houseboats, boats, or barges. Long times and difficulties encountered in buying a plot of water or obtaining construction permits to build on water strongly affect and increase the overall realization time of the projects.

The importance of user experience

Enhancing the attractiveness and user-friendliness of the framework for floating buildings can significantly impact its adoption and effective implementation. By transforming the set of guidelines into a user-friendly interface web-based tool, the framework can become more approachable, engaging, and valuable for stakeholders involved in floating infrastructure development and building design. The concise requirements are currently organized in a clear structure that could be easily translated into a visual interface, making it easier for users to locate specific information and navigate the guidelines effectively.

Instead of providing descriptive lists of guidelines, formulating the requirements as actionable steps and checklists helps to guide the users in applying the guidelines while having constant feedback on their project.

Moreover, a full version of the interactive and dynamic digital platform developed as a PoC, would make the guidelines more engaging and accessible, allowing the shift from performance-based to performance-driven. This way, the digital tool could be regularly updated, reflecting the latest advancements in floating technology, design practices, and regulatory requirements. The digital tool could implement feedback mechanisms to gather input from stakeholders and incorporate their suggestions for improvement. The shift to a performance-driven digital tool could also allow the integration of different versions of the guidelines according to the location, which vary in language and content. Multiple language versions could help reach a wider audience and facilitate international collaboration in floating development.

Cross-scale approach towards up-scaling

Both the design scenarios and the case studies have highlighted the importance of broadening the scale of focus of the framework from the single unit or building to a cluster of buildings, shifting the focus from the building scale to an urban perspective. The potential of the framework's approach lies in the possibility of extending its application to larger-scale projects, encompassing clusters of buildings and even entire districts. When considering floating buildings as standalone entities, the focus often falls on technical aspects. While these factors are undoubtedly important, they represent just one piece of the puzzle. By expanding the scope of the design framework to encompass multiple buildings and their interactions within a district, architects can address a broader range of considerations, including spatial organization and connectivity, infrastructure integration (shared transportation networks, energy grids, and waste management systems), social cohesion and community building, and economic feasibility and overall cost reduction. By addressing these considerations, the design framework for floating buildings could broaden its domain to embrace the relations more accurately between single structures into interconnected hubs. This shift in perspective from a single building to a district scale is crucial for unlocking the full potential

of floating architecture.
In this perspective, the PDSF could represent a starting point to transition towards floating communities and cities successfully and sustainably by broadening the scale (and integrating new requirements) and expanding its domain to cost considerations (construction and operation) and social-urban dynamics.

Awareness of negative aspects

The distinction between the natural and the anthropic is not merely a matter of semantics; it underscores the profound impact of human activity on the planet and our responsibility to coexist harmoniously with the natural world. The urban sprawl of artificial structures in marine environments has widespread ecological consequences, even if the structures are designed to reduce negative ecological impacts while promoting ecosystem services. No matter how embedded these structures are in the surrounding environment and how sustainable the construction process is, the entire process, from material extraction to the operation of the structure, irrevocably alters the natural state and ecological balance. For this reason, the PDSF is designed following an ecological engineering approach that implies incorporating ecological goals and principles into the design to limit the decline of marine species and degradation of habitats, maintain vital ecosystem services, and ensure more efficient use of natural resources. However, the local and regional effects of artificial structures on marine ecosystems are widely documented (Bulleri & Chapman, 2010; Dugan et al., 2011; Govarets & Lauwerts, 2009): direct physical disturbance, indirect physical disturbance (alteration to ecological balances), noise and light pollution. These impacts relate to different engineering stages (construction, operation, and end of life) across local and regional scales. Physical disturbances arise from adding or removing artificial materials during construction and decommissioning. The materials added during construction change the type of available resources by altering the proportion of sheltered, shaded, vertical, and floating surfaces. The orientation of structures (that interferes with currents) and the surface texture of construction materials can influence the colonization of marine organisms (Dafforn et al., 2015). Artificial structures may also host non-indigenous species, which have been found to occupy up to 80% more space on pilings or pontoons compared to natural reefs (Dafforn et al., 2012). Slight variations in concentrations of water quality parameters between open water and under or near floating structures can occur too. The expected impacts largely depend on the scale and number of floating buildings in a water body (de Lima et al., 2022). Therefore, the physical design of artificial structures has significant consequences at multiple trophic levels and across seascapes. In addition, the construction of coastal infrastructure and related changes to water flow can restrict or facilitate the movement of marine larvae and nutrients (Floerl & Inglis, 2003). The impacts of floating buildings on water ecosystems must be further investigated through dedicated environmental monitoring activities. The PDSF aims to integrate, as substantial features, design requirements that can contribute to restoring local biodiversity, facilitating carbon storage, monitoring the surrounding environmental quality, avoiding interference with marine habitat (light, noise, entanglement, sediment alteration), and using nature-based solutions and bio-materials. Overall, since the urbanization of the oceans is likely to increase, it is crucial to incorporate multiple targets into the design.

Another relevant aspect that must be considered is that floating buildings typically have higher building costs compared to traditional land-based constructions, mainly because of adaptation measures needed for dealing with rising water levels, maintenance costs, legal expenses, and additional infrastructure to connect the building to utilities (water supply, sewage disposal, power, gas). At the same time, the flood-resistant capacity of these structures has a positive effect on their value. Administrative delays, experienced by several case studies, often increase the overall implementation time and costs. Building the structure can be fast, especially if built elsewhere and tugged to its final mooring place. The development of a floating neighborhood can take longer, mainly because of administrative delays concerning authorization and safety standards of the whole interconnected block of floating buildings. A practical example is the floating neighborhood of Schoonschip in Amsterdam, which required about ten years to implement.

A third significant challenge in this drive for innovation is the imperative to be inclusive and equitable. As underlined in Paragraph 1.5.3.1, there is a risk of discriminating and further marginalizing communities by establishing floating ghettos or luxury enclaves. The politics of space entails struggles and conflicts over the process through which the space is produced and divided. Today, an emphasis on mobility, flexibility, and adaptation to continual change might be easily portrayed as complicit with neo-liberal capitalist urbanization's demands and the injustices it wreaks. Floating cities feed the narration of a fluid world, normalizing capitalist urbanization and hindering the drive to expand to overcome spatial barriers and find new opportunities for profitable investment.

For this reason, public bodies and governments must pave their way as soon as possible to ensure what Lefebvre calls the right to the city in his 1968 book *Le Droit à la Ville* (Lefebvre, 1967). Utopian visions of the city have always attracted critical perspectives. Sigfried Gideon and Constantinos Doxiadis were seen as technological fetishists giddy about the speed-up of capitalist gadgetry. The Marxist philosopher Henri Lefebvre asserted radical perspectives on mobile cities. He disparaged the proliferation of spatial schemes devised by urbanists and architects at the time. For urban change to be liberating, Lefebvre stressed, it must involve transforming everyday life and space. It requires the appropriation of urban spaces by inhabitants so that cities are no longer alienated products or commodities but oeuvres that inhabitants consciously and collectively inhabit. It involves claiming rights to the city and asserting use values over exchange values. The liberation cannot be ensured by spatial design or technological development alone. However innovative the forms proposed, their affirmation requires transforming fundamental social and spatial relationships. Social acceptance and political will play a crucial role in the implementation and success of floating cities. Without widespread support from the public and strong leadership from policymakers, the development of floating cities will likely face significant hurdles. Gaining community support is crucial for floating urban development, as it represents a significant departure from traditional land-based development. Engaging with residents, addressing their concerns, and highlighting the potential benefits of floating cities are essential for building public trust. As some citizens may have concerns about the safety, stability, and environmental impact of floating cities, a comprehensive shared framework and set of guidelines provides users with the confidence they need to deal with such an innovative transformation. Addressing these concerns through transparent communication, comprehensive quality measures, and ecological design practices can help dispel misconceptions and build public confidence. At the same time, governments need to provide clear policy frameworks and regulatory support for floating infrastructure development. This includes establishing building codes and permitting processes, and addressing insurance and liability issues to encourage FUD rather than lengthen permission acquisition and construction time. Governments could also encourage the development of floating cities by providing financial incentives, such as tax breaks or subsidies, to developers and investors. This support can help overcome the initial cost barriers associated with floating technology. Based on the Dutch example, governments can foster collaboration between public agencies, private developers, and research institutions to accelerate the development of floating technologies and design innovative solutions.

In conclusion, by addressing public concerns, fostering collaboration, and providing policy support, governments can pave the way for this innovative approach to urban development, offering a resilient and sustainable solution for waterfront communities facing the challenges of climate change.

Further research questions and future studies

This study aimed to assess the feasibility and practical potential of a performance-driven digital design support system (DSS) for floating residential buildings and to identify critical aspects requiring further refinement or expansion considering the limited PoC implementation.

First, the development of an algorithm thinking process for one class of demand proves the feasibility of applying the methodology to any other class and the replicability of the whole process on the rest of the framework, notwithstanding the limited PoC implementation.

Not only was the potential practical use of the tool confirmed by the interviewed designers, but novel applications also surfaced. What emerges from applying the tool to existing designs is that the dashboard can be used both for design and evaluation purposes. In the design phase of new buildings, it acts as a set of guidelines and checklist in the initial stages and as a design support tool in the technical final phases. At the same time, through slight adjustments, the tool could be applied in evaluating existing projects or built structures and used by technichal public officers as a certification system to evaluate their overall quality regarding the identified requirements.

Moreover, the development of a performance-driven design support tool for the small (building) scale shows the potential of upscaling the process to a cluster of buildings and eventually to the city scale through the integration of computational aid.

The authors are aware that the limited data available on floating buildings and floating urban development may represent a limit for the research due to the bias that can occur in the selection of indicators carried out by the authors. This limitation can be overcome by designing the tool as a flexible platform that undergoes constant development, thus allowing the inclusion of new metrics to improve multi-criteria evaluation and accuracy. Another limit is the application of the tool to an existing project, where the adjustment phase, specifically the feedback loop between the project and the output of the DSS tool, is absent. Nevertheless, our work could be conceived as one of the first iterations of a project that could be improved using the output delivered by the tool for future versions. Future studies could involve the integration of a 3D model to provide architects and designers with a tool aiding each stage of the design process rather than only design support for evaluation. Additionally, a set of default strategies, as briefly mentioned in Chapter 7, could be incorporated to guide users in making improvements based on real-time dashboard data. The tool could be implemented as a standalone platform designed for uploading IFC files or as a plug-in for BIM software that already integrates data into the model. This enhanced version would allow users to initiate their design in 3D and receive real-time feedback on the performance of each framework category and each requirement. The tool could be further developed to include affordability information, including average rough costs (price ranges). Providing users with a general estimate of construction costs would enhance the tool's ability to assess the economic feasibility and affordability of the design proposals. This feature would also facilitate comparing design scenarios based on cost implications.

In conclusion, the findings of this research suggest that one of the key areas of future research is the full development of the design support platform for floating architecture. This could include differentiating between baseline standard requirements (with which the project must necessarily comply) and optional requirements that provide additional value to the project. The tool could also be further developed to integrate, in addition to the features mentioned above, also several versions with different embedded regulations based on the country where the project is supposed to be built.

A natural progression of this work would be to enlarge the scale of the PDSF and the relevant tool at the district or urban level. This could entail the study of clustering and aggregation patterns and possible scenarios starting from vernacular architecture. If the debate is to be moved forward, a better understanding of the relationships between buildings and the intrinsic mobility character of floating structures must be developed.

A greater focus and investigation on urban waterfront adaptation strategies according to geomorphological, climate risk, and social features could produce interesting findings that could better frame floating architecture as one of the potential solutions within a hybrid integration of adaptation strategies for regeneration purposes.

Moreover, the findings of this research provide insights for merging the topic of floating architecture with other fields of study and application, including sustainable production or service availability. Overall, conducting research into new and innovative technologies for water and wastewater treatment, power generation, and waste disposal in water environments, engaging with the public to address their concerns and build trust in floating architecture, fostering collaboration between public agencies, private developers, and research institutions, would all contribute to accelerating the development of floating architecture and realize its potential to create more resilient, sustainable, and inclusive communities.

Stepping back to gain a broader perspective, this work contributes to advancing design for adaptation by challenging the need to consider adaptivity as an intrinsic characteristic of buildings and urban spaces from the earliest stages of their development. This dissertation proposes a novel design for adaptation approach by implementing a constant feedback loop within the design process of a building and possibly in the operation of the building itself. This entails considering the building and the environment it is set in as a dynamic and flexible integrated system. This approach enables lengthening the useful life of buildings by designing them to be more adaptable to climate changes, to the variation of users' needs, to the modification of functions and services required in a specific context, and to keep pace with social and urban changes.
All things considered, this thesis has raised important questions about the future of floating urban developments and urban adaptation in waterfront cities that remain to be answered.

References

Bechthold, M. (2013). Performalism or performance-based design? In *Performalism*. Routledge.

Bollinger, K., Grohmann, M., & Tessmann, O. (2010). Structured becoming: evolutionary processes in design engineering. *Architectural Design, 80*(4), 34–39. doi: 10.1002/ad.1103

Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology, 47*(1), 26–35. doi: 10.1111/j.1365-2664.2009.01751.x

Dafforn, K. A., Glasby, T. M., Airoldi, L., Rivero, N. K., Mayer-Pinto, M., & Johnston, E. L. (2015). Marine urbanization: an ecological framework for designing multifunctional artificial structures. *Frontiers in Ecology and the Environment, 13*(2), 82–90. doi: 10.1890/140050

Dafforn, K. A., Glasby, T. M., & Johnston, E. L. (2012). Comparing the invasibility of experimental "reefs" with field observations of natural reefs and artificial structures. *PLoS One, 7*(5), e38124.

de Lima, Rui L P, Boogaard, F. C., & Sazonov, V. (2022). Assessing the influence of floating constructions on water quality and ecology. *WCFS2020: Proceedings of the Second World Conference on Floating Solutions*, Rotterdam, 397–406.

Derix, C. (2010). Mediating spatial phenomena through computational heuristics. *Proceedings of the 30th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA),* New York, 61–66.

Dugan, J. E., Airoldi, L., Chapman, M. G., Walker, S. J., Schlacher, T., Wolanski, E., & McLusky, D. (2011). 8.02-Estuarine and coastal structures: environmental effects, a focus on shore and nearshore structures. *Treatise on Estuarine and Coastal Science, 8*, 17–41. Derix

Floerl, O., & Inglis, G. J. (2003). Boat harbour design can exacerbate hull fouling. *Austral Ecology, 28*(2), 116–127.

Govarets, A., & Lauwerts, B. (2009). Assessment of the impact of coastal defence structures. Biodiversity Series: OSPAR Commission.

Lefebvre, H. (1967). Le droit à la ville. *L'Homme et La Société, 6*(1), 29–35.

Luebkeman, C., & Shea, K. (2005). CDO: Computational design+ optimisation in building practice. *The Arup Journal, 40*(3), 17–21.

Oxman, R., & Oxman, R. (2010). New structuralism: design, engineering and architectural technologies. *Architectural Design, 4*(80), 14–23. doi: 10.1002/ad.1101

Pedreschi, R. (2008). Form, force and structure: a brief history. *Architectural Design, 78*(2), 12–19.

Pugnale, A. (2010). *Engineering Architecture: Advances of a technological practice.* Aalborg: Aalborg Universitet.

Turrin, M. (2013). *Performance Assessment Strategies: A computational framework for conceptual design of large roofs.* Delft: Tu Delft.

Appendixes

Performance-based Design-Support Framework (1.0)

Appendix A1

This document is the final version of the Performance-based Design-Support Framework (PDSF) for floating buildings.
The PDSF is a tool for evaluating the performance of floating buildings against a set of nine classes of demand: safety, wellbeing, usability, management, environmental regeneration, rational use of resources, integrability, buoyancy-stability, and plant system.
Each class of demand is further divided into subclasses of requirements, each with its set of performance-requirements. The performance-requirements can be conceived as the transposition of a demand into technical terms. For each performance requirement, a set of guidelines are provided, together with a list of relevant regulations sorted by color according to the relevant disciplinary field: grey (on land architecture and civil engineering), blue (floating architecture), red (shipping and naval engineering) and purple (offshore engineering).

The PDSF is based on the following principles:

- user-centeredness: the PDSF is designed to meet the needs of the users of floating buildings.
- life-cycle approach: the PDSF considers the performance of floating buildings over their entire life cycle, from de-sign and construction to operation and maintenance.
- adaptability: the PDSF is designed to be adaptable to the changing needs of users and the environment.
- multi-species approach and ecosystem integration: the PDSF considers the environment as a host organism (ecosystem) and the floating facilities (or cities) as grafts.

The PDSF is a valuable tool for designers, developers and policy makers to identify and prioritize the performance requirements that are most important for a particular project, evaluate the performance of a floating building against a set of predefined criteria, develop and implement design solutions that meet the performance requirements making informed decisions about the construction, operation and maintenance of the floating building.

Class of demand	Class of requirements	Requirement n°	Requirement
1. Safety	1.1. Structural stability	1.1.1.	Mechanical resistance to static actions
		1.1.2.	Mechanical resistance to dynamic actions
		1.1.3.	Structural continuity with sub-structure
	1.2. Fire safety	1.2.1.	Fire detection and alarm system
		1.2.2.	Structural fire integrity
		1.2.3.	Fire extinguishing facilities
		1.2.4.	Non-flammable materials
		1.2.5.	Safety platforms
		1.2.6.	Escape routes
	1.3. User security from external actions	1.3.1.	Collision risk reduction arrangements
		1.3.2.	Intrusion protection
	1.4. User security in use	1.4.1.	Fall protection devices
		1.4.2.	Climbing/holding devices
		1.4.3.	On-board safety equipment
		1.4.4.	Overtopping reduction (clearance above water)
		1.4.5.	Non-slip resistance
		1.4.6.	Smooth intersections between horizontal surfaces
		1.4.7.	Horizontal walkway illumination
2. Comfort	2.1. Thermal-hygrometric comfort	2.1.1.	Indoor temperature level and control
		2.1.2.	Indoor humidity level and control
		2.1.3.	Ventilation control
	2.2. Visual comfort	2.2.1.	Natural illumination level and control
		2.2.2.	Artificial illumination level and control
		2.2.3.	Emergency and signal lighting
		2.2.4.	Quality views
	2.3. Acoustic comfort	2.3.1.	Noise level limits
		2.3.2.	Indoor acoustic insulation/sound barriers
		2.3.3.	Reverberation time control
		2.3.4.	Sound reducing surfaces
	2.4. Respiratory-olfactory comfort	2.4.1.	Absence of unpleasant odors (ventilation control)
	2.5. Spatial comfort	2.5.1.	Minimum areas and volume
		2.5.2.	Minimum height
		2.5.3.	Occupancy rate
	2.6. Motion comfort	2.6.1.	Vertical acceleration control
		2.6.2.	Motion control
		2.6.3.	Vibration control
	2.7. Psycho-perceptive comfort	2.7.1.	Biophilia

Class of demand	Class of requirements	Requirement n°	Requirement
		2.7.2.	Behavioral engagement
		2.7.3.	Active lifestyle design
	2.8. Hygienic conditions	2.8.1.	Air quality
		2.8.2.	Microbe and mold control
		2.8.3.	Drinking water quality
		2.8.4.	Mosquito prevention
		2.8.5.	Dust and pest prevention and management
3. Usability	3.1. Accessibility	3.1.1.	Access (reachability) for all users
		3.1.2.	Circulation for all users
		3.1.3.	Uniformity and illumination of walkways' surfaces
	3.2. Adaptability	3.2.1.	Technical flexibility
		3.2.2.	Functional/spatial flexibility
		3.2.3.	Disassembly arrangements
		3.2.4.	Mobility (towing arrangements)
	3.3. Functionality	3.3.1.	Furniture integration
		3.3.2.	Ease of use and maneuver
4. Management	4.1. Design and construction management	4.1.1.	Cost-effective and efficient processing and manufacturing
		4.1.2.	Cost-effective and efficient transportation
		4.1.3	Cost-effective and efficient assembly and construction
	4.2. Operational management (Use an maintenance)	4.2.1.	Ease of intervention
		4.2.2.	Ease of repairability/replaceability
		4.2.3.	Chemical aggressive agents resistance
		4.2.4.	Atmospheric agents resistance
		4.2.5.	Hygroscopicity
		4.2.6.	Interstitial condensation control
		4.2.7.	Real-time/remote control optimization
		4.2.8.	Seasonal efficiency of heating/cooling systems
		4.2.9.	On-board user manual
	4.3. End-of-life management	4.3.1.	Disassembly arrangements
		4.3.2.	Disposal of building components and materials
5. Integrability	5.1. Integrability of technical elements	5.1.1.	Dimensional integrability
	5.2. Integration of plant systems	5.2.1.	Plant system integration
6. Environmental regeneration	6.1. Low environmental impact of building components	6.1.1.	Dry construction processes
		6.1.2.	Use of environmentally friendly materials
		6.1.3.	Toxic emission control of materials
		6.1.4.	Use of local materials
	6.2. Ecology and habitat preservation and enhancement	6.2.1.	Avoid interference with protected areas

Class of demand	Class of requirements	Requirement n°	Requirement
		6.2.2.	Avoid impingement/entrainment and entanglement
		6.2.3.	Minimize turbidity and sedimentation disturbance
		6.2.4.	Foster biodiversity
		6.2.5.	Avoid reduction/obstruction of incoming sunlight in water
		6.2.6.	External artificial illumination control
		6.2.7.	Reduce underwater noise sources (hydroacoustic energy)
	6.3. Landscape preservation	6.3.1.	Landscape-architecture integration
		6.3.2.	Landscape preservation
	6.4. Decarbonization	6.4.1.	CO_2 emissions reduction
		6.4.2.	CO_2 absorption design solutions
7. Rational use of resources	7.1. Rational use of materials	7.1.1.	Circular use of materials
		7.1.2.	Dry construction processes
	7.2. Rational use and management of water resources	7.2.1.	Water collection, treatment and reuse
		7.2.2.	Limited water consumption
	7.3. Rational waste management	7.3.1.	Solid waste reduction and diversion
		7.3.2.	Waste-water treatment optimization
		7.3.3.	Safe waste storage and disposal
	7.4. Rational use of climate energy resources	7.4.1.	Use of renewable energy resources (REs)
		7.4.2.	Use of renewable marine energy resources (MREs)
		7.4.3.	Use of bioclimatic passive solutions
8. Buoyancy and stability	8.1. Buoyancy	8.1.1.	Freeboard stability
		8.1.2.	Watertight compartmentation/ subdivision
		8.1.3.	Watertight integrity
		8.1.4.	Sink risk prevention indicators
	8.2. Stability and trim	8.2.1.	Adaptability to static load variation
	8.3. Asset - position	8.3.1.	Mooring arrangements
		8.3.2.	Anchoring provisions and arrangements
		8.3.3.	Under keel clearance
9. Plant system	9.1. Damage resistance	9.1.1.	Maintainability-repairability
		9.1.2.	Human damage resistance
		9.1.3.	Natural (biological or chemical) agents resistance
		9.1.4.	Pipeline watertight integrity
		9.1.5.	Safe placing
		9.1.6.	Emergency energy power storage
	9.2. Climate resistance	9.2.1.	Thermal variation resistance of pipelines.
		9.2.2.	Adaptability of pipelines to water fluctuations
10. Location	10.1. Vessel interaction	10.1.1.	Avoid areas interested by vessel routes

Class of demand	Class of requirements	Requirement n°	Requirement
		10.1.2.	Reduced vessel speed limits
	10.2. Climate features	10.2.1.	Temperature
		10.2.2.	Humidity
		10.2.3.	Solar radiation
		10.2.4.	Wind conditions (speed, direction)
	10.3. Hydrographic features	10.3.1.	Water surface temperature
		10.2.2.	Bathymetry
		10.2.3.	Water fluctuations
		10.2.4.	Waves (height, period, frequency, pressure load)

1. Safety (S)

1.1 Structural Stability (referring to super-structure)

1.1.1. Mechanical resistance to static actions. Ability of the structure to withstand loads that do not cause significant accelerations. Static actions are generally represented by forces or moments that act in a constant or uniformly variable way over time: permanent* and variable** loads; extraordinary loads***.

*Permanent loads include at least:
- the mass of main load-bearing structure (floating body, floors, pillars, beams);
- vertical closures;
- fixed installations:
- partition walls (>0.8kN/m).

**Variable loads include at least:
- vertically acting floor loads according to Eurocode (bulk inventory and people);
- Rain and snow load according to Eurocode;
- hydrostatic pressures due to the flow and the consequent anchoring forces, and hydrostatic pressures due to the action of the waves;

***Extraordinary loads include:
- acceptance loads (increase in weight caused by water collection, entry of water to extinguish fire).

Relevant regulations and documents:

- *EN 1990: 2002*
- *EN 1991-1-1: 2002*
- *EN 1991-1-3 :2002*
- *EN 1992: 2004*
- *EN 1993: 2005*
- *EN 1994: 2004*
- *EN 1995: 2008*
- *EN 1996: 2005*
- *EN 1999: 2009*
- *NTC 2018 (IT)*
- *NTA 8111_2011 - NL*
- *GC-02-E (KR)*
- *CFR-T46 -177 (USA)*

1.1.2. Mechanical resistance to dynamic actions. Ability of the structure to withstand loads that cause significant accelerations. Dynamic actions are generally represented by forces or moments that act in a variable way over time, for instance environmental loads (seismic forces, thermal variations, wind pressure) as well as machinery vibrations.

Relevant regulations and documents:

- *EN 1998: 2004*
- *EN 1991-1-4: 2002*
- *NTC 2018 (IT)*
- *NTA 8111_2011 - NL*
- *GC-02-E (KR)*

1.1.3. Structural continuity with sub-structure. Sides and main longitudinal and transverse structural elements are to be aligned with the structural lines or grid of the sub-structure. Where such arrangement in line is not possible, other effective support is to be provided. Arrangements are to be made to minimize the effect of discontinuities in erections. At the corners where the superstructure is attached to the deck of the sub-structure, attention is to be given to the arrangements to transmit load into the under deck supporting sub-structure.

Relevant regulations and documents:

- *IACS – CSR-H 2023*

1.2. Fire Safety

1.2.1. Fire detection and alarm system. Provision of an advanced automatic fire detection system; installation of automatic smoke detection devices; provision of manual call points in strategic points easy for people to reach; automatic sprinkler systems.

Relevant regulations and documents:

- *EN 1991-1-2:2004*
- *EN 54-23: 2010*
- *UNI 11744: 2019 (IT)*
- *GC-02-E-KRS*
- *Space@Sea (D7.2)*
- *BV – RCOU*
- *LR – RRCOU*
- *DNV-OS-D301*
- *ABS- RBCMOU*
- *NORSOK S–001*
- *IMO SOLAS (II-2)*
- *IMO MODU (9)*
- *IMO FSS Code*
- *EU 2020/411*
- *CDR (EU) 2020/411*

1.2.2. Structural fire resistance. Ability of the building structural components to resist the thermal actions of fire for a certain period of time; to maintain their structural integrity for a specified period of time; ability of the building to maintain its smoke and gas tightness for a certain period of time.

Relevant regulations and documents:

- *EN 1991-1-2:2004*
- *ISO 8421-2:1987*
- *BV – RCOU*
- *DNV-OS-D301*
- *ABS- RBCMOU*
- *IMO SOLAS (II-2)*
- *CDR (EU) 2020/411*

1.2.3. Fire extinguishing facilities. Presence in wharf of dry extinguishing hose; water supply and dry fire network of sufficient capacity; presence and easy access to fire extinguishers, gas fire-extinguishers, gas fire-fighting extinguisher, foam system, fire-fighter outfits; placement of fire extinguishing facilities so that no point on the floor of the floating buildings is either beyond the reach of a fully extended hose reel that is connected to the water supply and situated in or in the proximity of the floating building.

Relevant regulations and documents:

- *GC-02-E-KRS*
- *QDC MP 3.1.*
- *NTA 8111_2022-NL*
- *BV – RCOU*
- *LR – RRCOU*
- *ABS- RBCMOU*
- *NORSOK S–001*
- *IMO SOLAS (II-2)*
- *IMO FSS Code*
- *CDR (EU) 2020/411*
- *CFR-T46 -177 (USA)*

1.2.4. Non-flammable materials. Usage of non-flammable materials for interior finishes (e.g., paneling, ceilings, doors, staircases etc.); use of fire-retardant materials for soft furnishings (e.g., carpets, curtains, upholstery, mattresses etc.).

Relevant regulations and documents:

- *GC-02-E-KRS*
- *Space@Sea (D7.2)*
- *BV – RCOU*
- *IMO SOLAS (II-2)*
- *CDR (EU) 2020/411*
- *EU 2020/411*
- *CFR-T46-177 (USA)*

1.2.5. Safety platforms. Provision of safety platforms for ensuring shelter/safe places for people to flee to during fire, extreme storm conditions or sinking or platforms.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *IMO SOLAS (II-2)*
- *IMO MODU*
- *IMO FSS Code*

1.2.6. Escape routes. Design escape routes of adequate width to provide access to safety platforms, to shore, to a pontoon or wharf.

Relevant regulations and documents:

- *ISO 21542:2021*
- *NTA 8111_2022-NL*
- *LR – RRCOU*
- *CDR (EU) 2020/411*
- *CFR-T46 -177 (USA)*
- *IMO SOLAS (II-2)*

- *IMO MODU Code, Chapter 9*
- *IMO FSS Code*

1.3. User Security from External Actions

1.3.1. Collision risk reduction arrangements. Include architectural or infrastructural measures to prevent collisions, such as the construction of barriers or other structures. Subdivide the structure into different compartments (bulkheads). Avoid areas interested by vessel routes.

Relevant regulations and documents:

- *ABS - RBCMOU*
- *IMO R MSC.252 (83)*
- *IRPCS*
- *IMO COLREGs*
- *NMFS /FHWA (BMPs)*

1.3.2. Intrusion protection. Provision of systems for entrance control or locking. Provision of internal/external unbreakable laminated double (shatterproof) glazing at the ground level. Integration of alarm systems connected to perimeter sensors/cameras.

Relevant regulations and documents:

- *ISO 23234:2021*
- *CEI - EN 50131-1*
- *CEI 79-3*
- *UNI 7697 (IT)*
- *EN 12600: 2002*
- *UNI EN 356 (IT)*
- *NTA 8111_2011 – NL*
- *CFR-T46 -177 (USA)*

1.4. User Security in Use

1.4.1. Fall protection devices. If the difference in height between the pontoon floor and the water is less than 1 m, a balustrade/handrail/partition element must be installed along installed along the border to prevent users from falling into the water. For upper levels, provision of protection devices (barriers) on the perimeter of stairways, ramps and similar elements, must be (in compliance with local building codes).

Relevant regulations and documents:

- *EN 13374:2013*
- *UNI 10805:1999 (IT)*
- *UNI 10806 :1999 (IT)*
- *UNI 10807:1999 (IT)*
- *UNI 10808:1999 (IT)*
- *UNI 10809:1999 (IT)*
- *NTA 8111_2011-NL*
- *QDC MP 3.1.*
- *Space@Sea (D7.2)*
- *Directive 2013/53/EU*

- *CFR-T46 -177 (USA)*
- *CDR (EU) 2020/411*

1.4.2. Climbing/holding devices. Provision of climbing/holding devices at some strategic points on the perimeter of gangways, pontoons, wharfs, external spaces which provide access to a floating buildings, to assure that a person falling into the water is able to get out of the water independently.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *NTA 8111_2011-NL*

1.4.3. On-board safety equipment. Provision of appropriate life safety devices suitable for marine use e vests or buoys should be available at those places. Provision of a protection mechanism which prevents the person from being sucked under the platforms.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *NTA 8111_2011-NL*
- *QDC MP 3.1.*
- *CFR-T46 -177 (USA)*
- *CDR (EU) 2020/411*

1.4.4. Overtopping reduction (clearance above water). The minimum clearance above water as measured from the water line to the top of the lowest point on the floor or deck (of walking surfaces) under usual dead load conditions, must avoid risk of overtopping[1].

Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *QDC MP 3.1.*

1. *Wave overtopping is the average amount of water that is discharged per linear meter by waves over a structure whose crest is higher than the still water level (SWL).*

1.4.5. Non-slip resistance. Use of slip-resistant materials for all external horizontal surfaces (deck coverings like gangways, pontoons, wharfs, stairways, ramps) where occasional water or liquid on the floors is expected.

Relevant regulations and documents:

- *CEN EN 13845:2017*
- *EN ISO 10874:2012*
- *QDC MP 3.1.*
- *ABS - RBCMOU*

1.4.6. Smooth intersections between horizontal surfaces. Provide minimum distances between neighboring platforms and/or visual indicators of gap/junctions (material change, height variance, buffer or railing) to avoid people tripping on gaps or junctions.

Relevant regulations and documents:

- *Space@Sea (D7.2)*

1.4.7. Horizontal walkway illumination. Minimum horizontal illumination on outdoor walking surfaces; provision of emergency lighting devices.

Relevant regulations and documents:

- *EN 1838:2013*
- *NTA 8111_2011 – NL*

1. Comfort (C)

1.1 Thermal Hygrometric Comfort

2.1.1. Indoor temperature level and control. Maintain adequate range of temperature levels: (i.e. 20°C + 2°C of tolerance in winter; 26°C – 2°C of tolerance in summer). Increase thermal control of the space, by allowing control of either the conditions of a thermal zone or movement between thermal zones. Provision of direct control on indoor climate by occupants[2]. Functional layout design according to orientation and exposition. Provision of shading protection devices. Integration of heating and cooling systems.

Relevant regulations and documents:

- *ISO 7730:2005*
- *DPR 74/2013 (IT)*
- *WELL – T03*
- *WELL– T08*
- *DGNB – SOC1.1*
- *DGNB – SOC1.5*
- *9 FHB*
- *W GBC*
- *ABS- RBCMOU*
- *DNV-OS-A301*

2. Aside from the actual conditions in the building, users' satisfaction also depends on the ability to adjust ventilation, shading and glare protection, temperature and lighting to their individual preferences, beyond the standard settings. For instance, operable windows that can be opened at different elevations to provide desired air flow at different outdoor temperatures.

2.1.2. Indoor humidity level and control. Provide optimum relative humidity levels that are conducive to human health and well-being (i.e. 40-50% of relative humidity in winter, 50-60% of relative humidity in summer*). Provide operable windows that can be opened at different elevations to provide desired air flow at different outdoor temperatures.

Relevant regulations and documents:

- *ISO 7730:2005*
- *DGNB – SOC1.1*
- *WELL – T07*
- *WELL – T08*
- *9 FHB*
- *ABS- RBCMOU*

2.1.3. Ventilation control. Control air speed and ventilation rate through mechanical and/or natural means according to temperature and humidity levels (i.e. 0,01-0,1 m/s in winter, 0,1 – 9,2 m/s in summer).

Relevant regulations and documents:

- *ISO 7730:2005*
- *ISO 16814:2008*
- *EN 13779:2007*
- *EN 14134:2019*
- *EN 15251:2007*
- *CEN CR 1752:1998*
- *WELL–A03*
- *DGNB – SOC1.5*
- *ABS- RBCMOU*
- *CFR-T46 -177 (USA)*

2.2. Visual Comfort

2.2.1. Natural illumination level and control. Provide appropriate light exposure in indoor environments through lighting strategies, designing spaces to integrate daylight as much as possible; integrate solar shading devices; provide individuals with access to customizable lighting environments (occupant lighting control). Adequate lighting conditions involve luminance distribution glare control, directionality and color.

Relevant regulations and documents:

- *DGNB – SOC1.4*
- *DGNB – SOC1.5*
- *9 FHB*
- *W GBC*
- *WELL – L01*
- *WELL – L05*
- *WELL – L09*
- *ABS- RBCMOU*
- *DNV-OS-A301*

2.2.2. Artificial illumination level and control. Identifying and utilizing lighting fixtures that emit a high quality of light and do not display signs of flicker. Manage glare from electric lighting by using strategies, such as calculation of glare and choosing the appropriate light fixtures for the space.

Relevant regulations and documents:

- *DGNB – SOC1.4*
- *DGNB – SOC1.5*
- *WELL – L04*
- *WELL – L08*
- *ABS- RBCMOU*
- *DNV-OS-A301*

2.2.3. Emergency and signal lighting[3]. Provide lighting devices that turn on automatically when the normal lighting fails, to provide sufficient illumination to enable people to safely evacuate.

Relevant regulations and documents:

- *ISO 30061:2007*

3. Applied (as mandatory) only to public facility. The relevant ISO 300061:2007 is principally applicable to locations where the public or workers have access.

2.2.4. Quality views. Provides visual connection to pleasant outdoor spaces through windows.
Relevant regulations and documents:

- • *W GBC*
- • *DGNB – SOC1.4*
- • *WELL – L05*

2.3. Acoustic Comfort

2.3.1. Noise level limits. Reduce background noise levels according to the room functionality (i.e. Background noise levels in residential facilities must not exceed 35 dBA).

Relevant regulations and documents:

- *IBC-2018*
- *OSHA*
- *ICC G2-2010*
- *NBC 2015 (CA)*
- *DPCM 14/11/97 (IT)*
- *WELL – S02*
- *WELL – S06*
- *W GBC*
- *9 FHB*
- *ABS- RBCMOU*
- *DNV-OS-A301*

2.3.2. Indoor acoustic insulation/sound barriers. Ability of external partitions to provide adequate isolation (resistance to the passage of noise) from airborne noise between different building units, from external noise, from trampling noise, from continuous and discontinuous operating systems (mechanical equipment and machinery). Ability of walls and doors to meet a minimum degree of acoustical separation to provide adequate sound isolation and improve speech privacy (i.e. between circulation zones and regularly occupied spaces: 40 STC)*.

Relevant regulations and documents:

- *DPCM 14/11/97 (IT)*
- *ASTM E413-16*
- *WELL – S03*
- *EU 2020/411*
- *DGNB – SOC1.3*

2.3.3. Reverberation time control. Control of reverberation time based on room functionality (i.e. provide residential space with a maximum reverberation time of 0.7 seconds).
Relevant regulations and documents:

- *DPCM 5/12/97*

- *ASHRAE 189.1*
- *WELL – S04*
- *W GBC*
- *9 FHB*

2.3.4. Sound reducing surfaces. Use of acoustic materials that absorb and/or block sound to support concentration and reduce reverberation. Use of mechanical connections that limit joint friction.

Relevant regulations and documents:

- *WELL – S05*
- *Space@Sea (D7.2)*

2.4. Olfactory-Respiratory Comfort

2.4.1. Absence of unpleasant odors. Provide ventilation through mechanical and/or natural means to reduce CO_2 saturation of indoor air and bas smells.

Relevant regulations and documents:

- *WELL –A03*
- *DGNB – SOC1.5*
- *DGNB – SOC1.2*
- *WHO HG*
- *9 FHB*
- *CFR-T46 -177 (USA)*

2.5. Spatial Comfort

2.5.1. Minimum areas and volume. Ensure minimum surface area increased by a certain amount for each contemporary user greater than the first established by specific legislation based on the environmental-functional unit. Areas of living spaces, bedrooms, kitchens, bathrooms, and for public facilities must comply with local on land building codes.

Relevant regulations and documents:

- *D n°2002-120 (FR)*
- *RD 314/2006 (ES)*
- *Bouwbesluit 2012 (NL)*
- *DM 5 luglio 1975 (IT)*

2.5.2. Minimum height. Ensure minimum surface area increased by a certain amount for each contemporary user greater than the first established by specific legislation based on the environmental-functional unit. Floor-to-ceiling height for living spaces, for storage and distribution spaces and bathrooms, and for public facilities must comply with local on land building codes.
Relevant regulations and documents:

- *D n°2002-120 (FR)*
- *RD 314/2006 (ES)*
- *Bouwbesluit 2012 (NL)*
- *DM 5 luglio 1975 (IT)*

- *HBO - 2018 (DE)*
- *BBR -2019 (SE)*
- *CFR-T46 -177 (USA)*

2.5.3. Occupancy rate (crowding level). Avoid overcrowding/occupancy rate (maximum numbers of persons per area unit), assigning adequate living space to each occupant based on the function/activity and on the local regulations. Provide minimum volume that is increased by a total for each contemporary user higher than the first established by specific legislation based on the environmental-functional unit.

Relevant regulations and documents:

- *UN-HABITAT-2007*
- *Eurostat OR 2014*
- *DM 5/07/1075 (IT)*
- *D n°2002-120 (FR)*
- *RD 314/2006 (ES)*
- *Bouwbesluit 2012 (NL)*
- *ACI (USA)*
- *WHO HG*
- *CFR-T46 -177 (USA)*

2.6. Motion Comfort

2.6.1. Vertical acceleration control. Control acceleration limits according to the function and whether its outdoor or indoor space. For Residential/office/retail/cultural or leisure activities and streets with 0.05 < a RMS (m/s2) < 0.10 (Return period 1:1 - yr) - people do not perceive motions (i.e. typical house), with 0.10 < a RMS (m/s2) < 0.20 (Return period 1:10 - yr) – sensitive people may perceive motions, hanging objects may show motions; with 0.20 < a RMS (m/s2) < 0.40 (Return period 1:100 - yr) – motions may affect desk work, majority of people perceive motions (i.e. skyscraper in a storm, airplane cruising); with 0.40 < a RMS (m/s2) < 0.50 (Return period 1:1000 - yr) – Desk work becomes difficult, most standing people keep balance and walking is still possible, long term exposure may cause motion sickness (i.e. train/metro ride).

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *DNV GL – OS-C301*

2.6.2. Motion control. Avoid excessive swinging, lifting and tilting of the structure due to forces acting on it. Transversal accelerations (roll motions), are closely related to stability such that GM (metacentric height) values are inverse proportional to the roll period. One must find an equilibrium, not “stiff” nor “tender” as each of these extreme states gives disadvantages: one regarding safety (“tender”) and one regarding comfort (“stiff”)[5]. Avoid wave frequencies around 0.18-0.25 Hz (as motion sickness occurs more frequently).

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *Space@Sea (D7.2)*
- *DNV-OS-A301*

5. The general formula that re-lates the roll period to stability is: Troll [s]= 2πk√gGM; where: k = roll radius of gyration [m]; g = acceleration due to gravity [m/s^2]; GM = metacentric height [m].

6.3. Vibration control. Accepted vibration limits must be met according to the function. (i.e. maximum of 0.4m/s^2 for new structures and maximum of 0.8m/s^2 for existing structures)[6].

Relevant regulations and documents:

- *ISO 2631-1: 2003*
- *ISO 2631-2:2003*
- *ISO 8041:2017*
- *Directive 2002/44/EC*
- *BS 6472-1:2008*
- *SBR- B (NL)*
- *ANSI-S2.71-1983 (USA)*
- *DIN 4150-3:2016 (DE)*
- *NS 8176:2017 (NO)*
- *UNI 9614:2017 (IT)*
- *NTA 8111_2011 – NL*
- *ABS- RBCMOU*
- *DNV-OS-A301*
- *ISO 20283-2:2008*
- *ISO 20283-5:2016*

6. *Human response to the vibration of a building is a complex mix of psychological and physiological factors, including tactile, vestibular, kinaesthetic, visual and audio signals (Pizzolato, 2014). Regarding sensitivity, the threshold of human perception can vary significantly from subject to subject. Particularly sensitive people can therefore be disturbed even by vibrations of very low intensity.*

2.7. Psycho-Perceptive Comfort

2.7.1. Biophilia. Integrate nature and nature inspired design both indoors and outdoors.

Relevant regulations and documents:

- *9 FHB*
- *W GBC*

2.7.2. Behavioral engagement. Foster participation process in the design phase; Implement strategies to improve community and neighborhood engagement and participation.

Relevant regulations and documents:

- *WELL Standards -C02*
- *W GBC*

2.7.3. Active lifestyle design. Design spaces to foster active lifestyles and physical activity; provide access to a physical activity space at no cost through an on-site fitness facility, nearby facility or nearby outdoor spaces.

Relevant regulations and documents:

- *W GBC*

- *WELL– V03*
- *WELL – V08*
- *WELL– V09*

2.8. Hygienic Conditions

2.8.1. Air quality. Ensure high levels of indoor air quality through diverse strategies that include source elimination or reduction, active and passive building design and operation strategies and human behavior interventions. Meet thresholds for particulate matter; for organic gasses: Benzene, Formaldehyde, Toluene Total VOC; for inorganic gases: Carbon monoxide, Ozone; for Radon. Pollution infiltration management reducing transmission of air and pollutants from outdoors to indoors through the building envelope and entrance.

Relevant regulations and documents:

- *W GBC*
- *WELL– A01*
- *WHO HG*
- *DGNB – SOC1.2*

2.8.2. Microbe and mold control. Usage of UVGI systems and/or conduct regular inspections on components of the cooling system to reduce or eliminate growth of microbes and mold.

Relevant regulations and documents:

- *WELL– A14*
- *DGNB – SOC1.2*
- *BR2010 (UK)*

2.8.3. Drinking water quality. Provide access to drinking water that complies with health-based limits on chemical composition: meet thresholds for chemicals and for organics and pesticides.

Relevant regulations and documents:

- *WHO HG*
- *WELL– W02*
- *WELL– W04*
- *9 FHB*
- *W GBC*

2.8.4. Mosquito prevention. Avoid presence of still water where mosquitoes may lay eggs; Tightly cover water storage containers; Use mosquito prevention screens on windows and doors.

Relevant regulations and documents:

- *CDC 24/7*
- *NTA 8111-2011 -NL*

2.8.5. Dust and pest prevention and management. Interior finish materials and furnishings are designed to ease cleaning efforts and improve maintenance.

Relevant regulations and documents:

- *9 FHB*
- *ABS- RBCMOU*

3. Usability (U)

3.1 Accessibility

3.1.1. Access (reachability) **for all users.** A floating building must have adequate means of access to and from the shore appropriate to the likely number of people accommodated in the floating facility. Water means of transportation (provision of docks or small harbor) / Land means of transportation (gangway or bridges that give access to the shore; or a pontoon, float or wharf or similar structure giving permanent access to the shore. The access arrangement must be able to adapt to water fluctuations just as the floating facility. Access has to be designed to be suitable for user with any kind of physical disability.

Relevant regulations and documents:

- *ISO 21542:2021*
- *QDC MP 3.1.*

3.1.2. Circulation and accessibility for all users. Minimum width of access/escape route must allow a person on a wheelchair to easily turn around; Doors and French windows must be wide enough to allow the passage of a person on a wheelchair/pushchair; Thresholds and height differences must not affect the smooth passage of a wheelchair/pushchair; ramp slope must be easily accessible for a person on or pushing a wheelchair/pushchair.

Relevant regulations and documents:

- *DGNB – SOC 2.1*
- *ISO 21542:2021*
- *DM 236/1989 (IT)*
- *ÖNORM B 1600 (AT)*
- *ÖNORM B 1601 (AT)*
- *ÖNORM B 1602 (AT)*

3.1.3. Uniformity and illumination of walkways' surfaces. Avoid the risk of tripping over gap junctions through adequate illumination and limited distance between walkable components.

Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *ABS- RBCMOU*

3.2. Adaptability

3.2.1. Technical flexibility. Suitability to update or replace technical building components, technological devices, machinery, plumbing systems. This includes the suitability to become barrier free if necessary.

Relevant regulations and documents:

- *L. 13/1989*
- *DM 236/1989 (IT)*
- *UNI 8289:1981 (IT)*

3.2.2. Functional/spatial flexibility[7]. Design space in order to guarantee spatial or functional changes over time (daily, decades) and/or multifunctionality; design furniture that can be folded.

7. This requirement is not found in regulatory references, but several authors consider it extremely significant, thus it is included in the PBBD framework supported by literature:

Altaş, N. E., & Özsoy, A. (1998). Spatial adaptability and flexibility as parameters of user satisfaction for quality housing. Building and environment, 33(5), 315-323

Nakib, F. (2010). Toward an adaptable architecture guidelines to integrate adaptability in building. In Building a Better World: CIB World Congress.

Magdziak, M. (2019). Flexibility and adaptability of the living space to the changing needs of residents. In IOP Conference Series: Materials Science and Engineering (Vol. 471, No. 7, p. 072011). IOP Publishing.

Calcagnini, L. (2018). Flessibilità: una dimensione strategica per l'architettura. Edizioni ETS.

3.2.4. Disassembly arrangements (DfD). Facilitate the disassembly of components for easy reassembling of the structure elsewhere. This involves material quality (strength), ease and energy cost effectiveness of the process, mechanical fastenings.

Relevant regulations and documents:

- *ISO 14040:2006*
- *ISO 14044:2018*
- *NTA 8111_2011-NL*

3.2.5. Mobility[8] (towing arrangements). Towing arrangements and equipment in order to allow to transfer the structure to another location. Provision of tow-lines (if the structure is meant to be movable via water) and of a delta plate (depending on size of overall structure) of adequate mechanical strength according to the structure overall weight. Provision of towing hook and of a towing capstan.

Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *GC-02-E (KR)*
- *RB-12-E (KR)*

8. Mobility allows the structure to be reused elsewhere with the same function and avoid having to dismantle it. If a floating structure is moved to another location for maintenance or concession purposes with a new berth, the structure at the new location will in principle be tested against the new building requirements of the local construction ordinance.

3.3. Functionality

3.3.1. Furniture integration. Avoid heavy or large free standing safety in order to prevent risks related to furniture moving or falling around; provide folding furniture.
Relevant regulations and documents:

- *UNI 8289:1981 (IT)*
- *CLC SOR/2010-120 (CA)*

3.3.2. Ease of use and maneuver. Optimal height of light controls is more or less at elbow level (i.e. at 1.10m); Height of door handles between hand and elbow height (i.e. at 0.90m); height of socket switches must be placed in order to avoid risk of being in contact with water; Electrical appliances and general switchboards must located at a height easily accessible for control and maintenance (between 40-140 cm). distribution space.

Relevant regulations and documents:

- *CEI 64-8 (IT)*
- *CEI 64-50 (IT)*

4. Management (M)

4.1. Design and Construction Management[9]

4.1.1. Cost-effective and efficient processing and manufacturing. The building design should be optimized for efficient and cost-effective manufacturing. This includes using standard components and materials, minimizing design complexity, designing for modularity, using digital fabrication process that minimize waste and leftovers. Make use of EPDs (Environmental product declaration) for construction products and integrated technical systems.

Relevant regulations and documents:

- *ISO 15392:2019*
- *ISO 21930:2017*
- *UNI 10721:2012 (IT)*

4.1.2. Cost-effective and efficient transportation. Prefer usage of raw material or building components available near the construction site (if respondent to requirement 6.1.2 and 7.1.1), in order to reduce transportation costs and related emissions. Make use of EPDs (Environmental product declaration) for construction products and integrated technical systems: critical transportation features in terms of environmental impact include mode of transportation, distance traveled, type of fuel used and load factor.

Relevant regulations and documents:

- *ISO 14040:2006*
- *ISO 14025:2006*
- *ISO 21930:2017*

4.1.3. Cost-effective and efficient assembly and construction. Prefer assembly modes that are carried out in a controlled environment to reduce time, water, waste and emissions according to the site.

Relevant regulations and documents:

- *ISO 21930:2017*
- *ISO 15392:2019*
- *UNI 10721:2012 (IT)*

9. *The following set of requirements is provided by some ISO standards in general terms and objectives but no performance levels (or benchmarks) are provided. As stated by the ISO 15392:2019, it is necessary to go beyond established construction works requirements to contribute further to sustainable development.*

4.2. Operational Management

4.2.1. Ease of intervention. Provide easy systems or to guarantee intervention on the building (i.e. provide perimeter border arrangement around the floating structure for repairs or cleaning fixtures to avoid substances ending up in the water during maintenance work such as paint residues); or provide easy access to dry dock where maintenance activities can be easily carried out.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*

4.2.2. Ease of repairability/replaceability. Use modular and separate building components which can be replaced or repaired without having to change the whole part or element; use prefabricated and/or preassembled building components allow to significantly reduce construction times and thus costs.

Relevant regulations and documents:

- *ISO 14040:2006*
- *ISO/TC 59/SC 17*

4.2.3. Chemical aggressive agents resistance. *A*bility of materials and building components to endure themselves from chemical attack for a specific period of time. Usage of corrosion resistant materials for submerged and semi-submerged parts of the floating body. Usage of corrosion resistant materials for submerged and semi-submerged plumbing (or constant maintenance for materials highly prone to corrosion).

Relevant regulations and documents:

- *ISO 12944-9:2018*
- *UNI 8290-2:1983 (IT)*

4.2.4. Atmospheric agents resistance. Ability of building materials and components not to undergo disintegration and/or changes in size and appearance and/or in chemical-physical characteristics due to the formation of ice, or to the exposure to radiant energy.

Relevant regulations and documents:

- *UNI 8290-2:1983 (IT)*

4.2.5. Hygroscopicity. Aptitude of building materials and components (that are exposed to contact with water) not to undergo changes in appearance and/or morphology, size and behavior following the absorption of water or water vapor. Usage of closed cell insulation materials is advisable for elements exposed to contact with water.

Relevant regulations and documents:

- *UNI 8290-2:1983 (IT)*

4.2.6. Interstitial condensation control. Ability of the building elements and materials to avoid the formation of condensation water inside them.
Relevant regulations and documents:

- *UNI 8290-2:1983 (IT)*

4.2.7. Real-time/remote control optimization. Arrangement of real-time remote sensors for the acquisition of information about the energy consumption and relevant comfort parameters in order to adjust heating/ cooling/ ventilation/ humidity according to the specific needs with a view to reducing consumptions. Arrangement of remote sensing devices for the acquisition of information about the state of the plant system (especially underwater) in order to avoid in situ or on-site observation.

Relevant regulations and documents:

- *EN ISO 16484:2020*
- *EN ISO 50001:2018*
- *ISO 50006:2014*

4.2.8. Seasonal efficiency of heating/cooling systems. Seasonal efficiency control by tracking a system's daily operations to include temperature fluctuations and standby periods, providing data that gives a more in-depth and reliable overview of a systems energy consumption.
Relevant regulations and documents:

- *Directive 2012/27/EU*
- *Directive 2009/125/EC*

4.2.9. On-board user manual. The user of the floating structure is supplied with a manual containing the load limitations and the instructions regarding watertight doors, material maintenance program and any other site-specific information.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *Directive 2013/53/EU*

4.3. End-of-life Management

4.3.1. Disassembly arrangements (DfD)[10]**.** Facilitate the disassembly of components for easy reassembling of the structure elsewhere. This involves material quality (strength), ease and energy cost effectiveness of the process, mechanical fastenings.

Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *ISO 14040:2006*
- *ISO 14044:2018*

10. *Identical to requirement 3.2.4. Disassembly arrangements (DfD).*

4.3.2. Disposal of building components and materials. Reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, recycling, and composting materials, or by waste to energy processes. This can already be planned during the design phase

Relevant regulations and documents:

- *LEED v4*
- *BREEAM 07*

5. Integrability (I)

5.1. Integrability of Technical Elements.

5.1.1. Dimensional integrability. Aptitude to morphological and dimensional connection with contiguous elements to allow assembly of components.

Relevant regulations and documents:

- *UNI 8289:1981 (IT)*

5.2. Integration of Plant Systems

5.2.1. Plant system integration. Suitability of the facility to integrate the passage, housing and fixing of the components of the plant systems within the non-plant engineering building elements. Plant systems include electrical, hydro-sanitary, gas, heating-cooling, telecommunication systems.

Relevant regulations and documents:

- *UNI 8289:1981 (IT)*
- *GC-02-E (KR)*

6. Environmental regeneration (ER)

6.1. Use of Low-environmental Impact Building Components

6.1.1. Dry construction processes. Adopt dry stratified technology in favor of traditional wet construction systems; suitability of connections between components to be easily disconnected in order to ensure the recovery of the different components/materials and reuse elsewhere.

Relevant regulations and documents:

- *CAM (IT)*

6.1.2. Use of environmentally friendly materials. Use of materials according to a Life Cycle Assessment approach: biodegradable, renewable, durable, bio-derived, by-product derived, reusable, recycled or recyclable, CO2 absorbing materials.

Relevant regulations and documents:

- *DGNB - ENV 1.2*
- *CAM (IT)*
- *EU n. 305/2022*
- *ISO 14025:2006*

6.1.3. Toxic emission control of materials. Avoid the use of materials that could release toxic substances into the environment (air or water). Avoid usage of materials such as zinc, copper and lead for purposes that involve contact with fresh water or rainwater (as they slowly dissolve when in contact with water; avoid usage of leaching and other preservatives harmful to the environment).

Relevant regulations and documents:

- *CAM (IT)*
- *Directive 2008/105/EC*
- *Directive 2008/56/EC*
- *NTA 8111_2011 – NL*

6.1.4. Use of local materials. Prefer the use of local harvested and produced materials for building components.

Relevant regulations and documents:

- *ISO 14040:2006*
- *ISO 14044:2006*
- *CE n. 66/2010*

6.2. Ecology and Habitat Preservation and Enhancement

6.2.1. Avoid interference with protected areas. Avoid Special Protection Areas, Sites of Community Importance and Special Areas of Conservation in the marine environment.

Relevant regulations and documents:

- *Directive 92/43/EEC*
- *Directive 79/409/ECC*
- *Directive 2009/147/CE*

6.2.2. Avoid impingement/entrainment and entanglement. Ensure any in-water lines, ropes, or chains are made of materials and installed in a manner (properly spaced) to minimize the risk of entanglement; attach any cables or utility lines to structures above the water, instead of locating them in water or within the substrate; allow all fish to exit an enclosed area prior to any dewatering; properly secure turbidity control measures and design them in a manner that does not block entry to or exit from critical habitat; monitor turbidity control measures to ensure aquatic species are not entangled or trapped. Use submerged drones for monitoring.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *NMFS /FHWA (BMPs)*

6.2.3. Minimize turbidity and sedimentation disturbance. Position new structures to avoid altering natural sediment accretion rates and patterns; maintain or stabilize upstream and downstream channel and bank conditions if an existing stream crossing structure causes erosion or accretion problems; limit the amount and extent of turbidity and sedimentation by using appropriate sedimentation and turbidity controls such as silt curtains, settling basins, cofferdams; install erosion control measures prior to ground-disturbance; prevent sediment and debris from entering the water using geo-textile fabric, haybales, or other methods. Use nets, tarps, and pans when demolishing any structure or part of structure; design the dredge footprint to avoid sensitive habitats and provide appropriate buffers to protect these areas from accretion of sediment resuspended during dredging; develop a project schedule and plan prior to construction, which avoids or minimizes sediment disturbance, during sensitive life stages (migration and spawning) of local species (this may include isolating in-water work or implementing TOY restrictions. Use submerged drones for monitoring. Ensure that all water likely to

come in contact with building occupants meets thresholds for turbidity and coliforms.
Relevant regulations and documents:

- *WHO HG*
- *WELL– W01*
- *NMFS /FHWA (BMPs)*

6.2.4. Foster biodiversity. Integrate green and blue infrastructure such as green walls, green roofs, permeable surfaces, rainwater harvesting, tree planting, water phyto-treatment systems, in the building design. To ensure habitat connectivity and potentially increase the delivery of ecosystem services. Use submerged drones for monitoring biological changes.

Relevant regulations and documents:

- *CIRIA C753, 2015*
- *SuRe*
- *W GBC*
- *BREEAM SE 11*
- *DGNB - ENV 2.4*
- *DGNB - ENV 1.2*
- *COM/2021/572*

6.2.5. Avoid reduction/obstruction of incoming sunlight in water. Dimensional and morphological design of the floating building must avoid excessive shading of water through building footprint. Adequate distances[11] between buildings must be ensured reduce impact on underwater marine environment (i.e. oxygen levels). Use of submerged drones for monitoring.
Relevant regulations and documents:

- *ABS- RBCMOU*
- *NMFS /FHWA (BMPs)*

11. *The wind tunnelling effect, that can occur between buildings - increases turbulence and hence water mixing, reducing the adverse impact on dissolved oxygen levels compared to open water. There are no standards or regulations providing specific requirements, but several authors agree that it is an extremely relevant requirement:*

Penning-Rowsell, E. (2020). Floating architecture in the landscape: climate change adaptation ideas, opportunities and challenges. *Landscape Research, 45*(4), 395–411. doi: 10.1080/01426397.2019.1694881

Foka, E., Rutten, M., Boogaard, F. C., de Graaf, R. E., de Lima, R. L. P., & de Giesen, N. (2015). The effect of floating houses on water quality. In *Conference Proceedings: International Water Week.*

6.2.6. External artificial illumination control. Orient artificial lighting to avoid illumination of the surrounding waters at night. Use submerged drones for monitoring.

Relevant regulations and documents:

- *NMFS /FHWA (BMPs)*

6.2.7. Reduce underwater noise sources (hydroacoustic energy). Consider the relative impacts of blasting versus mechanical demolition and select the method that has the least acoustic impacts on the environment. Develop a detailed blast plan with minimization measures. Conduct noise-generating work in a way that minimizes acoustic effects and avoids injury (single strike and cumulative exposure) to local species and habitats. Develop a project schedule and plan prior to construction, which avoids or minimizes noise during sensitive life stages (migration and spawning) of local species. This may include implementing time of year (TOY) restrictions; conduct hydroacoustic monitoring during the

project to confirm assumptions regarding zones of injury and behavioral effects.
Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *ABS PCUNC*
- *NMFS /FHWA (BMPs)*
- *IMO MEPC.1*
- *Directive 2008/56/EC*
- *ISO 17208-1:2016*
- *ANSI/ASA S12.64*

6.2.8. Surrounding water quality preservation. Avoid dirt or rubbish falling into water from pathways, walkways or outdoor spaces; minimize the amount of new impervious surfaces; control roadway sanding and the use of deicing chemicals and avoid side casting of road materials to reduce their entry into water; remove contaminants and sediments from water discharge prior to entering aquatic habitats; treat roof and road runoff before discharging into a water body to avoid and minimize the direct input of contaminants and pollutants into aquatic areas.; place a geotextile barrier under any temporary platforms and/or access fills to completely remove any fill at the end of construction.

Relevant regulations and documents:

- *Directive 2000/60/EC*
- *Directive 91/676/EEC*
- *NMFS /FHWA (BMPs)*

6.2.9. Ecologically friendly waste disposal. Provide simple storage and direct collection; provide on-site treatment of waste before collection (i.e. composting systems, food waste digesters) towards zero-waste, up-cycling and cradle-to cradle objectives.

Relevant regulations and documents:

- *Directive 2018/851/EU*
- *Directive 2018/852/EU*
- *UNI 8289:1981 (IT)*
- *BS 5906:2005 (UK)*
- *SCS Zero Waste*
- *Space@Sea (D.7.2)*

6.2.10. Environmentally friendly water management. Avoid dirt or rubbish falling into water from pathways, walkways or outdoor spaces; minimize the amount of new impervious surfaces; control roadway sanding and the use of dicing chemicals and avoid side casting of road materials to reduce their entry into water; remove contaminants and sediments from water discharge prior to entering aquatic habitats; treat roof and road runoff before discharging into a water body to avoid and minimize the direct input of contaminants and pollutants into aquatic areas.; place a geotextile barrier under any temporary platforms and/or access fills to completely remove any fill at the end of construction.

Relevant regulations and documents:

- *Directive 2000/60/EC*
- *Directive 91/676/EEC*
- *NMFS /FHWA (BMPs)*

6.3. Landscape Preservation

6.3.1. Landscape-architecture integration. Design buildings (material, position, dimension and morphology) taking into consideration the specific landscape it is set in (i.e. waterfront relationship).

Relevant regulations and documents:

- *D. Lgs. 42/2004*
- *ETS No. 176*

6.3.2. Landscape preservation. Adopt conservation and maintenance actions to preserve the characteristics, the constitutive values, the morphologies of significant or characteristic aspects of a landscape and of its heritage value; adopt regeneration actions for the redevelopment of the compromised or degraded parts of the landscape.

Relevant regulations and documents:

- *D. Lgs. 42/2004*
- *ETS No. 176*

6.4 Decarbonization

6.4.1. CO_2 emissions reduction. Avoid energy consuming heating/cooling/ventilation/domestic hot water systems and prefer use of bioclimatic and passive design strategies.

Relevant regulations and documents:

- *Directive 2010/31/EU*
- *NZEB Standard*
- *D 26/06/2015 (IT)*
- *DGBRS (UAE)*
- *GEG(DE)*
- *CAIP (CA)*
- *CDRLA (USA)*

6.4.2. CO_2 absorption design solutions. Include green CO_2 subtraction-conversion solutions (i.e. urban greening reforestation) and grey CO_2 subtraction-conversion solutions.

Relevant regulations and documents:

- *COM/2021/572*
- *DM n. 493 2021 (IT)*

7. Environmental regeneration (ER)

7.1. Rational Use of Materials

7.1.1. Circular use of materials. Use of materials according to a Life Cycle Assessment approach: biodegradable, renewable, durable, bio-derived, by-product derived, reusable, recycled or recyclable, CO2 absorbing materials.

Relevant regulations and documents:

- *DGNB - ENV 1.2*
- *EU n. 305/2022*
- *ISO 14025:2006*
- *UNI 8289:1981 (IT)*
- *CAM (IT)*
- *NTA 8111:2011 NL*
- *Space@Sea (D.7.2)*

7.1.2. Dry construction processes. Adopt dry stratified technology in favor of traditional wet construction systems; suitability of connections between components to be easily disconnected in order to ensure the recovery of the different components/materials and reuse elsewhere.

Relevant regulations and documents:

- *CAM (IT)*

7.2. Rational Use and Management of Water Resources

7.2.1. Water collection, treatment and reuse[12]. Installation (and maintenance) of one or more water collection and treatment systems for domestic or irrigation purposes. These include rainwater harvesting, greywater recycling, blackwater treatment. Treatment methods include filtration (by using carbon filters, sediment filters, or phyto-depuration), reverse osmosis, aeration, disinfection (through chemicals or UV sanitization to kill bacteria and microorganisms). Space must be provided for storage tans and sized accordingly to the location. In case of communities or districts provided a municipal recycled water system, it is sufficient to design the plumbing such that domestic and irrigation system water demand is supplied by municipal recycled water.

Relevant regulations and documents:

- *EU 2020/741*
- *EN 16941-1:2018*
- *COM(2018) 337*
- *LEED v3 - WEc1*
- *LEED v4.1.*
- *WELL W02*
- *DGNB - ENV 2.2*
- *NMFS /FHWA (BMPs)*

12. Rainwater and graywater capture systems are subject to local codes and may require special permits. Note that the water quality should meet local standards, and consult manufacturers' recommendations to determine the compatibility of plumbing fixtures with graywater.

7.2.2. Limit water consumption[13]. Usage of water-saving taps flow restrictors, of re-circulating showers, of certified low water consumption domestic devices, of flushing control systems (push and automatic shut-off taps).

Relevant regulations and documents:

- *BREEAM 05*
- *RE 2020*
- *DGNB - ENV 2.2*

13. This performance requirement is not specifically addresses in performance-based codes and guidelines but just in certification systems.

7.3. Rational Waste Management

7.3.1. Solid waste reduction and diversion. Provide on-site treatment of solid organic waste (i.e. composting systems, anaerobic digesters, etc.); usage of bio-digest processes for toilet solid waste.

Relevant regulations and documents:

- *Directive 2018/851/EU*
- *Directive 2018/852/EU*
- *BS 5906:2005 (UK)*
- *LEED v4*
- *BREEAM 07*
- *SCS Zero Waste*
- *Space@Sea (D.7.2)*

7.3.2. Wastewater treatment optimization. Provide systems with physical, biological and chemical unit processes for evacuating supplements, inorganic salts, pathogens, coarse solids and so forth, which are truly perilous for environment and human.

Relevant regulations and documents:

- *CIRIA C753, 2015*
- *Directive 2000/60/EC*
- *Directive 91/271/EEC*
- *LEED v4.1.*
- *Space@Sea (D.7.2)*

7.3.3. Safe waste storage and disposal optimization. Provide waste storage containers located in a dedicated, non-obstructive position, easily accessible to all users, that require low maintenance and easily cleanable, enclosed to manage odor and pest issues. This will contribute to mitigate environmental contamination and associated exposure to hazards present in certain waste.

Relevant regulations and documents:

- *BREEAM 07*
- *WELL X09*
- *Space@Sea (D7.2)*

7.4. Rational Use of Environmental Energy Resources

7.4.1. Use of renewable energy resources. Use of resources in an integrated design concept to meet NZEB targets. Maximize the use of renewable energy sources (RES) such as geothermal energy, wind energy, biomass, photovoltaic and solar thermal systems.

Relevant regulations and documents:

- *CR (EU) 2016/1318*
- *Directive 2010/31/EU*
- *DM 26 giugno 2015 (IT)*
- *D. Lgs. 28/2011 (IT)*

7.4.2. Use of renewable marine energy resources in an integrated design concept to meet NZEB targets. Maximize the use of MRE, such as marine current power, osmotic power, ocean thermal energy, tidal power, and wave power. Foster the use of wave power converters (in open coastal areas with significant waves), tidal turbines placed in coastal and estuarine areas; in-stream turbines in fast-moving rivers; ocean current turbines in areas of strong marine currents; ocean thermal energy converters in deep tropical waters.

Relevant regulations and documents:

- *CR (EU) 2016/1318*
- *Directive 2010/31/EU*
- *DM 26 giugno 2015 (IT)*
- *D. Lgs. 28/2011 (IT)*

7.4.3. Use of bioclimatic passive solutions in an integrated design concept to meet NZEB targets, such as:

a. Low S/V ratio (surface/volume). Design a compact building in order to reduce the dispersant surface area (e.g., walls, ceilings, roofs, and the surface areas of windows) in relation to the enclosed volume V of the building. The larger the ratio, the higher the S/V value, the larger the thermal energy requirement of the living space/usable space, for a given set of energy efficiency measures.
b. Effectiveness of shading systems and solar transmission factor. Prefer use of external shading systems to reduce solar gains in summer. In this wat the short-wave solar energy that is absorbed by the shading system is converted into long wave energy (i.e., heat) and radiated outside the building without reaching the glazing.
c. Adequate thermal inertia and thermal transmittance (according to location) of envelope. Ensure adequate thermal insulation of the envelope according to the specific context.
d. Adequate orientation. Plan building orientation to maximise solar gain/shadow according to local climate needs.
e. Nature based solutions integration. Use of nature-based solutions (green/brown roofs, green walls, permeable surfaces, rainwater harvesting, tree planting, water phyto-treatment systems) to increase comfort and deliver services in a cost-effective way.

Relevant regulations and documents:

- *Directive 2018/844/EU*

8. Buoyancy - Stability (BS)

8.1. Buoyancy

8.1.1. Freeboard stability. A floating building must have a floatation system which maintains an acceptable level of stability appropriate to the use or likely use of the building: a minimum freeboard value (distance between the waterline and the upper deck level, measured at the lowest point of sheer) must ensure the safety and stability of the floating structure and must be calculated according to site-specific water conditions, people on-board, intended use and building design..

Relevant regulations and documents:

- *QDC MP 3.1.*

- *IMO ICLL*

8.1.2. Watertight compartmentation/subdivision. The buoyancy of the modules should be guaranteed by applying compartmentation within the structures, monitoring and warning systems in case of damage or leakage. Each compartment (bulkhead) shall be watertight.

Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *ABS - RBCMOU*
- *CDR (EU) 2020/411*

8.1.3. Watertight integrity. Use of closures or fittings that prevent the entrance of water to certain compartments. External openings whose lower edges are below the levels to which weathertight integrity is to be ensured, are to have weathertight closing appliances. A plan, identifying the disposition (open or closed) of all non-automatic closing devices and locations of all watertight and weathertight closures, is to be incorporated into the Operating User Manual.

Relevant regulations and documents:

- *DNV – OS-C301*
- *ABS - RBCMOU*
- *CDR (EU) 2020/411*

8.1.4. Sink risk prevention indicators. Indicators shall be provided for all doors and other closing appliances which, if left open or not properly secured, could lead to flooding of the facility; video surveillance or water leakage detection system shall be arranged to provide an indication of any leakage.
Relevant regulations and documents:

- *CDR (EU) 2020/411*

8.2. Stability and Trim

8.2.1. Adaptability to static load variation. Buoyancy of modules shall be, within acceptable limits, future proof regarding addition or removal of weights (i.e. additional heavy furniture, machinery).

Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *LR – RRCOU*
- *IMO ICLL*

8.3. Asset-Position

8.3.1. Mooring arrangements. Provision of connectors having the capacity and mechanical strength to hold the structure in place under reasonably expected conditions (currents, wind, waves and torsion). The number and locations for mooring connectors varies according to the specific structure and site conditions. Consider

a. Compartmentation of mooring bracket and floating bracket: in case the mooring float sinks, the mooring bracket must break before the bracket anchors to the sinking mooring float.
b. Limit noise (squeaking, rubbing, creaking) through use of appropriate materials for mooring devices and their connections.

c. Mooring systems typology must allow vertical mobility of the floating body in order to adapt to water fluctuations
   - mooring on ropes makes mobility of the floating body possible;
   - steel cables with possible springs are advisable where the water level does not fluctuate or barely fluctuates (the cables hold the structure against the dock or bank protection, often with an intermediate bearing and the springs are used to absorb movement of the structure)
   - sliding strips with cables are advisable when the structure must be moored as close to a dock as possible and must float with the water level (the sliding strips act as gliders for the structure);
   - shock-absorbing restraint (with pulled cables) is advisable with reasonable swell and floating water and can absorb the movements of the structure.

Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *GC-02-E KRS*
- *PCC – T28-FS*
- *QDC MP 3.1.*

8.3.2. Anchoring provisions and arrangements. Provision of anchors, anchor chains of adequate mechanical strength according to floating structure. The anchor providing in forward direction are linked with anchor chains and the length of holding area of chains is to be more than three shackles. The length of each chain linked anchor is to be more than the sum length of catenary part and holding part.

Relevant regulations and documents:

- *GC-02-E (KR)*
- *PCC – T28-FS*

8.3.3. Under keel clearance (min water depth under floating body)[14]. The UKC depends on measurements of tide height, bathymetry and prevailing meteorological conditions, and helps to minimize the risk of grounding. For site-specific prescriptions, one must look into the nearest harbor/ port regulations.

Relevant regulations and documents:

- *PCC – T28-FS*
- *UKC – Port of Darwin*

14. Under-Keel Clearance, or UKC, is the vertical distance between the lowest part of the ship's hull and the seabed. Maintaining a minimum UKC is essential for the safety of navigation. Static UKC is the minimum clearance available between the deepest point on a vessel at rest in still water and the bottom. Static UKC = (Charted Depth of Water + Height of Tide) – (Static Deep Draft) Dynamic factors such as squat, pitch, roll and heave effect a ship's draft and these need to be accounted for in any determination of minimum UKC (UKC – Port of Darwin).

9. Plant system (PS)

9.1. Damage Resistance

9.1.1. Maintainability-repairability. Accessibility of pipelines routes under all circumstances (e.g., search for leakage or malfunction); replaceability of parts, cleanability of all parts.

Relevant regulations and documents:
- *NTA 8111_2011-NL*

9.1.2. Human damage resistance. Mechanical resistance in case of intentional or unintentional human damage; integration of solutions to prevent damage caused by ill-intentioned people and risk of theft of water and energy.

Relevant regulations and documents:

- *NTA 8111_2011-NL*

9.1.3. Natural (biological or chemical) agents resistance. Capability to avoid performance degradation due to the presence of living organisms (animals, plants, microorganisms). Ability of materials/components to endure themselves from chemical attack for a specific period of time. Usage of corrosion resistant materials for submerged pipelines.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *UNI 8289:1981 (IT)*
- *DNV-ST-F101*

9.1.4. Pipeline watertight integrity. Capability to withstand liquid fluid penetration to avoid leakages in any direction.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*

9.1.5. Safe placing. Placing of electrical installations, overhead power drops, transformer pads, heating, air conditioning, ventilating, gas pipelines in such a way that they are in a dry environment not exposed to the water. Heavy machinery and plant equipment must avoid excessive vibration and be located accordingly to buoyancy requirements.

Relevant regulations and documents:

- *GC-02-E (KR)*
- *PCC – T28-FS*

9.1.6. Emergency electric power storage. Plan the use and installation space for built-in energy storage batteries.
Relevant regulations and documents:

- *GC-02-E (KR)*

9.2. Climate resistance

9.2.1. Thermal variation resistance of pipelines. Pipelines must be designed (technically and physically) to accommodate thermal expansion and frost without exceeding allowable stresses.

Pipelines must be installed in a manner that allows for thermal expansion and contraction due to temperature changes. Adequate positioning of pipelines containing liquids, to avoid their disintegration and/or possible changes in size and appearance due to ice formation.
Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *ISO 13628-5:2009*
- *DNV-ST-F101*

9.2.2. Adaptability of pipelines to water fluctuations. Ability of pipelines to be flexible enough to accommodate water fluctuations and withstand other environmental loads (like wave movement or tidal events).

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *ISO 13628-5:2009*
- *DNV-ST-F101*
- *API Specification 5L*

Performance-based Design-Support Framework (2.0)

Appendix A2

This document is the final version of the Performance-based Design-Support Framework (PDSF) for floating buildings.

The PDSF is a tool for evaluating the performance of floating buildings against a set of nine classes of demand: safety, wellbeing, usability, management, environmental regeneration, rational use of resources, integrability, buoyancy-stability, and plant system. The definitions of each class of demand can be found in Chapter 3.1. of the Thesis[1].

Each class of demand is further divided into subclasses of requirements, each with its set of performance-requirements. The performance-requirements can be conceived as the transposition of a demand into technical terms. For each performance requirement, a set of guidelines are provided, together with a list of relevant regulations sorted by color according to the relevant disciplinary field: grey (on land architecture and civil engineering), blue (floating architecture), red (shipping and naval engineering) and purple (offshore engineering).

The PDSF is based on the following principles:

- user-centeredness: the PDSF is designed to meet the needs of the users of floating buildings.
- life-cycle approach: the PDSF considers the performance of floating buildings over their entire life cycle, from de-sign and construction to operation and maintenance.
- adaptability: the PDSF is designed to be adaptable to the changing needs of users and the environment.
- multi-species approach and ecosystem integration: the PDSF considers the environment as a host organism (ecosystem) and the floating facilities (or cities) as grafts.

The PDSF is a valuable tool for designers, developers and policy makers to identify and prioritize the performance requirements that are most important for a particular project, evaluate the performance of a floating building against a set of predefined criteria, develop and implement design solutions that meet the performance requirements making informed decisions about the construction, operation and maintenance of the floating building.

1. If the framework were given to a designer, the definitions for each class of demand would be integrated directly into the framework.

Class of demand	Class of requirements	Requirement n°	Requirement
1. Safety	1.1. Structural stability	1.1.1.	Mechanical resistance to static actions
		1.1.2.	Mechanical resistance to dynamic actions
		1.1.3.	Structural continuity with sub-structure
	1.2. Fire safety	1.2.1.	Fire detection and alarm system
		1.2.2.	Structural fire integrity
		1.2.3.	Fire extinguishing facilities
		1.2.4.	Non-flammable materials
		1.2.5.	Safety platforms
		1.2.6.	Escape routes
	1.3. User security from external actions	1.3.1.	Collision risk reduction arrangements
		1.3.2.	Intrusion protection
	1.4. User security in use	1.4.1.	Fall protection devices
		1.4.2.	Climbing/holding devices
		1.4.3.	On-board safety equipment
		1.4.4.	Overtopping reduction (clearance above water)
		1.4.5.	Non-slip resistance
		1.4.6.	Smooth intersections between horizontal surfaces
		1.4.7.	Horizontal walkway illumination
2. Wellbeing	2.1. Thermal-hygrometric comfort	2.1.1.	Indoor temperature level and control
		2.1.2.	Indoor humidity level and control
		2.1.3.	Ventilation control
	2.2. Visual comfort	2.2.1.	Natural illumination level and control
		2.2.2.	Artificial illumination level and control
		2.2.3.	Emergency and signal lighting
		2.2.4.	Quality views
	2.3. Acoustic comfort	2.3.1.	Noise level limits
		2.3.2.	Indoor acoustic insulation/sound barriers
		2.3.3.	Reverberation time control
		2.3.4.	Sound reducing surfaces
	2.4. Olfactory-respiratory comfort	2.4.1.	Absence of unpleasant odors (ventilation control)
	2.5. Spatial comfort	2.5.1.	Minimum areas and volume
		2.5.2.	Minimum height
		2.5.3.	Occupancy rate
	2.6. Motion comfort	2.6.1.	Vertical acceleration control
		2.6.2.	Motion control
		2.6.3.	Vibration control
	2.7. Psycho-perceptive comfort	2.7.1.	Biophilia
		2.7.2.	Behavioral engagement

Class of demand	Class of requirements	Requirement n°	Requirement
	2.8. Hygienic conditions	2.8.1.	Air quality
		2.8.2.	Microbe and mold control
		2.8.3.	Drinking water quality
		2.8.4.	Pest and dangerous animal prevention
		2.8.5.	Dust prevention and management
3. Usability	3.1. Accessibility	3.1.1.	Access (reachability) for all users
		3.1.2.	Circulation and accessibility for all users
		3.1.3.	Uniformity and illumination of walkways' surfaces
	3.2. Adaptability	3.2.1.	Technical flexibility
		3.2.2.	Functional/spatial flexibility
		3.2.3.	Disassembly arrangements
		3.2.4.	Mobility (towing arrangements)
	3.3. Functionality	3.3.1.	Furniture integration
		3.3.2.	Ease of use and maneuver
4. Management	4.1. Design and construction management	4.1.1.	Cost-effective and efficient processing and manufacturing
		4.1.2.	Cost-effective and efficient transportation
		4.1.3	Cost-effective and efficient assembly and construction
	4.2. Operational management (Use an maintenance)	4.2.1.	Ease of intervention
		4.2.2.	Ease of repairability/replaceability
		4.2.3.	Biological agents resistance
		4.2.4.	Chemical aggressive agents resistance
		4.2.5.	Atmospheric agents resistance
		4.2.6.	Hygroscopicity
		4.2.7.	Interstitial condensation control
		4.2.8.	Real-time/remote control optimization
		4.2.9.	Seasonal efficiency of heating/cooling systems
		4.2.10.	On-board user manual
	4.3. End-of-life management	4.3.1.	Disassembly arrangements
		4.3.2.	Disposal of building components and materials
5. Integrability	5.1. Integrability of technical elements	5.1.1.	Dimensional integrability
	5.2. Integration of plant systems	5.2.1.	Plant system integration
6. Environmental regeneration	6.1. Low environmental impact of building components	6.1.1.	Dry construction processes
		6.1.2.	Use of certified low environmental impact materials
		6.1.3.	Toxic emission control of materials
	6.2. Ecology and habitat preservation and enhancement	6.2.1.	Avoid interference with protected areas
		6.2.2.	Avoid impingement, entrainment and entanglement of biostructure and aquatic vegetation
		6.2.3.	Minimize turbidity and sedimentation disturbance

Class of demand	Class of requirements	Requirement n°	Requirement
		6.2.4.	Foster biodiversity
		6.2.5.	Avoid unnecessary reduction/obstruction and facilitate incoming sunlight in water
		6.2.6.	Reduce light pollution and avoid underwater illumination at night
		6.2.7.	Reduce underwater noise sources (hydroacoustic energy)
	6.3. Landscape preservation	6.3.1.	Landscape-architecture integration
		6.3.2.	Landscape preservation
	6.4. Decarbonization	6.4.1.	CO2 emissions reduction
		6.4.2.	CO2 absorption design solutions
7. Rational use of resources	7.1. Rational use of materials	7.1.1.	Circular use of materials
		7.1.2.	Dry construction processes
	7.2. Rational use and management of water resources	7.2.1.	Water collection, treatment and reuse
		7.2.2.	Limited water consumption
	7.3. Rational waste management	7.3.1.	Solid waste reduction and diversion (construction phase)
		7.3.2.	Solid waste reduction and diversion (use phase)
		7.3.3.	Waste-water treatment optimization
		7.3.4.	Safe waste storage and disposal optimization
	7.4. Rational use of climate energy resources	7.4.1.	Use of renewable energy resources (REs)
		7.4.2.	Use of renewable marine energy resources (MREs)
		7.4.3.	Use of bioclimatic passive solutions
8. Buoyancy and stability	8.1. Buoyancy - flotation	8.1.1.	Freeboard
		8.1.2.	Watertight compartmentation/ subdivision
		8.1.3.	Watertight integrity
		8.1.4.	Sink risk prevention indicators
	8.2. Stability and trim	8.2.1.	Adaptability to static load variation
		8.2.2.	Adaptability to dynamic load variation (environmental agents)
	8.3. Asset - position	8.3.1.	Mooring arrangements
		8.3.2.	Anchoring provisions and arrangements
		8.3.3.	Under keel clearance
9. Plant system	9.1. Damage resistance	9.1.1.	Maintainability-repairability
		9.1.2.	Human damage resistance
		9.1.3.	Natural (biological or chemical) agents resistance
		9.1.4.	Pipeline watertight integrity
		9.1.5.	Safe placing
		9.1.6.	Emergency energy power storage
	9.2. Climate resistance	9.2.1.	Thermal variation resistance of pipelines.
		9.2.2.	Adaptability of pipelines to water fluctuations

1. Safety (S)

1.1 Structural Stability (referring to super-structure)

1.1.1. Mechanical resistance to static actions. Ability of the structure to withstand loads that do not cause significant accelerations. Static actions are generally represented by forces or moments that act in a constant or uniformly variable way over time: permanent* and variable** loads; extraordinary loads***.

*Permanent loads include at least:
- the mass of main load-bearing structure (floating body, floors, pillars, beams);
- vertical closures;
- fixed installations:
- partition walls (>0.8kN/m).

**Variable loads include at least:
- vertically acting floor loads according to Eurocode (bulk inventory and people);
- rain and snow load according to Eurocode;
- hydrostatic pressures due to the flow and the consequent anchoring forces, and hydrostatic pressures due to the action of the waves;

***Extraordinary loads include:
- acceptance loads (increase in weight caused by water collection, entry of water to extinguish fire).

Relevant regulations and documents:

- *EN 1990: 2002*
- *EN 1991-1-1: 2002*
- *EN 1991-1-3 :2002*
- *EN 1992: 2004*
- *EN 1993: 2005*
- *EN 1994: 2004*
- *EN 1995: 2008*
- *EN 1996: 2005*
- *EN 1999: 2009*
- *NTC 2018 (IT)*
- *NTA 8111_2011 - NL*
- *GC-02-E (KR)*
- *CFR-T46 -177 (USA)*

1.1.2. Mechanical resistance to dynamic actions. Ability of the structure to withstand loads that cause significant accelerations. Dynamic actions are generally represented by forces or moments that act in a variable way over time, for instance environmental loads (seismic forces, thermal variations, wind pressure) as well as machinery vibrations.

Relevant regulations and documents:

- *EN 1998: 2004*
- *EN 1991-1-4: 2002*
- *NTC 2018 (IT)*
- *NTA 8111_2011 - NL*
- *GC-02-E (KR)*

1.1.3. Structural continuity with sub-structure. Sides and main longitudinal and transverse structural elements are to be aligned with the structural lines or grid of the sub-structure. Where such arrangement in line is not possible, other effective support is to be provided. Arrangements are to be made to minimize the effect of discontinuities in erections. At the corners where the superstructure is attached to the deck of the sub-structure, attention is to be given to the arrangements to transmit load into the under deck supporting sub-structure.

Relevant regulations and documents:

- *IACS – CSR-H 2023*

1.2. Fire Safety

1.2.1. Fire detection and alarm system. Provision of an advanced automatic fire detection system; installation of automatic smoke detection devices; provision of manual call points in strategic points easy for people to reach; automatic sprinkler systems.

Relevant regulations and documents:

- *EN 1991-1-2:2004*
- *EN 54-23: 2010*
- *UNI 11744: 2019 (IT)*
- *GC-02-E-KRS*
- *Space@Sea (D7.2)*
- *BV – RCOU*
- *LR – RRCOU*
- *DNV-OS-D301*
- *ABS- RBCMOU*
- *NORSOK S–001*
- *IMO SOLAS (II-2)*
- *IMO MODU (9)*
- *IMO FSS Code*
- *EU 2020/411*
- *CDR (EU) 2020/411*

1.2.2. Structural fire resistance. Ability of the building structural components to resist the thermal actions of fire for a certain period of time; to maintain their structural integrity for a specified period of time; ability of the building to maintain its smoke and gas tightness for a certain period of time.

Relevant regulations and documents:

- *EN 1991-1-2:2004*
- *ISO 8421-2:1987*
- *BV – RCOU*
- *DNV-OS-D301*
- *ABS- RBCMOU*
- *IMO SOLAS (II-2)*
- *CDR (EU) 2020/411*

1.2.3. Fire extinguishing facilities. Presence in wharf of dry extinguishing hose; water supply and dry fire network of sufficient capacity; presence and easy access to fire extinguishers, gas fire-extinguishers, gas fire-fighting extinguisher, foam system, fire-fighter outfits; placement of fire extinguishing facilities so that no point on the floor of the floating buildings is either beyond the reach of a fully extended hose reel that is connected to the water supply and situated in or in the proximity of the floating building.

Relevant regulations and documents:

- *GC-02-E-KRS*
- *QDC MP 3.1.*
- *NTA 8111_2022-NL*
- *BV – RCOU*
- *LR – RRCOU*
- *ABS- RBCMOU*
- *NORSOK S–001*
- *IMO SOLAS (II-2)*
- *IMO FSS Code*
- *CDR (EU) 2020/411*
- *CFR-T46 -177 (USA)*

1.2.4. Non-flammable materials. Usage of non-flammable materials for interior finishes (e.g., paneling, ceilings, doors, staircases etc.); use of fire-retardant materials for soft furnishings (e.g., carpets, curtains, upholstery, mattresses etc.).

Relevant regulations and documents:

- *GC-02-E-KRS*
- *Space@Sea (D7.2)*
- *BV – RCOU*
- *IMO SOLAS (II-2)*
- *CDR (EU) 2020/411*
- *EU 2020/411*
- *CFR-T46-177 (USA)*

1.2.5. Safety platforms. Provision of safety platforms for ensuring shelter/safe places for people to flee to during fire, extreme storm conditions or sinking or platforms.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *IMO SOLAS (II-2)*
- *IMO MODU*
- *IMO FSS Code*

1.2.6. Escape routes. Design escape routes of adequate width to provide access to safety platforms, to shore, to a pontoon or wharf.

Relevant regulations and documents:

- *ISO 21542:2021*
- *NTA 8111_2022-NL*
- *LR – RRCOU*
- *CDR (EU) 2020/411*

- *CFR-T46 -177 (USA)*
- *IMO SOLAS (II-2)*
- *IMO MODU Code, Chapter 9*
- *IMO FSS Code*

1.3. User Security from External Actions

1.3.1. Collision risk reduction arrangements. Include architectural or infrastructural measures to prevent collisions, such as the construction of barriers or other structures. Subdivide the structure into different compartments (bulkheads). Avoid areas interested by vessel routes.

Relevant regulations and documents:

- *ABS - RBCMOU*
- *IMO R MSC.252 (83)*
- *IRPCS*
- *IMO COLREGs*
- *NMFS /FHWA (BMPs)*

1.3.2. Intrusion protection. Provision of systems for entrance control or locking. Provision of internal/external unbreakable laminated double (shatterproof) glazing at the ground level. Integration of alarm systems connected to perimeter sensors/cameras.

Relevant regulations and documents:

- *ISO 23234:2021*
- *CEI - EN 50131-1*
- *CEI 79-3*
- *UNI 7697 (IT)*
- *EN 12600: 2002*
- *UNI EN 356 (IT)*
- *NTA 8111_2011 – NL*
- *CFR-T46 -177 (USA)*

1.4. User Security in Use

1.4.1. Fall protection devices. If the difference in height between the pontoon floor and the water is less than 1 m, a balustrade/handrail/partition element must be installed along installed along the border to prevent users from falling into the water. For upper levels, provision of protection devices (barriers) on the perimeter of stairways, ramps and similar elements, must be (in compliance with local building codes).

Relevant regulations and documents:

- *EN 13374:2013*
- *UNI 10805:1999 (IT)*
- *UNI 10806 :1999 (IT)*
- *UNI 10807:1999 (IT)*
- *UNI 10808:1999 (IT)*
- *UNI 10809:1999 (IT)*
- *NTA 8111_2011-NL*

- *QDC MP 3.1.*
- *Space@Sea (D7.2)*
- *Directive 2013/53/EU*
- *CFR-T46 -177 (USA)*
- *CDR (EU) 2020/411*

1.4.2. Climbing/holding devices. Provision of climbing/holding devices at some strategic points on the perimeter of gangways, pontoons, wharfs, external spaces which provide access to a floating buildings, to assure that a person falling into the water is able to get out of the water independently.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *NTA 8111_2011-NL*

1.4.3. On-board safety equipment. Provision of appropriate life safety devices suitable for marine use e vests or buoys should be available at those places. Provision of a protection mechanism which prevents the person from being sucked under the platforms.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *NTA 8111_2011-NL*
- *QDC MP 3.1.*
- *CFR-T46 -177 (USA)*
- *CDR (EU) 2020/411*

1.4.4. Overtopping reduction (clearance above water). The minimum clearance above water as measured from the water line to the top of the lowest point on the floor or deck (of walking surfaces) under usual dead load conditions, must avoid risk of overtopping[1].

Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *QDC MP 3.1.*

1. Wave overtopping is the average amount of water that is discharged per linear meter by waves over a structure whose crest is higher than the still water level (SWL).

1.4.5. Non-slip resistance. Use of slip-resistant materials for all external horizontal surfaces (deck coverings like gangways, pontoons, wharfs, stairways, ramps) where occasional water or liquid on the floors is expected.

Relevant regulations and documents:

- *CEN EN 13845:2017*
- *EN ISO 10874:2012*
- *QDC MP 3.1.*
- *ABS - RBCMOU*

1.4.6. Smooth intersections between horizontal surfaces. Provide minimum distances between neighboring platforms and/or visual indicators of gap/junctions (material change, height variance, buffer or railing) to avoid people tripping on gaps or junctions.

Relevant regulations and documents:

- *Space@Sea (D7.2)*

1.4.7. Horizontal walkway illumination. Minimum horizontal illumination on outdoor walking surfaces; provision of emergency lighting devices.

Relevant regulations and documents:

- *EN 1838:2013*
- *NTA 8111_2011 – NL*

1. Wellbeing (W)

1.1 Thermal Hygrometric Comfort

2.1.1. Indoor temperature level and control. Maintain adequate range of temperature levels: (i.e. 20°C + 2°C of tolerance in winter; 26°C – 2°C of tolerance in summer). Increase thermal control of the space, by allowing control of either the conditions of a thermal zone or movement between thermal zones. Provision of direct control on indoor climate by occupants[2]. Functional layout design according to orientation and exposition. Provision of shading protection devices. Integration of heating and cooling systems.

Relevant regulations and documents:

- *ISO 7730:2005*
- *DPR 74/2013 (IT)*
- *WELL – T03*
- *WELL– T08*
- *DGNB – SOC1.1*
- *DGNB – SOC1.5*
- *9 FHB*
- *W GBC*
- *ABS- RBCMOU*
- *DNV-OS-A301*

2. Aside from the actual conditions in the building, users' satisfaction also depends on the ability to adjust ventilation, shading and glare protection, temperature and lighting to their individual preferences, beyond the standard settings. For instance, operable windows that can be opened at different elevations to provide desired air flow at different outdoor temperatures.

2.1.2. Indoor humidity level and control. Provide optimum relative humidity levels that are conducive to human health and wellbeing (i.e. 40-50% of relative humidity in winter, 50-60% of relative humidity in summer*). Provide operable windows that can be opened at different elevations to provide desired air flow at different outdoor temperatures.

Relevant regulations and documents:

- *ISO 7730:2005*
- *DGNB – SOC1.1*

- *WELL – T07*
- *WELL – T08*
- *9 FHB*
- *ABS- RBCMOU*

2.1.3. Ventilation control. Control air speed and ventilation rate through mechanical and/or natural means according to temperature and humidity levels (i.e. 0,01-0,1 m/s in winter, 0,1 – 9,2 m/s in summer).

Relevant regulations and documents:

- *ISO 7730:2005*
- *ISO 16814:2008*
- *EN 13779:2007*
- *EN 14134:2019*
- *EN 15251:2007*
- *CEN CR 1752:1998*
- *WELL–A03*
- *DGNB – SOC1.5*
- *ABS- RBCMOU*
- *CFR-T46 -177 (USA)*

2.2. Visual Comfort

2.2.1. Natural illumination level and control. Provide appropriate light exposure in indoor environments through lighting strategies, designing spaces to integrate daylight as much as possible; integrate solar shading devices; provide individuals with access to customizable lighting environments (occupant lighting control). Adequate lighting conditions involve luminance distribution glare control, directionality and colour.

Relevant regulations and documents:

- *DGNB – SOC1.4*
- *DGNB – SOC1.5*
- *9 FHB*
- *W GBC*
- *WELL – L01*
- *WELL – L05*
- *WELL – L09*
- *ABS- RBCMOU*
- *DNV-OS-A301*

2.2.2. Artificial illumination level and control. Identifying and utilizing lighting fixtures that emit a high quality of light and do not display signs of flicker. Manage glare from electric lighting by using strategies, such as calculation of glare and choosing the appropriate light fixtures for the space.

Relevant regulations and documents:

- *DGNB – SOC1.4*
- *DGNB – SOC1.5*
- *WELL – L04*
- *WELL – L08*

- *ABS- RBCMOU*
- *DNV-OS-A301*

2.2.3. Emergency and signal lighting[3]. Provide lighting devices that turn on automatically when the normal lighting fails, to provide sufficient illumination to enable people to safely evacuate.

Relevant regulations and documents:

- *ISO 30061:2007*

3. Applied (as mandatory) only to public facility. The relevant ISO 300061:2007 is principally applicable to locations where the public or workers have access.

2.2.4. Quality views. Provides visual connection to pleasant outdoor spaces through windows.

Relevant regulations and documents:

- *W GBC*
- *DGNB – SOC1.4*
- *WELL – L05*

2.3. Acoustic Comfort

2.3.1. Noise level limits. Reduce background noise levels according to the room functionality (i.e. Background noise levels in residential facilities must not exceed 35 dBA).

Relevant regulations and documents:

- *IBC-2018*
- *OSHA*
- *ICC G2-2010*
- *NBC 2015 (CA)*
- *DPCM 14/11/97 (IT)*
- *WELL – S02*
- *WELL – S06*
- *W GBC*
- *9 FHB*
- *ABS- RBCMOU*
- *DNV-OS-A301*

2.3.2. Indoor acoustic insulation/sound barriers. Ability of external partitions to provide adequate isolation (resistance to the passage of noise) from airborne noise between different building units, from external noise, from trampling noise, from continuous and discontinuous operating systems (mechanical equipment and machinery). Ability of walls and doors to meet a minimum degree of acoustical separation to provide adequate sound isolation and improve speech privacy (i.e. between circulation zones and regularly occupied spaces: 40 STC)*.

Relevant regulations and documents:

- *DPCM 14/11/97 (IT)*
- *ASTM E413-16*
- *WELL – S03*
- *EU 2020/411*

- *DGNB – SOC1.3*

2.3.3. Reverberation time control. Control of reverberation time based on room functionality (i.e. provide residential space with a maximum reverberation time of 0.7 seconds).

Relevant regulations and documents:

- *DPCM 5/12/97*
- *ASHRAE 189.1*
- *WELL – S04*
- *W GBC*
- *9 FHB*

2.3.4. Sound reducing surfaces. Use of acoustic materials that absorb and/or block sound to support concentration and reduce reverberation. Use of mechanical connections that limit joint friction.

Relevant regulations and documents:

- *WELL – S05*
- *Space@Sea (D7.2)*

2.4. Olfactory-Respiratory Comfort

2.4.1. Absence of unpleasant odors. Provide ventilation through mechanical and/or natural means to reduce CO_2 saturation of indoor air and bas smells.

Relevant regulations and documents:

- *WELL –A03*
- *DGNB – SOC1.5*
- *DGNB – SOC1.2*
- *WHO HG*
- *9 FHB*
- *CFR-T46 -177 (USA)*

2.5. Spatial Comfort

2.5.1. Minimum areas and volume. Ensure minimum surface area increased by a certain amount for each contemporary user greater than the first established by specific legislation based on the environmental-functional unit. Areas of living spaces, bedrooms, kitchens, bathrooms, and for public facilities must comply with local on land building codes.

Relevant regulations and documents:

- *D n°2002-120 (FR)*
- *RD 314/2006 (ES)*
- *Bouwbesluit 2012 (NL)*
- *DM 5 luglio 1975 (IT)*

2.5.2. Minimum height. Ensure minimum surface area increased by a certain amount for each contemporary user greater than the first established by specific legislation based on the environmental-

functional unit. Floor-to-ceiling height for living spaces, for storage and distribution spaces and bathrooms, and for public facilities must comply with local on land building codes.
Relevant regulations and documents:

- *D n°2002-120 (FR)*
- *RD 314/2006 (ES)*
- *Bouwbesluit 2012 (NL)*
- *DM 5 luglio 1975 (IT)*
- *HBO - 2018 (DE)*
- *BBR -2019 (SE)*
- *CFR-T46 -177 (USA)*

2.5.3. Occupancy rate (crowding level). Avoid overcrowding/occupancy rate (maximum numbers of persons per area unit), assigning adequate living space to each occupant based on the function/activity and on the local regulations. Provide minimum volume that is increased by a total for each contemporary user higher than the first established by specific legislation based on the environmental-functional unit.

Relevant regulations and documents:

- *UN-HABITAT-2007*
- *Eurostat OR 2014*
- *DM 5/07/1075 (IT)*
- *D n°2002-120 (FR)*
- *RD 314/2006 (ES)*
- *Bouwbesluit 2012 (NL)*
- *ACI (USA)*
- *WHO HG*
- *CFR-T46 -177 (USA)*

2.6. Motion Comfort

2.6.1. Vertical acceleration control. Control acceleration limits according to the function and whether its outdoor or indoor space. For Residential/office/retail/cultural or leisure activities and streets with 0.05 < a RMS (m/s2) < 0.10 (Return period 1:1 - yr) - people do not perceive motions (i.e. typical house), with 0.10 < a RMS (m/s2) < 0.20 (Return period 1:10 - yr) – sensitive people may perceive motions, hanging objects may show motions; with 0.20 < a RMS (m/s2) < 0.40 (Return period 1:100 - yr) – motions may affect desk work, majority of people perceive motions (i.e. skyscraper in a storm, airplane cruising); with 0.40 < a RMS (m/s2) < 0.50 (Return period 1:1000 - yr) – Desk work becomes difficult, most standing people keep balance and walking is still possible, long term exposure may cause motion sickness (i.e. train/metro ride).

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *DNV GL – OS-C301*

2.6.2. Motion control. Avoid excessive swinging, lifting and tilting of the structure due to forces acting on it. Transversal accelerations (roll motions), are closely related to stability such that GM (metacentric height) values are inverse proportional to the roll period. One must find an equilibrium, not “stiff” nor “tender” as each of these extreme states gives disadvantages: one regarding safety (“tender”) and one regarding comfort (“stiff”)[5]. Avoid wave frequencies around 0.18-0.25 Hz (as motion sickness occurs

more frequently).
Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *Space@Sea (D7.2)*
- *DNV-OS-A301*

5. The general formula that re-lates the roll period to stability is: Troll [s]= $2\pi k\sqrt{gGM}$; where: k = roll radius of gyration [m]; g = acceleration due to gravity [m/s^2]; GM = metacentric height [m].

6.3. Vibration control. Accepted vibration limits must be met according to the function. (i.e. maximum of $0.4 m/s^2$ for new structures and maximum of $0.8 m/s^2$ for existing structures)[6].

Relevant regulations and documents:

- *ISO 2631-1: 2003*
- *ISO 2631-2:2003*
- *ISO 8041:2017*
- *Directive 2002/44/EC*
- *BS 6472-1:2008*
- *SBR- B (NL)*
- *ANSI-S2.71-1983 (USA)*
- *DIN 4150-3:2016 (DE)*
- *NS 8176:2017 (NO)*
- *UNI 9614:2017 (IT)*
- *NTA 8111_2011 – NL*
- *ABS- RBCMOU*
- *DNV-OS-A301*
- *ISO 20283-2:2008*
- *ISO 20283-5:2016*

6. Human response to the vibration of a building is a complex mix of psychological and physiological factors, including tactile, vestibular, kinaesthetic, visual and audio signals (Pizzolato, 2014). Regarding sensitivity, the threshold of human perception can vary significantly from subject to subject. Particularly sensitive people can therefore be disturbed even by vibrations of very low intensity.

2.7. Psycho-Perceptive Comfort

2.7.1. Biophilia. Integrate nature and nature inspired design both indoors and outdoors.

Relevant regulations and documents:

- *9 FHB*
- *W GBC*

2.7.2. Behavioral engagement. Foster participation process in the design phase; Implement strategies to improve community and neighborhood engagement and participation.

Relevant regulations and documents:

- *WELL Standards -C02*
- *W GBC*

2.7.3. Active lifestyle design. Design spaces to foster active lifestyles and physical activity; provide access to a physical activity space at no cost through an on-site fitness facility, nearby facility or nearby outdoor spaces.

Relevant regulations and documents:

- *W GBC*
- *WELL– V03*
- *WELL – V08*
- *WELL– V09*

2.8. Hygienic Conditions

2.8.1. Air quality. Ensure high levels of indoor air quality through diverse strategies that include source elimination or reduction, active and passive building design and operation strategies and human behaviour interventions. Meet thresholds for particulate matter; for organic gasses: Benzene, Formaldehyde, Toluene Total VOC; for inorganic gases: Carbon monoxide, Ozone; for Radon. Pollution infiltration management reducing transmission of air and pollutants from outdoors to indoors through the building envelope and entrance.

Relevant regulations and documents:

- *W GBC*
- *WELL– A01*
- *WHO HG*
- *DGNB – SOC1.2*

2.8.2. Microbe and mold control. Usage of UVGI systems and/or conduct regular inspections on components of the cooling system to reduce or eliminate growth of microbes and mold.

Relevant regulations and documents:

- *WELL– A14*
- *DGNB – SOC1.2*
- *BR2010 (UK)*

2.8.3. Drinking water quality. Provide access to drinking water that complies with health-based limits on chemical composition: meet thresholds for chemicals and for organics and pesticides.

Relevant regulations and documents:

- *WHO HG*
- *WELL– W02*
- *WELL– W04*
- *9 FHB*
- *W GBC*

2.8.4. Pest and dangerous animal prevention. Avoid presence of still water where mosquitoes, fleas, ticks (and any other local insect) may lay eggs; Tightly cover water storage containers; Use pest and undesired insect prevention screens on windows and doors.

Relevant regulations and documents:

- *CDC 24/7*
- *NTA 8111-2011 -NL*

2.8.5. Dust prevention and management. Interior finish materials and furnishings are designed to ease cleaning efforts and improve maintenance. Ensure effectiveness of air filters.

Relevant regulations and documents:

- *9 FHB*
- *ABS- RBCMOU*

3. Usability (U)

3.1 Accessibility

3.1.1. Access (reachability) **for all users.** A floating building must have adequate means of access to and from the shore appropriate to the likely number of people accommodated in the floating facility. Water means of transportation (provision of docks or small harbor) / Land means of transportation (gangway or bridges that give access to the shore; or a pontoon, float or wharf or similar structure giving permanent access to the shore. The access arrangement must be able to adapt to water fluctuations just as the floating facility. Access has to be designed to be suitable for user with any kind of physical disability.

Relevant regulations and documents:

- *ISO 21542:2021*
- *QDC MP 3.1.*

3.1.2. Circulation and accessibility for all users. Minimum width of access/escape route must allow a person on a wheelchair to easily turn around; doors and French windows must be wide enough to allow the passage of a person on a wheelchair/pushchair; Thresholds and height differences must not affect the smooth passage of a wheelchair/pushchair; ramp slope must be easily accessible for a person on or pushing a wheelchair/pushchair.

Relevant regulations and documents:

- *DGNB – SOC 2.1*
- *ISO 21542:2021*
- *DM 236/1989 (IT)*
- *ÖNORM B 1600 (AT)*
- *ÖNORM B 1601 (AT)*
- *ÖNORM B 1602 (AT)*

3.1.3. Uniformity and illumination of walkways' surfaces. Avoid the risk of tripping over gap junctions through adequate illumination and limited distance between walkable components.

Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *ABS- RBCMOU*

3.2. Adaptability

3.2.1. Technical flexibility. Suitability to update or replace technical building components, technological devices, machinery, plumbing systems. This includes the suitability to become barrier free if necessary.

Relevant regulations and documents:

- *L. 13/1989*
- *DM 236/1989 (IT)*
- *UNI 8289:1981 (IT)*

3.2.2. Functional/spatial flexibility[7]. Design space in order to guarantee spatial or functional changes over time (daily, decades) and/or multifunctionality; design furniture that can be folded.

7. This requirement is not found in regulatory references, but several authors consider it extremely significant, thus it is included in the PBBD framework supported by literature:

Altaş, N. E., & Özsoy, A. (1998). Spatial adaptability and flexibility as parameters of user satisfaction for quality housing. Building and environment, 33(5), 315-323

Nakib, F. (2010). Toward an adaptable architecture guidelines to integrate adaptability in building. In Building a Better World: CIB World Congress.

Magdziak, M. (2019). Flexibility and adaptability of the living space to the changing needs of residents. In IOP Conference Series: Materials Science and Engineering (Vol. 471, No. 7, p. 072011). IOP Publishing.

Calcagnini, L. (2018). Flessibilità: una dimensione strategica per l'architettura. Edizioni ETS.

3.2.4. Disassembly arrangements (DfD). Facilitate the disassembly of components for easy reassembling of the structure elsewhere. This involves material quality (strength), ease and energy cost effectiveness of the process, mechanical fastenings.

Relevant regulations and documents:

- *ISO 14040:2006*
- *ISO 14044:2018*
- *NTA 8111_2011-NL*

3.2.5. Mobility[8] (towing arrangements). Towing arrangements and equipment in order to allow to transfer the structure to another location. Provision of tow-lines (if the structure is meant to be movable via water) and of a delta plate (depending on size of overall structure) of adequate mechanical strength according to the structure overall weight. Provision of towing hook and of a towing capstan.

Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *GC-02-E (KR)*
- *RB-12-E (KR)*

8. Mobility allows the structure to be reused elsewhere with the same function and avoid having to dismantle it. If a floating structure is moved to another location for maintenance or concession purposes with a new berth, the structure at the new location will in principle be tested against the new building requirements of the local construction ordinance.

3.3. Functionality

3.3.1. Furniture integration. Avoid heavy or large free standing safety in order to prevent risks related to furniture moving or falling around; provide folding furniture.

Relevant regulations and documents:

- *UNI 8289:1981 (IT)*
- *CLC SOR/2010-120 (CA)*

3.3.2. Ease of use and maneuver. Optimal height of light controls is more or less at elbow level (i.e. at 1.10m); Height of door handles between hand and elbow height (i.e. at 0.90m); height of socket switches must be placed in order to avoid risk of being in contact with water; Electrical appliances and general switchboards must located at a height easily accessible for control and maintenance (between 40-140 cm). distribution space.

Relevant regulations and documents:

- *CEI 64-8 (IT)*
- *CEI 64-50 (IT)*

4. Management (M)

4.1. Design and Construction Management[9]

4.1.1. Cost-effective and efficient processing and manufacturing. The building design should be optimized for efficient and cost-effective manufacturing. This includes using standard components and materials, minimizing design complexity, designing for modularity, using digital fabrication process that minimize waste and leftovers. Make use of EPDs (Environmental product declaration) for construction products and integrated technical systems.

Relevant regulations and documents:

- *ISO 15392:2019*
- *ISO 21930:2017*
- *UNI 10721:2012 (IT)*

4.1.2. Cost-effective and efficient transportation. Prefer usage of raw material or building components available near the construction site (if respondent to requirement 6.1.2 and 7.1.1), in order to reduce transportation costs and related emissions. Make use of EPDs (Environmental product declaration) for construction products and integrated technical systems: critical transportation features in terms of environmental impact include mode of transportation, distance traveled, type of fuel used and load factor.

Relevant regulations and documents:

- *ISO 14040:2006*
- *ISO 14025:2006*
- *ISO 21930:2017*

4.1.3. Cost-effective and efficient assembly and construction. Prefer assembly modes that are carried out in a controlled environment to reduce time, water, waste and emissions according to the site.

Relevant regulations and documents:

- *ISO 21930:2017*
- *ISO 15392:2019*
- *UNI 10721:2012 (IT)*

9. *The following set of requirements is provided by some ISO standards in general terms and objectives but no performance levels (or benchmarks) are provided. As stated by the ISO 15392:2019, it is necessary to go beyond established construction works requirements to contribute further to sustainable development.*

4.2. Operational Management

4.2.1. Ease of intervention. Provide easy systems or to guarantee intervention on the building (i.e. provide perimeter border arrangement around the floating structure for repairs or cleaning fixtures to avoid substances ending up in the water during maintenance work such as paint residues); or provide easy access to dry dock where maintenance activities can be easily carried out.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*

4.2.2. Ease of repairability/replaceability. Use modular and separate building components which can be replaced or repaired without having to change the whole part or element; use prefabricated and/or preassembled building components allow to significantly reduce construction times and thus costs.

Relevant regulations and documents:

- *ISO 14040:2006*
- *ISO/TC 59/SC 17*

4.2.3. Biological agents resistance. Prevention of algae formation and parasites of the submerged parts (structure, pipelines, etc.) either thanks to intrinsic properties or through ecological coatings.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *UNI 8289:1981 (IT)*

4.2.4. Chemical aggressive agents resistance. Ability of materials and building components to endure themselves from chemical attack for a specific period of time. Usage of corrosion resistant materials for submerged and semi-submerged parts of the floating body. Usage of corrosion resistant materials for submerged and semi-submerged plumbing (or constant maintenance for materials highly prone to corrosion).

Relevant regulations and documents:

- *ISO 12944-9:2018*
- *UNI 8290-2:1983 (IT)*

4.2.5. Atmospheric agents resistance. Ability of building materials and components not to undergo disintegration and/or changes in size and appearance and/or in chemical-physical characteristics due to the formation of ice, or to the exposure to radiant energy.

Relevant regulations and documents:

- *UNI 8290-2:1983 (IT)*

4.2.6. Hygroscopicity. Aptitude of building materials and components (that are exposed to contact with water) not to undergo changes in appearance and/or morphology, size and behavior following the absorption of water or water vapor. Usage of closed cell insulation materials is advisable for elements exposed to contact with water.

Relevant regulations and documents:

- *UNI 8290-2:1983 (IT)*

4.2.7. Interstitial condensation control. Ability of the building elements and materials to avoid the formation of condensation water inside them.

Relevant regulations and documents:

- *UNI 8290-2:1983 (IT)*

4.2.8. Real-time/remote control optimization. Arrangement of real-time remote sensors for the acquisition of information about the energy consumption and relevant comfort parameters in order to adjust heating/ cooling/ ventilation/ humidity according to the specific needs with a view to reducing consumptions. Arrangement of remote sensing devices for the acquisition of information about the state of the plant system (especially underwater) in order to avoid in situ or on-site observation.

Relevant regulations and documents:

- *EN ISO 16484:2020*
- *EN ISO 50001:2018*
- *ISO 50006:2014*

4.2.9. Seasonal efficiency of heating/cooling systems. Seasonal efficiency control by tracking a system's daily operations to include temperature fluctuations and standby periods, providing data that gives a more in-depth and reliable overview of a systems energy consumption.

Relevant regulations and documents:

- *Directive 2012/27/EU*
- *Directive 2009/125/EC*

4.2.10. On-board user manual. The user manual should provide clear instructions on how to operate the floating building safely and efficiently, how to maintain the floating building properly and how to respond to emergencies. It should also provide detailed information on the floating building's systems and equipment, on maximum occupancy and load limitations, and any other site-specific information.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *Directive 2013/53/EU*

4.3. End-of-life Management

4.3.1. Disassembly arrangements (DfD)[10]**.** Facilitate the disassembly of components for easy reassembling of the structure elsewhere. This involves material quality (strength), ease and energy cost effectiveness of the process, mechanical fastenings.
Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *ISO 14040:2006*
- *ISO 14044:2018*

10. *Identical to requirement 3.2.4. Disassembly arrangements (DfD).*

4.3.2. Disposal of building components and materials. Reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, recycling, and composting materials, or by waste to energy processes. This can already be planned during the design phase

Relevant regulations and documents:

- *LEED v4*
- *BREEAM 07*

5. Integrability (I)

5.1. Integrability of Technical Elements.

5.1.1. Dimensional integrability. Aptitude to morphological and dimensional connection with contiguous elements to allow assembly of components.

Relevant regulations and documents:

- *UNI 8289:1981 (IT)*

5.2. Integration of Plant Systems

5.2.1. Plant system integration. Suitability of the facility to integrate the passage, housing and fixing of the components of the plant systems within the non-plant engineering building elements. Plant systems include electrical, hydro-sanitary, gas, heating-cooling, telecommunication systems.

Relevant regulations and documents:

- *UNI 8289:1981 (IT)*
- *GC-02-E (KR)*

6. Environmental regeneration (ER)

6.1. Use of Low-environmental Impact Building Components

6.1.1. Dry construction processes. Adopt dry stratified technology in favor of traditional wet construction systems; suitability of connections between components to be easily disconnected in order to ensure the recovery of the different components/materials and reuse elsewhere.

Relevant regulations and documents:

- *CAM (IT)*

6.1.2. Use of certified low-environmental impact materials. Use of materials, the harvesting, manufacturing and disposal of which minimizes CO2, GHG emissions, water and energy consumption. Examples include biodegradable, bio-derived, by-product derived materials, as well as carbon capture materials or materials that require low water and energy consumption manufacturing processes and/or with limited leftover waste. Low environmental impact may also refer to locally sourced materials, if their extraction avoids long distance transportation and if they do not represent a rare local natural resource that should avoid being exploited.

Relevant regulations and documents:

- *DGNB - ENV 1.2*
- *CAM (IT)*
- *EU n. 305/2022*
- *ISO 14025:2006*
- *ISO 14040:2006*
- *ISO 14044:2006*
- *CE n. 66/2010*

6.1.3. Toxic emission control of materials. Avoid the use of materials that could release toxic substances into the environment (air or water). Avoid usage of materials such as zinc, copper and lead for purposes that involve contact with fresh water or rainwater (as they slowly dissolve when in contact with water; avoid usage of leaching and other preservatives harmful to the environment).

Relevant regulations and documents:

- *CAM (IT)*
- *Directive 2008/105/EC*
- *Directive 2008/56/EC*
- *NTA 8111_2011 – NL*

6.2. Ecology and Habitat Preservation and Enhancement

6.2.1. Avoid interference with protected areas. Avoid Special Protection Areas, Sites of Community Importance and Special Areas of Conservation in the marine environment.

Relevant regulations and documents:

- *Directive 92/43/EEC*
- *Directive 79/409/ECC*
- *Directive 2009/147/CE*

6.2.2. Avoid impingement, entrainment and entanglement of biostructure and aquatic vegetation. Ensure any in-water lines, ropes, or chains are made of materials and installed in a manner (properly spaced) to minimize the risk of entanglement; attach any cables or utility lines to structures above the water, instead of locating them in water or within the substrate; allow all fish to exit an enclosed area prior to any dewatering; properly secure turbidity control measures and design them in a manner that does not block entry to or exit from critical habitat; monitor turbidity control measures to ensure aquatic species are not entangled or trapped. Use submerged drones for monitoring.

Relevant regulations and documents:

- *Space@Sea (D7.2)*
- *NMFS /FHWA (BMPs)*

6.2.3. Minimize turbidity and sedimentation disturbance. Position new structures to avoid altering natural sediment accretion rates and patterns; maintain or stabilize upstream and downstream channel and bank conditions if an existing stream crossing structure causes erosion or accretion problems; limit the amount and extent of turbidity and sedimentation by using appropriate sedimentation and turbidity controls such as silt curtains, settling basins, cofferdams; install erosion control measures prior to ground-disturbance; prevent sediment and debris from entering the water using geo-textile fabric, haybales, or other methods. Use nets, tarps, and pans when demolishing any structure or part of structure; design the dredge footprint to avoid sensitive habitats and provide appropriate buffers to protect these areas from accretion of sediment resuspended during dredging; develop a project schedule and plan prior to construction, which avoids or minimizes sediment disturbance, during sensitive life stages (migration and spawning) of local species (this may include isolating in-water work or implementing TOY restrictions. Use submerged drones for monitoring. Ensure that all water likely to come in contact with building occupants meets thresholds for turbidity and coliforms.

Relevant regulations and documents:

- *WHO HG*
- *WELL– W01*
- *NMFS /FHWA (BMPs)*

6.2.4. Foster biodiversity. Integrate green and blue infrastructure such as green walls, green roofs, permeable surfaces, rainwater harvesting, tree planting, water phyto-treatment systems, in the building design. To ensure habitat connectivity and potentially increase the delivery of ecosystem services. Use submerged drones for monitoring biological changes.

Relevant regulations and documents:

- *CIRIA C753, 2015*
- *SuRe*
- *W GBC*
- *BREEAM SE 11*
- *DGNB - ENV 2.4*
- *DGNB - ENV 1.2*
- *COM/2021/572*

6.2.5. Avoid unnecessary reduction/obstruction and facilitate incoming sunlight in water. Dimensional and morphological design of the floating building must avoid excessive shading of water through building footprint. Adequate distances[11] between buildings must be ensured reduce impact on underwater marine environment (i.e. oxygen levels). Use of submerged drones for monitoring.

Relevant regulations and documents:

- *ABS- RBCMOU*
- *NMFS /FHWA (BMPs)*

11. *The wind tunnelling effect, that can occur between buildings - increases turbulence and hence water mixing, reducing the adverse impact on dissolved oxygen levels compared to open water. There are no standards or regulations providing specific requirements, but several authors agree that it is an extremely relevant requirement:*

Penning-Rowsell, E. (2020). Floating architecture in the landscape: climate change adaptation ideas, opportunities and challenges. *Landscape Research, 45*(4), 395–411. doi: 10.1080/01426397.2019.1694881

Foka, E., Rutten, M., Boogaard, F. C., de Graaf, R. E., de Lima, R. L. P., & de Giesen, N. (2015). The effect of floating houses on water quality. In *Conference Proceedings: International Water Week*.

6.2.6. Reduce light pollution and avoid underwater illumination at night. Orient artificial lighting to avoid illumination of the surrounding waters at night. Use submerged drones for monitoring.

Relevant regulations and documents:

- *NMFS /FHWA (BMPs)*

6.2.7. Reduce underwater noise sources (hydroacoustic energy). Consider the relative impacts of blasting versus mechanical demolition and select the method that has the least acoustic impacts on the environment. Develop a detailed blast plan with minimization measures. Conduct noise-generating work in a way that minimizes acoustic effects and avoids injury (single strike and cumulative exposure) to local species and habitats. Develop a project schedule and plan prior to construction, which avoids or minimizes noise during sensitive life stages (migration and spawning) of local species. This may include implementing time of year (TOY) restrictions; conduct hydroacoustic monitoring during the project to confirm assumptions regarding zones of injury and behavioral effects.

Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *ABS PCUNC*
- *NMFS /FHWA (BMPs)*
- *IMO MEPC.1*
- *Directive 2008/56/EC*
- *ISO 17208-1:2016*
- *ANSI/ASA S12.64*

6.2.8. Surrounding water quality preservation. Avoid dirt or rubbish falling into water from pathways, walkways or outdoor spaces; minimize the amount of new impervious surfaces; control roadway sanding and the use of deicing chemicals and avoid side casting of road materials to reduce their entry into water; remove contaminants and sediments from water discharge prior to entering aquatic habitats; treat roof and road runoff before discharging into a water body to avoid and minimize the direct input of contaminants and pollutants into aquatic areas.; place a geotextile barrier under any temporary platforms and/or access fills to completely remove any fill at the end of construction; ensure low levels of nutrient concentration to guarantee minimal variations in physical-chemical water parameters (below the local ecological resilience threshold).

Relevant regulations and documents:

- *Directive 2000/60/EC*
- *Directive 91/676/EEC*
- *NMFS /FHWA (BMPs)*

6.3. Landscape Preservation

6.3.1. Landscape-architecture integration. Design buildings (material, position, dimension and morphology) taking into consideration the specific landscape it is set in (i.e. waterfront relationship).

Relevant regulations and documents:

- *D. Lgs. 42/2004*
- *ETS No. 176*

6.3.2. Landscape preservation. Adopt conservation and maintenance actions to preserve the characteristics, the constitutive values, the morphologies of significant or characteristic aspects of a landscape and of its heritage value; adopt regeneration actions for the redevelopment of the compromised or degraded parts of the landscape.

Relevant regulations and documents:

- *D. Lgs. 42/2004*
- *ETS No. 176*

6.4 Decarbonization

6.4.1. CO_2 emissions reduction. Avoid energy consuming heating/cooling/ventilation/domestic hot water systems and prefer use of bioclimatic and passive design strategies.

Relevant regulations and documents:

- *Directive 2010/31/EU*
- *NZEB Standard*
- *D 26/06/2015 (IT)*
- *DGBRS (UAE)*
- *GEG(DE)*
- *CAIP (CA)*
- *CDRLA (USA)*

6.4.2. CO_2 absorption design solutions. Include green CO_2 subtraction-conversion solutions (i.e. urban greening reforestation) and grey CO_2 subtraction-conversion solutions (i.e. photocatalytic materials, natural materials with embodied carbon properties).

Relevant regulations and documents:

- *COM/2021/572*
- *DM n. 493 2021 (IT)*

7. Environmental regeneration (ER)

7.1. Rational Use of Materials

7.1.1. Circular use of materials. Use of materials according to a Life Cycle Assessment approach: biodegradable, renewable, durable, bio-derived, by-product derived, reusable, recycled or recyclable, CO2 absorbing materials.
Relevant regulations and documents:

- *DGNB - ENV 1.2*
- *EU n. 305/2022*

- *ISO 14025:2006*
- *UNI 8289:1981 (IT)*
- *CAM (IT)*
- *NTA 8111:2011 NL*
- *Space@Sea (D.7.2)*

7.1.2. Dry construction processes. Adopt dry stratified technology in favor of traditional wet construction systems; suitability of connections between components to be easily disconnected in order to ensure the recovery of the different components/materials and reuse elsewhere.

Relevant regulations and documents:

- *CAM (IT)*

7.2. Rational Use and Management of Water Resources

7.2.1. Water collection, treatment and reuse[12]. Installation (and maintenance) of one or more water collection and treatment systems for domestic or irrigation purposes. These include rainwater harvesting, greywater recycling, blackwater treatment. Treatment methods include filtration (by using carbon filters, sediment filters, or phyto-depuration), reverse osmosis, aeration, disinfection (through chemicals or UV sanitization to kill bacteria and microorganisms) . Space must be provided for storage tans and sized accordingly to the location.
In case of communities or districts provided a municipal recycled water system, it is sufficient to design the plumbing such that domestic and irrigation system water demand is supplied by municipal recycled water.

Relevant regulations and documents:

- *EU 2020/741*
- *EN 16941-1:2018*
- *COM(2018) 337*
- *LEED v3 - WEc1*
- *LEED v4.1.*
- *WELL W02*
- *DGNB - ENV 2.2*
- *NMFS /FHWA (BMPs)*

12. Rainwater and graywater capture systems are subject to local codes and may require special permits. Note that the water quality should meet local standards, and consult manufacturers' recommendations to determine the compatibility of plumbing fixtures with graywater.

7.2.2. Limit water consumption[13]. Usage of water-saving taps flow restrictors, of re-circulating showers, of certified low water consumption domestic devices, of flushing control systems (push and automatic shut-off taps).

Relevant regulations and documents:

- *BREEAM 05*
- *RE 2020*
- *DGNB - ENV 2.2*

13. This performance requirement is not specifically addresses in performance-based codes and guidelines but just in certification systems.

7.3. Rational Waste Management

7.3.1. Solid waste reduction and diversion (construction phase). Reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, recycling, and composting materials, or by waste to energy processes.
Relevant regulations and documents:

- *LEED v4*
- *BREEAM 07*

7.3.2. Solid waste reduction and diversion (use phase). Provide on-site treatment of solid organic waste (i.e. composting systems, anaerobic digesters, etc.); usage of bio-digest processes for toilet solid waste.

Relevant regulations and documents:

- *Directive 2018/851/EU*
- *Directive 2018/852/EU*
- *BREEAM 07*
- *SCS Zero Waste*
- *BS 5906:2005 (UK)*
- *Space@Sea (D.7.2)*

7.3.3. Wastewater treatment optimization. Provide systems with physical, biological and chemical unit processes for evacuating supplements, inorganic salts, pathogens, coarse solids and so forth, which are truly perilous for environment and human.

Relevant regulations and documents:

- *CIRIA C753, 2015*
- *Directive 2000/60/EC*
- *Directive 91/271/EEC*
- *LEED v4.1.*
- *Space@Sea (D7.2)*

7.3.4. Safe waste storage and disposal optimization. Provide waste storage containers located in a dedicated, non-obstructive position, easily accessible to all users, that require low maintenance and easily cleanable, enclosed to manage odor and pest issues. This will contribute to mitigate environmental contamination and associated exposure to hazards present in certain waste.

Relevant regulations and documents:

- *BREEAM 07*
- *WELL X09*
- *Space@Sea (D7.2)*

7.4. Rational Use of Environmental Energy Resources

7.4.1. Use of renewable energy resources. Use of resources in an integrated design concept to meet NZEB targets. Maximize the use of renewable energy sources (RES) such as geothermal energy, wind energy, biomass, photovoltaic and solar thermal systems.
Relevant regulations and documents:

- *CR (EU) 2016/1318*
- *Directive 2010/31/EU*
- *DM 26 giugno 2015 (IT)*
- *D. Lgs. 28/2011 (IT)*

7.4.2. Use of renewable marine energy resources in an integrated design concept to meet NZEB targets. Maximize use of MRE, such as marine current power, osmotic power, ocean thermal energy, tidal power, and wave power. Foster the use of wave power converters (in open coastal areas with significant waves), tidal turbines placed in coastal and estuarine areas; in-stream turbines in fast-moving rivers; ocean current turbines in areas of strong marine currents; ocean thermal energy converters in deep tropical waters.

Relevant regulations and documents:

- *CR (EU) 2016/1318*
- *Directive 2010/31/EU*
- *DM 26 giugno 2015 (IT)*
- *D. Lgs. 28/2011 (IT)*

7.4.3. Use of bioclimatic passive solutions in an integrated design concept to meet NZEB targets, such as:

a. Low S/V ratio (surface/volume). Design a compact building in order to reduce the dispersant surface area (e.g., walls, ceilings, roofs, and the surface areas of windows) in relation to the enclosed volume V of the building. The larger the ratio, the higher the S/V value, the larger the thermal energy requirement of the living space/usable space, for a given set of energy efficiency measures.
b. Effectiveness of shading systems and solar transmission factor. Prefer use of external shading systems to reduce solar gains in summer. In this wat the short-wave solar energy that is absorbed by the shading system is converted into long wave energy (i.e., heat) and radiated outside the building without reaching the glazing.
c. Adequate thermal inertia and thermal transmittance (according to location) of envelope. Ensure adequate thermal insulation of the envelope according to the specific context.
d. Adequate orientation. Plan building orientation to maximise solar gain/shadow according to local climate needs.
e. Nature based solutions integration. Use of nature-based solutions (green/brown roofs, green walls, permeable surfaces, rainwater harvesting, tree planting, water phyto-treatment systems) to increase comfort and deliver services in a cost-effective way.

Relevant regulations and documents:

- *Directive 2018/844/EU*

8. Buoyancy - Stability (BS)

8.1. Buoyancy and Flotation

8.1.1. Freeboard. A floating building must have a floatation system which maintains an acceptable level of buoyancy appropriate to the use or likely use of the building: a minimum freeboard value (distance between the waterline and the upper deck level, measured at the lowest point of sheer) must ensure the safety and stability of the floating structure and must be calculated according to site-specific water conditions, people on-board, intended use and building design. This requirement is intended to ensure that the floating building has a sufficient watertight volume above the water (reserve buoyancy) in order to carry a certain amount of overload in addition to the full load displacement.

Relevant regulations and documents:

- *QDC MP 3.1.*
- *IMO ICLL*

8.1.2. Watertight compartmentation/subdivision. The buoyancy of the modules should be guaranteed by applying compartmentation within the structures, monitoring and warning systems in case of damage or leakage. Each compartment (bulkhead) shall be watertight.

Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *ABS - RBCMOU*
- *CDR (EU) 2020/411*

8.1.3. Watertight integrity. Use of closures or fittings that prevent the entrance of water to certain compartments. External openings whose lower edges are below the levels to which weathertight integrity is to be ensured, are to have weathertight closing appliances. A plan, identifying the disposition (open or closed) of all non-automatic closing devices and locations of all watertight and weathertight closures, is to be incorporated into the Operating User Manual.

Relevant regulations and documents:

- *DNV – OS-C301*
- *ABS - RBCMOU*
- *CDR (EU) 2020/411*

8.1.4. Sink risk prevention indicators. Indicators shall be provided for all doors and other closing appliances which, if left open or not properly secured, could lead to flooding of the facility; video surveillance or water leakage detection system shall be arranged to provide an indication of any leakage.

Relevant regulations and documents:

- *CDR (EU) 2020/411*

8.2. Stability and Trim

8.2.1. Adaptability to static load variation. Buoyancy of modules shall be, within acceptable limits, future proof regarding addition, removal and shaft of weights (i.e. additional heavy furniture, machinery) and the floating system shall have relevant shape to maintain acceptable trim. The onboard use manual should provide information on how and where the additional payload can be added. The ideal metacentric height should be sufficiently, but not excessively, high, according to the site conditions. A larger metacentric height implies greater initial stability against overturning. The metacentric height also influences the natural period of rolling of a hull, with very large metacentric heights being associated with shorter periods of roll which are uncomfortable for inhabitants.

Relevant regulations and documents:

- *Space@Sea (D.7.2)*
- *LR – RRCOU*
- *IMO ICLL*

8.2.2. Adaptability to dynamic load variations (environmental agents). The floating building shall have sufficient stability considering environment loads (wind, wave, snow) and the manufacturer's maximum recommended load. Hence, wind profile shall be carefully considered regarding stability calculations and possible limits on height of topsides shall be imposed. Snow load determination must be carried out according to the geographical-climate region in order to correctly design the building and pontoon structure. The main dimension of the structure (along the direction of the wave) is designed according to the wave length of the typical wave in the building site and consequently considering also the wave period.

Relevant regulations and documents:

- *ISO 4355:2013 (EN)*
- *Space@Sea (D. 7.2)*

8.3. Asset-Position

8.3.1. Mooring arrangements. Provision of connectors having the capacity and mechanical strength to hold the structure in place under reasonably expected conditions (currents, wind, waves and torsion). The number and locations for mooring connectors varies according to the specific structure and site conditions. Consider

a. Compartmentation of mooring bracket and floating bracket: in case the mooring float sinks, the mooring bracket must break before the bracket anchors to the sinking mooring float.
b. Limit noise (squeaking, rubbing, creaking) through use of appropriate materials for mooring devices and their connections.
c. Mooring systems typology must allow vertical mobility of the floating body in order to adapt to water fluctuations
    - mooring on ropes makes mobility of the floating body possible;
    - steel cables with possible springs are advisable where the water level does not fluctuate or barely fluctuates (the cables hold the structure against the dock or bank protection, often with an intermediate bearing and the springs are used to absorb movement of the structure)
    - sliding strips with cables are advisable when the structure must be moored as close to a dock as possible and must float with the water level (the sliding strips act as gliders for the structure);
    - shock-absorbing restraint (with pulled cables) is advisable with reasonable swell and floating water and can absorb the movements of the structure.

Relevant regulations and documents:

- *NTA 8111_2011-NL*
- *GC-02-E KRS*
- *PCC – T28-FS*
- *QDC MP 3.1.*

8.3.2. Anchoring provisions and arrangements. Provision of anchors, anchor chains of adequate mechanical strength according to floating structure. The anchor providing in forward direction are linked with anchor chains and the length of holding area of chains is to be more than three shackles. The length of each chain linked anchor is to be more than the sum length of catenary part and holding part.

Relevant regulations and documents:

- *GC-02-E (KR)*
- *PCC – T28-FS*

8.3.3. Under keel clearance (min water depth under floating body)[14]. The UKC depends on measurements of tide height, bathymetry and prevailing meteorological conditions, and helps to minimize the risk of grounding.
For site-specific prescriptions, one must look into the nearest harbor/port regulations.

Relevant regulations and documents:

- *PCC – T28-FS*
- *UKC – Port of Darwin*

14. Under-Keel Clearance, or UKC, is the vertical distance between the lowest part of the ship's hull and the seabed. Maintaining a minimum UKC is essential for the safety of navigation. Static UKC is the minimum clearance available between the deepest point on a vessel at rest in still water and the bottom. Static UKC = (Charted Depth of Water + Height of Tide) – (Static Deep Draft) Dynamic factors such as squat, pitch, roll and heave effect a ship's draft and these need to be accounted for in any determination of minimum UKC (UKC – Port of Darwin).

9. Plant system (PS)

9.1. Damage Resistance

9.1.1. Maintainability-repairability. Accessibility of pipelines routes under all circumstances (e.g., search for leakage or malfunction); replaceability of parts, cleanability of all parts.

Relevant regulations and documents:

- *NTA 8111_2011-NL*

9.1.2. Human damage resistance. Mechanical resistance in case of intentional or unintentional human damage; integration of solutions to prevent damage caused by ill-intentioned people and risk of theft of water and energy.

Relevant regulations and documents:

- *NTA 8111_2011-NL*

9.1.3. Natural (biological or chemical) agents resistance. Capability to avoid performance degradation due to the presence of living organisms (animals, plants, microorganisms). Ability of materials/components to endure themselves from chemical attack for a specific period of time. Usage of corrosion resistant materials for submerged pipelines.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *UNI 8289:1981 (IT)*
- *DNV-ST-F101*

9.1.4. Pipeline watertight integrity. Capability to withstand liquid fluid penetration to avoid leakages in any direction.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*

9.1.5. Safe placing. Placing of electrical installations, overhead power drops, transformer pads, heating, air conditioning, ventilating, gas pipelines in such a way that they are in a dry environment not exposed to the water. Heavy machinery and plant equipment must avoid excessive vibration and be located accordingly to buoyancy requirements.

Relevant regulations and documents:

- *GC-02-E (KR)*
- *PCC – T28-FS*

9.1.6. Emergency electric power storage. Plan the use and installation space for built-in energy storage batteries.

Relevant regulations and documents:

- *GC-02-E (KR)*

9.2. Climate resistance

9.2.1. Thermal variation resistance of pipelines. Pipelines must be designed (technically and physically) to accommodate thermal expansion and frost without exceeding allowable stresses. Pipelines must be installed in a manner that allows for thermal expansion and contraction due to temperature changes. Adequate positioning of pipelines containing liquids, to avoid their disintegration and/or possible changes in size and appearance due to ice formation.

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *ISO 13628-5:2009*
- *DNV-ST-F101*

9.2.2. Adaptability of pipelines to water fluctuations. Ability of pipelines to be flexible enough to accommodate water fluctuations and withstand other environmental loads (like wave movement or tidal events).

Relevant regulations and documents:

- *NTA 8111_2011 – NL*
- *ISO 13628-5:2009*
- *DNV-ST-F101*
- *API Specification 5L*

Acronyms and abbreviations of regulatory and certification systems

Appendix Ab

This appendix provides a comprehensive list of all abbreviations and acronyms related to regulation systems used in the Performance-based Design-Support Framework (Appendix A1 and Appendix A2.
The documents are sorted into four categories according to four different disciplinary areas:

- naval and shipping engineering;
- offshore engineering;
- floating architecture;
- on-land architecture and civil engineering.

This list is organized alphabetically for ease of reference. Each entry includes:

- Abbreviation/Acronym: the abbreviated or shortened form of the regulation.
- Full Name: The complete and written-out version of the regulatory document.

By consulting this appendix, readers can readily understand the meaning of any abbreviation or acronym they encounter while reading the PDSF[1].

Please note that not all documents or entities referenced in the framework have a recognized abbreviation or acronym. In these cases, abbreviations have been created based on the full name for internal consistency and brevity.

1. If the framework were given to a designer, the Appendix Ab would be integrated directly into the PDSF.

Naval and Shipping Engineering

ABS- RBCMOU	ABS Rules for Building and Classing Mobile Offshore Units, Part 5 Fire and safety
ABS – PCUNC	ABS Practical Considerations For Underwater Noise Control, 2021
CLC SOR/2010-120 (CA)	Canada Labour Code -Maritime Occupational Health and Safety Regulations

CDR (EU) 2020/411	Commission Delegated Regulation (EU) 2020/411 of 19 November 2019 amending Directive 2009/45/EC of the European Parliament and the Council on safety rules and standards for passenger ships, as regards the safety requirements for passenger ships engaged on domestic voyages (Text with EEA relevance)
CDC 24/7	CDC24/7: Saving Lives, Protecting People – Centers for disease Control and Prevention – Chapter 8 Travel by Air, Land & Sea
ECC n. 1382/1987	Commission Regulation establishing detailed rules concerning the inspection of fishing vessels
Codice Nautica	IL CODICE DELLA NAUTICA D. L.vo 18 luglio 2005, n.171 (agg. 2018) - D 2013/53/EU
Directive 2013/53/EU	Directive of the European Parliament and of the Council of 20 November 2012 on recreational craft and personal watercraft and repealing Directive 94/25/EC
Directive, 2008/56/EC	European Union Marine Strategic Framework Directive, 2008/56/EC
EU 2020/411	REGULATIONS - COMMISSION DELEGATED REGULATION (EU) 2020/411of 19 November 2019 amending Directive 2009/45/EC of the European Parliament and the Council on safety rules and standards for passenger ships, as regards the safety requirements for passenger ships engaged on domestic voyages.
IMO COLREGs	IMO Convention on the International Regulations for Preventing Collisions at Sea (COLREGs)
IMO FSS Code	IMO - International Code for Fire Safety Systems (FSS)
IMO MEPC.1	IMO - MEPC.1/Circ.833 Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life
IACS – CSR-H 2023	IACS (International Association of Classification Societies) Common Structural Rules for Bulk Carriers and Oil Tankers - 2023
IMO ICLLIMO	International Convention on Load Lines
IMO SOLAS (II-2)	IMO SOLAS, Consolidated Edition – Chapter II-2, Construction – Fire protection, fire detection and fire extinction, Part B – Prevention of fire, Part C – Suppression of fire
IMO MODU (9)	IMO MODU Code, Chapter 9 – Fire safety
IMO R A.1045	IMO Resolution A.1045
IMO RA.1108	IMO Resolution A.1108
IMO R A 689	IMO Resolution: TESTING OF LIFE-SAVING APPLIANCES (adopted on 6 November 1991)

IMO R MSC 252 (83)	IMO Resolution MSC.252 (83) – Adoption of the revised performance standards for integrated navigation systems (INS)
IMO 2008 IS	International Code on Intact Stability
IRPCS	International Regulations for the Prevention of Collision at Sea
ISO 17208-1:2016	Underwater acoustics – Quantities and procedures for description and measurement of underwater sound from ships
ANSI/ASA S12.64	ANSI/ASA S12.64-2009 (R2014) -Quantities And Procedures For Description And Measurement Of Underwater Sound From Ships - Part 1: General Requirements
NMFS /FHWA (BMPs)	National Marine Fisheries Service/Federal Highway Administration Best Management Practices Manual For Transportation Activities in the Greater Atlantic Region (2018)
NRF – MNSI	Netherlands Regulatory Framework–Maritime of the Netherlands Shipping Inspectorate; Regulation Safety Seagoing Vessels
RB-12-E (KR)	Korean Register (KR) Rules for the Towing Survey of Barges and Tugboats. 2014
SOLAS Regulation V/23	SOLAS - International Convention for the Safety of Life at Sea – Chapter V –Safety of navigation - Regulation 23 - Pilot transfer arrangements
SPS Code	Code for Safety for Special Purpose Ships - Ch.2 Stability and subdivision
UKC – Port of Darwin	UKC Requirements for Port of Darwin Regional Harbourmaster's Direction 01/2015
CFR-T46 -177	US Government Code of Federal Regulations – Title 46 Shipping – Part 177 – Construction and arrangement (USA)

Offshore Engineering

API Specification 17J	American Petroleum Institute – Specification 17J – Specification for Unbonded Flexible Pipe
BV – RCOU	Bureau veritas - Rules for the Classification of Offshore Units, Part C, Ch.4, Sec.4, 5, 6, 7, 9, 10, 11
DNV GL – OS-C301	Det Norske Veritas - Stability and watertight integrity
DNV-OS-D301	Det Norske Veritas – Offshore Standard DNV-OS-D30 – Fire protection
DNV-OS-A301	Det Norske Veritas – Offshore Standard DNV-OS-A301 – 2016 Edition – Human comfort
DNV-ST-F101	Det Norske Veritas - Offshore Standard DNV-ST-F101 – 2021 Edition – Submarine pipeline systems

ISO 13628-5:2009	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 5: Subsea umbilicals
LR – RRCOU	Lloyds' Register – Rules and Regulations for the Classification of Offshore Units, Part 7, Ch.1, 3
NORSOK S–001	NORSOK S–001, Technical Safety (Norway)

Floating Architecture

GC-02-E (KR)	GC-02-E Korean Register (KR) of Shipping – "Guidance for Floating Structures"
NTA 8111_2011-NL	Netherlands Standards for Floating Constructions
PCC – T28-FS	Portland city Code – Title 28 Floating Structures
QDC MP 3.1.	Queensland Development Code MP 3.1. "Floating Buildings"
Space@Sea (D7.2)	Space@Sea - A catalogue of technical requirements and best practices for the design

On-land Architecture and Civil Engineering

ACI (USA)	American Crowding Index
ANSI-S2.71-1983 (USA)	ANSI-S2.71 -1983 (R2006) Guide To The Evaluation Of Human Exposure To Vibration In Buildings
ASHRAE 189.1	ASHRAE Standard 189.1-2017 Design of High-Performance Green Buildings.
ASTM E413-16	ASTM E413-16 Classification for Rating Sound Insulation
Bouwbesluit 2012 (NL)	Integrale Tekst van hEt Bouwbesluit 2012 Zoals dit Luidt Met Ingang van 1 juli 2013. Deze Tekstnis Samengesteld uit de Staatsbladen 2011, 416; 2011, 676; 2013, 75 en 2013, 244. (Dutch Building Decree – Bouwbesluit)
BREEAM SE 11	BREEAM Communities /2012/02 – Social and Economic Wellbeing / SE 11- Green Infrastruture
BREEAM 05	BREEAM New Construction /UK/2011/05 – Water / Wat01 – Water consumption
BREEAM 07	BREEAM New Construction /UK/2011/07 – Waste
BR2010 (UK)	The Building regulations 2010 – HM government UK – Approved Document C - Site preparation and resistance to contaminants and moisture (2004 Edition incorporating 2010 and 2013 amendments)
BS 6472-1:2008	BS standards (EU) 6472-1 Guide to evaluation of human exposure to vibration in buildings Vibration sources other than blasting

BS 5906:2005 (UK)	BS 5906:2005 (Great Britain) - Waste management in buildings – Code of practice
CAIP (CA)	Climate Action Incentive Payment (2022, Canada)
CAM (IT)	Criteri Ambientali Minimi Per L'affidamento Del Servizio Di Progettazione Ed Esecuzione Dei Lavori Di Interventi Edilizi
CDC24/7	CDC 24/7: Saving Lives, Protecting People - Centers for Disease Control and Prevention
CDRLA (USA)	Carbon Dioxide Removal Leadership Act / CDRLA (A8597/S8171) (January 2022, United States)
CE n. 66/2010	REGOLAMENTO (CE) N. 66/2010 DEL PARLAMENTO EUROPEO E DEL CONSIGLIO del 25 novembre 2009 relativo al marchio di qualità ecologica dell'Unione europea (Ecolabel UE)
CEI 79-3 (IT)	STANDARD CEI (Comitato Elettrotecnico Italiano) - Impianti antintrusione a regola d'arte
CEI 64-8 (IT)	STANDARD CEI (Comitato Elettrotecnico Italiano) 64-8 minimum heights
CEI 64-50 (IT)	STANDARD CEI (Comitato Elettrotecnico Italiano) 64-50 optimal heights
CEI - EN 50131-1	Sistemi di allarme – Sistemi di allarme intrusione – Parte 1: Prescrizioni generali
CEN EN 13845:2017	Resilient floor coverings – Polyvinyl chloride floor coverings with particle based enhanced slip resistance – Specification
CEN CR 1752:1998	Ventilation for buildings – Design criteria for the indoor environment
CIRIA C753, 2015	CIRIA SuDS Manual
COM (2013) 762	Implementing the Energy Efficiency Directive 2012/27/EU – Commission Guidance
COM(2018) 337	Regulation of the European Parliament and of the Council on minimum requirements for water reuse
COM/2021/572	New EU Forest Strategy for 2030
CR (EU) 2016/1318	Commission Recommendation (EU) 2016/1318 of 29 July 2016 on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings
DGNB - ENV 1.2	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – ENV1.2 / Local environmental impact
DGNB - ENV 2.2	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – ENV2.2 / Potable water demand and waste water

	volume
DGNB - ENV 2.4	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) - ENV2.4 / Biodiversity at the site
DGNB – SOC1.1	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – SOC 1.1 / Thermal comfort
DGNB – SOC1.2	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – SOC 1.2/ Indoor Air quality
DGNB – SOC1.3	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – SOC 1.3 / Acoustic comfort
DGNB – SOC1.4	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – SOC 1.4 / Visual comfort
DGNB – SOC1.5	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – SOC 1.5 / User control
DGNB – SOC2.1	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council) – SOC 2.1 / Design for All
DIN 4150-3:2016 (DE)	DIN 4150-3:2016-12 - Erschütterungen im Bauwesen - Teil 3: Einwirkungen auf bauliche Anlagen (Vibrations in buildings - Part 3: Effects on structures)
Directive 79/409/ECC	Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds
Directive 91/271/EEC	Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment
Directive 91/676/EEC	Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources
Directive 92/43/EEC	Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
Directive 2000/60/EC	Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy
Directive 2002/44/EC	Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) - Joint Statement by the European Parliament and the Council
Directive 2008/105/EC	Directive 2008/105/EC of the European Parliament and of the Council

	of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council
Directive 2008/56/EC	Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance)
Directive 2009/125/EC	EU Energy related Products directive (ErP)
Directive 2009/147/EC	Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds
Directive 2009/125/EC	European Ecodesign Directive
Directive 2010/31/EU	Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings
Directive 2012/27/EU	Energy Efficiency Directive 2012
Directive 2018/851/EU	Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste
Directive 2018/852/EU	Directive 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste.
Directive 2018/844/EU	Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency
DM n. 493 2021 (IT)	Decreto Ministeriale 30novembre 2021, n.493 – Piano di forestazione urbana ed extraurbana
DM 5 luglio 1975 (IT)	Decreto ministeriale Sanità 5 luglio 1975 - Modificazioni alle istruzioni ministeriali 20 giugno 1896, relativamente all'altezza minima ed ai requisiti igienico-sanitari principali dei locali di abitazione.
DM 26 giugno 2015 (IT)	Decreto interministeriale 26 giugno 2015 - Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici.
DM 236/1989 (IT)	Decreto del Ministro dei lavori pubblici 14 giugno 1989, n. 236 – Prescrizioni tecniche necessarie a garantire l'accessibilità, l'adattabilità e la visitabilità degli edifici privati e di edilizia residenziale pubblica, ai fini del superamento e dell'eliminazione delle barriere architettoniche
DPCM 14/11/97 (IT)	DPCM 14/11/97 (in Gazzetta Ufficiale - Serie generale n. 280 del 1/12/97) Determinazione dei valori limite delle sorgenti sonore.

DPCM 5/12/97 (IT)	DPCM 5/12/97 - Requisiti acustici passivi degli edifici
DPR 74/2013 (IT)	D.P.R. 16 aprile 2013, n. 74 (1).Regolamento recante definizione dei criteri generali in materia di esercizio, conduzione, controllo, manutenzione e ispezione degli impianti termici per la climatizzazione invernale ed estiva degli edifici e per la preparazione dell'acqua calda per usi igienici sanitari
D. Lgs. 42/2004	Decreto Legislativo -Codice dei beni culturali e del Paesaggio
D. Lgs. 28/2011	Decreto legislativo 3 marzo 2011, n. 28 Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili, recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE
D 26/06/2015	MISE - Decreto 26 giugno 2015 Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici.
EC -DGE (2017)	European Commission, Directorate-General for Energy, Good practice in energy efficiency : for a sustainable, safer and more competitive Europe, Publications Office, 2017, https://data.europa.eu/doi/10.2833/75367
EN ISO 10874:2012	Resilient, textile and laminate floor coverings - Classification (ISO 10874:2009)
EN ISO 16484:2020	Building automation and control systems (BACS)
EN 1990: 2002	EUROCODE 0: Basis of structural design
EN 1991-1-1: 2002	EUROCODE 1: Actions on structures : Part 1-1 : General actions - Densities, self-weight, imposed loads for buildings
EN 1991-1-3 :2002	EUROCODE 1: Actions on structures : Part 1-3 : Snow loads
EN 1991-1-4 :2002	EUROCODE 1: Actions on structures : Part 1-4 : Wind actions
EN 1992: 2004	EUROCODE 2 : Design of concrete structures
EN 1993: 2005	EUROCODE 3 : Design of steel structures
EN 1994: 2004	EUROCODE 4 : Design of composite steel and concrete structures
EN 1995: 2008	EUROCODE 5 : Design of timber structures
EN 1996: 2005	EUROCODE 6 : Design of masonry structures
EN 1998: 2004	EUROCODE 8: Design of structures for earthquake resistance
EN 1999 : 2009	EUROCODE 9 : Design of aluminum structures
EN 12600: 2002	Glass in building – Pendulum test – Impact test method and classification for flat glass

EN 13374:2013	Temporary edge protection systems – Product specification – Test methods
EN 13779:2007	Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems
EN 14134:2019	Ventilation for buildings – Performance measurement and checks for residential ventilation systems
EN 15251:2007	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
EN 16941-1:2018	On-site non-potable water systems – Part 1: Systems for the use of rainwater
EN 54-23: 2010	Fire detection and fire alarm systems – Part 23: Fire alarm devices - Visual alarm devices
ETS No. 176	European Landscape Convention of the Council of Europe (Florence Convention)
Eurostat OR 2014	Eurostat Overcrowding Rate 2014
EU 2020/741	Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse (Text with EEA relevance) + Guidelines
EU n. 305/2022	REGOLAMENTO (UE) N. 305/2011 DEL PARLAMENTO EUROPEO E DEL CONSIGLIO del 9 marzo 2011 che fissa condizioni armonizzate per la commercializzazione dei prodotti da costruzione e che abroga la direttiva 89/106/CEE del Consiglio. It includes EU Construction Products Regulation (CPR) - Declaration of Performance and CE marking.
D n°2002-120 (FR)	Décret n° 2002-120 du 30 Janvier 2002 Relatif aux Caractéristiques du Logement Décent Pris Pour L’application de L’article 187 de la loi n° 2000-1208 du 13 Décembre 2000 Relative à la Solidarité et au Renouvellement Urbains (Version en Vigeur au 11 Février 2021.
CCH (FR)	Code de la construction et de l'habitation – 2023 (France)
GEG (DE)	Buildings Energy Act (2020, Germany)
HBO - 2018 (DE)	Hessische Bauordnung (HBO). Vom 28. Mai 2018. (Deutchland)
IBC-2018	IBC - 2018 - STC/IIC stipulation for Group-R occupancies (Residential buildings)
ICC G2-2010	International Code Council (ICC) G2-2010 Guideline for Acoustics
I.R.P.C.S.	International Regulations for the Prevention of Collision at Sea

ISO/TC 59/SC 17	Sustainability in buildings and civil engineering works
ISO/TR 16576:2017	Fire safety engineering – Examples of fire safety objectives, functional requirements and safety criteria
ISO IEC -71:2001	Guidelines for standards developers to address the needs of older persons and persons with disabilities.
ISO 10137:2007	Bases for design of structures – Serviceability of buildings and walkways against vibrations
ISO 10252:2020	Bases for design of structures – Accidental actions
ISO 11697:1995	Bases for design of structures – Loads due to bulk materials
ISO 12944-1:2017	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 1: General introduction
ISO 12944-2:2017	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 2: Classification of environments
ISO 12944-3:2017	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 3: Design considerations
ISO 12944-4:2017	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 4: Types of surface and surface preparation
ISO 12944-5:2019	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 5: Protective paint systems
ISO 12944-6:2018	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 6: Laboratory performance test methods
ISO 12944-7:2017	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 7: Execution and supervision of paint work
ISO 12944-8:2017	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 8: Development of specifications for new work and maintenance
ISO 12944-9:2018	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 9: Protective paint systems and laboratory performance test methods for offshore and related structures
ISO 13033:2013	Bases for design of structures – Loads, forces and other actions – Seismic actions on non structural components for building applications
ISO 13823:2008	General principles on the design of structures for durability
ISO 14040:2006	ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework

ISO 14025:2006	Environmental labels and declarations (EPD) – Type III environmental declarations – Principles and procedures. The EPD methodology is based on the Life Cycle Assessment (LCA) tool that follows ISO series 14040.
ISO 14044:2006	Environmental management - Life cycle assessment - Requirements and guidelines
ISO 15392:2019	Sustainability in buildings and civil engineering works – General principles
ISO 15928-4:2017	Houses – Description of performance – Part 4: Fire safety
ISO 15928-7:2021	Houses– Description of performance – Part 7: Accessibility and usability
ISO 16814: 2008	Building environment design – Indoor air quality –Methods of expressing the quality of indoor air for human occupancy
ISO 20283-2:2008	Mechanical vibration –Measurement of vibration on ships – Part 2: Measurement of structural vibration
ISO 20283-5:2016	Mechanical vibration –Measurement of vibration on ships – Part 5: Guidelines for measurement, evaluation and reporting of vibration with regard to habitability on passenger and merchant ships.
ISO 21542:2021	Building construction – Accessibility and usability of the built environment
ISO 21650:2007	Actions from waves and currents on coastal structures
ISO 21930:2017	Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services
ISO 22111:2019	Bases for design of structures – General requirements
ISO 23234:2021	Buildings and civil engineering works – Security –Planning of security measures in the built environment
ISO 2394:2015	General principles on reliability for structures
ISO 2631-1: 2003	Mechanical vibration and shock –Evaluation of human exposure to whole-body vibration – Part 1: General requirements
ISO 2631-2:2003	Mechanical vibration and shock –Evaluation of human exposure to whole-body vibration – Part 2: Vibration in buildings (1 Hz to 80 Hz)
ISO 30061: 2007	Emergency lighting
ISO 3010:2017	Bases for design of structures – Seismic actions on structures
ISO 37122:2019	Sustainable cities and communities – Indicators for smart cities
ISO 37123:2019	Sustainable cities and communities – Indicators for resilient cities
ISO 4354:2009	Wind actions on structures

ISO 4355:2013	Bases for design of structures – Determination of snow loads on roofs
ISO 4355:2013 (EN)	Bases for design of structures – Determination of snow loads on roofs
ISO 46001:2019	Water efficiency management systems – Requirements with guidance for use
ISO 50006:2014	Energy management systems – Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) – General principles and guidance.
ISO 6243:1997	Climatic data for building design – Proposed system of symbols
ISO 7730:2005	Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. (Soon replaced by ISO/DIS 7730)
ISO 8041: 2017	Human response to vibration – Measuring instrumentation
ISO 8421-2:1987	Fire protection – Vocabulary – Part 2: Structural fire protection
ISO 8421-6:1987	Fire protection – Vocabulary – Part 6: Evacuation and means of escape
ISO 9194:1987	Bases for design of structures – Actions due to the self-weight of structures, non-structural elements and stored materials — Density
LEED v3 - WEc1	LEED BD+C: Homes – v3 – LEED 2008 – Water reuse – Water Efficiency WEc1
LEED v4	LEED BD+C: New Construction v4 - LEED v4 - Construction and demolition waste management - Materials and Resources
LEED v4.1.	LEED BD+C: New Construction v4.1 – LEED v4.1– Innovation: Sustainable wastewater management
NBC 2015	National Building Code of Canada 2015 (NBC 2015) – Apparent sound transmission class (ASTC)
NS 8176:2017 (NO)	Vibration and shock - Measurement of vibration in buildings from land-based transport, vibration classification and guidance to evaluation of effects on human beings
NTC 2018 (IT)	Norme tecniche per le costruzioni 2018 (IT)
NZEB Standard	Nearly Zero Energy Building Standard -Sustainable Energy Authority of Ireland
ÖNORM B 1600 (AT)	Barrierefreies Bauen – Planungsgrundlagen
ÖNORM B 1601 (AT)	Barrierefreie Gesundheitseinrichtungen, assistive Wohn- und Arbeitsstätten – Planungsgrundlagen

ÖNORM B 1602 (AT)	Barrierefreie Bildungseinrichtungen - Planungsgrundlagen
OSHA	OSHA Regulations noise level
R UE 305/2011	Regolamento (UE) 305/2011 del Parlamento Europeo e del Consiglio del 9 marzo 2011.
SBR- B (NL)	SBR Trillingsrichtlijn B: Hinder voor personen in gebouwen (SBR Vibration Guideline B: Damage to people in structures, NL)*
SCS Zero Waste	SCS Standards – Zero Waste Project Standard (2021)
BBR -2019 (SE)	Boverket's Building Regulations—Mandatory Provisions and General Recommendations, BBR. https://www.boverket.se/en/start/publications/publications/2019/boverkets-building-regulations--mandatory-provisions-and-general-recommendations-bbr/ [Ref list]
RD 314/2006 (ES)	Real Decreto 314/2006, de 17 de Marzo, poe el que se Aprueba el Codigo Técnico de la Edificacion.
DGBRS (UAE)	Dubai's Green Building Regulations & Specifications (UAE) (2021)
EN 1838:2013	Lighting applications - Emergency lighting
EN ISO 50001:2018	Energy management systems - Requirements with guidance for use
UN HABITAT-2007	UN Habitat (Principles and reccomendations for population and housing censuses, UN, 2007)
UNI 10721:2012 (IT)	Servizi di controllo tecnico applicati all'edilizia e alle opere di ingegneria civile
UNI 10805:1999 (IT)	Ringhiere, balaustre o parapetti prefabbricati: Determinazione della resistenza meccanica a carico statico di colonne e colonne-piantone
UNI 10806:1999 (IT)	Ringhiere, balaustre o parapetti prefabbricati: Determinazione della resistenza meccanica ai carichi statici distribuiti
UNI 10807:1999 (IT)	Ringhiere, balaustre o parapetti prefabbricati: Determinazione della resistenza meccanica ai carichi dinamici
UNI 10808:1999 (IT)	Ringhiere, balaustre o parapetti prefabbricati: Determinazione della resistenza meccanica ai carichi statici concentrati sui pannelli
UNI 10809:1999 (IT)	Ringhiere, balaustre o parapetti prefabbricati: Dimensioni, prestazioni meccaniche e sequenza delle prove
UNI 8289:1981 (IT)	Edilizia. Esigenze dell' utenza finale. Classificazione.
UNI 8290-2:1983 (IT)	Edilizia residenziale. Sistema tecnologico. Analisi dei requisiti
UNI 9614:2017	Misura delle vibrazioni negli edifici e criteri di valutazione del disturbo

WELL A03	WELL Standards – A03 – Ventilation Design
WELL A14	WELL Standards – A14 – Microbe and mold control
WELL C02	WELL Standards - C02 – Integrative Design
WELL L01	WELL standards – L01 – Light Exposure
WELL L04	WELL standards – L04 - Electric Light Glare Control
WELL L05	WELL standards – L05 - Daylight Design Strategies
WELL L08	WELL standards- L08 - Electric Light Quality
WELL L09	WELL standards – L09 – Occupant Lighting Control
WELL S02	WELL Standards – S02 Maximum Noise Levels*
WELL S03	WELL Standards – S03 - Sound Barriers
WELL S04	WELL Standards – S04 Reverberation Time
WELL S05	WELL Standards – S05 - Sound reducing surfaces
WELL S06	WELL Standards – S06 Minimum Background Sound
WELL T03	WELL Standards – T03 - Thermal Zoning
WELL T07	WELL Standards – T07 – Humidity control
WELL T08	WELL Standards – T08 – Enhanced Operable Windows
WELL V03	WELL Standards – V03 - Circulation Network
WELL V08	WELL Standards – V08 - Physical Activity Spaces and Equipment
WELL V09	WELL Standards – V09 - Physical Activity Promotion
WELL W01	WELL standard – W01 - Water Quality Indicators
WELL W02	WELL standard – W02 – Drinking Water Quality
WELL W04	WELL standard – W04 – Enhanced Water Quality
WELL X09	WELL standard – X09 – Waste Management
W GBC	World GBC Protocol - Better Places for People
WHO-HG	World Health Organization Housing Guidelines
9 FHB	9 Foundations of a Healthy Building- Harvard

Case study assessment form

Appendix B

[PROJECT NAME]

[x]

● [Location, City, Country]

IDENTIFICATION DATA

ARCHITECT: [name]

CLIENT: [name]

DATE: [year]

BUDGET: [x] €/m²

ADVISORS: [name]

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SITE FEATURES

- Typology: [sea/lake/lagoon/harbor/river/canal]
- Batimetry: [x] m
- Water fluctuation: [x] cm
- Climate: [Koppen climate classification]

SCALE

SINGLE UNIT | MULTI-UNIT | DISTRICT

FUNCTIONAL TYPOLOGY

RESIDENTIAL | LEISURE RECREATIONAL | TERTIARY DIRECTIONAL

TOURISM | PRODUCTION | GREEN

CULTURAL EDUCATIONAL | COMMERCIAL | CIVIL

MORFOLOGICAL - DIMENSIONAL ANALYSIS

DIMENSIONS:
[x] m²

GEOMETRICAL LAYOUT
[form]

MAIN OBJECTIVES

☐ **Ecosystem preservation/regeneration**
[brief description]

☐ **Resource circularity**
[brief description]

☐ **Affordable and renewable energy efficiency**
[brief description]

☐ **High levels of comfort and well-being**
[brief description]

☐ **Economic feasibility**
[brief description]

REQUIREMENT COMPLIANCE

1. SAFETY

- ☐ 1.1.1.
- ☐ 1.1.2.
- ☐ 1.1.3.
- ☐ 1.2.1.
- ☐ 1.2.2.
- ☐ 1.2.3.
- ☐ 1.2.4.
- ☐ 1.2.5.
- ☐ 1.2.6.
- ☐ 1.3.1
- ☐ 1.3.2
- ☐ 1.4.1.
- ☐ 1.4.2.
- ☐ 1.4.3.
- ☐ 1.4.4.
- ☐ 1.4.5.
- ☐ 1.4.6.
- ☐ 1.4.7.

2. WELLBEING

- ☐ 2.1.1.
- ☐ 2.1.2.
- ☐ 2.1.3.
- ☐ 2.2.1.
- ☐ 2.2.2.
- ☐ 2.2.3.
- ☐ 2.2.4.
- ☐ 2.3.1.
- ☐ 2.3.2.
- ☐ 2.3.3.
- ☐ 2.3.4.
- ☐ 2.4.1.
- ☐ 2.5.1.
- ☐ 2.5.2.
- ☐ 2.5.3.
- ☐ 2.6.1.
- ☐ 2.6.2.
- ☐ 2.6.3.
- ☐ 2.7.1.
- ☐ 2.7.2.
- ☐ 2.7.3.
- ☐ 2.8.1.
- ☐ 2.8.2.
- ☐ 2.8.3.
- ☐ 2.8.4.
- ☐ 2.8.5.

3. USABILITY

- ☐ 3.1.1.
- ☐ 3.1.2.
- ☐ 3.1.3.
- ☐ 3.2.1.
- ☐ 3.2.2.
- ☐ 3.2.3.
- ☐ 3.2.4.
- ☐ 3.3.1.
- ☐ 3.3.2.

4. MANAGEMENT

- ☐ 4.1.1.
- ☐ 4.1.2.
- ☐ 4.1.3.
- ☐ 4.2.1.
- ☐ 4.2.2.
- ☐ 4.2.3.
- ☐ 4.2.4.
- ☐ 4.2.5.
- ☐ 4.2.6.
- ☐ 4.2.7.
- ☐ 4.2.8.
- ☐ 4.2.9.
- ☐ 4.2.10
- ☐ 4.3.1.
- ☐ 4.3.2.

5. INTEGRABILITY

- ☐ 5.1.1.
- ☐ 5.2.1.

6. ENVIRONMENTAL REGENERATION

- ☐ 6.1.1.
- ☐ 6.1.2.
- ☐ 6.1.3.
- ☐ 6.2.1.
- ☐ 6.2.2.
- ☐ 6.2.3.
- ☐ 6.2.4.
- ☐ 6.2.5.
- ☐ 6.2.6.
- ☐ 6.2.7.
- ☐ 6.3.1.
- ☐ 6.3.2.
- ☐ 6.4.1.
- ☐ 6.4.2.

7. RATIONAL USE OF RESOURCES

- ☐ 7.1.1.
- ☐ 7.1.2.
- ☐ 7.2.1.
- ☐ 7.2.2.
- ☐ 7.3.1.
- ☐ 7.3.2.
- ☐ 7.3.3.
- ☐ 7.3.4.
- ☐ 7.4.1.
- ☐ 7.4.2.
- ☐ 7.4.3.

8. BUOYANCY AND STABILITY

- ☐ 8.1.1.
- ☐ 8.1.2.
- ☐ 8.1.3.
- ☐ 8.1.4.
- ☐ 8.2.1.
- ☐ 8.2.2.
- ☐ 8.3.1.
- ☐ 8.3.2.
- ☐ 8.3.3.

9. PLANT SYSTEM

- ☐ 9.1.1.
- ☐ 9.1.2.
- ☐ 9.1.3.
- ☐ 9.1.4.
- ☐ 9.1.5.
- ☐ 9.1.6.
- ☐ 9.2.1.
- ☐ 9.2.2.

CONSTRUCTION COMPONENTS

BUOYANT FOUNDATION
[material and typology]

LOAD BEARING STRUCTURE
[material and typology]

CLADDING
[material and typology]

FIGURES (© credits)

[PROJECT NAME]

Expert reviewers' questionnaire

Appendix C1

Expert reviewers' feedback evaluation

Appendix C2

The Questionnaire in Appendix C1 contains 20 items and is structured in two sections:

1. **Section 1 [Q1]**: The items (13) pertain to Appendix A[1];
2. **Section 2 [Q2]**: The items (7) pertain to Appendix B[2].

The Questionnaire was administered to gather feedback from expert reviewers on two key aspects of the thesis: the effectiveness and completeness of the PDSF and the quality and clarity of the case study analysis. The four expert reviewers cover a wide range of disciplinary fields related to the topics included in the framework:

1. Environmental Architecture: Full. **Prof. Arch. Alessandra Battisti** (environmental architect), Department of Planning, Design and Technology of Architecture, Sapienza University of Rome.
2. Energy Engineering: **Prof. Ing. Claudio Lugni** (hydraulic and mechanic marine engineer), CNR - Institute of Marine Technology.
3. Ecology: **Prof. Mattia Azzella** (ecological scientist), Department of Planning, Design and Technology of Architecture, Sapienza University of Rome.
4. Structural and safety engineering: **Prof. Eng. Artur Karczewski** (naval engineer), Shipbuilding Institute, Ocean Engineering and Shipbuilding, Gdańsk University of Technology.

Reviewers are advised to:

- Read specific appendix sections (A2, Ab, and B) before answering the questionnaires
- Provide specific feedback and suggestions for improvement beyond simple "yes/no" answers[3].
- Skip and leave blank irrelevant questions based on their area of expertise.

Appendix C2 provides the feedback recieved from the Expert Reviewers. It is structured as the Appendix C1 in two sections:

1. **Q1**: Feedback regarding the questionnaire Q1 pertaining to the Appendix A[1];
2. **Q2**: Feedback regarding the questionnaire Q2 pertaining to Appendix B[2].

1. Performance-based Design-Support Framework.

2. Case Study data sheet.

3. Open-ended questions are there to encourage reviewers to do so.

Questionnaire for expert reviewers

Evaluation and validation

Before answering the questionnaire, you are asked to go through the Performance-based design framework (Appendix A1) and the Case study data sheet (Appendix B).
The questionnaire is structuredin two parts:

Questionnaire 1: Performance-based design framework (Appendix A1)
Questionnaire 2:Case study data sheet (Appendix B).

If the answer to the question is either *more or less* or *no*, please provide further clarification and suggestions for improvement.
If you consider the question is not relevant to your field of expertise, please leave the answer blank.
A glossary of the acronyms (Annex D) and definitions for each class of demand are provided.

Questionnaire 1 - Appendix A1

1	Is the overall framework structure clear?	yes	no	more or less
	Click or tap here to enter your text.			
2	Are the classes of demand an explanation of end-user demands?	yes	no	more or less
	Click or tap here to enter your text.			
3	Are the performance requirements properly, clearly and sufficiently defined?	yes	no	more or less
	Click or tap here to enter your text.			
4	Are the performance requirements within the Safety (S) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
5	Are the performance requirements within the Comfort (C) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			

6	Are the performance requirements within the Usability (U) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
7	Are the performance requirements within the Management (M) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
8	Are the performance requirements within the Integrability (I) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
9	Are the performance requirements within the Environmental Regeneration class (ER) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
10	Are the performance requirements within the Rational use of resources (RUR) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
11	Are the performance requirements within the Buoyancy-stability (B) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
12	Are the performance requirements within the Plant system (P) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			
13	Are the performance requirements within the Location (L) class of demand clear and correct?	yes	no	more or less
	Click or tap here to enter your text.			

Questionnaire 2 - Appendix B

1	Is the overall analytical template clear and readable?	yes	no	more or less
	Click or tap here to enter your text.			
2	Is the general organisation of the contents adequate for an overall understanding of the project?	yes	no	more or less
	Click or tap here to enter your text.			
3	The case studies have been selected according to their compliance to specific objectives. Are these objectives ("Main objectives") relevant to the field of study and to international goals and programs within the building sector?	yes	no	more or less
	Click or tap here to enter your text.			
4	Is the rating scale (yes- no- partially) suitable for evaluating to what degree the case study meets a certain requirement?	yes	no	more or less
	Click or tap here to enter your text.			
5	Are the positive features pertaining construction components exhaustive? If the answer is no, which features should be added/deleatedwhich should be deleted?	yes	no	more or less
	Click or tap here to enter your text.			
4	Is the case study analytical methodology useful for evaluating the importance (weight) of each requirement within the practice field?	yes	no	more or less
	Click or tap here to enter your text.			
5	Does the case study analytical methodology enable to identify requirements, within the practice field, that could further integrate the theoretical performance-based design framework?	yes	no	more or less
	Click or tap here to enter your text.			

Thank you for answering.

Q1	Expert reviewer 1		Expert reviewer 2	
N°	Evaluation	Notes	Evaluation	Notes
1	More or less	I would suggest inserting a note within the framework to clarify two aspects: first, reminding the reader that the definitions of each class of demand can be found in chapter 3.1. of the thesis; secondly, specifying that if the framework were given to a designer, the definitions for each class of demand would be integrated directly into the framework.	Yes	
2	Yes		More or less	An evaluation of the energy demand should be required
3	Yes		Yes	
4			More or less	I don't see any mention to the safety requirements related to the sea loads (dynamic loads). For offshore structures, excessive dynamics loads can be risky for the structural integrity. They must be properly predicted during the design in order to avoid structural and/or mooring lines failure. It is also important to consider local loads that can occur as consequence of slamming and water on deck events. The proposed floating structure can work both on shallow and larg water depth: typically in coastal areas water depth are lower and, in case of long waves, larger loads can occur.
5	More or less	I would replace the name of the class Comfort with Wellbeing. Wellbeing is a broader concept that encompasses physical, mental, emotional, and social health.	More or less	Typically for floating structures, the comfort conditions depend on the maximum accelerations in some critical points.

Expert reviewer 3		Expert reviewer 4	
Evaluation	Notes	**Evaluation**	Notes
More or less	The “requirement numbers” are not unique. If you want to use codes (that could be useful later on for the "Case study datasheet") I suggest using a 3-level coding that identifies a unique code for each requirement. For instance: 1 safety; 1.1 fire 1.1.1 Fire detection and alarm system.	**Yes**	
Yes		**Yes**	
Yes		**Yes**	
More or less	I think there is one aspect missing that perhaps should go into this category. More precisely in requirement class 4 (structural stability). Anything placed in a natural context immediately becomes an employable ecological niche. In our homes there have been, for thousands of years, more or less welcomed guests. Think about termites or woodworms and what a problem they represent for wooden buildings. Given that there are few examples of floating structures, we cannot establish before hand what the implications of coexistence with marine animals and plants could be. But we know something from the problems faced by ship hulls, or the stilts of a pier. So I am referring to Teredini which can represent a serious problem for wooden structures. Or mussels, which if they massively colonize a floating structure can compromise its stability, shifting the center of gravity with their weight. Scrolling through the questionnaire and then the classes I see that in “Plant system adequacy 1. Damage-risk resistance” there is “1.3. Biological agents resistance”. So I imagine that you have considered what I wrote in this class, and due to ignorance on the subject I did not know that "safety" is a macro-category that only includes safety for the inhabitants. While for structures a separate chapter opens. Correct? This makes me think that perhaps, if the PBD framework is to be aimed at different categories of experts, a small explanation of what the "Class of demand" considers is needed. The explanation for non-experts of the various categories which could be included in the attachment.	**Yes**	
More or less	As regards requirement 8.5, I would not limit myself to mosquitoes, which in any case are decidedly fewer in the sea than other things, unless there are accumulations of stagnant fresh water where the larvae can develop. I would leave	**Yes**	

Q1	Expert reviewer 1		Expert reviewer 2	
6	Yes		Yes	
7	More or less	I would further describe and clarify the information that should be contained in the user manual (On-board user manual), including clear instructions on how to operate the floating building safely and efficiently, how to maintain the floating building properly and how to respond to emergencies.	Yes	
8	Yes		Yes	
9	More or less	I would suggest avoiding overlaps between requirements and making the distinction between Environmental Regeneration and Rational Use of Resources more straightforward.	Yes	

Expert reviewer 3		Expert reviewer 4	
	this category more generic. “Pest and dangerous animals prevention”. And I would remove the reference to “pest” from category 8.6.		
Yes		**Yes**	
Yes		**Yes**	
Yes		**Yes**	
More or less	I would change some things. The adjective "friendly" is often used, which I would change with "Sustainable". Because sustainability is defined and codified. The term “friendly” on the other hand is open to interpretation. 1.3 The use of "local" materials is not always desirable if the area is significantly impoverished by human impact. Example: Black alder wood (*Alnus glutinosa*) is great for your purposes because it is very water resistant and does not rot. The foundations of Venice are made of black alder. But if I have to build in Rome and alder forests are rare and therefore protected, where do I get the wood from? In our case, locally sourced means doing greater ecological damage than importing it from far away where it may still be abundant. As long as it is cut sustainably. So the suggestion is to change this item from “Use of local materials” to “use of certified low impact materials”. Which, however, is implicit in item 1.1 (Environmental sustainable materials) as I suggested it in the previous point. I would integrate 2. Surrounding water quality with item 2.2 “Ensure low levels of nutrient concentration.” More generally, in this category I would write that as a requirement you should “ensure minimal variations in physical-chemical water parameters (below the local ecological resilience threshold).” Because we may be in different places with different needs. Example: at the mouths of large rivers, ecosystems are established that are adapted to "manage" a certain quantity of nutrients or suspended materials. If you put a house at the mouth of the Ganges that discharges directly into the water, the ecosystem will practically not even notice! If, however, we are in an oligotrophic area, on coasts where the ecological conditions of the water are rigidly controlled by other factors, even a minimal deviation from the	**Yes**	

Q1	Expert reviewer 1		Expert reviewer 2	
10	More or less	Regarding waste management, I would reccomend adopting the same approach used in the management phase - distinguishing the construction phase from the use phase.	More or less	The designer should look at the possible energy independence of the structure's functionality and user's life. It is well recognized that in the near future, wind and sun energy devices at sea are much more efficient of the wave energy devices. Moreover, though tides and sea current devices are definitely efficient, they are critical for the floaitng structure loads. Similar for the waves: if the floating buildin should work on "calm water", I don't understand why the floating building shoul account for the wave energy devices (that actually are not economically effective).
11			No	I suppose that the floating building can experience periodical changes of the static loads (goods and structures) and/or of thei position (i.e. additional weight in the buildin or storage of foods and so on). So it is important to establish criteria on the variation of the Metacentric height (and probably more in particular on the COG position), as well as on the additional "payload" that can be added and in which position in order to avoid criticalities. This i typical for the ships that can work in variabl load conditions. Moreover, the dynamic behaviour of a floating structure is fundamental, in a first approx, the ratio between the wavelength of the "typical wav and the main dimension of the structure (along the direction of the wave). The resonance condition of the floating structur in fact, can be identified though this parameter. The wavelength depends on the wave period. So in my opinion not only the wave height matters but first the wave period. The typical size of the floating structure is chosen as function of the wave

Expert reviewer 3		Expert reviewer 4	
	starting conditions can lead to an ecological disaster. 4.2 “Avoid impingement/entrainment and entanglement”. Do you mean with vegetation or other aquatic biostructures (corals for example)? In this case correct but I would specify it. “Avoid impingement, entrainment, entanglement and impairment of biostructure and aquatic vegetation”. That is to avoid that the anchoring or movements of the structures could, for example, ruin a posidonia grove. Requirement 4.6 “Avoid reduction/obstruction of incoming sunlight in water” is perhaps too limiting. I would rephrase it as “Avoid unnecessary reduction/obstruction and facilitate incoming sunlight in water” 4.7 “Artificial illumination control”. This is also a bit generic and I would specify better: “Reduce light pollution and avoid underwater illumination during the night.”		
Yes		**Yes**	
Yes		**More or less**	I would change the name of the class of demand 8.1. into Buoyancy anf floatation and the requirement 8.1.1. into Freeboard instead of freeboard stability. I would re-arrange the requirement as follows: "Freeboard. A floating building must have a floatation system which maintains an acceptable level of buoyancy appropriate to the use or likely use of the building: a minimum freeboard value (distance between the waterline and the upper deck level, measured at the lowest point of sheer) must ensure the safety of the floating structure and must be calculated according to site-specific water conditions, people on-board, intended use and building design. This requirement is intended to ensure that the floating building has a sufficient water tight volume above the water (reserve buoyancy) in order to carry a certain amount of overload in addition to the full load displacement. For what concerns the requirement 8.2.1. Adaptability to static load variation, I would recommend to

Q1	Expert reviewer 1		Expert reviewer 2	
				period. Pls note that this is quite critical for floating building where the weights (and distribution) can change quite often (depending on the number of people living during the day, etc…). I suppose that a weig compensation system (for example with water caisson that can be filled or emptied) should be proposed.
12			Yes	
13	More or less	Location cannot be considered a parameter referring to the design of the building system, as there is no qualitative standard for climate and hydrographic features.	More or less	The following requirement: the project site located in “calm waters” is in my opinion quite misleading. The cited note n. 65339 defined the calm water conditions for navigation which means “depending on the seasonal condition”. Calm water can occur mainly during the summer and, in any case, in some days for which the sea state is withi certain limits. Although these prescriptions work for ships that temporarily sail in a wel described area, they cannot be applied for floating structures that cannot be moved periodically depending on the metocean condition. I suggest to look at the following analysis “https://www.governo.it/sites/governo.it/ es/DLGS_DIRETTIVA_2019_1159_AIR.pdf”

	Expert reviewer 3	Expert reviewer 4
a ht		replace the word removal with shaft, as the floating system should have relevant shape to maintain acceptable trim. For requirement 8.2.2. I would add that the floating building shall have sufficient stability considering its environment loads (wind, wave, snow) and the manufacturer’s maximum recommended load.
	Yes	**Yes**
is in l fil	**Yes**	**Yes**

Q2	Expert reviewer 1		Expert reviewer 2	
N°	**Evaluation**	**Notes**	**Evaluation**	**Notes**
1	Yes		Yes	
2	More or less	I would recommend to uniform the data regarding the site features among case studies and using the Köppen Climate classification to describe the climate of the sites, as it is one of the most well-established and widely recognized systems used for climate classification in the world.	Yes	
3	Yes		Yes	
4	Yes		Yes	
5	Yes		Yes	
6	Yes		More or less	At least to me, more case studies should be proposed, depending on t local sea depth and wave period. Bu understand that this can be quite demanding.
7	Yes		Yes	

	Expert reviewer 1		Expert reviewer 1	
	Evaluation	**Notes**	**Evaluation**	**Notes**
	Yes		Yes	
	More or less	As mentioned, I suggest including a brief explanation of the classes and what they "include". Even shorter here. And then there is the problem of codes. If at 3 levels I think it would make it easier to understand that 1.1 in safety is not 1.1 in usability. As for the blue squares, I don't understand how they turn on. Half full and empty for individual requirements I can imagine. But the 5 little squares for the classes? When they are all lit (blue) is it because I have met 100% of the requirements? At 80%? Are there any thresholds?	Yes	
	Yes		Yes	
	More or less	As mentioned before, I understood the reason why the squares could be blue, white or half full. I think the yes/no /partially scale is sufficient. But I repeat the suggestion for the general organization. A legend that explains.	Yes	
	Yes		Yes	
the ut-	Yes		Yes	
	Yes		Yes	

Video tutorial of the digital tool

Appendix D

The video tutorial of the digital tool is available at this link: https://drive.google.com/file/d/1n_FhiEAcNFKubDn8M1c-spOz4isLWgJZ/view?usp=drive_link or by sending an email to livia.calcagni@uniroma1.it.

The video tutorial is meant to enhance clarity and accessibility by showcasing the tool's features and functionalities in a more intuitive and engaging way than text alone.

Multi-evaluation matrix

Appendix E

The Multi-evaluation matrix is developed and used in phase 2. It is built by placing on the alternative axis (x) the case studies and on the criteria axis (y) the performance requirements grouped in classes of demand. The multi-evaluation matrix has two objectives and related outputs:

1. Identification of best practices amongst case studies, according to their level of compliance with the performance requirements
2. Identification of the different weights each requirement has compared to the others and of a priority order amongst requirements based on their fulfillment in practice.

Class of requirements	R n°	Requirement (R)
1.1. Structural stability	1.1.1.	Mechanical resistance to static actions
	1.1.2.	Mechanical resistance to dynamic actions
	1.1.3.	Structural continuity with sub-structure
1.2. Fire safety	1.2.1.	Fire detection and alarm system
	1.2.2.	Structural fire integrity
	1.2.3.	Fire extinguishing facilities
	1.2.4.	Non-flammable materials
	1.2.5.	Safety platforms
	1.2.6.	Escape routes
1.3. User security from external actions	1.3.1.	Collision risk reduction arrangements
	1.3.2.	Intrusion protection (access control or alarm system, shatterproof glazing)
1.4. User security in use	1.4.1.	Fall protection devices
	1.4.2.	Climbing/holding devices
	1.4.3.	On-board safety equipment
	1.4.4.	Overtopping reduction - clearance above water
	1.4.5.	Non-slippery resistance
	1.4.6.	Smooth intersections between horizontal surfaces
	1.4.7.	Horizontal walkway illumination
2.1. Thermal-hygrometric comfort	2.1.1.	Indoor temperature level and control
	2.1.2.	Indoor humidity level and control
	2.1.3.	Ventilation control
2.2. Visual comfort	2.2.1.	Natural illumination level and control
	2.2.2.	Artificial illumination level and control
	2.2.3.	Emergency and signal lighting
	2.2.4.	Quality views
2.3. Acoustic comfort	2.3.1.	Noise level limits
	2.3.2.	Indoor acoustic insulation/sound barriers
	2.3.3.	Reverberation time control
	2.3.4.	Sound reducing surfaces
2.4. Respiratory-olfactory comfort	2.4.1.	Absence of unpleasant odors (Ventilation control)
2.5. Spatial comfort	2.5.1.	Minimum areas and volume
	2.5.2.	Minimum heights
	2.5.3.	Occupancy rate
2.6. Motion comfort	2.6.1.	Vertical acceleration control
	2.6.2.	Motion control
	2.6.3.	Vibration control
2.7. Psycho-perceptive comfort	2.7.1.	Biophilia
	2.7.2.	Behavioral engagement
	2.7.3.	Active lifestyle design
2.8. Hygienic conditions	2.8.1.	Air quality
	2.8.2.	Microbe and mold control
	2.8.3.	Drinking water quality
	2.8.4.	Pest and dangerous animals prevention
	2.8.5.	Dust prevention and management
3.1. Accessibility	3.1.1.	Access (reachability) for all users
	3.1.2.	Circulation for all users
	3.1.3.	Uniformity and illumination of walkways' surfaces
3.2. Adaptability	3.2.1.	Technical flexibility (of building structure and components)
	3.2.2.	Functional/spatial flexibility
	3.2.3.	Disassembly arrangements (DfD)
	3.2.4.	Mobility (towing arrangements)
3.3. Functionality	3.3.1.	Furniture integration
	3.3.2.	Ease of use and maneuver
4.1. Design and construction management	4.1.1.	Cost-effective and efficient processing and manufacturing
	4.1.2.	Cost-effective and efficient transportation
	4.1.3	Cost-effective and efficient assembly and construction

Case studies

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Score
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
					1		1			1		0	0	0		1	1		0,5	1		0	1	0	30%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
0	0	0	0,5	0			0	0	0	1		0	0	0	0	1	1	0	0,5	1	0	0	0	0	20%
0,5	0,5	1	1	0,5	1	0,5	0,5	1	0,5	0,5	1	0,5	0,5	1	0,5	1	1	0,5	1	1	1	1	1	1	78%
0,5	0,5	1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	1	1	0	1	0	1	0	0	0	74%
0,5	0,5	1	1	1	1	1	1	1	1	1	1	0,5	1	0,5	1	1	1	1	1	1	1	0	0	1	84%
1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	24%
1	1	0,5	1	0,5	1	1	0,5	0,5	0,5	1	0,5	0,5	0,5	0,5	1	1	1	0,5	1	1	1	1	0,5	1	78%
1	1	0	0	0	1	0	0,5	0,5	0	0	1	0,5	1	1	1	1	1	0,5	1	1	1	0	0	1	60%
1	1	0	1	1	1	1	1	0	0,5	1	0	0	0	0	0	1	0	1	0	1	1	1	1	1	62%
1	1	0	0	0	1	0	1	1	0	0	0	1	0	0	0	1	1	1	0	1	1	1	1	1	56%
1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	96%
1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	96%
1	1		1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0,5	1	1	1	90%
0,5	0,5	0,5	0,5	1	0,5	1	1	0	1	1	0	0,5	1	1	1	1	1	0,5		1	1	1	1	1	74%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	1	1	1	98%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	1	1			0	0	0	0	0	8%
0,5	1	0	1	1	1	1	1	0,5	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	88%
1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	0,5	0,5	1	1		1	1	1	1	1	1	90%
1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	0,5	1	1	1		1	1	1	1	1	1	92%
											1		1			1	0,5		0,5						16%
										1	1		1		0,5	1	0,5		1			0			24%
1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	98%
1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0,5	1	92%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		0,5	1	94%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	98%
1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	98%
1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	98%
1	1	0,5	1	1	1	1	1	1	1	1	1	1	0,5	1	1	0	0	1	1	1	0,5	1	1	1	86%
1	1	0	1	1	1	0	0,5	0	0,5	0,5	0	0	0,5	1	0	0,5	0	1	1	0	0	0	0	0	42%
1	0,5	0,5	1	0	1	0	0	0	0	1	0	0,5	0	1	0	0	0	1	0,5	0	0,5	0	0	1	38%
1	1	1	1	0	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	94%
0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5		1		1	1	1	1	1	1	1	1	66%
1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1				1	1		1	1	80%
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0,5					0	0				6%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	98%
1	1	1	0	1	1	1	1	1	0,5	1	1	0,5	1	1	1	1	1	0	1	1	1	0	0	1	80%
0,5	0,5	1	0	1	0	0	0	0,5	0,5	1	1	0	0	1	1	1	1	0	1	0	0	0	0	1	48%
1	1	1	1	1	1	1	1	0,5	1	1	0,5	0	1	0,5	1	1	1	1	1	1	0,5	0	1	1	84%
0,5	0,5	1	0,5	0	1	1	1	0	1	1	0,5	1	1	1	0	0	1	0,5	0,5	0	0,5	1	0	1	62%
0,5	0,5	1	1	1	1	0,5	0,5	0,5	1	1	1	1	1	1	1	1	1	0,5	1	0	1	1	0,5	0,5	80%
1	0,5	0,5	1	0	1	1	1	0,5	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	88%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	96%
0	0,5	1	0,5	0,5	0,5	1	0,5	1		0,5	0	1	0,5	1	1	1	0,5	1		1	1	1	1	0,5	66%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	0	1	1	1	1	1	1	1	1	0,5	1	0,5	0,5	1	1	1	1	1	1	0	1	86%
0,5	0,5	0,5	1		1	1	0,5	1	0	1	0,5	1	0,5	1		0,5	0,5					1	1		52%
1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	96%

Class of requirements	R n°	Requirement (R)	Cas
			1
4.2. Operational management (Use an maintenance)	4.2.1.	Ease of intervention	1
	4.2.2.	Ease of repairability/replaceability	1
	4.2.3.	Biological attack resistance (exposed materials and components)	0
	4.2.4.	Chemical aggressive agents resistance (exposed materials and components)	0,5
	4.2.5.	Atmospheric agents resistance (exposed materials and components)	1
	4.2.6.	Hygroscopicity (exposed materials and components)	1
	4.2.7.	Interstitial condensation control	
	4.2.8.	Real-time/remote control optimization	0
	4.2.9.	Seasonal efficiency of heating/cooling systems	1
	4.2.10.	On-board user manual	0
4.3. End-of-life management	4.3.1.	Disassembly arrangements (DfD)	1
	4.3.2.	Disposal of building components	0,5
5.1. Integrability of technical elements	5.1.1.	Dimensional integrability	1
5.2. Integration of plant systems	5.2.1.	Plant system integration	1
6.1. Low environmental impact of building components	6.1.1.	Dry construction processes	1
	6.1.2.	Use of certified low environmental impact materials	0
	6.1.3.	Toxic emission control of materials	0,5
6.2. Ecology and habitat preservation and enhancement	6.2.1.	Avoid interference with protected areas	1
	6.2.2.	Avoid impingement/entrainment and entanglement	1
	6.2.3.	Minimize turbidity and sedimentation disturbance	0,5
	6.2.4.	Foster biodiversity	0
	6.2.5.	Avoid reduction/obstruction of incoming sunlight in water (ensure adequate water oxygen levels)	1
	6.2.6.	External artificial illumination control (during night)	1
	6.2.7.	Reduce underwater noise sources/hydroacoustic energy	0,5
6.3. Landscape preservation	6.3.1.	Landscape-architecture integration	1
	6.3.2.	Landscape preservation	1
6.4. Decarbonization	6.4.1.	CO_2 emissions reduction	0,5
	6.4.2.	CO_2 absorption design solutions	0
7.1. Rational use of materials	7.1.1.	Circular use of materials	0
	7.1.2.	Dry construction processes	1
7.2. Rational use and management of water resources	7.2.1.	Water collection, treatment and reuse	1
	7.2.2.	Limited water consumption	0
7.3. Rational waste management	7.3.1.	Solid waste reduction and diversion through reuse, recycling, composting, waste to energy processes (construction phase)	0,5
	7.3.2.	Solid waste reduction and diversion through reuse, recycling, composting, waste to energy processes (use phase)	0
	7.3.3.	Waste-water treatment optimization	0
	7.3.4.	Safe waste storage and disposal	0
7.4. Rational use of climate energy resources	7.4.1.	Use of renewable energy resources (REs)	0
	7.4.2.	Use of renewable marine energy resources (MREs)	0
	7.4.3.	Use of bioclimatic passive solutions	0,5
8.1. Buoyancy	8.1.1.	Freeboard stability	1
	8.1.2.	Watertight compartmentation/ subdivision	0
	8.1.3.	Watertight integrity	1
	8.1.4.	Sink risk prevention indicators	0
8.2. Stability and trim	8.2.1.	Adaptability to static load variation	0,5
	8.2.2.	Adaptability to dynamic load variation (climate agents like wind, snow, rain, etc.)	0,5
8.3. Asset - position	8.3.1.	Mooring arrangements	1
	8.3.2.	Anchoring provisions and arrangements	1
	8.3.3.	Under keel clearance	1
9.1. Damage resistance	9.1.1.	Maintainability-repairability	1
	9.1.2.	Human damage resistance	0,5
	9.1.3.	Natural (biological or chemical) agents resistance	0,5
	9.1.4.	Pipeline watertight integrity	1
	9.1.5.	Safe placing	1
	9.1.6.	Emergency energy power storage	0
9.2. Climate resistance	9.2.1.	Thermal variation resistance of pipelines.	1
	9.2.2.	Adaptability of pipelines to water fluctuations	1
			69%

e studies **Score**

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Score
1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	98%
1	1	1	0	0,5	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	90%
0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	50%
0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	1	54%
1	1	1	1	1	1	1	1	1	1	1	0,5	0,5	1	1	1	1	1	1	1	1	1	1	1	96%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
									1	1	1		1	1	1	1	1	1	1	1	1	1	1	56%
1	0	0	0	0	0	0	0	1	1	1	1	0	1		0		0		0		0	1	1	32%
1	0,5	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	86%
0,5	0,5	0,5	0,5		0	0,5	0	0	0,5	0,5	0,5				0,5	0,5						0,5	1	26%
0,5	0,5	1	0	1	1	1	0,5	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	88%
0,5	0,5	0,5	0	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5	0,5	0,5	0,5	0,5	1	1	1	0,5	0,5	1	0,5	1	60%
1	1	0,5	0	1	1	1	0,5	1	1	1	1	0,5	1	0,5	0	1	1	1	0	1	1	0	1	76%
1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	96%
1	1	1	0	1	1	1	0	1	1	1	1	1	1	0,5	0,5	1	1	1	1	1	1	1	1	88%
0,5	1	0,5	0,5	1		0,5	0,5	0,5		0,5	0	1	0,5	0	0,5		1	1			0,5	0	1	44%
0,5	0,5	0,5	0,5	0,5	0,5	1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	84%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	96%
0,5	0,5	1	0,5	0,5	0,5	1	0,5	0,5	0,5	1	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5	0,5	1	0,5	62%
1	1	0,5	0,5	0,5	0,5	1	0,5	0,5	0,5	1	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5	0,5	1	1	64%
1	0,5	0,5	0	1	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0,5	34%
1	0	1	0,5	0,5	0	0,5	0,5	1	0	1	0	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	54%
1	1	1	1	1	1	1	1	1	1	1	1	0,5	1	0	0,5	1	0	1	0,5	0,5	0,5	0,5	1	80%
0,5	0,5	1	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0	0,5	0,5	0,5	0,5		1	1	0,5	1	1	0,5	58%
1	1	1	1	0,5	0,5	1	1	1	1	1	1	1	1	1	1	0,5	1	1	1	1	1	1	1	94%
1	1	1	1	0,5	1	1	1	0,5	1	1	0,5	0,5	1	1	1	0,5	1	1	0	1	1	0	1	82%
1	1	0,5	1	1	1	1	1	1	1	1	1	0	1	0,5	0,5	1	0,5	1	0	1	1	1	1	82%
1	0,5	0	0	1	0	0	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0,5	36%
1	1	0,5	0	1	0	0	0		1	0,5	0	0,5	1	0,5	0,5	0,5	1	1	0,5	0,5	1	0	1	52%
1	1	1	0	1	1	1	0	1	1	1	1	1	1	0,5	0,5	1	1	1	1	1	1	1	1	88%
1	1		0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	1	52%
1	0	0	1	0	0	0	1	0		0	0,5	0	1		0	0	0	0	0	0		0	0	18%
1	1	0,5	0	0,5	0	0	1	0,5	0,5	0	0	0	0,5	0,5	0	1	1	1	0,5	0,5	1	0,5	0,5	46%
1	0	0	0	0	0	1	0	1	1	0,5	1	0	0	0	0	0	0	0	0	0	1	1	1	34%
1	0	0	0	0	0	1	0	1	1	1	1	0	1	0	0	0	0		0	0	1	1	1	40%
1	1	1	1	0	1	1	1	1	1	1	0	1		1	1	1	1	1	1	1	1	1	1	84%
1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	0	0	0	0	0	1	1	1	1	64%
0	0	0	1	1	0	0	0	1	1	1	0	0	1	0	1	0	0	0	0	0	0,5	0	0	30%
1	1	0,5	1	1	0,5	1	1	0,5	1	1	0,5	1	1	1	1	1	1	1	0,5	1	1	0,5	1	86%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
0	0	0,5	0	0	1	0	0	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	1	58%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0								1	0	8%
0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5	54%
0,5	0,5	0,5	0,5	0,5	0,5	1	1	0,5	1	1	1	1	1	1	1	1	1	1	0,5	1	1	1	0,5	80%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	92%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
0,5	0,5	0,5	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	90%
0,5	0,5	0,5	1	1	1	1	0,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	90%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
[illegible]	0	0	1	0,5	0			1	0,5	1	0,5	0	0,5						0	0,5	1	1	1	38%
[illegible]	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,5	0,5	0,5	1	1	0,5	60%
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	96%
78%	68%	72%	63%	77%	68%	77%	67%	76%	84%	81%	69%	67%	78%	67%	75%	76%	68%	74%	68%	74%	75%	72%	84%	