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URBAN PLANNING

Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland

Edited by Carola Hein, Sabine Luning, Han Meyer, Stephen J. Ramos, and Paul van de Laar

Volume 8

Issue 3

2023

Open Access Journal

ISSN: 2183-7635

Urban Planning, 2023, Volume 8, Issue 3
Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland

Published by Cogitatio Press
Rua Fialho de Almeida 14, 2º Esq.,
1070–129 Lisbon
Portugal

Design by Typografia®
http://www.typografia.pt/en/

Cover image: © Tom Fisk from Pexels

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Available online at: www.cogitatiopress.com/urbanplanning

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2023, Volume 8, Issue 3, Pages 259–262
https://doi.org/10.17645/up.v8i3.7619

Editorial

Shipping Canals in Transition

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Submitted: 21 September 2023 | Published: 26 September 2023

Abstract
Shipping canals have supported maritime traffic and port development for many centuries. Radical transformations of these shipping landscapes through land reclamation, diking, and canalization were celebrated as Herculean works of progress and modernity. Today, shipping canals are the sites of increasing tension between economic growth and associated infrastructural interventions focused on the quality, sustainability, and resilience of natural systems and spatial settlement patterns. Shifting approaches to land/water relations must now be understood in longer political histories in which pre-existing alliances influence changes in infrastructure planning. On the occasion of the 150th Anniversary of the New Waterway (Nieuwe Waterweg), the Leiden–Delft–Erasmus universities PortCityFutures Center hosted an international symposium in October 2022 to explore the past, present, and future of this channel that links Rotterdam to the North Sea. Symposium participants addressed issues of shipping, dredging, and planning within the Dutch delta, and linked them to contemporary debates on the environmental, spatial, and societal conditions of shipping canals internationally. The thematic issue builds on symposium conversations, and highlights the importance of spatial, economic, and political linkages in port and urban development. These spatial approaches contribute to more dynamic, responsive strategies for shipping canals through water management and planning.

Keywords
geoengineering; inland waterways; port territory; ports; shipping and environment; shipping canals; urban canals

Issue
This editorial is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

Shipping canals have been at the heart of economic and spatial restructuring for many centuries. They are hubs of political claims, economic development projects, and visions of national identity. They are key infrastructures for sea-land connections, at the heart of the development of port city territories and of the ecological rethinking of urban deltas. Shipping canals are not only important for spatial development on a horizontal plane; they are also key to vertical development: think of the depth of the sea and dredging.

Canals have a long history. The Grand Canal in China, a UNESCO World Heritage Site and the longest artificial canal in the world, goes back more than 2500 years. Most of the canals that are relevant today date to the "second industrial revolution" of the late nineteenth century, when shipping canals were part of complex inland waterway systems, constructed by states as a way to extend production networks into the hinterlands to gain access to cheaper labor and to facilitate resource extraction. Along with railroads, shipping channels formed the networks that imprinted a new territorial "mosaic of industrial urbanism" (Brenner, 2004, p. 119). They spatially redistributed value unevenly across territories with new cores and peripheries.

The relationship between global systems and canal infrastructure is marked by the shaping of international shipping canals. The Suez Canal and the Panama Canal are examples. They shifted global shipping flows and changed the fate of many cities, such as the Mediterranean ones that once again thrived as ships from Asia no longer took the long way around Africa to reach Europe. Both canals proved to be major logistical chains in a network of empire and colonial relationships that continued after 1945 and were essential links in the new geopolitical order during the Cold War. Their depth and width have even become a measurement for the size and draught of ships.

Similarly, the New Waterway in the Netherlands, created in the nineteenth century, was and is inextricably linked to this global infrastructure and the ongoing spatial transformations. It served as a catalyst for a fundamental transition, which led to the explosive growth of the port and city of Rotterdam. The transition was accompanied by a structural change in the river drainage system, and of the ecological systems in and around the estuary, including the development of the industrial port complex Botlek-Europoort-Maasvlakte in the mid-twentieth century. The Maas changed from an estuary to an industrial port canal that must now be dredged annually.

Rotterdam owes its world port status to the New Waterway. Houston's status arrived via the Houston Ship Channel, and Shanghai's came from the Huangpu River, an artificially dug shipping channel of the Yangtze River Delta, which, like Rotterdam, transformed Shanghai into an industrial port after WWII. The economic globalization of the 1990s created the conditions for China to become a new world and maritime power. China's Belt and Road Initiative uses major works of infrastructure—including existing and new maritime and land-based construction to extend its global power. Like France, England, and America in the past, China uses shipping canals—existing and planned new ones—as part of a world infrastructure. China's new power regime is based on logistical superiority in shipping and global trade.

Today, shipping canals continue to be excellent objects for the study of extended urbanization and for reflections on infrastructure as socio-cultural objects and on ecosystems and geopolitical relations. In 2017, the 56 countries of the United Nations Economic Commission for Europe signed the European Agreement on Main Inland Waterways of International Importance, hoping water transport would enhance the efficiency of logistics distribution, with fewer greenhouse gas emissions generated from truck cargo. But the "waterways as roads" strategy reduces and instrumentalizes ecology to service offsite wealth accumulation. In this service, waterway dredging and maintenance perpetually disturb marine and riparian habitat, threatening the life cycles of the deeper ecology. As Joshua Lewis (2023, p. 264) writes, "balancing the needs for efficient navigation, coastal restoration, and flood protection is becoming challenging for responsible agencies in the [Mississippi Delta] region."

New fundamental transitions are needed, raising the question as to whether shipping canals can act globally as catalysts for change in multiple, inextricably linked fields: water management and flood protection, biodiversity, estuarian ecosystem restoration, energy transition in the industrial port complex, regional spatial structure, and strong "green-blue" structures, all with consideration for the history and heritage of culture, territory, and the built environment.

This thematic issue includes contributions that consider contemporary regional, economic, global, logistical, and natural dimensions of international shipping canals. The editors invited participants to consider the values that drive water engineering, economies of scale, and the political and legal instruments that have allowed for the construction and maintenance of the canals—land ownership, expropriation, and land use—as constituting essential elements of nature-culture ecosystems.

The contributions explore waterways in diverse geographies, including the Deux-Rives project in Strasbourg (Biscaya & Elkadi, 2023) and the Grand Maritime Port of Nantes Saint-Nazaire and Loire Estuary in France (Duval & Bahers, 2023); the Manchester Ship Canal (Biscaya & Elkadi, 2023) as well as the broad inland waterway network in the UK (Terziev et al., 2023); the Lower Vistula inland waterway (Gołędzinowska, 2023), the Ports of Gdańsk and Elbląg in Poland (Marciniak, 2023), and their international connection through the Danish Straits (Krośnicka & Wawrzyńska, 2023); the port city of Skikda on the banks of the Safsaf River in northeastern Algeria (Ghennaï et al., 2023); the Tagus Estuary in Portugal (Costa et al., 2023); and the Mississippi River Ship Channel (Lewis, 2023) and Gulf Intracoastal Waterway (Lessoff, 2023) in the US.

The thematic issue illustrates that shipping canal strategies remain path dependent on older regimes. It examines how cities and ports became disconnected and how the ongoing transformations of river deltas due to shipping canal dredging will demand new perspectives on port-hinterland relationships that will impact future urban planning processes. For instance, older canal networks in Amsterdam and London are linked to long-term processes of urban development. Post-industrial interpretations of mobility and inner-city connections have proved to be of value in reconsidering functional diversity and local development in these two cities (Alsavada & Karimi, 2023). Shanghai's future strategies are dependent on its location in an area with abundant waterways and the possibilities of reconnecting the urban with a rural hinterland. Economic and commercial rationalities are leading, but often geopolitical considerations play a fundamental role in the finalization of decision-making (den Hartog, 2023). The case study of the Elbląg port addresses the geopolitical situation associated with Poland's accession to the EU in 2004, which led to deterioration of economic relations with the Russian Federation. Russia's invasion of the Ukraine in February 2022 has urged another approach to canal through the Vistula Spit to allow for shipping to bypass Russian territory (Breś & Lorens, 2023).

The articles incorporate a range of methods, including the catalytic-based approach, hydrodynamic performance analysis, development thresholds analysis, SWOT analysis, PESTEL (political, economic, sociocultural, technological, environmental, legal strategic planning tool) and the MICMAC (micro/macro) scenario method, with theoretical frames ranging from urban metabolism to the UNESCO historic urban landscape. Many contributions emphasize that ship channels are not just navigation networks but have to be placed in the broader dynamics of water/land and city/territory relations. The concepts of (hydrological) porosity and fluid territories serve to bring home the shifting ways in which water and land are articulated in port city territories and call for new types of visualization (Hein et al., 2023).

Today, more than in the past, new shipping canals and the necessity of dredging have become controversial, and negative effects on the environment are taken more seriously. The agendas of politicians, transnational business, maritime economists, urban planners, and environmentalists reveal different priorities. The case studies show that innovations, planning decisions, and technological adaptations dominate the outcomes. The decision-making process is embedded in "hydrocracies" (Carse & Lewis, 2017) that operate as state bureaucracies in control of water management and their associated network of shipping firms, maritime industries, port authorities, government and academic institutions, and NGOs effectively block regime shifts that are needed to address these fundamental transitions. Ports and shipping canals have become too dependent on global supply chains that emphasize capacity, efficiency, and volumetric output. Regime shifts demand new political and social contracts as is evident from anthropological studies of distributive power regimes. Urban planners need to address the ultimate ecological question and develop hydrocracies-resistant design strategies. The issues discussed boil down to a fundamental question: Who owns the river?

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 263–274
https://doi.org/10.17645/up.v8i3.6954

Article

Pathologies of Porosity: Looming Transitions Along the Mississippi River Ship Channel

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Submitted: 25 March 2023 | Accepted: 6 June 2023 | Published: 26 September 2023

Abstract

This article explores recent developments along the Mississippi River Ship Channel, the Mississippi River Delta, and the port city territory of New Orleans, US. The lower reaches of the Mississippi River through which the ship channel is maintained have become increasingly porous over the past decade, as flooding events have triggered or expanded multiple breaches or crevasses along the river's eastern bank. This increasing porosity has generated debates between political and economic assemblages favoring different approaches to navigation management, flood control, and ecosystem restoration. The tensions and contradictions facing delta residents, planners, managers, and engineers come down to a question of hydrological porosity in the Mississippi River Delta, both in the river's navigation channel itself, but also in the estuarine basins that extend from its banks towards the Gulf of Mexico. This article describes how over the past several decades different modes of porosity have emerged in scientific and public discourse around water management. The science and politics of these competing modes of porosity animate a great deal of environmental decision-making in the region today. The article's analytical framework bridges research focused on the theme of porosity in port city territories, the political ecology of infrastructure standards, and management pathologies in ecosystem management.

Keywords

dredging; infrastructure; management pathologies; Mississippi River; ship channels; urbanized deltas

Issue

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1. Introduction

Ship channels are critical pathways for waterborne trade, supporting economic activities across vast areas, and driving land use/land change dynamics in port city territories (Hein, 2021; Rodrigue, 2020). Sea level rise, increasing storm intensities, and other phenomena related to climate change present significant threats to the operation of coastal/riverine ship channels and port city territories in the coming decades (Carse & Lewis, 2020; Lewis & Ernstson, 2019). These threats are especially acute in low-lying river deltas, home to between 328 (Edmonds et al., 2020) and 500 (Giosan et al., 2014) million people, nearly 90% of whom live in latitudes where tropical cyclones are an annual threat (Edmonds et al., 2020). A recent study by Edmonds et al. (2020) estimated that 41% of the global population exposed to tropical cyclone threats reside in river deltas. Recent analyses examining current and future risks associated with global inland waterways and climate change showed that infrastructure investments in regions with relatively high GDPs like the Rhine and Mississippi systems have achieved a high degree of stability and sustainability (Tessler et al., 2015; Wang et al., 2020). However, Tessler et al. (2015) also point out that future changes in energy costs and economic growth could trigger a crisis in which the maintenance demands of these systems lead to increased risk for both the Rhine and Mississippi navigation systems. These findings shed light on the massive financial and technological demands involved with maintaining delta sustainability in systems subject to complex infrastructural interventions and climate risks.

The Mississippi River Ship Channel (MRSC) is a deep-water ship channel maintained through the Lower Mississippi River, extending 410 km between the city of Baton Rouge and the Gulf of Mexico. The ports of South Louisiana, New Orleans, St. Bernard, and Plaquemines comprise along with Baton Rouge the largest port cluster in the United States by volume (Hartman et al., 2022). The MRSC port cluster connects oceangoing trade routes with the Mississippi River Navigation System and the Gulf Intracoastal Waterway, making it a central node in the largest and most utilized network of inland waterways on Earth. This strategic location has driven the growth of the region's ports and riverbank communities, including the City of New Orleans, which anchors the broader port city territory. The MRSC was recently deepened to a standardized depth of 15.2 m (50 ft) to match the dimensions of the newly expanded Panama Canal. Several major new investments in port terminals are currently being considered and undertaken, including a $21 billion liquified natural gas terminal in Plaquemines Parish and a planned $1.8 billion container terminal for the Port of New Orleans. These recent investments underscore the continued growth in port and maritime industrial facilities in the region. The MRSC's banks are home to one of the largest petrochemical and chemical processing/manufacturing clusters in the United States, a sector still experiencing growth despite public concern over air and water pollution (Younes et al., 2021). Another growth area is the export of bulk agricultural commodities. Soybeans, corn, and other grains are shipped by barge through the Mississippi inland navigation system to the MRSC for export. The recent deepening of the MRSC creates additional incentives for agricultural export terminals. Containerized shipping represents a significant but relatively small portion of trade through the MRSC, though a newly planned container terminal near New Orleans aims to make the region more competitive in the container trade.

As trade volume grows in the region, the landscape itself has been shrinking for over a century. Between 1932 and 2016, the Mississippi River Delta (MRD) experienced the loss of 5,000 km^2 of land (Blum et al., 2023). The vulnerability of the MRD to accelerating rates of land loss due to sediment starvation, sea-level rise, subsidence, and several other factors is also well documented. In the nearly two decades since Hurricane Katrina struck the region in 2005, the City of New Orleans and coastal Louisiana have become global avatars for the risks that climate change poses to urbanized coasts and deltas. The measures being undertaken to address this crisis have also garnered attention from scientists, planners, and environmental advocates in recent years. The State of Louisiana's Coastal Master Plan, a well-financed and scientifically robust suite of restoration projects, has been promoted as a global model for climate adaptation (Kline & Maloz, 2023), and has been subject to scrutiny and critique from social scientists (Barra, 2021; Domingue, 2022; Nost, 2019). A central focus of the coastal master plan is the reintroduction of riverine freshwater and sediment into the deltaic plain to mitigate land loss. The planned diversions of the Mississippi are promoted as critical for the long-term sustainability of MRD and its communities and industries, while critics have pointed to potential negative impacts on navigation and fisheries as a reason to reconsider the approach, instead prioritizing the use of dredged material to rebuild land (Lewis & Ernstson, 2019).

The proliferation of naturally occurring passes (or *crevasses*) along the lowermost sections of the MRSC has brought these competing visions for the MRD and MRSC into sharper focus (Figures 1 and 2). A recent analysis by geomorphologists and hydrological modelers at Tulane University found that the final reach of the MRSC through the "birdfoot" of the lower delta is increasingly unstable due to sediment deprivation and marine encroachment. As a result of recent flooding events, hurricane impacts, and containment breaches, only 20% of the river's freshwater and 5% of its sediment load is reaching the terminus of the MRSC at the Gulf of Mexico (Allison et al., 2023). The decreasing supply of sediment and reduction in stream power is occurring at precisely the moment that new value is being placed on these flows for their potential to reduce land loss further upstream. Balancing the needs for efficient navigation, coastal restoration, and flood protection is becoming challenging for responsible agencies in the region. This article provides an overview of recent developments in the management and operation of the MRSC and articulates a conceptual framework for grappling with the management pathologies that animate the politics of hydrological porosity along the MRSC.

2. Conceptual Framework

2.1. Infrastructural Zones, Hydrocracies, and Disturbance Regimes

Infrastructural zones are complex systems which apply technological interventions to link environmental, hydrological, and economic systems through standards (Barry, 2006; Carse & Lewis, 2017). In the case of navigable waterways, locks, levees, pumps, floodwalls, dredging technologies, and bank protection structures are all utilized to ensure the smooth circulation of goods and prevent flooding in communities. Infrastructural zones are designed and managed by large, sometimes transnational water bureaucracies or "hydrocracies" (Molle et al., 2009) that work to ensure waterway connectivity and predictability. The need for consistent waterway dimensions, efficient transit times, and safe docking conditions has led to decades and even centuries of layered hydrological modifications in such regions (Carse & Lewis, 2017). Establishing port city territories in river deltas involves the modulation of historical patterns of environmental disturbances like river floods and coastal storm surges to enable urbanization and

Figure 1. Porosities along the MRSC during the 2019 flood. Notes: The black dashed line shows MRSC; the white dashed line shows the route of Mississippi Gulf Outlet (MRGO); the red lines show flood protection levees; the yellow arrow shows flood control spillway; the white arrows are naturally occurring channels or outlets; the blue arrows are existing and planned coastal restoration projects; the arrow size represents approximate relative flow rates; the red dot indicates Head of Passes; all flows in cubic meters/second; the water losses were measured on March 10, 2019, during a maximum flow scenario below Bonnet Carre Spillway (40918 cm/s at Tarbert Landing). Source: Author's work based on ESRI images and the analysis in Allison et al. (2023).

waterborne transportation. The disturbance regime concept is intended to capture the varying ways that the frequency and magnitude of disturbances like floods, fires, and droughts undergird broad-scale ecological patterns (Turner, 2010). For example, levees designed to prevent overbank flooding along the MRSC deprived deltaic wetlands of freshwater and sediment input, contributing to staggering rates of land loss and compromising ecosystem function and resilience in the region (Edmonds et al., 2023). This demonstrates how infrastructural zones can modulate disturbance regimes, altering the historical range of variability that previously determined landscape-scale environmental dynamics. In response to the unintended consequences of these changes, hydrocracies are being called upon to implement so-called "nature-based" or "green/blue infrastructure" strategies. However, no simple solutions exist for reestablishing the historical disturbance regimes in systems that have been so profoundly altered. These efforts are confronting centuries of path dependencies and infrastructural/institutional lock-ins that circumscribe the potential nature-based initiatives precisely when they are most urgently needed (Markolf et al., 2018).

2.2. Management Pathologies

Management pathologies have been the focus of considerable research in ecosystem management and the study of social-ecological systems (Allen & Gunderson, 2011; Cox, 2016; Holling & Meffe, 1996). Scholars in this area have identified common tendencies within water governance bureaucracies that prevent broad stakeholder engagement and the adoption of adaptive management strategies. In delta systems like the Lower Mississippi, environmental and water governance systems were largely developed with a "command and control" philosophy deeply embedded in the design and management of water systems and infrastructural zones (Carse & Lewis, 2017; Holling & Meffe, 1996). Environmental change and extreme events are increasingly reaching magnitudes and frequencies that existing systems can no longer efficiently absorb. Each earlier wave of adaptation, the deepening of a ship channel for example, or the construction of flood diversion structures constrain contemporary attempts to maintain deltaic sustainability in the face of accelerating change. According to Holling and Meffe (1996, p. 329), the command-and-control approach:

> Implicitly assumes that the problem is well-bounded, clearly defined, and generally linear with respect to cause and effect. But when these same methods of control are applied to a complex, nonlinear, and poorly understood natural world, and when the same predictable outcomes are expected but rarely obtained, severe ecological, social and economic repercussions result.

As centuries of layered infrastructural interventions in natural systems reflecting these pathologies accumulate and face changing patterns of environmental disturbance, cascading sequences of unpredictable events can begin to unfold (Carse & Lewis, 2017; Cox, 2016; Lewis & Ernstson, 2019).

A multi-scalar matrix of economic and political power clustered around ship channels influences the dynamics of political contention surrounding their adaptation. This arises through the combination of economic and environmental dynamism that characterizes deltaic port city territories. Different economic or public policy goals generate varied engineering strategies for hydrological control, with constellations of interests seeking to optimize the territory for economic development goals. Port city territories have economic constituencies that extend far beyond the territory itself, adding political complexity to seemingly localized hydrological management decisions. For instance, New Orleans and Rotterdam serve as transhipment points between oceanic trade networks and inland waterway systems. Oceanic and inland navigation systems are utilized by different shipping technologies: large ocean-going vessels entering from the sea and inland vessels like barges arriving from within the continent. These port city territories are thus organized to stitch together infrastructural zones with different standards, in this case, deep and shallow waterway dimensions (in addition to road, rail, and pipeline connections). This interstitial character also alters the economics and politics of environmental governance in the port city territory and its major shipping channels. Agricultural commodity, global shipping, energy firms, and even individual farmers operating thousands of kilometers away have a direct stake in how hydrological flows are configured in port city territories. Conversely, this may mean that natural systems with a high value to small-scale, local interests (take fisheries for example) may be devalued relative to the demands of the major industries that seek to optimize port-city territories and ship channel systems for navigation alone.

The command-and-control system that frequently governs large navigable waterways has historically negotiated this complexity with crude bureaucratic instruments like cost-benefit analysis or other mitigation mechanisms (Carse, 2021). With the operation of large global shipping and commodity firms in the balance, local interests may find that their political power to guide key decisions regarding infrastructural zones may be constrained. Indeed, in many countries, political and patronage relationships between hydrocracies, political leaders, and businesses form so-called "iron triangles" (McCool, 1994). Molle et al. (2009, p. 337) describe iron triangles as "systems of vested interests that encourage…overestimation of benefits and neglect of costs in order to secure a steady flow of projects." This assessment is echoed by Holling and Meffe (1996, p. 331), who suggest that management pathologies often lead to "less resilient and more vulnerable ecosystems, more myopic and rigid institutions, and more dependent and selfish economic interests all attempting to maintain short-term success." The authors continue with a warning that command-and-control approaches to challenges like flood control and navigational access in the MRSC are typically successful initially, but ultimately "the result is increasing dependency on continued success in controlling nature while, unknown to most, nature itself is losing resilience and increasing the likelihood of unexpected events and eventual system failure" (Holling & Meffe, 1996, p. 331). While recent policy development has emphasized "nature-based solutions" that better attend to ecological impacts of infrastructural zones, the same hydrocracies that dominate water resources development retain some control over such programs, exposing them to the influence of management pathologies despite programmatic or discursive shifts.

In the case of the MRSC and MRD region, the preeminent hydrocracy is the United States Army Corps of Engineers (USACE), a branch of the military with a broad mandate to manage water resources, build and maintain flood protection systems, and maintain waterborne transportation systems. Increasingly, the USACE has also developed programs that emphasize *engineering with nature*, an attempt to mitigate the pathologies inherent to command-and-control approaches and better balance economic development and natural resources management. It bears mentioning however that this also represents more authority and scope for the USACE in water management, not less, and will likely mean that more public finances will flow to the USACE to build and maintain projects framed discursively as green infrastructure, nature-based solutions, or as mentioned above, engineering with nature. Following Hurricane Katrina in 2005, the State of Louisiana established the Coastal Protection and Restoration Authority (CPRA). This state-level agency, established in 2007, drew inspiration in part from the Dutch state's Rijkswaterstaat. The CPRA, infused with legal settlement funding following the BP oil disaster in 2010, has been gradually challenging the historical role of the USACE in the areas of ecosystem management. While the USACE now focuses primarily on its navigation and flood protection role along the MRSC, the CPRA and its supporters have moved forward on an ambitious plan to increase the MRSC's porosity for coastal restoration purposes. This emerging tension speaks to our next section exploring competing modes of porosity along the MRSC.

2.3. Modes of Porosity

The concept of "porosity" has recently received attention in this journal as a way of viewing planning dilemmas in port city territories (Hein, 2021). This thematic issue included several fascinating case studies viewed through the lens of porosity and its attendant concepts of boundaries, flows, and territories was explored. Interestingly, given porosity's frequent usage in relation to the movement of water, the issue broadened this to explore the movements of people, characteristics of the built environment, and the movement of capital. In this article, I will draw on this work but in a perhaps more orthodox way—Here I am interested in the hydrological porosity of the MRSC itself, as well as the porosity of the estuarine landscapes through which the channel passes. In doing so I identify three *modes of porosity* that have historically competed for influence along the MRSC and port city territory of New Orleans (Table 1). Within the three modes of porosity, I identify intensities (high/low) and configurations of porosity emphasized in each. By *riverine porosity*, I am referring to the spatial patterns and flow intensities of freshwater and sediment from the Mississippi's main channel/distributaries into surrounding deltaic wetlands, though during low water this flow can be reversed with marine waters entering the MRSC channel. *Estuarine porosity* refers to the spatial patterns and flow intensities through which marine waters and sediments penetrate and circulate within the deltaic wetland landscapes in the MRSC's vicinity. *Mixed riverine porosity*, here explored in the context of flood control, refers to the varied spatial patterns and flow intensities that engineers seek to optimize to reduce riverine flood risk to infrastructure and human settlements. It should be noted that this is not an exhaustive hydrological typology, but is intended to capture the dominant modes of porosity inscribed into infrastructural zones in the study region.

Each mode of porosity explored here can be viewed as distinct imaginaries of an ideal disturbance regime for the region. The higher riverine porosity currently occurring in the MRSC's lower reach is a window into the natural disturbance regime that created the landscape itself via overbank flooding and crevasse formation. Lower estuarine porosity translates into reduced maritime encroachment, and in some instances, a broader range of estuarine salinities (and therefore landscape diversity). Engineers and planners in the region are engaged in a process of discerning the benefits and limitations of each of these modes, understanding where they may overlap in some circumstances, and balancing the tradeoffs between constituencies clustered around them.

2.3.1. The Navigation Mode

The first mode of porosity we can identify is the *navigation mode*. In this view of the deltaic system, efficient and predictable navigational access to port terminals is paramount. Historically this has been pursued by maritime industrial interests and state authorities through command-and-control interventions (Barry, 2007; Lewis,

Table 1. Modes of porosity in the MRSC context.

Mode of porosity	Emphasis	Hydrocracies and constituencies	Engineering tools
Navigation	Low riverine porosity, high estuarine porosity	USACE, maritime industry, port authorities	Navigation dredging, levees, port terminals, navigation locks, and shipping canals meant to maximize economic flows
Flood control	Mixed riverine porosity, low estuarine porosity	USACE, nearly all residents, businesses, most local interests	Levees, floodwalls, pumping systems, and spillways meant to strategically manage river flows
Delta mimicry	High riverine porosity, low estuarine porosity	CPRA, environmental NGOs, conservation organizations, freshwater fishing interests	Freshwater and sediment diversion structures meant to build land and mitigate land loss over a multi-decade time scale, restoration of compromised distributary ridges

2019). The infrastructural zone organized around this mode includes river levees, jetties, navigation locks, shipping canals, and bank protection systems. Dredging plays a central role both in terms of maintaining standardized depths within the MRSC and also creating linear shipping canals through estuaries to enhance navigational access. This mode emphasizes the low porosity of the MRSC channel and Mississippi River, while historically prioritizing high porosity within the estuarine ecosystems comprising much of the delta's landforms. Pathologies associated with this mode arise from the economic imperatives of waterborne transportation for the local, national, and global economies. The demands of navigation interests have historically far overpowered local concerns over flood risk and ecosystem impacts from near complete MRSC containment, in line with the pathologies of command-and-control approaches described above (Lewis & Ernstson, 2019).

Prior attempts at achieving maritime connectivity via estuarine porosity led to disastrous outcomes for communities and ecosystems. These failures effectively rendered the MRSC the obligatory point of passage for ocean-going deep-water trade in the Mississippi system and limited possible solutions to emerging contemporary navigation issues. The MRGO Channel was a 120 km long ship channel dredged through the Lake Borgne and Breton Sound estuaries southeast of New Orleans in the late 1950s (Figure 1). The channel was intended to become the main ship channel for the Port of New Orleans, reducing transit times and avoiding the water level variations, mouth shoaling, and fog on the MRSC that caused problems for navigation access. The project was supported by economic interests and political leaders throughout the Mississippi Basin like bulk agricultural export companies (Freudenburg et al., 2012). Because the MRGO directly accessed the urban center of New Orleans by connecting with an inner harbor canal, the MRGO was an attempt by port officials in New Orleans to preempt port regionalization along the MRSC, attracting the bulk of oceanic trade into the city itself, and opening up large areas of marshlands in the eastern part of the city for maritime industrial development. The Port of New Orleans, local political leaders, and USACE were closely linked institutions in the 1950s, with a revolving door of leadership between the two, an arrangement described by scholars as an "iron triangle" or "growth machine" (Freudenburg et al., 2012; Youngman, 2015).

The dredging of the MRGO altered the disturbance regime in the estuaries east of New Orleans, perforating coastal ridges that controlled tidal circulation and salinity over a 2,500 km^2 area, and led to the direct destruction or habitat conversion of 265 km^2 of deltaic wetlands (Day et al., 2006). The loss of storm surge-buffering wetlands brought on by this increase in estuarine porosity elevated flooding risk in New Orleans dramatically, and the MRGO was a key conduit for floodwaters during Hurricane Betsy in 1965 and Hurricane Katrina in 2005 (Shaffer et al., 2009). Due to these destructive impacts, the MRGO was decommissioned by the US Congress in 2008, and new flood protection measures were undertaken in the area, including a massive storm surge barrier that enclosed part of the Lake Borgne estuary, reducing the porosity of the degraded wetlands along the city's eastern margin.

The MRGO's economic promise also never fully materialized, and, by 1998, 95% of ships were simply using the MRSC instead (Campanella, 2022). The dramatic environmental changes triggered by the MRGO (e.g., land loss, subsidence) prevented maritime industrial expansion along its banks, and the broader process of port regionalization along the MRSC had already begun by the time the channel was completed. The MRGO's failure solidified a "river only" navigation scenario, where the MRSC became the only option for most ocean-going trade. These events influence contemporary decision-making around the MRSC, where discussions of "alternative outlets" for navigation in the face of looming environmental changes confront political opposition forged through the experience of flooding and economic losses from the MRGO (Lewis & Ernstson, 2019). Projects like river and sediment diversions, which ostensibly would help address some of the ecological damages wrought by the MRGO face resistance from coastal communities and fishing groups. The MRGO catastrophe undermined public trust in hydrocracies, and the echoes of this failure are frequently heard in public hearings about MRSC management and new port investments (Lewis & Ernstson, 2019).

2.3.2. The Flood Control Mode

The second mode of porosity in our case is the *flood control mode*. Like the navigation mode, this mode has historically emphasized the containment of the Mississippi River and urban settlements behind levees and other flood control structures. Management pathologies in this mode usually relate to forced tradeoffs between navigational access, urban spatial planning, and fisheries health. The pursuit of river containment has on the one hand prevented overbank flooding in populated areas and enabled greater urbanization in the delta by attenuating risks associated with annual riverine flooding. This effort to limit the river's porosity had the major side effect of depriving nearly the entire deltaic plain of new freshwater and sediment inputs, which along with other drivers, has triggered a land loss crisis that threatens the entire region with coastal inundation (Blum & Roberts, 2009). As infrastructural zones reduced riverine porosity and the frequency and/or magnitude of flood disturbances, urbanization expanded into areas previously deemed too hazardous. As disturbance regimes began to change in response to infrastructural zones, novel vulnerabilities emerged, making infrastructure failures more costly and potentially deadly for people (Kates et al., 2006). This phenomenon is referred to by scholars as the "levee effect" (Collenteur et al., 2015) or "safe development paradox" (Breen et al., 2022; Burby, 2006). In the case of communities along the MRSC, river and perimeter storm surge levees reduce both riverine and estuarine porosity, preventing flooding for annual and fairly typical disturbances, while dramatically increasing potential losses when flood control standards are overwhelmed by extreme events (Kates et al., 2006).

In the case of the MRSC, the pathologies associated with the "levees only" approach were recognized following a major river flood in 1927. The USACE constructed two large flooding diversion structures upriver from New Orleans, signifying a willingness on the part of the nation's dominant hydrocracy to allow greater porosity along the MRSC, but in highly controlled and strategic locations which enabled impacts to be managed. Spillways like the Bonnet Carre near New Orleans were not intended for ecosystem restoration purposes, and indeed significant fisheries losses and natural resource damages can be incurred during their use (Posadas & Posadas, 2017). Flood control, as previously mentioned, has also contributed to the overall degradation of the lower MRD via sediment, freshwater, and nutrient starvation of deltaic wetlands. As this degradation process has taken hold in the past century, marine encroachment into previously freshwater wetlands has created more favorable fishery habitats for certain commercially important species like shrimp, oysters, and finfish. As fishing communities adapted to this mode of porosity and its attendant disturbance regime and ecological systems, over decades, an additional pathology emerged: Increasing riverine porosity for flood control or ecosystem restoration is now likely to negatively impact marine fisheries, despite the practice reflecting the historical disturbance regime and range of hydrological variability. This can be observed in contemporary disputes over the reintroduction of river flows into deltaic wetlands that place fishing interests at odds with both flood control agencies and ecosystem restoration advocates (Lewis & Ernstson, 2019).

2.3.3. The Delta Mimicry Mode

The final mode of porosity is *delta mimicry*. Actors within this mode generally advocate for high riverine porosity, restoring aspects of the delta's historical disturbance regime. Reduced estuarine porosity is also frequently advocated, through both restoration of coastal ridges and perimeter marshes and in-filling of fragmented interior wetlands via sediment diversions. Within this mode, we find a political assemblage comprised of primarily urban residents, state lawmakers, large national environmental NGOs like the National Wildlife Federation and Environmental Defense Fund, the state hydrocracy CPRA, and, increasingly, the USACE with its "Engineering With Nature" program. This mode emphasizes high MRSC porosity both through naturally occurring overbank flooding and new distributary formation in the river's lower uninhabited reaches and through large-scale sediment diversions slated to begin construction in 2023. These sediment diversions are designed to capture bedload sand and suspended river sediments and convey them into estuarine basins lining the MRSC banks. Proponents point to overbank flooding and crevasses that were the main physical process through which the delta itself was built over millennia. Discourses around "allowing nature to take its course" and other organicist ontologies are prevalent in this mode (Snell, 2022). In reference to strategically placed and heavily engineered river diversions soon to begin construction, the executive director of the CPRA recently stated that "the fundamental problem in coastal Louisiana is [a] lack of sediment, and so we're trying to mimic the way Mother Nature would have delivered that sediment to our coast in the past" (Santana, 2019). As the MRSC begins to lose containment in its lower reaches, proponents of the delta mimicry mode have advocated for leaving these new outlets open to allow the Mississippi to flow into nearby estuaries, leading to tensions with navigation and fisheries interests (Snell, 2022).

The broader impacts of sediment diversions and the emerging loss of containment on the MRSC can be veiled through discourse claiming that these developments might restore a "natural" or "balanced" deltaic system. Due to the temporal sequence of infrastructural zone development and altered disturbance regimes, projects promoted for their "natural" attributes also carry significant risks to commercial fisheries and marine mammals that have taken advantage of the more saline estuarine conditions brought on by the flood control measures (Smith, 2023). A further contradiction with delta mimicry occurs during acute low water stages resulting from droughts. Higher salinity water is denser than freshwater, creating a wedge of saltwater along the river bottom, especially during low water. The passes/crevasses (pores, for our purposes) along the lower MRSC provide additional pathways for marine encroachment into the main river channel. The propagation of this saltwater wedge upstream places drinking water intakes for communities at risk of contamination. During low water years, like 2022, the USACE has been forced to build a massive underwater sill structure along the river bottom to intercept the saltwater wedge. In this sense, the MRSC bank failures hailed by delta mimicry proponents as environmentally beneficial may also negatively impact drinking water quality in New Orleans and other nearby communities.

3. Looming Transitions Along the Mississippi River Ship Channel

Climate change threatens to further alter the frequency and magnitude of floods and storms, presenting novel conditions that may exceed flood protection levels in unexpected ways and trigger abrupt environmental changes. In the spring and summer of 2019, a sequence of hydrological and meteorological events

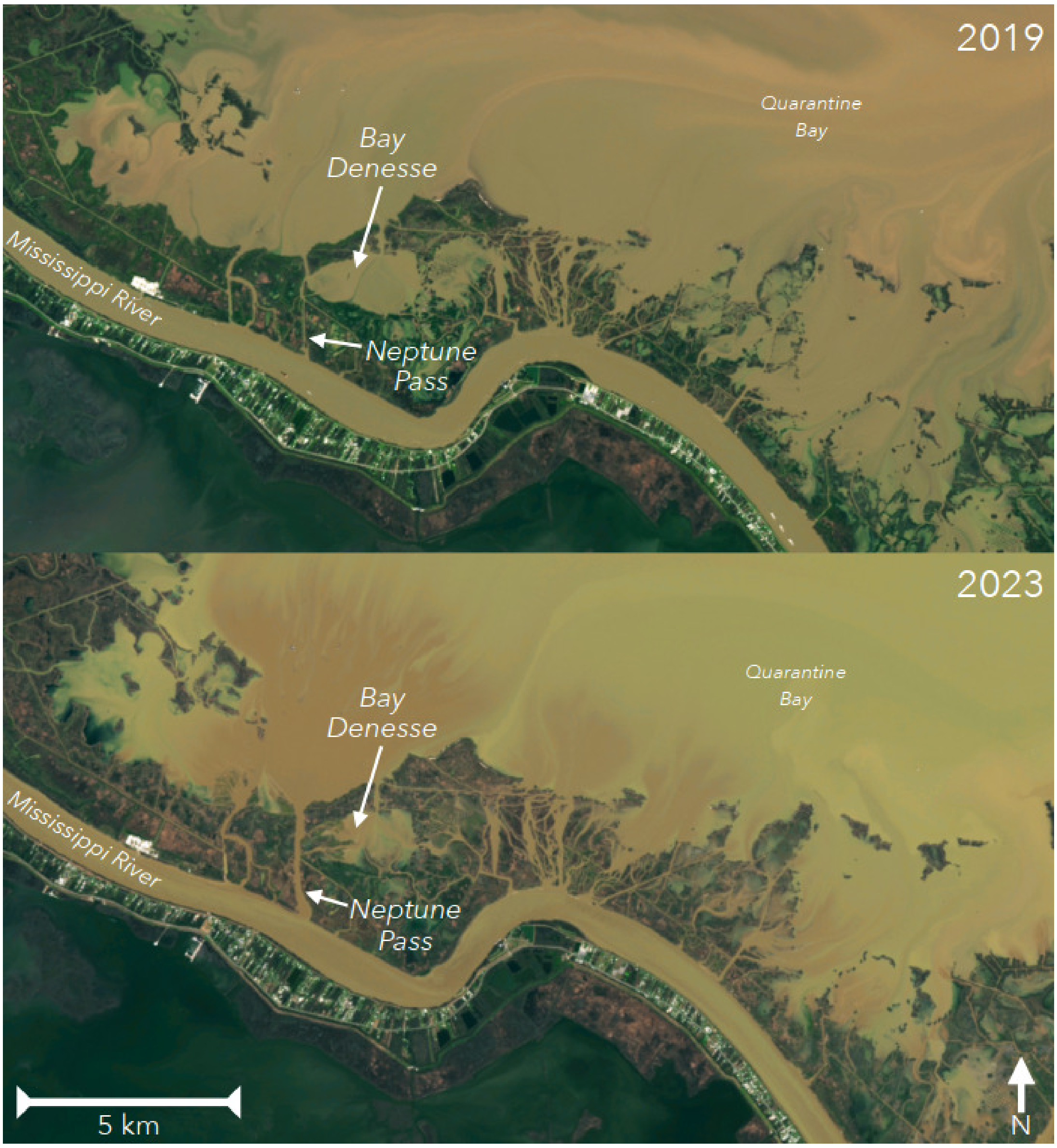

Figure 2. Expansion of Neptune Pass and nearby outlets between 2019 and 2023: Widening of outlets and land formation in Bay Denesse, as well as suspended sediment on the north side of the river versus the lack of sediment on the southern side where levees preserve channel containment. Source: Author's work overlaying USGS Landsat 8 Imagery (see Nussbaum, 2023).

revealed serious problems with the infrastructural zones governing the MRSC. The Lower Mississippi River experienced its longest flood stage duration ever recorded, exceeding the previous record set during the 1927 flood. The Bonnet Carre Spillway, a flood control structure designed to mitigate riverine flood risk and maintain consistent navigation conditions was opened twice in a single year for the first time, and remained open for several months, injecting unprecedented volumes of freshwater and nutrient loads into coastal estuaries near New Orleans, producing harmful algal blooms and impacting marine fisheries up to 100 km away (Parra et al., 2020; Schleifstein, 2022). Navigation was disrupted along the MRSC and further upstream in the inland navigation system by the high water, interrupting bulk agricultural commodity exports through New Orleans (Sullivan et al., 2019). With the Mississippi still in flood stage into the summer, an early season hurricane approached the Louisiana coast, generating an alarm in the region that a storm surge near the MRSC mouth could cause storm surge to propagate upriver, potentially causing riverine flooding in New Orleans for the first time in over a century. Initial forecasts of a 20 ft (6.1 m) river crest in New Orleans, fortunately, did not materialize. Such a crest could have overtopped river levees in the city and wider region (Schleifstein, 2019). The summer of 2019 signaled that climate change's expected impacts in the region, which are likely to include higher flood stages for longer durations and increasingly frequent and intense tropical storms, were perhaps already evident.

The 2019 flood also exposed worrying trends at the mouth of the MRSC, at the tip of the river delta known as the "birdfoot," so named for its exposed sinuous shape extending into the Gulf of Mexico (Figure 1). This shape reveals an important reality—This landscape is a historical anomaly. Previous delta lobe formations have likely not extended as far towards the continental shelf (Blum et al., 2023). The birdfoot is an artifact of the infrastructural zones in place to prevent riverine flooding and maintain navigational access. Flood control and navigation interventions like levees, jetties, and dredging have historically increased stream power in the river's lower reach and helped maintained ship channel containment. Without these modifications, the river's main distributary would have likely shifted further upstream in the past century, as it would naturally seek the shortest route to the Gulf by gravity during high-water events. Even so, multiple flooding events in the past two decades have led to an increasing share of the river's flow escaping the main channel along a portion of its east bank where levees are lower or nonexistent and no human settlements exist to incentivize further interventions (Figures 1 and 2).

The aforementioned study by Tulane researchers (Allison et al., 2023) shows that the Mississippi is losing a significant portion of its stream power, flow volume, and sediment load before it reaches its terminus in the Gulf of Mexico. The analysis showed that only 20% of the river's freshwater and only 5% of its suspended sediment reaches the Gulf. The MRSC's main channel through Southwest Pass was losing an additional 50% of its freshwater just in its final reach below the head of passes (Figure 1). This trend has gathered pace significantly over the past two decades, as bank failures have proliferated during recent floods and new artificial diversions have been opened to stave off land loss further upstream. This trend has several implications, including, according to Allison et al. (2023), "river containment and the sustainability of the navigation channel is threatened." Some of the effects of this process are already becoming apparent. The decrease in stream power is likely to blame for the increasing dredging demands in the southwest pass of the MRSC. Historically, the river has only required dredging in its lower reach below a consistent point at and below the head of passes, where the river branches out into its final major distributaries. As the edges of the lower MRSC become more porous, stream power and velocity decrease, leading to greater volumes of sediment being deposited in the streambed. This is increasing dredging demand, and the point at which dredging operations are necessary is gradually shifting further upriver and triggering draft restrictions (Hartman et al., 2022). The analysis shows further that this deprivation of sediment in the delta's terminal reach may lead to increased maritime encroachment, and ultimately, rising instability of the birdfoot landform itself. In short, the infrastructural zones designed to confine the river are reaching the limits of delta progradation in their current arrangement, suggesting that the risk of rapid delta backstepping (landward retreat) may be looming.

A debate has developed over what to do about these new distributaries forming in the MRSC's lower reach. For navigation interests and the USACE hydrocracy, the channel of the MRSC needs to remain as integral as possible, which will increase stream power and reduce sedimentation and dredging demands. For interests more aligned with a delta mimicry mode of MRD porosity, the loss of MRSC containment demonstrates precisely the power of the river to create new land and mitigate land loss. Indeed, new delta splays have emerged in the past two years at Neptune Pass and other new openings (Figure 2). For environmental groups and residents concerned with land loss and the increased coastal flooding hazard it represents, these developments serve as a proof of concept for the highly engineered sediment diversion structures soon to be constructed further upstream. Creating additional outlets for river and sediment flow, artificial or naturally occurring, could further compound the dredging issues and navigation concerns at the Southwest Pass of the MRSC. Whether or not greater porosity in the MRSC lower reach would mitigate potential storm surge propagation upriver has not been firmly established at present.

These dynamics in the birdfoot of the delta are relevant for port and maritime planning closer to the urban core of New Orleans. For the past two decades, competing proposals for container terminals have coalesced. One proposal has advocated for building a massive intermodal container terminal in the birdfoot itself, only a few kilometers from the MRSC's terminus (Figure 1). This proposal failed to attract sufficient financing and regulatory approval, was widely criticized for its hazard-prone location, and was superseded by the proposal for a similar terminal some 80 km further upstream. Investors and partners in this second project have also recently pulled out when the Port of New Orleans acquired land only 20 km downstream from the current container terminal, which, unlike most major container terminals, remains located near the city center (McCormack, 2022). Like the hydrological and geomorphological dynamics of the lower MRSC, the container terminal proposals have been migrating upstream, as has the human population in riverside communities. Between 2000 and 2020, there was a 60% decline in population in communities downstream from Mardi Gras Pass (Figure 1; US Census Bureau, 2023). The Port of New Orleans' proposed container terminal closer to the urban core (Figure 1) is facing staunch political opposition from the communities around the proposed site, with opponents frequently referencing the port's failed MRGO project as a reason to doubt the port's claims that the terminal would benefit local communities (Chapman, 2022). MRSC channel instability and ongoing land loss in the river's lower reach are pushing infrastructure investment upstream, while community opposition to port regionalization is placing pressure back downstream. This social-hydrological "squeeze" effect (combined with the failure of the MRGO project) threatens to limit the spatial range of port regionalization in the future.

4. Conclusions

With the limits of delta progradation potentially at hand and the possibility of delta backstepping emerging, the centuries-long arc of disturbance regime alteration through infrastructural zones is confronting new patterns of extreme events. As a USACE official stated at a recent panel, "We don't have normal river years anymore, it always changes" (panel discussion, Kornick, 2023). This uncertainty vexes a system of global economic exchange that thrives on standardization and predictability. As political constituencies and economic interests cluster around different modes of porosity, emerging contradictions and pathologies have created a landscape of high-stakes political contestation around MRSC and coastal estuary management that eludes straightforward solutions. Barring the emergence of stronger coordination among these interests, critical decisions around the future alignment of the MRSC in its lower reach, the fate of the birdfoot landmass, and the sustainability of human communities in the area may only occur when abrupt environmental changes or disturbance events force a public policy response. This sentiment was expressed by a representative of navigation interests at a recent panel discussion, who warned that "if we don't secure the eastern side [of the MRSC], somebody else might be making decisions for us" (panel discussion, Duffy, 2023), implying poorly coordinated policy responses will ultimately cede major decisions around the MRSC to dynamics of the river itself.

Different modes of porosity point towards narrow policy prescriptions to confront future uncertainty. Dredging, engineered river diversions, and "naturally" occurring passes and crevasses are all posited by proponents as singular best practices in public events and communication materials. The USACE operates a "beneficial use" program for the dredged material it excavates from the MRSC, pumping sediment over MRSC banks and into adjoining estuaries, creating new platforms for marsh colonization. The bulk of this program, however, is focused on the birdfoot. While these landforms may modestly contribute to MRSC bank stability, the storm surge mitigating effects for cities and other settlements is not established. Similarly, proponents of the delta mimicry mode may be technically correct that the newly opened outlets in the lower MRSC represent "free diversions" that will build new land (Snell, 2022). However, the land built by these outlets is not in a highly strategic area for land loss mitigation or storm surge buffering and will take decades to build significant acreages—during which sea level rise may nullify the benefits. For delta mimicry skeptics, the beneficial use of dredged material further upstream, closer to New Orleans, represents an alternative solution to coastal land loss—quickly creating new land (panel discussion, Duffy, 2023). Whatever the eventualities, the dredging industry will see its business opportunities grow. Greater porosity in the MRSC, engineered or "natural," will increase the need for navigation dredging to maintain MRSC standard depths. Decreased MRSC porosity or poor performance of sediment diversions may lead to increased demand for beneficial use and dredge and fill operations to address land loss. Proponents of the delta mimicry mode point to the fuel costs and carbon footprint of dredging operations, arguing for natural and engineered river diversions as a low-carbon option that can be operated for decades at low cost once the initial diversion structure is built (Renfro, 2022).

The CPRA hydrocracy is occupying a novel space vis-à-vis these competing modes of porosity. To implement its ambitious coastal master plan, it must work against the pathologies of the flood control, navigation, and delta mimicry modes, synthesizing their critical insights and avoiding any totalizing ontological positions they may carry about the proper infrastructural matrix for the MRSC in the coming century. Regardless of the sustainability of the region and its population centers, access to the Mississippi River's inland navigation system is an economic imperative for the United States and the global economy. The potential shifts at the MRSC's terminus are a harbinger of the hydrological, geomorphological, and ecological future of the region. The political assemblages and public debates animating infrastructural responses to this process will, as I have argued here, cluster around competing modes of hydrological porosity in the MRD.

Acknowledgments

This research was supported by an Early Career Research Fellowship from the National Academies of Sciences Gulf Research Program. The author would like to acknowledge Ehab Meselhe, Barbara Kleiss, and Mead Allison for their input on the ideas and analysis in this article.

Conflict of Interests

The author declares no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 275–288
https://doi.org/10.17645/up.v8i3.6892

Article

Shaping the New Vistula Spit Channel: Political, Economic, and Environmental Aspects

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Submitted: 1 March 2023 | Accepted: 5 July 2023 | Published: 26 September 2023

Abstract

In September 2022, the new shipping channel in Poland was opened for service. It connects the Port of Elbląg and the Gdańsk Bay in Poland, cutting through the Vistula Spit and the Vistula Lagoon. It was intended to enable direct access to the Baltic Sea from the Port of Elbląg without crossing Russian territory. Originally conceptualized decades ago, it has taken its final shape only recently. Its construction was associated with several issues, including economic, political, and environmental ones. But at the same time, the rationale of its construction has to be confronted with the analysis of the long-term consequences for the city's economy and the environment of the Vistula Lagoon. Many of these issues are presented and discussed in the article, along with some initial conclusions regarding future opportunities and threats associated with operational and maintenance-related issues.

Keywords

access; Elbląg; infrastructure; Vistula Lagoon; Vistula Spit

Issue

This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

The Port of Elbląg is located in northern Poland (Figure 1). The port is connected to the Vistula Lagoon, part of the internal marine waters of the Baltic Sea, through the River Elbląg. Providing access to the Port of Elbląg has been an important issue since medieval times. Being one of the many ports located within the Gdańsk Bay area, it gradually lost its importance to other main cities in the region—mainly Gdańsk and present-day Kaliningrad (former Konigsberg; see Krośnicka et al., 2021). At the same time, it has become a part of the porous harbor region (Hein, 2021), subdivided by numerous boundaries—including political ones. Additionally, due to changes in inland water management (mostly related to the Vistula River delta), the Port of Elbląg has become more shallow. As a result, it lost its commercial importance and has become a tertiary port center when compared to Gdańsk and Gdynia. Still, along with other small- and medium-sized ports, it has become a potential hub of water-based recreation and tourism (Palmowski, 2010). This was further spurred by the fact that in the Baltic Sea, the tides are much reduced in comparison to other waters and that in the case of the Vistula Spit, these are almost unnoticeable. These issues are discussed in other sources, although the authors believe the discussion on types of waters, landscapes, etc., goes beyond the scope of this article.

Further development of the Port of Elbląg as a regional transshipment center has become endangered due to restrictions resulting from the existence of the state border separating the Polish and Russian parts of the Vistula Lagoon. To deal with this issue, the vision of a channel crossing the Vistula Spit and connecting the Vistula Lagoon and the Gdańsk Bay had already been conceptualized in the early 1990s (Sas-Bojarska, 2010).

Figure 1. Location of Elbląg in the European context. Source: Own elaboration using Google Maps.

Along with ideas of regenerating the commercial functions of the Port of Elbląg, it has become a strategic project for the Polish government as its separation from the Gdańsk Bay—and, in general, the entire Baltic Sea—was perceived as a significant development threshold (Moretti, 2020). Overcoming this barrier was perceived as a significant opportunity for the regeneration of both the city and port of Elbląg as well as of other minor ports located within the catchment area of the Vistula Lagoon (Sosidko, 2002; Szwankowska & Szwankowski, 2002). Therefore, it was hoped that the processes undergone in other port cities in Europe would also be initiated in the case of Elbląg (Ast, 1999; Schubert, 2011). Moreover, this concept was perceived as an opportunity to transform and activate the entire part of the Vistula River delta, as was discussed, i.e., concerning the Dutch cases (Meyer et al., 2010, 2015).

After many years of consideration, this project was finally introduced in the years 2020–2022, and the new channel provided new opportunities for the development of the Port of Elbląg. This still has to be treated as a half-done project as many other improvements are still awaiting execution before it will be possible to provide credible data on the success or failure of this strategy. Therefore, the main aim of this article is to present the scope of political, economic, and environmental issues associated with the construction of this new waterway. In addition, the authors intended to discuss the possible consequences of this construction on the economy of the city and the entire region as well as on the local environment of the Vistula Lagoon. At the same time, authors have to note that, due to the fact this new waterway has just recently been made available for commercial traffic and many construction works associated with dredging the waterway to the Port of Elbląg have not been completed yet, it is impossible to discuss the real impact of this development on the economy and environment of the region.

2. Methods

This article is based on both the analysis of the existing literature and the authors' own analysis of the selected case study: the Vistula Spit channel. This analysis was developed both regarding the development trends of the city and Port of Elbląg as well as other minor cities and ports located within the area of Vistula Lagoon. The authors were able to present a specific perspective on the topic based on their personal experience since they were involved in the process of maritime and spatial planning for the area. At the same time, it has to be noted that there is very little literature available on both the development of the channel and the redevelopment of the Port of Elbląg. Therefore, this article to a large extent reflects the authors' own opinions and observations. Thus, the literature review also includes an overview of papers and books dealing with port-city relations and the transformation of water-related areas.

The analysis of the outcomes of the construction process of the Vistula Spit channel discussed in this article has been embedded in the description of the history of the city and Port of Elbląg. This allowed for providing the proper background related to the main topic.

3. Literature Review

Since this article, to a large extent, is based on the review of existing literature, the authors decided to provide an overview of the existing body of research concerning four major aspects that are crucial to the topic.

These include (a) city–port relations, (b) regeneration of urban waterfronts and transformation of waterfront cities, (c) the situation in Poland regarding shaping the port cities and maritime areas, and (d) specific issues in shaping the Port of Elbląg and Vistula Spit channel.

Regarding city–port relations and issues in shaping port cities, some of the key publications include works by B. Hoyle (1988, 1996), dealing with the development dynamics of the port–city interface as well as with issues in shaping the economic relations between ports, cities, and coastal zones. These works shall be regarded as the basis for any further research on this topic. Additional works on port–city relations were developed by Meyer (1999), Schubert (2011), Hein (2011, 2021), and Moretti (2020). Most of these works deal with spatial issues in shaping port–city relations and consequences for urban transformation processes coming from these issues. In addition, it is necessary to mention Polish research, developed—among others—by K. Krośnicka, P. Lorens, and E. Michałowska (see Krośnicka, 2018; Krośnicka et al., 2021). It is also advisable to mention works on "delta urbanism" and—within these—point out works by Meyer et al. (2010, 2015).

Concerning urban transformation and waterfront revitalization, the major body of research includes works by Breen and Rigby (1994, 1996), as well as Bruttomesso (1991) and Schubert (2018). Also in the case of Poland, several works can be identified, namely Lorens (2009a, 2009b, 2013) and Ast (1999).

Since this article deals with a specific case study, the authors also decided to analyze the Polish body of literature dealing with the topics related to shaping the port and maritime areas. Relevant legal acts on the subject must also be mentioned (see Council of Ministers, 2019; Marshal of the Sejm of the Republic of Poland, 1991). However, there is a much larger scope of existing works associated with seaside regions and the role of maritime ports in the process of economic development. Within this group, the most important works were developed by Gawlikowska-Hueckel (2007), Bocheński and Palmowski (2015; see also Bocheński, 2022), Dutkowski and Kulawczuk (2009), as well as Sosidko (2002) and Szwankowska and Szwankowski (2002).

Finally, concerning the Port of Elbląg and the Vistula Spit channel, the issues in shaping local identity and landscape must be mentioned (Golędzinowska, 2018) as well as cultural, social, and economic aspects of development (Palmowski, 2010). Concerning issues of shaping the Port of Elbląg, publications dealing with its history, present-day, and future development scenarios have to be mentioned (Breś, 2020; Czaja, 1993; Gierszewski, 1978; Gierszewski & Groth, 1993; Krośnicka & Zavorotynskiy, 2016; Matczak et al., 2015; Myślińska, 1998; Palmowski, 2001; Salomon, 2018). Of no less importance are more popular articles and publications (ANA, 2023; Kojzar, 2022; Libudzka, 2022; Milszewski, 2022; PAP, 2022), as well as the Port of Elbląg website (http://www.port.Elbląg.pl/o-porcie). Regarding the Vistula Lagoon and the Vistula Spit channel, important publications include works by Różyński et al. (2015) and Sas-Bojarska (2010).

4. Political and Economic Aspects Behind the Construction of the Vistula Spit Channel

The development of the Vistula Spit channel was proposed as early as the middle ages but never executed due to numerous reasons. The concept of providing a direct link between the harbour of Elbląg and the Gdańsk Bay was rediscovered only a few years ago, when—after political changes coming with the collapse of the communist system in 1989 and political changes in Poland resulting in its integration into the European Union—the economic and political ties with Russia weakened. In addition, Russia started to perceive Poland as a hostile country, which resulted in the strengthening of restrictions concerning access to the Port of Elbląg through its territorial waters. This happened despite international treaties, which are still in force, that provided access to the harbour of Elbląg through an existing water connection.

As a result, the Polish national government decided to come back to this idea, which was also supported by potential internal political gains. The ruling party (right-wing) perceived this development as an opportunity to reinforce the regional centre—the city of Elbląg—and catch some of the regional cargo, which by now was shipped through the large ports in Gdańsk and Gdynia. This was supposed to result in reinforcing the political importance of the political party in Elbląg and diminishing the importance of the Port of Gdańsk and the Port of Gdynia. Both were perceived as remaining under the influence of the political opposition to the ruling party. Therefore, the first ideas were developed in the years 2007–2009 (during the first period, when the right-wing party was in charge of the national government) and then refreshed after 2015 (when the same right-wing party retook charge of the national government).

Therefore, it can be stated that the decision on the development of the Vistula Spit channel was made due to political reasons and not purely economic ones. Although, it has to be stated that the extensive discussion on the rationale for shaping this channel took place in Poland after the concept took its final shape after 2015. This discussion included topics associated with environmental issues (dealing with mixing the waters and touching the sediments that might be potentially harmful to the environment of the Vistula Lagoon) and economic ones (reinforcing the regional centres, not the main cities and ports like Gdańsk and Gdynia). In addition, it was discussed that the Port of Elbląg could play a complementary role to the ports of Gdańsk and Gdynia, especially in light of the burning need to improve the transportation infrastructure providing access to these large transhipment centres.

All these discussions and arguments must be further analysed, which goes beyond the scope of this article.

But the authors believed that a short overview of the political and economic background needed to be presented to discuss the selected case study.

5. Development of the Maritime Harbour of Elbląg

5.1. Historical Background of Elbląg's Port in the Context of Waterway Development

The city of Elbląg was founded by the Teutonic Order in 1237 (Czaja, 1993). The settlement was initially located on an island at the mouth of the river and later moved to the area of today's Old Town, where the Teutonic Castle was built. In the vicinity of the castle, an original settlement was developed (Figure 2a) and later, in the 14th century, another settlement called New Town was established east of the Old Town (Figure 2b; see Gierszewski, 1978). Both of these were governed according to the Lubeck law, which regulated most aspects of urban life. The port of Elbląg was initially located on the right riverbank within the Old Town (Figure 2a). The port soon grew to the left side of the river on Granary Island (Figure 2b). Thanks to the connection to the Vistula River and access to the Baltic Sea, the city became a flourishing port city—which, at the end of the 13th century, was the largest seaport in the region (Gierszewski & Groth, 1993). Back then, the Port of Elbląg was an important military and trade center with economic and legal ties with other Hanseatic port cities. The city was a starting point for further Teutonic expansion due to its favorable location near the mouth of the Elbląg River to the Vistula Lagoon and on the Vistula Delta (Gierszewski, 1978).

The growth of shipping activity in Elbląg continued in the 14th century, which included trade with England and other Western countries. However, the development of the port slowed down at the beginning of the 15th century, in favour of the port of Gdańsk. This was largely due to insufficient navigation conditions, a change in the transhipment profile (from trading luxury goods to bulk), and the imposition of fees on ships crossing the Pilawa Strait on their way to Elbląg's port. The port of Gdańsk, situated directly by the Baltic Sea, had a more advantageous location and trade connections. Thus, Elbląg became a hinterland port for the port of Gdańsk. Changing the layout of waterways in the 15th century, including directing the Nogat riverbed directly to the Vistula Lagoon and thus bypassing the area of Elbląg, meant cutting off the city from important inland waters. Secondly, the navigation conditions of the fairway towards the sea deteriorated due to the accumulation of sand. Already in the 14th century, constructions preventing the sanding of the fairway were erected in the port roadstead, which was financed by the authorities of the city and merchants from Elbląg. The waterway from the port of Elbląg to the lagoon was a 10 km shallow route with a narrow section through the Pilawa Depth, which was constructed in the 16th century. After the collapse of trade in the mid-17th century, carrying out work preventing silting of the bottom was difficult for economic reasons (Gierszewski, 1978). At the same time, both city and port facilities were gradually growing (Figure 2).

In the 17th century, the city, with its new bastion-type fortifications (Figure 2c), suffered from an attack by the Swedish army, followed by the first partition of Poland in the 18th century when it went under Prussian jurisdiction. The poor condition of the fairway was greatly affected by the Polish-Swedish war, after which access to the Port of Elbląg was blocked. The war was followed by the first partition of Poland in the 18th century when it went under Prussian jurisdiction. New authorities invested major funds in deepening the riverbed, however, from the middle of the 18th century, dredging activities were no longer sufficient. Access to the port in Elbląg was hindered by the high growth rate of

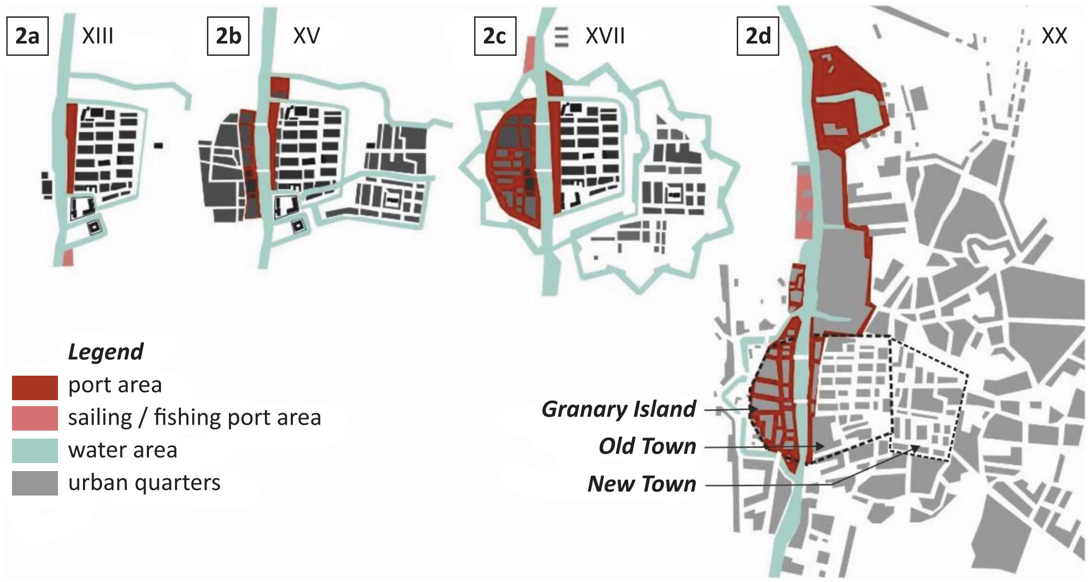

Figure 2. Scheme of the historic development of Elbląg concerning water and port activity. Source: Breś (2020).

the lagoon shore, which negatively impacted the access from the port to the sea. As a result, most of the cargo was transshipped not in the Port of Elbląg, but in the Port of Pilawa. Soon, the city would transform from a port city to an industrial one. The shipbuilding industry developed in the 19th century largely due to the launch of the first Schichau shipyard in 1854. Many new industrial activities were taking place by the riverfront such as automotive, heavy mechanics, military, and brewing. Along with the gradual relocation of port activities to the north, where the industrial hub was spreading (Figure 2d), the historic waterfront no longer performed its original function (Breś, 2020).

World War II had a destructive impact on Elbląg's historic city centre. The Old Town together with Granary Island and New Town were practically destroyed (it is claimed that 90% of the buildings in Old Town and almost 100% of the New Town were destroyed; see Myślińska, 1998), even though industrial infrastructure remained almost intact. However, it must be noted that the looting of the industrial plants' equipment by the Red Army in 1945 made the resumption of production in these plants difficult. In the post-war years (1945–1990), local ports, including the Port of Elbląg, had little importance for the Polish economy, which resulted from the specificity of the political system and centrally controlled economy. They were not properly adjusted to serve marine traffic, i.e., bridges reconstructed in Elbląg after the war did not take into account the size of sea vessels.

5.2. Current Investments Related to Access to the Seaport in Elbląg

After years of neglect, the port of Elbląg started to develop in terms of reestablishing sea connections at the break of the 20th and 21st centuries. A limitation of the port's growth, apart from lack of funds, was the railway bridge limiting the size of the ships entering the city centre. New quays could therefore develop only to the north of the European Union bridge, including freight and passenger terminals. A new route was developed to connect the northern port quays with the hinterland of the port at the beginning of the 21st century—the so-called European Union Road, which allows traffic connection with the express road bypassing the city from the south and bypassing the city centre (Elbląg University of Humanities and Economics, 2019). Among port investments completed in the 21st century, the most important include the development of the European Union route (also bridge), which connects the city and port with the S7 national road; a transhipment terminal with a border and customs control site; a passenger terminal with an international check-in point; and renovation of the waterfront with passenger quay within the Old Town of Elbląg, including the conversion of two drawbridges and the development of the yacht marina.

The Port of Elbląg is classified as a medium-sized port in Poland (Supreme Audit Office Gdańsk Branch, 2018). It is a regional port serving the Vistula Lagoon and Baltic Sea cargo and passenger shipping (Council of Ministers, 2019). The area of the port is about 400 ha, the length of the quays is less than 4,000 m, and the depth of the fairway in the port is 2 m. The annual transhipment capacity of the port is estimated at 0.5–1 million tons (bulk cargo) and 0.1 thousand tons (general cargo). The terminal serves ships with a carrying capacity of up to 3–3.5 thousand DWT (Elbląg University of Humanities and Economics, 2019). More than 30,000 passengers are transported annually in Elbląg. Cargo turnover in the port is currently approximately 100,000 tons (Statistics Poland Statistical Office in Szczecin, 2022). Since 2015, Elbląg's port has recorded a decrease in the volume of transshipped goods. The decrease in transhipment (from 200,000 to 100,000 t) was largely due to a decrease in trade with the ports of the Kaliningrad Oblast (Russia Federation enclave), which accounted for approximately 97% of its total turnover. This was caused by the imposition of sanctions by the Russian Federation and the European Union. The tourist shipping in the port of Elbląg, however, did not record a significant decrease (Supreme Audit Office Gdańsk Branch, 2018). As a result, there was not much change to the structure of the Port of Elbląg and the city's waterfront (Figure 3).

The ongoing construction of the waterway connecting the Vistula Lagoon with the Gdańsk Bay (Figure 4) is an opportunity to increase the economic attractiveness of the Warmia and Masuria Voivodeship and to develop further medium and small ports of the Vistula Lagoon, in particular the Port of Elbląg. The Vistula Lagoon was split between Poland and the Soviet Union after World War II. The Polish-Russian agreement on navigation within the Vistula Lagoon, signed after the war, did not allow foreign ships to cross the Polish-Russian border. Currently, the lagoon is shared between the Republic of Poland and the Kaliningrad Oblast. Until the recent construction of the channel through the Vistula Spit, the only inlet was located in the Russian part through the Pilawa Strait (Figure 5; see also Różyński et al., 2015). The water route from Elbląg to the Baltic Sea, which until the 21st century used to lead through the Pilawa Strait controlled by Russia, is now shortened by almost 100 km as it leads through the channel through the Vistula Spit. The channel was built in 2022; however, all additional investments were forecasted to be completed in the last quarter of 2023 (Libudzka, 2022). Despite these declarations, keeping this deadline seems to be unlikely since the agreement on dredging the waterway to the Port of Elbląg has not yet been signed. The planned waterway includes the construction of a shipping channel through the Vistula Spit, connecting the Vistula Lagoon with the Gdańsk Bay, the introduction of a new port on the side of the Gdańsk Bay, construction of road and bridge connections across the channel, construction of an artificial island in the Vistula Lagoon, improvement of a fairway and entrance to the Port of Elbląg, and construction of a new bridge over the Elbląg River (Supreme Audit Office

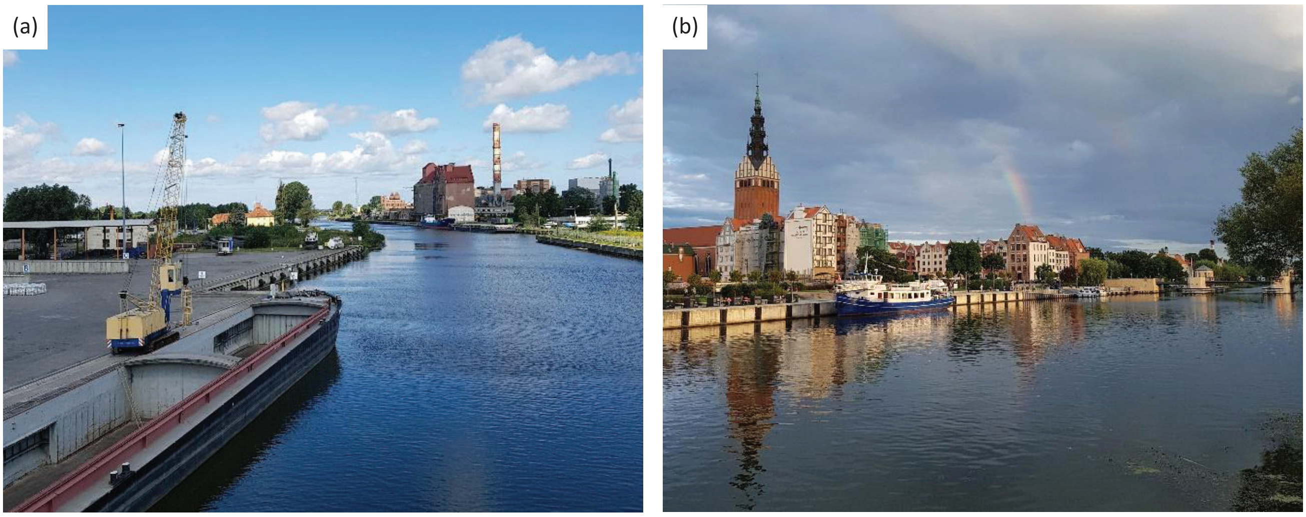

Figure 3. Current images of the city and Port of Elbląg: (a) the northern part of the seaport in Elbląg (transshipment terminal); (b) the waterfront in the Old Town of Elbląg (post-port areas).

Gdańsk Branch, 2018). The new waterway will enable vessels up to 100 m long and 20 m wide with a 4.5 m draft to enter Elbląg's port. The channel and the entire fairway will ultimately be 5 m deep. It has been estimated that this investment will shorten the sea route from Elbląg to Gdańsk by approximately 90 km, to ports of Western Europe by 60 km, and to the eastern Baltic Sea by 15 km. The construction of the channel through the Vistula Spit is, from the perspective of Elbląg, more advantageous than the improvement of the inland waterway connection with Gdańsk which would entail significantly higher investment expenditures (Figure 5a). The inland waterway leads along Elbląg River, Jagiellonian Canal, Nogat River, Szkarpawa River, Wisła River, and through flood gates, which are the remnants of the Bielnica water lock built in 1898 and the 19th-century water lock in Przegalina built in 1895 (Figures 5b and 5c). The cost is associated with deepening the inland fairways and rebuilding existing constructions (Elbląg University of Humanities and Economics, 2019).

In order to take advantage of the channel through the Vistula Spit for the Port of Elbląg, reconstruction of the infrastructure and deepening of the Elbląg River is necessary. The construction of a fairway to the Port of Elbląg is a complex undertaking partly implemented outside the city limits that can only be conducted by the Maritime Office. In the city, the Elbląg Seaport Authority is responsible for the reconstruction of quays (Council of

Figure 4. Current view of the Vistula Spit channel.

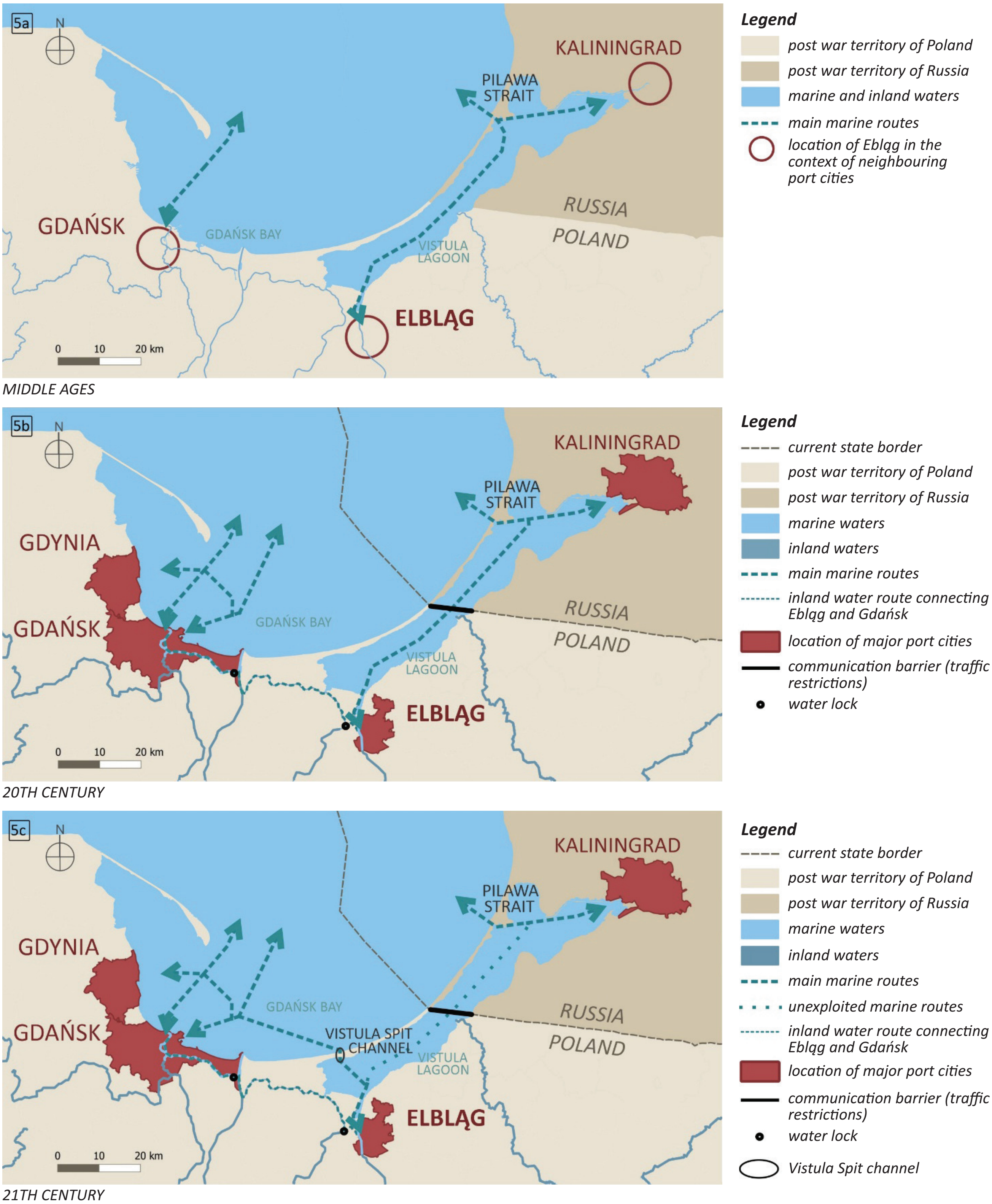

Figure 5. Transformation of marine routes connecting the Port of Elbląg with its foreground. Source: Own elaboration based on data published on https://www.geoportal.gov.pl (accessed on January 18, 2023).

Ministers, 2023). The dispute over competencies in this area caused some problems at the stage of coordinating the implementation of the entire project. Furthermore, there are plans to build a turntable for ships with a diameter of up to 180 m, along with strengthening the quays and construction of a transhipment wharf for a new universal terminal with the accompanying infrastructure such as storage yards, warehouses, and railway siding. This investment, provided by the Elbląg Seaport Authority, will increase the port's capacity and facilitate the navigation of larger vessels.

5.3. Strategy for the Development of the Port of Elbląg and Its Connection to the Baltic Sea

Spatial planning in the seaport of Elbląg is based on separate spatial plans for the area of the territory and the water reservoir. The spatial planning system at the edge of sea and land in Poland consists of different legal documents on land and water areas, which are prepared at various administrative levels. Adoption of the study of conditions and directions of spatial development and local spatial development plans (based on the study) on the land is within the competence of the city authorities. Maritime spatial development plans, on the other hand, are prepared at the national level by the maritime office. Elbląg Seaport Authority also developed its own strategy for the development of the port—a guideline for the development of the port, which is not, however, a planning document itself.

Although the city authorities are working on a new document, the 2010 *Study of Conditions and Directions of Spatial Development of the City of Elbląg* (Elbląg City Authorities, 2010) is currently in force. Among the strategic development goals, this document mentions the development of the seaport function and taking advantage of the connection between Elbląg and the Gdańsk Bay through the channel through the Vistula Spit. The study provides for the expansion of the port in the areas to the north of the Old Town within the boundaries of the port, as well as beyond the boundaries of the city to the west of the boundaries of the seaport, after concluding relevant inter-municipal agreements. In addition, the document mentions the creation of a new railway stop in the vicinity of the port and the provision of a railway siding to the quays, as well as securing the port areas against flooding. However, the study does not refer in detail to the development of the port's territory or aquifer itself, it only outlines the area intended for the development of the industrial and port function, as well as the location of the new railway stop.

The draft spatial development plan for the waters of the seaport in Elbląg and the spatial development plan for the internal sea waters of the Vistula Lagoon are currently being prepared. The plan for the seaport in Elbląg reserves sea areas on the Elbląg River for the development of the water transport system, which includes the fairway to the port, the planned turntable, and ensures their width in accordance with the investment in the construction of a waterway connecting the Vistula Lagoon with the Gdańsk Bay. Additionally, north of the European Union bridge in Elbląg, the location of infrastructural elements was limited to at least 20 m above the water level (Maritime Office in Gdynia, 2022). Nevertheless, the maritime plans do not include provisions regarding the depth of fairways or the detailed location of the expanded quays and bridge connections. The provisions of the maritime plan enable the construction of a waterway connecting the Port of Elbląg with the Gdańsk Bay while maintaining highly liberal provisions and limiting itself to very general guidelines for the development of water transport.

When discussing the development of the Port of Elbląg, its existing and potential functional area has to be taken into account. It might also require redevelopment of some parts of the area, including conversion of the land uses and differentiating the modes of access to the waterfront. The current situation of the area is presented in Figure 6.

According to the *Strategy for the Development of the Sea Port in Elbląg* (Matczak et al., 2015), the subject of the port's service includes inland passenger and cargo shipping, inland and sea yachts, and short-sea shipping, including potential ferries. In the context of maritime shipping, this strategy indicates the port's development potential based on two shipping ranges: ports of the Vistula Lagoon and ports of the Baltic and North Seas. Currently, shipping to the Baltic and the North Sea ports is incidental due to Russia's restrictions. This situation may change in the future, due to the construction of a channel through the Vistula Spit in 2022. This will theoretically allow cargo ships with 3.5 to 4.0 DWT to enter Elbląg and passenger's vessels with a length of up to 120 m. Sea sailing is also a prospective source of income for the port of Elbląg in the context of the new water connection. According to this strategy, the construction of the channel allows for forecasting an increase in terminal turnover of up to 100,000 tons (general cargo) and 1 million tons (bulk cargo). These perspectives require the use of all land reserves on the eastern bank of the river provided in the city plans. In addition, the necessary actions listed in the strategy include ensuring the depth of the fairway to 5 m in the northern part of the port, construction of a turning basin, ensuring appropriate depths at port terminals on both sides of the river, enlarging the existing transshipment terminal on the left bank of the river, and creating an integrated cargo and passenger terminal with the possibility of rail service (Elbląg University of Humanities and Economics, 2019).

6. Results

The main results of this article are associated with possibilities for the development of the Port of Elbląg in reference to the Vistula Split channel. However, it must be noted that the marine activities of Vistula Lagoon ports in the Polish part may significantly change after the construction of the new waterway connecting the Vistula Lagoon with the Gdańsk Bay is completed. This investment might have a noticeable impact on the economy of the city of Elbląg; however, it is not yet known to what extent it will enable the development of the port. Some previous economic research estimates that the investment will be cost-effective in the long term,

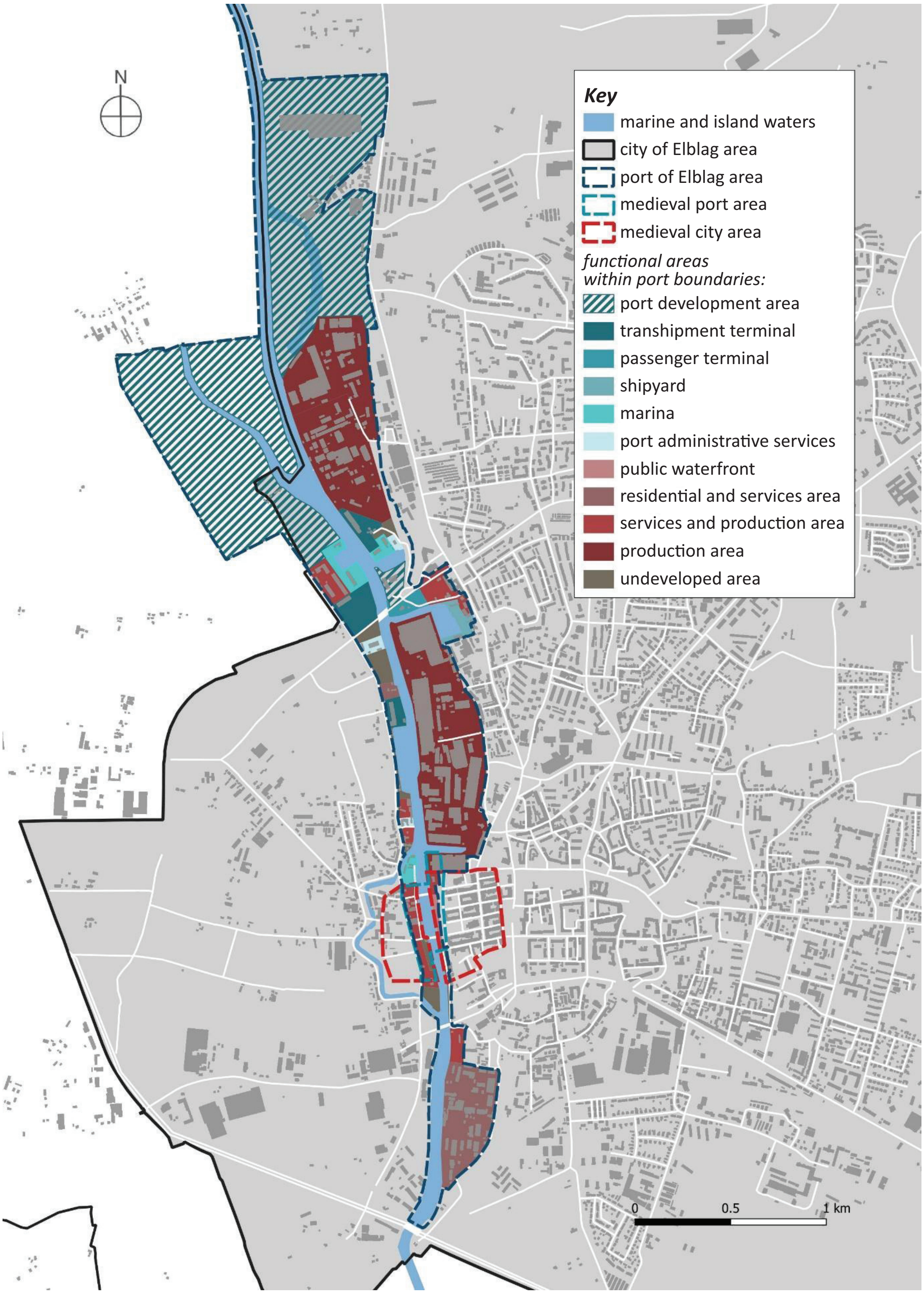

Figure 6. Functional area of the seaport of Elbląg. Source: Source: Own elaboration based on data published on https://www.geoportal.gov.pl (accessed on January 18, 2023).

but it is not known what economic benefits it will provide and whether new infrastructures will bring prosperity to other Polish ports near the Vistula Lagoon. It is also unknown whether the nearby ports in Gdańsk and Gdynia will take advantage of the channel (Różyński et al., 2015).

So far, after almost a year of operations in the channel (as per the writing of this article, on July 2023), the channel was used very little. According to statistical data gathered by the Maritime Office and published in the economic portal Businessinsider, during the first eight months of operations (from September 18, 2022, until

March 3, 2023) the Vistula Spit channel was used by only 545 vessels, including pleasure boats (such as yachts and motorboats) and vessels involved in the construction process of the channel. This means that the channel was used by three vessels per day. This resulted in the shortening of the channel's operation hours—at this moment, it remains operational only for four hours per day (ANA, 2023).

This low volume of traffic may result in the fact that funds invested in the development of the channel will not be recovered—as of 2023—any time soon. It is estimated that it may take approximately 500 years to recover the sum of more than 2 bln Polish Zloty invested in this development (Kojzar, 2022). Although, as was discussed in previous parts of this article, the economic calculations were not the reason for deciding on the development of the Vistula Spit channel—the main reasons were political, meaning, making the Port of Elbląg more attractive and providing access to the Vistula River Lagoon independent from the agreements (or lack of these) with the Russian Federation. This reasoning is well justified by the situation that took place in the years between 2006 and 2010—within these years the Russian Federation imposed a blockade on traffic through its territorial waters which resulted in minimizing the volume of cargo transhipped in Elbląg: It was approximately 3,000 tons, mostly of bulk products like sand, etc. Additionally, after the 2010s, when the new international treaty between the Republic of Poland and the Russian Federation was signed concerning access to these waters, obtaining permits for the access of vessels to the Port of Elbląg in many cases was questionable.

These numbers prove that developing the Vistula Spit channel was not justified by economic reasons, especially since within the range of approximately 60 km, there is a deep-water cargo terminal in Gdańsk, where the volume of the cargo is increasing year by year: For example, in 2021, more than 2 mln containers were transhipped there. Also, the environmental aspects of this development are questionable: Numerous experts were discussing the ecological value of the Vistula Lagoon, which may be largely diminished by the construction of the new waterway. For example, the issue of bird migration corridors was discussed along with the fact that the entire construction was supposed to take place within the areas designated as Landscape Park (which, according to the Polish legal system, is one of the forms of preservation of nature) and/or Nature 2000. The main environmental organisation, the Polish Ecological Club (Polski Klub Ekologiczny) also pointed out that the construction might lead to the worsening of the quality of water within the Vistula Lagoon, as well as the destruction of its flora (Kojzar, 2022). However, it must be stated that more thorough research on the environmental and economic consequences of this development can be made only after some time of functioning of the channel—the current perspective on this may be incomplete.

Based on the above analysis, it is possible to discuss a set of opportunities and threats associated with the current development. These were discussed separately for the Port of Elbląg (economic functions) and the city of Elbląg (city forming issues) and are presented in Tables 1 and 2.

As can be derived from the above analysis, the development of the Vistula Spit channel can bring little consequences for the urban development processes of the City of Elbląg, mainly due to the location of existing and future waterfront redevelopment processes south of the potential port development areas. On the other hand, the chances for the development of the Port of Elbląg are much higher, although it is possible to point out three main possible directions of its transformation:

1. Independent transshipment port: Expansion of the northern port areas within the city of Elbląg and in the municipality of Elbląg according to the *Strategy for the Development of the Sea Port in Elbląg* (Matczak et al., 2015), deepening of the fairway within the city limits by the Elbląg Seaport Authority and in the area of sea waters outside the city by the Maritime Office in Gdynia, constituting

Table 1. Economic development of the Port of Elbląg: Presentation of possible opportunities and threats.

Opportunities	Threats
Development of the transshipment activities in a partnership or separate from the activities of the Port of Gdańsk.	Over-investments associated with the port infrastructure.
Development of the inland waterways allows water-based connections with Gdańsk and other parts of the region.	Under-utilization of the port areas.
Activation of the port-related industries within the area of the Port of Elbląg and/or the entire City of Elbląg.	Lack of cooperation with the Ports of Gdańsk and Gdynia.
Regeneration of the "working waterfront" areas.	Under-development of the water-related industries.
Diversification of the economic base of the city.	Lack of interest in the tourist industry and leisure sector.
	Potential conflicts with the development of other city-related functions.
	Issues associated with environmental preservation and protection.

Table 2. Urban development of the City of Elbląg: Presentation of possible opportunities and threats.

Opportunities	Threats
Reinforcing the economic base of the city.	Diminishing the opportunities of the waterfront redevelopment processes.
Spurring the development of the tourist infrastructure.	Differentiation of the economic rationale of the port and city areas.
Spurring the redevelopment of the urban waterfront (especially within the area of the Old Town and Granary Island).	Lack of city-port integration processes.
Reinstating the maritime identity of the city.	

a direct connection between Elbląg and the Baltic Sea (ports of the Baltic Sea basin), which will create conditions for the development of transshipment terminals.

2. Transhipment feeder port for the seaport in Gdańsk: Expansion of the northern port areas within the city of Elbląg and in the municipality of Elbląg according to the Port Development Strategy, deepening of the fairway within the city limits and in the area of sea waters outside the city, constituting a sea connection between Elbląg and Gdańsk which will create conditions for the development of the back-up transshipment terminals and facilities of the seaport in Gdańsk.
3. Touristic port: Expansion of the northern port areas within the city of Elbląg for the needs of the passenger terminal, deepening of the fairway within the city limits and in the area of marine waters outside the city, constituting a direct connection between Elbląg and the Baltic Sea (ports of the Baltic Sea basin), which will create conditions for the development of an international passenger terminal, development of the southern areas within the port boundaries, located near the Old Town for maritime, and inland tourism for small water vessels (current residential and commercial area with abandoned post-port buildings), additional deepening of the inland waterway in the direction of Gdańsk: Elbląg River–Jagiellonian Canal–Nogat–Szkarpawa–Wisła for maritime and inland tourism for small water vessels.

The materialization of any of the above-mentioned scenarios will depend on several factors, including the effectiveness of the new marine route connecting the Port of Elbląg and the Gdańsk Bay as well as opportunities for developing port function within the structure of the city and in its close vicinity. However, this last part will depend on the economic demand and the condition of the Port of Gdańsk. This last factor has not been taken into account until very recently (Fall 2022) when the increase in demand for imported coal has led to the rapid increase in the transshipment of this type of cargo. Since the Port of Gdańsk was not ready for this, it proved incapable of handling this increase in demand for the transshipment of coal.

7. Conclusions

Development of the Vistula Spit channel has just been completed. In addition, there are ongoing works on additional infrastructure improvements and many more works still have to be completed concerning the transformation of the Port of Elbląg facilities. Therefore, the impact of this development on the future of the Port of Elbląg is still to be determined. The same relates to the transformation of the urban structure of the city of Elbląg.

The development of the Vistula Spit channel was conceptualized as an economic project, helping the development of the Port of Elbląg. However, one must conclude that the reasons for this development were mostly political. Furthermore, this development may result in some environmental harm. The real impact of this development must still be determined and needs further research. On that basis, one must also conclude that the development of new channels and waterways does not always have to be economically justified, as political arguments may prevail. In light of the current conflicts (war in Ukraine, for example), these reasons must be taken into account.

All of these arguments also relate to the development of the Port of Elbląg and the transformation of the urban space of the city of Elbląg. At this stage, it is already possible to conclude that the previously obvious direction of transformation of the port into a recreational hub is not decided yet. Therefore, the commercial functions of this facility may be restored and/or improved. This may be spurred not only by the presence of the new channel but also by the development of the situation in the Port of Gdańsk as well as by the future directions of the region's development. Considering current political issues associated with the Russo-Ukrainian conflict, many new (mainly political) factors may have to be taken into account. One thing is obvious: For now, this channel contributes towards securing the day-to-day operations of the Port of Elbląg, as transit through Russian territory at this moment is unthinkable due to political tensions.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 289–304
https://doi.org/10.17645/up.v8i3.6737

Article

A New Shipping Canal Through the Vistula Spit as a Political and Transportation Project

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Submitted: 29 January 2023 | Accepted: 10 April 2023 | Published: 26 September 2023

Abstract

In September 2022, a new shipping canal was opened connecting the Polish part of the Vistula Lagoon to the Baltic Sea. Largely political, the project links the lagoon and the port in Elbląg to the southern part of the Baltic, independent of the Russian Federation. In addition, its economic dimension enables the handling of small ships, as well as supporting tourism and yachting without the need to pass through the Russian-controlled Piława Strait. The scale of the new canal is relatively small—one and a half kilometre long and 25 metres wide. Nonetheless, it is sufficient for the navigation of small marine vessels of up to five-metre draft. The shipping canal through the Vistula Split is certainly not as important as the Corinth or North Sea Canals, still, it frees maritime and tourist traffic from Russian jurisdiction. The planned key port in the Vistula Lagoon is the port in Elbląg, a historic city that was once a member of the Hanseatic League, which brought together all the major cities of the Baltic Sea basin in the 14th and 15th centuries. The purpose of this article is to present the project's historical context, its urban, technical, and shipping solutions, as well as the correlations between the new transport development and its anticipated impact on the environment (including the natural environment). The findings are complemented by a PESTEL analysis which shows the leading trends that are relevant to the implementation of the project in the region. The analysis identified areas that have a significant effect on the social, political, and economic settings of the new canal.

Keywords

Elbląg; PESTEL analysis; port city; shipping canal; transport; Vistula Lagoon; Vistula Spit

Issue

This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

Throughout history, access to the Baltic Sea has been a major issue in Polish foreign and economic policy. An independent connection between the Vistula Lagoon and the Baltic Sea had been considered for many years. Hence the construction of a canal connecting the two is largely an outcome of the difficult Polish-Russian relations and the division of the lagoon between Poland and the Soviet Union. In the early 2000s, the Polish government formally decided to build a new waterway to Elbląg and a cross-cut through the Vistula Spit. This generated discussions and antagonisms that polarised public opinion on the project's rationale.

The new canal between the Polish part of the lagoon and the open sea is an important development due to both its scale and the potential impact on the wider environment. The project is largely political but has also an economic dimension associated with higher ship traffic and the expansion of the port in Elbląg. Furthermore, it may affect the growth of tourism by making yachting independent of Russian jurisdiction.

The article aims to present the wider historical, political, and economic context to evaluate the project and the solutions that affect the economic, environmental, and transport-related settings. The analysis is based on small-scale research and strategic analysis methods. Desk research (gathering and analysing information, secondary data, available texts, documents, planning, and design studies) provided a historical review of the Vistula Lagoon and the role of the Elbląg port. It also provided a scientific evaluation of the planning and design solutions and their impacts. An analysis of press publications explored trends and public sentiment, whilst a PESTEL analysis presented an overall assessment of the project.

The literature addressing the problem of the crosscut through the Vistula Spit and the construction of a new canal is scarce. In general, it is available in Polish and covers a range of environmental issues (Cieśliński, 2013; Dobrzycka-Krahel & Kozakiewicz, 2011; Dubrawski & Zachowicz, 1997; Kaczmarek, 2009; Szydłowski et al., 2019), legal concerns (Palmowski, 2008), and technical problems (Drążkiewicz, Golan, Hińcza, et al., 2020; Drążkiewicz, Golan, Kasprzak, et al., 2020; Zwolan & Czaplewski, 2015). A few problem-based studies have been produced to date (Fabiszewski, 2020; Jednorał, 2004; Modzelewski, 2017; Puzdrakiewicz & Połom, 2021; Sajkiewicz, 2016). A large number of texts concerning the canal are of an informative nature, published on institutional websites (Maritime Office in Gdynia) and in the press (Chudzyński, 2019; Krawiel, 2022; Pałczyński, 2023).

2. The Vistula Lagoon and the Importance of the Elbląg Port

2.1. The Vistula Lagoon and the Vistula Spit

The Vistula Lagoon is an inner body of seawater, approximately 91-kilometre long and up to 13-kilometre-wide, with an average depth of about 2.7 metres. In the north, the shoreline touches the Vistula Spit, and in the west, the Vistula Fens. The western and southern parts are divided by Elbląg Bay and the River Elbląg. The lagoon is a freshwater reservoir with a periodical inflow of saline seawater through the Piława Strait (Cieśliński, 2013, pp. 15–16). Important locations include the seaports in Kaliningrad and Baltiysk, ports in the area of Svetly and Pribrezhny (on the Russian side), the Elbląg port, and the towns/villages of Krynica Morska, Frombork, Tolkmicko, and Kąty Rybackie (on the Polish side). There are also two large Polish seaports near the lagoon, namely Gdynia and Gdańsk located on Gdańsk Bay (Puzdrakiewicz & Połom, 2021, p. 3).

The Vistula Spit is a narrow sandy strip of land located between the Baltic Sea and the Vistula Lagoon. It stretches for 96 kilometres, starting near Gdańsk in the west to Lochstedt in the northeast. The western, longer part lies in Poland, and the shorter part is in Russian territory. Its width ranges from several hundred metres on the Russian side to approximately two kilometres on the Polish side. The western part adjoining the Vistula Fens is divided into three locations lying at the former and present Vistula estuary (Martwa Wisła, Wisła Śmiała, and Przekop Wisły). The eastern side is divided by the Piława Strait (now the Strait of Baltiysk) situated within the territorial waters of the Russian Federation. Up until now, this was the only waterway connecting the Vistula Lagoon with Gdańsk Bay. The spit is sparsely urbanised and the former fishing villages are now holiday resorts (Mikoszewo, Jantar, Stegna, Kąty Rybackie, Krynica Morska, and Piaski).

The Vistula Lagoon has shipping routes to Gdańsk and Elbląg, as well as fairways to the ports and harbours on the Vistula Spit, for example to Kąty Rybackie and Krynica Morska in the north, and Suchacz and Tolkmicko in the south (Palmowski, 2008). The deepened seaway through the new canal across the spit is now a key element as far as accessibility is concerned (Salomon, 2018, pp. 103–105; Figure 1).

2.2. Importance of the Elbląg Port

The construction of the fairway and canal aims to create new access by water to Elbląg, the largest port city in the Polish section of the Vistula Lagoon. Elbląg is a city located on both sides of the River Elbląg, in Warmińsko-Mazurskie Voivodeship, with a population of approximately 118,000 (Statistics Poland, 2021). Its history begins in 1237, when a settlement and castle were built on the site by the Teutonic Order. Surrounded by favourable natural conditions (located at the mouth of the River Elbląg on the Vistula Lagoon and sheltered from the open sea), it became an important port in the 14th century.

At that time, the depth of the fairway was sufficient for navigation and handling marine vessels, albeit the most conducive to the port's development was Elbląg's economic rank, contingent on its convenient connection with the River Vistula and the Baltic Sea. Elbląg was connected with the Vistula through the River Nogat, and further with the sea through several isthmuses in the delta of the Vistula Spit. Until the end of the 15th century, the main fairway to the open sea led through the nonextant Balga Strait. From 1510 onwards, it led through the Piławska Strait, which was adapted to the navigation of larger ships (Palmowski, 2001, pp. 169–170).

Apart from Gdańsk, Elbląg was an important port and centre of commerce within the Gdańsk Bay. Its seaport status granted by the Peace of Toruń in 1466 (Palmowski, 2001, pp. 170–171) was further strengthened by its membership in the Hanseatic League. This was a major trading, political, and military force, whose member cities developed a common organ, the so-called Hansetage, to promote their economic interests. At its peak, the League counted around 160 cities united under the German city of Lübeck (Wójtowicz & Nalepa, 2015, pp. 105–106). Consequently, merchant ships from Elbląg reached all the Hanseatic cities in the Baltic and North Sea regions (Figure 2).

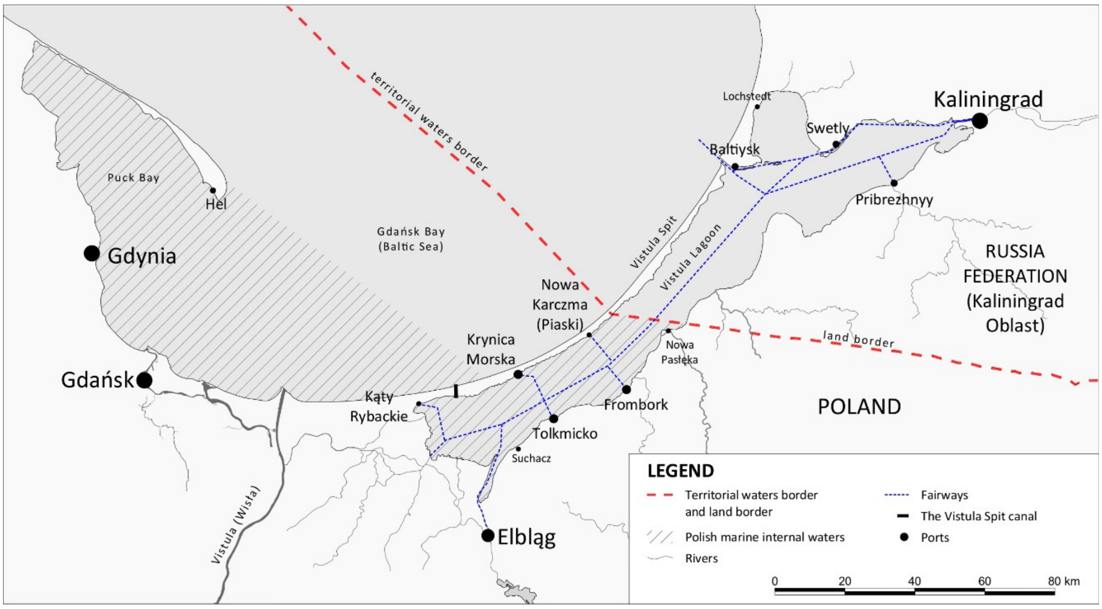

Figure 1. Vistula Spit and Gdańsk Bay region with major towns and cities.

3. Construction of a Canal Through the Vistula Spit: Background Information

3.1. History of Planning and Design Studies

The first concept of a canal through the Vistula Spit emerged following the Gdańsk rebellion of 1577. The then king, Stefan Batory, saw Elbląg's potential to compete with Gdańsk, contingent on a canal connecting it with the Vistula Lagoon. Another plan was proposed after the First Partition of Poland (1772), but the idea was ultimately abandoned after the Second Partition (1793) when Gdańsk was incorporated into Prussia (Figure 3).

In the 19th century, Elbląg experienced an economic revival following the construction of a railway line. Moreover, Friedrich Wilhelm IV of Prussia commissioned the Elbląg Canal, an inland shipping route connected with the Vistula Lagoon (completed in 1860; Wójtowicz & Nalepa, 2015, p. 105). With a total length of 187.2 kilometres and a height difference of 99.5 metres above mean sea level, the canal featured a course of five lakes lying at different levels between the town of

Figure 2. Extent of the Hanseatic League, ca. 1400. Source: Droysen (1886).

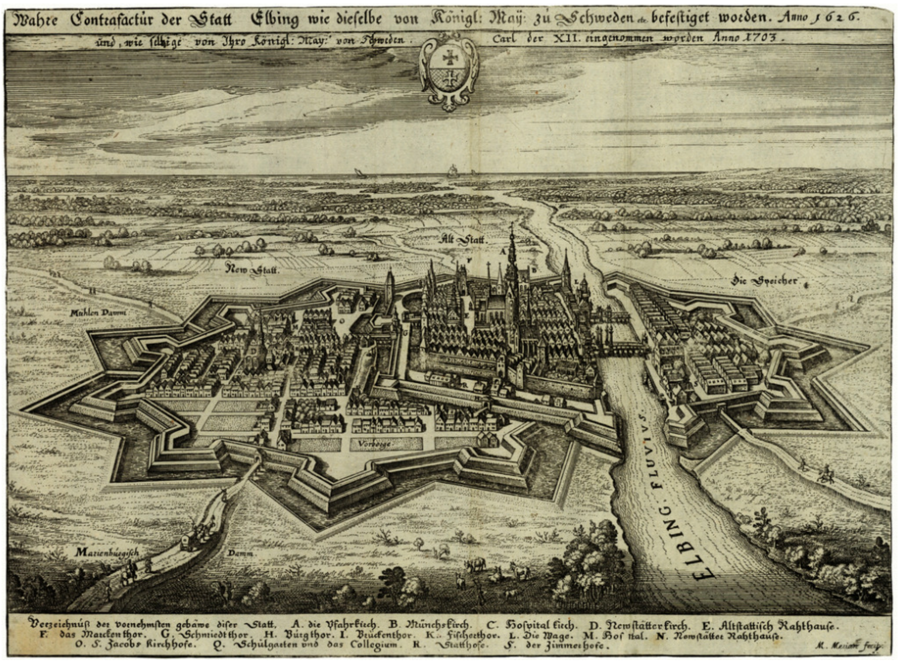

Figure 3. Elbląg in an engraving. Source: Merian (1635).

Ostróda and the Vistula Lagoon. The interesting technical solution combined five slipways for shunting ships on platforms which moved on rails (Furgala-Selezniow et al., 2006). The canal played an important economic role in the development of the Masurian Lake District in the 19th century, connecting it with the ports of Elbląg and Gdańsk for transporting industrial and agricultural products. It later lost its economic significance and now serves as a tourist attraction (Kowalski & Wawrzyński, 2012).

Following WWII and the incorporation of East Prussia into Poland, the concept of a navigable canal through the Vistula Spit was proposed by Eugeniusz Kwiatkowski (who also suggested the construction of the port and city of Gdynia). At that time, the proposal was not taken up (Sajkiewicz, 2016, p. 4) and it was not until much later, in 1996 and 2004, that further concepts were put forward by Polish hydrologist Tadeusz Jednorał (2004).

3.2. Elbląg as a Seaport

In 1945, Elbląg returned to Poland. Left in ruins in the aftermath of WWII, the city was rebuilt and the largest Polish port on the Vistula Lagoon was constructed. The port is located on the River Elbląg, six kilometres from its mouth on the lagoon. It connects to the Gdansk Bay via an inland waterway through the River Szkarpawa and Vistula, and until recently, through the Piława Strait in the Kaliningrad Oblast (Russian Federation).

Elbląg is a regional port serving coastal cargo shipping and passenger/ferry traffic around the lagoon and Gdańsk Bay (Krośnicka et al., 2021). It covers an area of 404 hectares with 3,686 kilometres of quays and an up to 2.5-metre-deep fairway. Three terminals handle cargo, passenger/ferry traffic and the transhipment of coal and breakbulk cargo. The cargo terminal covers five hectares (including 3.1 hectares of storage area). The key infrastructural elements are quays (196 metres), which can handle two vessels simultaneously. The maximum dimensions of the vessels are 85 by 15 metres, with a draught of 2.3 metres and a load capacity of 1,200 tonnes (Zarząd Portu Morskiego Elbląg, 2022). There is also a ramp for ro-ro ships. The passenger/ferry terminal located within the port can receive 30 cars at a time and check in 200 people. The specifications of these vessels are slightly smaller than those of cargo ships, i.e., 65 by 12 metres, with a draught of 2.5 metres. The port's logistics supra-structure includes a warehouse, roofed areas, a storage yard, and service barges. The port does not have facilities for handling container transhipment (Salomon, 2018).

The analysis of the port's location, infrastructure, and handling capacity shows that the highest growth rate in cargo turnover occurred up to the end of the 1990s (approximately 640,000 tonnes). Between 1999 and 2006, the volume of cargo did not exceed 100,000 tonnes. Between 2007 and 2009, trade fell dramatically due to the Russian blockade, causing the port considerable loss (Modzelewski, 2017, pp. 244–245). Moreover, before the Russian restrictions, the Elbląg port handled most tourist and freight traffic between Poland and the Kaliningrad Oblast. In the following years, the cargo volume fell to around 36,000 tonnes (Modzelewski, 2017, p. 235). Poland's accession to the EU further slowed it down to 3,500 tonnes in 2007. Two years later, a Polish-Russian agreement led to the revival of shipping and an increase in turnover. Consequently, transhipment grew steadily, reaching 358,300 tonnes in 2014. In recent years, there has been a decline to approximately 125,000 tonnes in 2021. The level of passenger traffic has fluctuated somewhat less (the highest number of passengers, 85,000, was recorded in 1993) and remains at an average level of 30,000 to 40,000 per year (Elbląg Maritime Port Authority, 2022; Figure 4). Despite the existence of a border checkpoint, traffic has been limited to tourist groups on domestic trips on passenger vessels (Kadłubowski, 2017). In the early 2000s, it was anticipated that in the future the port would depend on shipping beyond the Vistula Lagoon and the construction of connections with the ports of Gdańsk and Gdynia, as well as the Baltic ports in Scandinavia and Germany. The actual development was specified in Elbląg's development strategy, depending on the construction of a navigable canal through the Vistula Spit and on deepening the fairway to the port (Palmowski, 2001, p. 184).

4. Construction Conditions and Project Specifications

4.1. Construction Conditions

A key element impacting the fluctuating and declining turnover of the Elbląg port was the geopolitical situation associated with Poland's accession to the EU in 2004 and the subsequent deterioration of economic relations with the Russian Federation. Russia's sanctions on the import of food and construction products between 2005 and 2007 almost brought freight traffic to a halt. Access to the open waters of the Gdańsk Bay through the Piława Strait was restricted, and the bilateral agreements that were to ensure the passage of Polish ships were not respected, which fundamentally limited cargo and tourist traffic (Modzelewski, 2017). In later years, free navigation through the strait was a convenient blackmail tool used by the Russian Federation, since the strait was a passage whose access to international shipping was regulated solely by Russian law (Bugajski, 2006).

In practice, the Russian Federation had been blocking the passage of Polish vessels since 2006 and this was one of the main economically and historically-determined reasons for building a new shipping canal through the Vistula Spit.

4.2. Design and Construction of a Canal Through the Vistula Spit

Without direct access to the Baltic Sea, Elbląg lies over 20 kilometres away in a straight line from the Gdańsk Bay. It is separated by a narrow spit, whilst the only route through the Piława Strait is approximately 57-kilometre-long and takes about six hours to navigate. Hence analyses and studies were conducted to create a feasible concept for a new shorter shipping route across the Vistula Spit (Fabiszewski, 2020; Kaczmarek, 2009; Zwolan & Czaplewski, 2015).

In 2008, the Maritime Office in Gdynia commissioned a feasibility study, which considered four locations: the villages of Skowronki and Nowy Świat in Sztutowo municipality, and Przebrno and Piaski in Krynica Morska municipality (Figure 5). The study focused on creating a direct connection between the Vistula Lagoon and the Baltic Sea to make shipping independent of the Russian Federation. The plans featured a seaport in Elbląg that would be accessible to marine vessels under all flags. Ultimately, the village of Skowronki was chosen as the best option to provide the shortest and fastest route connecting Elbląg with the Tri-City (Gdańsk-Sopot-Gdynia).

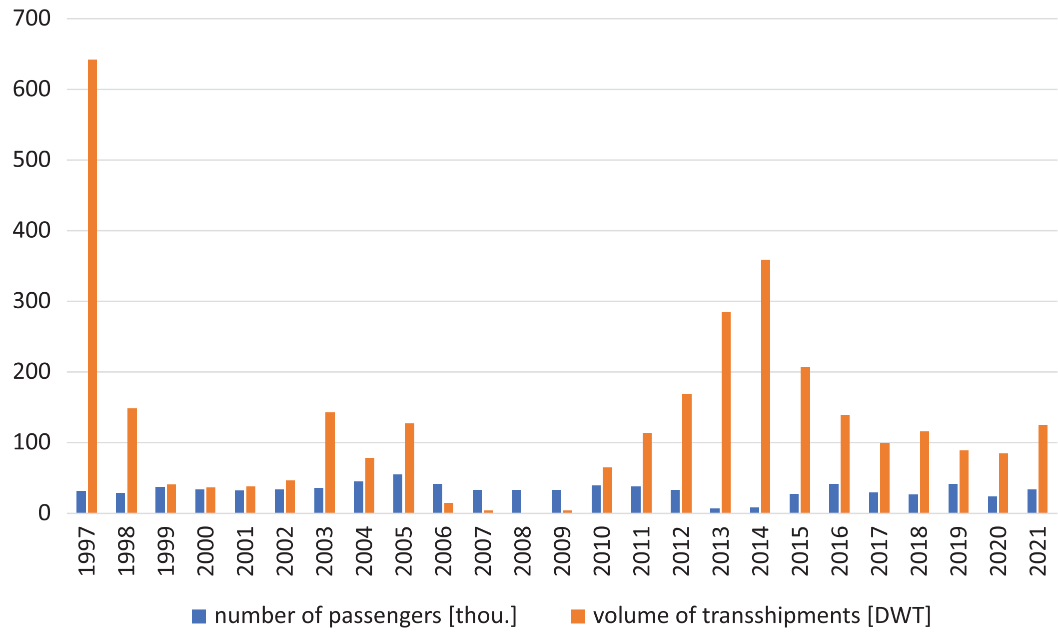

Figure 4. Shipping load and passenger traffic between 1997–2021 in the port of Elbląg. Source: Zarząd Portu Morskiego Elbląg (2022).

The planned canal was to be about 1.1-kilometre-long, 40 to 80-metre-wide and 5-metre-deep, equipped with one lock. Construction work was initially scheduled for 2009, to be completed in 2012. In response to these plans, the Russian side undertook diplomatic steps culminating in a Polish-Russian agreement on navigation in the lagoon (September 2009). Accordingly, the shipping route through the Piława Strait was reopened and work on the canal halted. Some years later, however, the Ministry of Infrastructure announced that the construction of the canal would commence in 2017 (Modzelewski, 2017, pp. 235–239).

In the following years, no action was taken regarding the canal, but the project re-emerged in 2014. Since the early 2000s, the construction of the canal was a subject of political contention between the pro-European Civic Coalition and the United Right parties. When the latter won the elections in 2015, it became a major regional socioeconomic programme. On 24 May 2016, the Polish Council of Ministers passed a resolution on a long-term project titled Construction of a Waterway Connecting the Vistula Spit with the Gdańsk Bay with an estimated cost of PLN 880 million. On 24 February 2017, Polish Parliament passed a special law on the cross-cut through the Vistula Spit to ensure efficient implementation (Law 217). By mid-2019, the value of the project more than doubled, reaching PLN 1.987 billion, to be financed entirely from the government budget. Finally, a location was chosen near the village of Nowy Świat, which had been abandoned since WWII (one of the locations considered in 2008).

The construction work has been divided into three stages, with the ultimate goal of providing a direct fairway to Elbląg. Currently, the planned total length of the route is 22.88 kilometres divided into three sections: a fairway of 10.38 kilometres on the River Elbląg; a fairway of 10,18 kilometres on the Vistula Lagoon; and (the key element) 2.32-kilometre-long shipping lane through the Vistula Spit with a sheltered outer harbour (Drążkiewicz, Golan, Kasprzak, et al., 2020, p. 231). Thus, the actual canal is only part of the discussed project, i.e., the waterway connecting the Vistula Lagoon with Gdańsk Bay. Construction work on this section commenced in late 2019 and Stage 1 was completed in summer 2022. The canal was officially opened on 17 September 2022. The two remaining stages include the deepening of the Vistula Lagoon (Stage 2) and the Elbląg River with an approach canal to the Elbląg port (Stage 3) to be completed in 2023.

4.3. Technical Specifications

As mentioned above, the canal is situated in the vicinity of the abandoned fishing settlement of Nowy Świat, between the villages of Przebrno and Skowronki (detailed technical specifications and design solutions are available in Drążkiewicz, Golan, Hińcza, et al., 2020 and Drążkiewicz, Golan, Kasprzak, et al., 2020). The actual canal forms a section of the fairway leading from the Gdańsk Bay to the Elbląg port. (Figure 6). The original tender documents specified the dimensions of the largest vessels to navigate the waterway as follows: Ships of up to 100 metres in length or barge convoys up to 180 metres in length, with a beam of 20 metres, and a 4.5-metre draught. The specifications apply to conventional vessels based on the largest dimensions. This

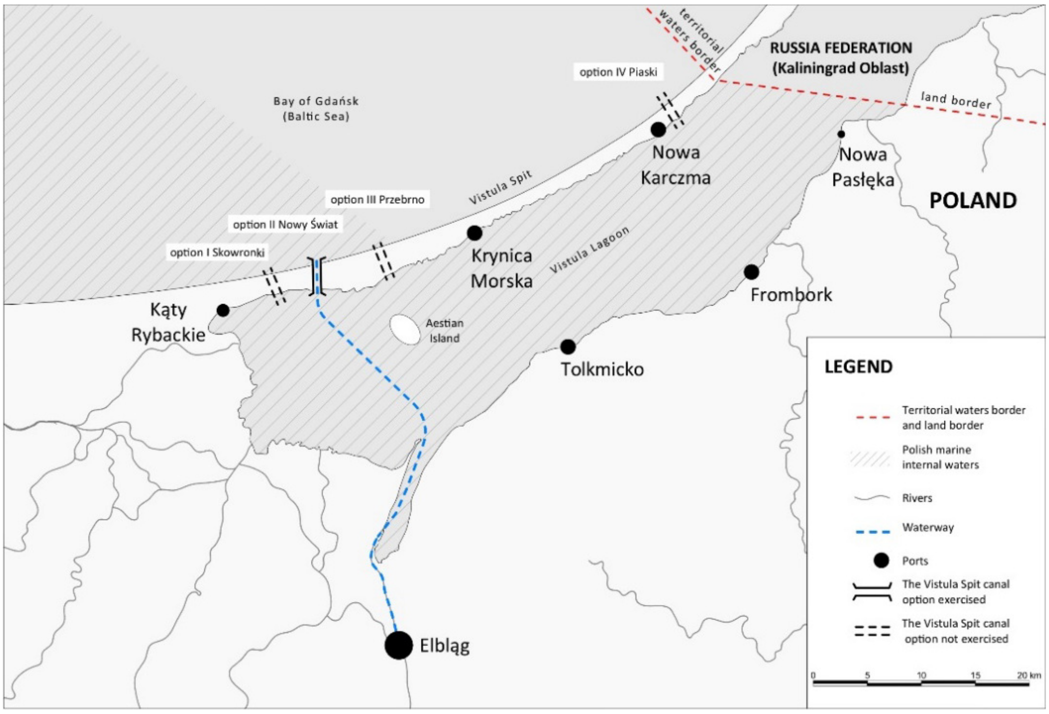

Figure 5. Alternative locations for the cross-cut through the Vistula Split and the new shipping canal.

corresponds to seagoing general cargo vessels of 2,500 DWT, 105 metres in length, with a 15.8-metre beam, and a 4.5-metre draught; or to barge convoys of 2,000 DWT, 180 metres in length, with a 9.0-metre beam, and a 2.5-metre draught. The planned maximum draught of 4.5 metres makes the canal navigable at medium water levels and above. An important caveat is that at lower water levels, navigation will not be possible (Drążkiewicz, Golan, Hińcza, et al., 2020).

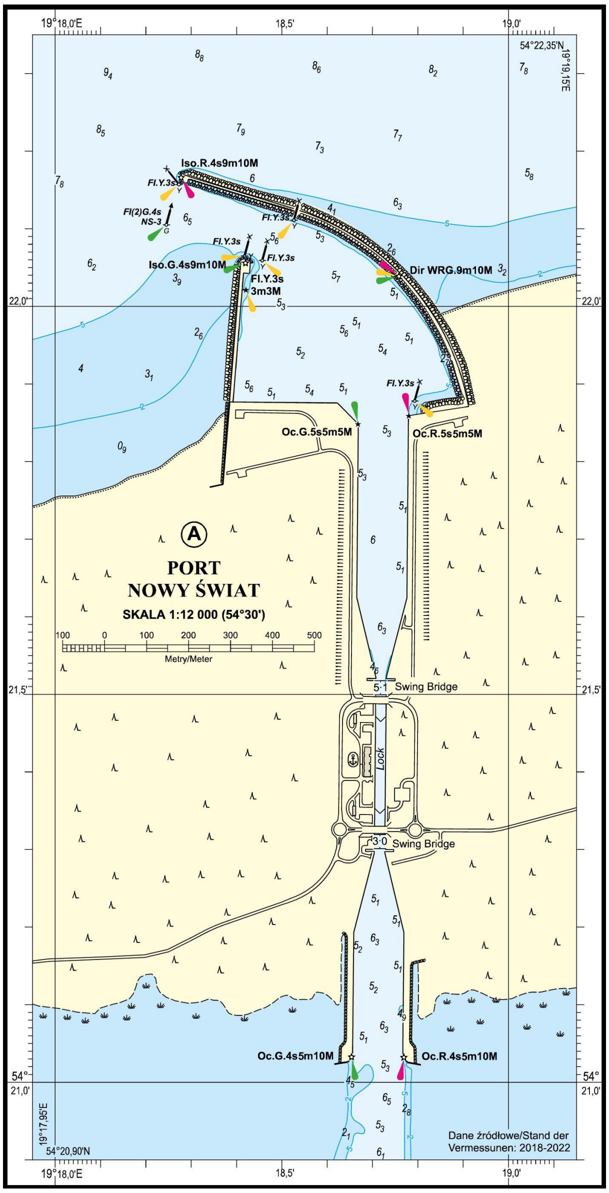

Figure 6. Nautical map of the Nowy Świat Port. Source: Naval Hydrographic Office (2022).

The approximately 1.526-kilometre-long shipping canal at Nowy Świat comprises: (1) a shipping canal and sluice, (2) a wharf with a "northern" waiting berth, (3) a sheltering harbour on Gdańsk Bay, (4) a road system in the canal area, (5) buildings including the harbour master's office, (6) a wharf with a "southern" waiting berth on the lagoon, (7) the Estyjska Island on the lagoon, (8) a swing bridge at Nowakowo, and (9) a fairway on the lagoon. The mainland transport route on the Vistula Spit is province road no. 501 situated transversely to the axis of the canal. Due to the planned increase in tourist traffic, a system of two crossings over the shipping canal was built featuring swing bridges. The bridges and sluice gates will open alternately to maintain traffic flow. Furthermore, navigational signage will be provided in the shipping canal (Drążkiewicz, Golan, Kasprzak, et al., 2020; Figure 7).

The sheltering harbour located on the Gdańsk Bay consists of two breakwaters (eastern and western), a "northern" berth with 20-metre-wide layby berths and a technical depth of 5.0 metres, a 200-metre-long by a 25-metre-wide lock with a water depth of 6.8 meters, and a "southern" berth with layby berths of similar specifications to the "northern" berth (Drążkiewicz, Golan, Hińcza, et al., 2020; Figure 8).

One of the key features of the new waterway connecting the Gdańsk Bay and the Elbląg port is a small artificial Estyjska Island. This is to serve as reclamation grounds for material dredged up while deepening the fairway in the lagoon and the River Elbląg. It is of an elliptical shape along a 1.932-metre-long axis and covers an area of 181 hectares. It is situated in the western part of the lagoon, about 1.65 kilometres from the shore of the Vistula Spit, and 1.6 kilometres to the east of the fairway (Drążkiewicz, Golan, Kasprzak, et al., 2020, pp. 232–233). Its name derives from the historical name of the lagoon (Old Prussian Aīstinmari). Since its mounding, it has become a refuge for waterfowl and vegetation.

The next stage of the fairway, starting in 2022, includes deepening and widening the shipping route on the Vistula Lagoon and the River Elbląg to 60 metres, financed from the government budget. A point of contention is the last section of 0.9 kilometres on the approach to the port, which is entirely the property of the local authorities who, according to the central government, should finance the works.

5. Analysis of Economic, Planning, and Transportation Solutions and Their Environmental Impact

5.1. Context

From its conception, the project has been highly controversial among politicians, economists, urban planners, and environmentalists. It has triggered a wide range of public responses from supporters and opponents alike. It has also been used in politics, especially in election campaigns, e.g., the early mayoral elections in Elbląg in 2013, won by a United Right candidate. When the project was formally announced in 2006 by Jarosław Kaczyński (Law and Justice), the then-opposition parties were very sceptical. Later, in 2013, the then Prime Minister Donald Tusk (Civic Platform) spoke of "a very expensive project, questionable economically and used by the opposition for political purposes" (Modzelewski, 2017, p. 249).

Figure 7. View of the completed canal through the Vistula Spit. Photo by EPA bought from Polish Press Agency.

He also emphasised its environmental safety. Attention was drawn to the high cost, estimated originally at around PLN 880 million (€186.4 million), which eventually rose to around PLN 2.0 billion (€423.7 million), excluding the last two stages.

The arguments criticising the project's rationale have included other issues. For example, the lagoon is a memorial site and a huge cemetery of victims fleeing the Soviet Army in early 1945, displaced from the former area of East Prussia. The number of people trying to cross the Vistula Lagoon is difficult to estimate due to the chaos of the time, but it is likely that only half of around one million made it to the other side. Ultimately, the number of victims who drowned with their belongings in the lagoon due to Soviet airstrikes is unknown (Gliniecki, 2021).

One of the most significant arguments against the canal is its adverse impact on the natural environment. Critics have pointed out the potential displacement of native species by invasive ones carried in with ballast water. Furthermore, the turbidity of water in the vicinity of reclamation works and the associated photosynthesis could significantly reduce vegetation and zooplankton. Studies have also suggested potential interference with biodiversity in the lagoon and other natural losses (Dobrzycka-Krahel & Kozakiewicz, 2011, pp. 212–213, 217). Another potential effect is increased salinity caused by water exchange with the Baltic Sea by approximately 1.3% in the Polish part of the lagoon and by 0.4% in total. This may change the composition of fish species, including the loss of freshwater fish (Dubrawski & Zachowicz, 1997). Ship traffic could also have a negative effect on fish spawning grounds and bird colonies in the Vistula Spit Landscape Park (Modzelewski, 2017). Other analyses, however, showed that water exchange between the bay and the lagoon would be negligible and would only occur during sluicing. A positive effect would be higher oxygenation of water in the lagoon due to the inflow of water from the sea (Salomon, 2018).

Another major concern is the impact of the canal and the artificial strait in the Vistula Spit on the hydrodynamics of water in the lagoon. Findings indicated, however, that the new canal could help reduce flood risk in a nearby polder area (Cieśliński, 2013; Kaczmarek, 2009; Szydłowski et al., 2019).

The Russian invasion of Ukraine in February 2022 has significantly changed the approach to the canal through the Vistula Spit. Until now, all vessels entering the Vistula Lagoon had to pass through the Russian-controlled Piława Strait where, in recent years, the Russian authorities have repeatedly blocked or obstructed transport and tourist traffic. An independent entry into the Vistula Lagoon from the sea is considered a strategic asset. According to government officials, the situation in Ukraine and the Russian invasion proves that "this type of infrastructure protects us from potential blockades, if only of ports" (Krawiel, 2022). On the other hand, military analysts respond that "from a military point of view, the cross-cut will not affect Poland's defence system" (Krawiel, 2022).

5.2. Arguments for and Against the Canal

Both the preparation and construction stages of the project have triggered a strong public response from the advocates and opponents of the canal. Several

Figure 8. Southern view of the completed canal through the Vistula Spit. Photo by Adam Warżawa bought from Polish Press Agency.

analyses, studies, and publications list arguments aiming to identify its strengths and weaknesses. Importantly, it has been observed that the evaluation should not only focus on the actual canal but also on the entire project, which encompasses a shipping route from the Baltic Sea to Elbląg and the development of the port (Chudzyński, 2019; Duczyc & Wendt, 2019; Modzelewski, 2017).

5.3. PESTEL Analysis

Using the PESTEL strategic planning tool, the author has produced an analysis to evaluate the objective of the project Construction of Shipping Canal with a Cross-cut through the Vistula Spit (Table 1). The process of surroundings general segmentation aims to single out the areas that are significantly related to the project. Using this method to enhance the earlier-mentioned conditions allows for obtaining complementary results. A PESTEL analysis involves determining the most significant factors and relating them to particular areas (political, economic, social, technological, environmental, and legal). They are then used to evaluate the impact of these factors on the project and to determine their interdependencies and mutual relations. Knowing the nature of particular factors, they were identified based on the author's observations of the existing situation in the Vistula Lagoon area, and on the author's research, including analyses of literature and source materials.

The analyses present the project and its impacts based on political factors interfering with project operation; economic factors affecting the economic environment and the ability to generate revenue; sociocultural factors determining the impact on society and its cultural dimension; technological factors affecting business operations, distribution processes, and product and service marketing; environmental factors related to the wider environment; and legal factors affecting the way the entire project operates (Kałkowska et al., 2010; Kozłowska, 2020; Yüksel, 2012).

The analysis was carried out in accordance with the PESTEL procedure (Table 2). The columns of the table show individual factors categorised in each group (political, economic, socio-cultural, environmental, and legal). To assess the impact on project implementation, point values were assigned on a scale of 0–5 (author's assessment, where 5 means a factor of significant importance, and 0 means a factor of marginal importance) and the probability of its impact on three phases: increase, stabilisation, and decrease of each factor's impact on project implementation. The total probability value for these must equal 1. Based on the calculations it was possible to interpret the trend (the dynamics of progressivity, indifference, and regression of each factor in each group). Factors (P), (I), and (R) stand for progressivity, indifference, and regression, respectively.

The growth trend for political factors shows the highest progressive dynamic in political independence, the significance of Elbląg, creating naval policy, and current internal affairs. Factors without direct impact include effective international cooperation and EU unity.

Table 1. Selected arguments for and against the canal.

Arguments for the canal	Arguments against the canal
• Open access to the Baltic Sea and using the full potential of Elbląg and other ports in the lagoon area • Economic development of Elbląg and adjacent municipalities, better trading conditions • Greater independence from Russia and limiting Russia's political and economic influence • An advantageous location for potential economic links with Baltic and Nordic countries • Better conditions for yachting and water sports • Higher attractiveness and tourist traffic in the Vistula Lagoon area • Sea traffic between localities on the southern shore of the Vistula Split and Tri-city • Better flooding prevention with an opening/locking canal	• High costs and doubtful economic rationale • Adverse impact on the natural environment and damage to the Natura 2000 protected areas • Insufficient transport accessibility for shipping routes • No military rationale • Ecologic and environmental risks, including increased salinity and impact on biodiversity • Annual expenditure on fairway conservation, dredging, and winter maintenance • Doubtful commercial and military advantages due to the small draught of ships • Public protests in some localities in the lagoon area • Impact on memorial sites in the lagoon area

The economic dynamic trend clearly shows higher transportation diversity and potential development of the Elbląg port, as well as higher tourist traffic and competitiveness in the region. The project's impact on the value of investment expenditure, higher budget deficit, and investment-related growth in the region is definitely regressive.

The growth trend in sociocultural factors shows a slightly progressive dynamic in social antagonisms, changes in lifestyle and quality of life. Factors with

Table 2. PESTEL analysis: Political factors.

		Increase/Progress		Stabilisation		Decline/Regress	
Factor	Trend	Impact [0–5]	Probability [0–1]	Impact [0–5]	Probability [0–1]	Impact [0–5]	Probability [0–1]
P (Political) factors							
Independence from the Russian Federation foreign policy	P	5	0.7	1	0.2	3	0.1
Importance of Elbląg in creating regional development policy	P	3	0.5	1	0.4	1	0.1
EU internal unity dynamic	I	2	0.2	1	0.7	1	0.1
International cooperation effectiveness	I	4	0.3	2	0.6	1	0.1
Higher level of safety and impact on military conflicts	P	1	0.3	3	0.5	1	0.2
Creating a naval policy	P	3	0.4	2	0.3	3	0.3
Current internal politics (parliamentary and local government elections)	P	4	0.7	3	0.2	1	0.1
Politics of remembrance and commemorative space	I	1	0.1	3	0.8	1	0.1
Factor (P)	P	**1.86**		**0.62**		**0.16**	
Factor (I)	I	**0.56**		**1.43**		**0.50**	
Factor (R)	R	—		—		—	

Table 3. PESTEL analysis: Economic factors.

Factor	Trend	Increase/Progress Impact [0–5]	Increase/Progress Probability [0–1]	Stabilisation Impact [0–5]	Stabilisation Probability [0–1]	Decline/Regress Impact [0–5]	Decline/Regress Probability [0–1]
E (Economic) factors							
Development of a seaport in Elbląg	P	5	0.7	3	0.2	1	0.1
Investment attractiveness and growth rate of developments in the region	P	4	0.3	3	0.6	1	0.1
Higher transportation diversity on a regional and international scale	P	3	0.6	3	0.3	1	0.1
Value of investment expenditure and condition of public finance	R	2	0.2	3	0.3	4	0.5
Higher competitiveness of the region	P	5	0.4	3	0.4	1	0.2
Level of tourist traffic	P	5	0.4	3	0.4	1	0.2
Higher local government budget deficit	R	4	0.1	2	0.3	3	0.6
Increased business attractiveness of the region	P	4	0.4	3	0.5	1	0.1
Factor (P)	P	**2.02**		**1.20**		**0.13**	
Factor (I)	I	—		—		—	
Factor (R)	R	**0.40**		**0.75**		**1.90**	

Table 4. PESTEL analysis: Sociocultural factors.

Factor	Trend	Increase/Progress Impact [0–5]	Increase/Progress Probability [0–1]	Stabilisation Impact [0–5]	Stabilisation Probability [0–1]	Decline/Regress Impact [0–5]	Decline/Regress Probability [0–1]
S (Sociocultural) factors							
Public antagonism related to constructing the canal	P	5	0.4	2	0.3	4	0.3
Higher life stability in the population	I	5	0.2	3	0.5	3	0.3
Higher cultural and recreation potential of the towns and localities	I	4	0.2	2	0.6	2	0.2
Migration	I	3	0.1	1	0.8	1	0.1
New quality of life	P	4	0.4	2	0.5	2	0.1
Change in lifestyle and cultural traditions	P	4	0.3	1	0.6	2	0.1
Population prosperity	I	4	0.1	2	0.8	1	0.1
Factor (P)	P	**1.6**		**0.63**		**0.53**	
Factor (I)	I	**0.63**		**0.33**		**0.38**	
Factor (R)	R	—		—		—	

Table 5. PESTEL analysis: Technological factors.

Factor	Trend	Increase/Progress Impact [0–5]	Increase/Progress Probability [0–1]	Stabilisation Impact [0–5]	Stabilisation Probability [0–1]	Decline/Regress Impact [0–5]	Decline/Regress Probability [0–1]
T (Technological) factors							
Development of transport infrastructure in the region	P	5	0.8	2	0.1	1	0.1
Number of engineering and technical professionals in the region	I	4	0.2	3	0.7	3	0.1
Development of energy-saving and pro-ecologic technologies	I	5	0.2	2	0.7	2	0.1
The emergence of substitution technologies	P	4	0.2	1	0.7	1	0.1
Factor (P)	P	**2.40**		**0.45**		**0.10**	
Factor (I)	I	**0.90**		**1.75**		**0.25**	
Factor (R)	R	—		—		—	

no direct impact include life stability, cultural potential in towns, migration and generally higher prosperity of the population.

The growth trend in technological factors suggests progressive dynamics in transportation infrastructure development in the region, as well as the emergence of substitution technologies (e.g., renewable energy). Factors without direct impact include the education level of technical professionals and the potential development of energy-saving and pro-ecologic technologies.

There is an obvious declining trend suggesting high regressive dynamics concerning disturbing the ecosystem and changing water conditions in the Vistula Lagoon caused by chemical pollution, as well as impact on plant

Table 6. PESTEL analysis: Environmental factors.

Factor	Trend	Increase/Progress Impact [0–5]	Increase/Progress Probability [0–1]	Stabilisation Impact [0–5]	Stabilisation Probability [0–1]	Decline/Regress Impact [0–5]	Decline/Regress Probability [0–1]
E (Environmental) factors							
Disturbing the Vistula Lagoon's ecosystem	R	5	0.1	3	0.2	5	0.7
Changed hydrological conditions in the Vistula Lagoon	R	1	0.1	4	0.4	3	0.5
Increased swell in the lagoon	I	4	0.2	2	0.6	2	0.2
Higher chemical pollution of the environment and water in the lagoon	R	3	0.2	2	0.4	5	0.4
Impact on the presence of plant species and nesting sites	R	4	0.3	3	0.3	5	0.4
Higher orientation towards care for public space	I	2	0.1	1	0.7	4	0.2
Impact on climate and environment	R	3	0.2	2	0.3	5	0.5
Factor (P)	P	—		—		—	
Factor (I)	I	**0.80**		**1.20**		**0.40**	
Factor (R)	R	**0.53**		**0.87**		**2.05**	

Table 7. PESTEL analysis: Legal factors.

Factor	Trend	Increase/Progress		Stabilisation		Decline/Regress	
		Impact [0–5]	Probability [0–1]	Impact [0–5]	Probability [0–1]	Impact [0–5]	Probability [0–1]
L (Legal) factors							
Maritime transport regulations	I	3	0.2	3	0.7	1	0.1
Scope of EU and Russian Federation formal and legal regulations	I	5	0.1	3	0.8	3	0.1
Maintaining EU funding for regional development	P	5	0.3	2	0.5	1	0.2
EU interference in construction of the cross-cut	I	3	0.1	3	0.8	2	0.1
Factor (P)	P	**1.50**		**0.60**		**0.20**	
Factor (I)	I	**0.47**		**2.30**		**0.2**	
Factor (R)	R	—		—		—	

species and nesting sites, and on climate and environment. Factors that have no direct impact include care for public space and swell in the lagoon.

Legal factors without direct impact include maritime transport regulations, EU and Russian Federation regulations, and the scope of EU interference in the construction of the canal. A slightly increasing trend can be seen in the scope of maintaining and receiving EU funding.

The PESTEL analysis of the project Construction of Shipping Canal with a cross-cut through the Vistula Spit assesses the progressive, stabilisation, and regressive dynamics for the particular factors in each group. The chart presenting the change dynamics of the planned investments suggests that there is a high potential (both internal and external) to implement the project based on the progressive trend. The findings show that the highest progressive dynamics are observed in particular groups of factors in the following order: technological (2.4), economic (2.02), political (1.86), sociocultural (1.6), and legal (1.5). As far as regression is concerned, it pertains primarily to environmental (2.05) and economic (1.9) factors. Interestingly, the analysis also shows that economic factors display similar progression and regression dynamics (Figure 9). This may stem from the fact that the region's economic potential, the significance of Elbląg as a port and existing infrastructure are conducive to growth dynamics, whereas financial outlays and subsequent burden on state and local budgets contribute strongly to regression. The highest regression concerns the middle indicators, which may stem from poorly implemented government policies and lacking consistent information policy.

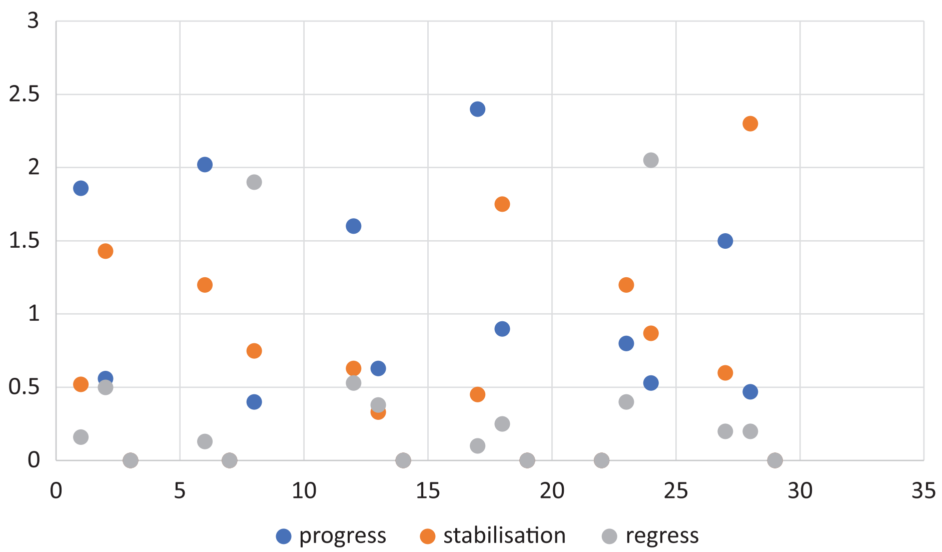

Figure 9. Factor change dynamics in the PESTEL analysis of the planned development.

6. Conclusions

The study of a wider context of building the cross-cut through the Vistula Spit and the new shipping canal proves the significant complexity of the project and the scale of the associated problems. The PESTEL analysis is complementary to the issues specified in the article and to the research carried out by the author. It is clear that the most significant factors are political, legal, and economic, including the key role of the Elbląg port within the economic environment.

Equally important is the historical, technical, and social context, which points to the commercial significance of the region as well as the effect of politics on its functioning. These determinants, combined with the factors from the PESTEL analysis, indicate leading trends in the region, both positive and negative ones, that impact project implementation. The author's analysis confirms evident significance of political, technological, and economic factors, whilst clearly observing disadvantageous environmental trends, which are indisputably regressive. The research indicates a potential for implementing the project based primarily on a progression trend that depends on obtaining financial support. This will enable not only the development of infrastructure but also the completion of the entire project, which seems crucial if it is to operate properly.

The construction of the canal through the Vistula Spit is now a fact. It certainly is an important project that changes the transport structure in the northern part of Poland. The planned facilitation of navigation and the higher importance of the Elbląg port will be contingent on the completion of the entire shipping route. This is a key element of the project as a whole. Without it, the forecasted benefits may prove illusory. At present, one cannot clearly estimate its economic impact, although based on analyses, it is likely that it may be important for local transport structure. However, this requires strong determination and a coherent transport policy on the part of central and local authorities. In view of international changes related to the politics of the Russian Federation and the war in Ukraine, the independence of local transport from transit through the Piława Strait (on Russian territory) is a substantial achievement. However, as far as military technology is concerned, the impact of the project is negligible. The key potential disadvantage is the project's regressive impact on the natural environment and its ecological consequences. A thorough review requires time and detailed studies to measure its effect on nature, whereas future assessments require a series of observations in a longer term. In a democratic country, the media have an important role to play, which consists of regular monitoring of the developments, and presenting practical dimensions and all possible outcomes of a project like this one.

The most recent report on the canal, from early 2023, reads:

> Currently, the statistics provided by the Maritime Office in Gdynia show that 467 boats and ships have crossed the Vistula Spit Canal up to 14 December 2022, including 309 in the first month, 194 in the first week and 95 on the first day. Looking at these figures, one can conclude that interest in the project is dropping. (Pałczyński, 2023)

This shows that as long as the project is not completed in full, it is, not possible to estimate its effect.

Acknowledgments

The author wishes to thank Joanna Kałkowska for her valuable insights and content-related suggestions and Filip Osiński for his support in developing the illustrations.

Conflict of Interests

The author declares no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 305–318
https://doi.org/10.17645/up.v8i3.6834

Article

Searching for Reconnection: Environmental Challenges and Course Changes in Spatial Development Along Shanghai's Shipping Channels

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Submitted: 14 February 2023 | Accepted: 2 June 2023 | Published: 26 September 2023

Abstract
Waterways played a crucial role in the emergence of Shanghai as a cosmopolitan city and world port. Over the years the spatial and functional relationships between the city and ports and hinterland have been changing continuously. In Shanghai, like other port cities, almost all ports and related industries are placed out beyond the urban fringes, to form decentralized regional clusters, while former docklands are quickly transformed into attractive urban waterfronts. Simultaneously there is a growing physical and socio-economic gap with the rural hinterland. During Shanghai's brutal lockdown in Spring 2022, due to China's rigid zero-Covid policy, citizens were without food and other supplies while fully loaded ships were lined up waiting in the port. Also, deliveries from surrounding rural areas were temporarily halted. This article focuses on recent developments but is based on experiences in previous centuries from a long *durée* perspective. It elaborates on how the Yangtze River Delta urbanized along shipping channels and examines changing relationships between city and port, between urban and rural, and between man and nature. What role did shipping channels play and how to rebalance various spatial claims: urban, rural, port interests, and environmental concerns?

Keywords
ecological civilization; flood risk; hydraulic engineering; lockdown; long *durée*; port city; rural hinterland; shipping channel; spatial decentralization; urban delta

Issue
This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

Worldwide spatial and functional relationships between ports and their hinterland have been loosening due to globalization and containerization, resulting in the outplacement of ports and related functions beyond urban borders, and an increasing disconnection between city and port (Bird, 1973; Ducruet & Lee, 2006; Meyer, 1999; Notteboom, 2004; Rodrigue & Notteboom, 2012). Somewhat late since the beginning of this century, this is also happening in Shanghai but at an accelerated speed and large scale. Not only the spatial configuration of ports is changing, but also the "global landscape as we know it is changing fast" regarding international trade "accompanied by uncertainty" (Notteboom & Haralambides, 2020, p. 347). This article reevaluates this process of spatial decentralization and disconnection between port, city, and rural hinterland, in the context of environmental challenges. It analyzes the chronology of interactions between urban and port development along shipping channels in Shanghai and the Yangtze River Delta.

Spatial and functional relationships between Shanghai's city and port have been changing continuously over the decades under the influence of natural and human events. Nowadays Shanghai's port areas are decentralized beyond the urban fringes while former docklands along the Huangpu River (and Suzhou Creek) are transformed into urban waterfronts (den Hartog, 2021a). In this article is argued that there is simultaneously an increasing disconnection between this metropolis and the surrounding countryside. To safeguard arable land, China has a policy that must guarantee a degree of self-sufficiency (Jacobson, 2012) in food supply, which means that agricultural land after urbanization needs to be compensated. Red lines have been introduced in Shanghai's latest master plan (Shanghai Municipal People's Government, 2016) to limit urban expansion and safeguard agricultural land.

The disconnection between city and port reached a dramatic peak with Shanghai's lockdown (den Hartog, 2023; James, 2022; Kuo et al., 2022) during Spring 2022 due to China's rigid zero-Covid policy, when more than 24 million citizens—according to some estimates even far above 30 million—were without fresh food and other basic supplies (medicines) for 10 days—and in several cases even longer, with dramatic consequences—while fully loaded ships were lined up waiting in the port and delivery from surrounding rural areas was temporarily halted. Although Shanghai's policy is geared toward urban and rural balance (Shanghai Municipal People's Government, 2016) and ecological civilization (Hansen et al., 2018) through ecological restoration and other means, this event represented—in a negative sense—an ultimate disconnection, not only between port and city but also between urban and rural, between citizens and leaders, even between man and nature. All of these themes have become even more relevant in our current post-pandemic era. What role did shipping channels play over time in the relationship between port and city, and between the port city and its deltaic hinterland with ecological and agricultural vulnerabilities? How to rebalance urban and rural spatial claims, port interests, and environmental concerns in the context of Shanghai in the Yangtze River Delta?

2. Huangpu River and Suzhou Creek as Backbones of Shanghai's Prosperity

To put things in long *durée* perspective (Braudel & Wallerstein, 2009; Hooimeijer et al., 2021), in the following sections the changing relations over time between human settlements and deltaic landscape are explained, i.e., how in the marshy low-lying vulnerable delta area, a long-term process of coastline growth and shipping channel adjustments by natural events (sedimentation in the estuary, flooding, silting along the coast, etc.) and human interventions (canalization, dredging, land reclamation, flood protection, waste disposal, irrigation, etc.) influenced urbanization, transportation, port development, agriculture, and natural values.

China's dynamic, highly urbanized Yangtze River Delta region with Shanghai as its central metropolis forms the engine of the national economy for centuries thanks to unique geographical conditions: fertile delta grounds for agriculture to feed the city (King, 1911), and a strategic location for port development (Dai, 2004) with international connections and access to remote hinterlands via the more than 6,300-km long Yangtze River. In particular, the role of shipping routes from the Tai Hu basin—with 2,250 square km, one of China's largest freshwater lakes—to the coast was crucial for the development of the city and port.

The Huangpu River and Suzhou Creek played a crucial role in the rise of the world port of Shanghai—and the wider Yangtze Delta and even China as a whole. Both contributed significantly to prosperity. Both shipping routes were created through an interplay between natural events and hydraulic engineering and dredging. Nowadays environmental concerns are a main concern since massive urban expansion (den Hartog, 2010; Hsing, 2010) conflicts with natural values while flood risk increases again due to sea level rise. Since China's economic reopening urban planning and spatial design have been characterized by a tabula rasa planning approach. Cultural-historical values (e.g., landscape, ecology, and built heritage) increasingly disappeared, though recently these values are rediscovered and partly protected. In line with this reappreciation for cultural-historical roots and natural protection—and in line with the thematic issue of this journal on the role of shipping channels and ports in the context of hinterland relations and ecological concerns—this article is grounded on a basic explanation of Shanghai's historical spatial development along shipping channels. This long *durée* perspective (Braudel & Wallerstein, 2009; Hooimeijer et al., 2021) as a frame is novel in the discourse of contemporary urban planning and spatial design in China. Data for this article is collected by review of literature and policy documents, and supplemented by interviews with local experts and field research (the author has been living and working in Shanghai for 14 years). The focus of this article is on changing relations between man and nature, between urban and rural, and between port-city and direct hinterland, in which the physical or functional distances are increasing. The conclusion calls for reconnection and strengthening of ties between the separated entities.

2.1. Emerging Metropolis and World Port in the Delta

The Huangpu River, a largely artificially dug shipping channel, was created on the basis of an ancient system of smaller creeks and streams in the tidal landscape of the Yangtze River Delta (Figure 1). For many centuries the Yangtze Delta was characterized by a network of waterways (King, 1911) that has "defined politics and ways of life for centuries" in China (Ball, 2017, p. 1). This delta area has one of the world's oldest rice cultures, inherently connected to this ingenious traditional water system here (King, 1911). Actually, Shanghai was not always the most important port in this delta. Respectively the cities of Suzhou and Songjiang had this position, and at that time Shanghai did not even exist. Looking at the map, one can see that Suzhou and Songjiang are respectively

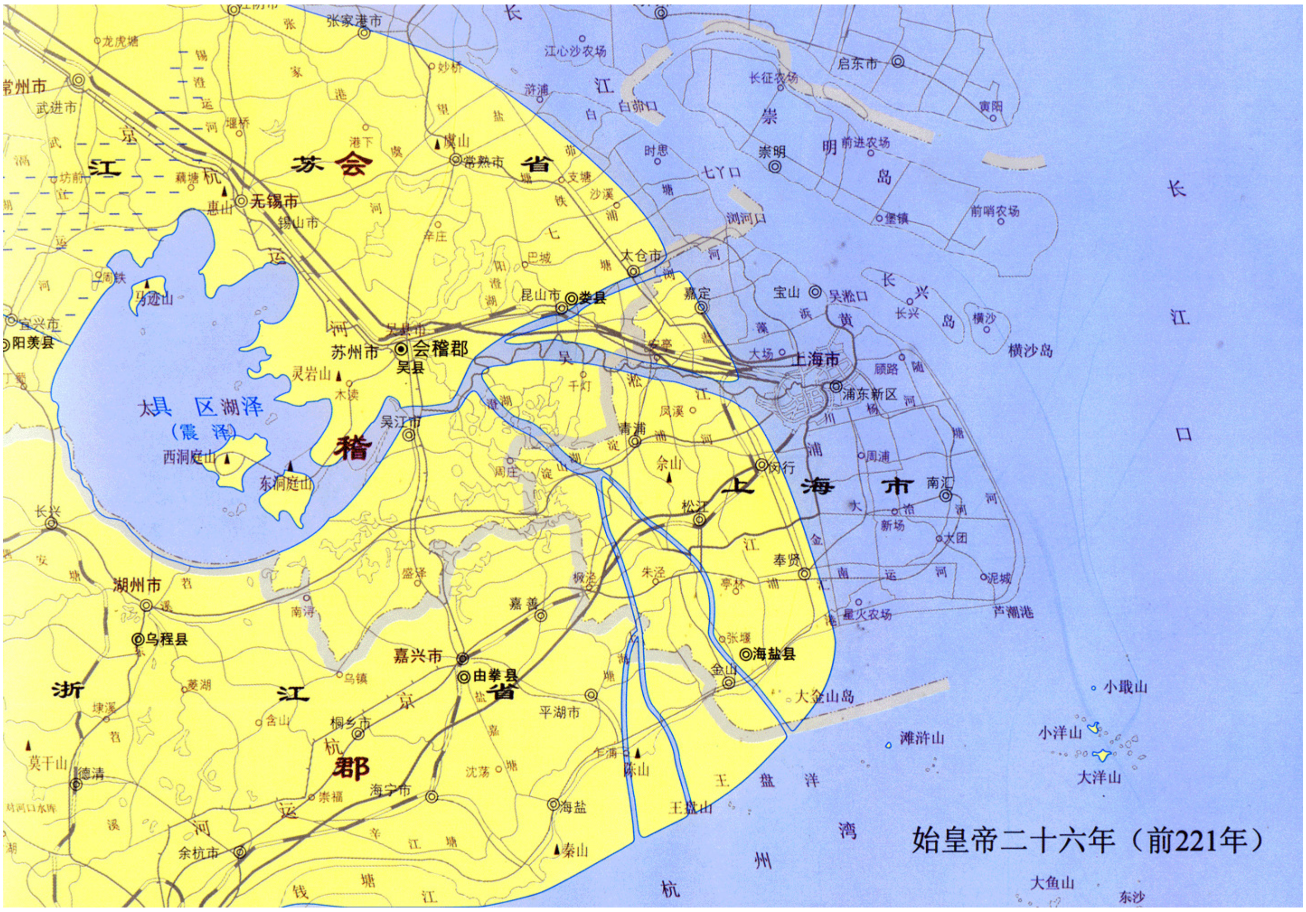

Figure 1. Main waterways and coastline in the year 221. Note: In light grey the situation in 1999. Source: Zhou (1999).

120 and 60 km away from the current coastline. Over the years the coastline shifted as a result of sedimentation processes in the estuary of the Yangtze River. When the coastline was still near Suzhou this city was the prime metropolis in the wider region as the capital of the state of Wu (12th century BCE–473 BCE). Suzhou reached a golden age during the Han Dynasty (206 BCE–220 CE) when thanks to international trade Suzhou could grow quickly and it became one of the 10 largest cities on earth (Chandler, 1987). Due to silting up of shipping channels, flooding, as well as the shifting coastline due to sedimentation—enhanced since the late Han dynasty by hydraulic interventions—Songjiang emerged as Suzhou's outer port and became the new regional center during the Tang Dynasty (618–906). At that time the Wusong River (current Suzhou Creek) was called "Song Jiang," after which the eponymous city was named, and which is now a suburban district of Shanghai. Early Yuan Dynasty (1279–1368) Shanghai was founded after the construction of the Huangpu River. Before that, during the Song dynasty (960–1279), a dike was built to keep saltwater out as much as possible so agriculture could develop. A small fishing settlement called Hudu arose. Apart from fishing, salt production was also an important source of income. In 1074 Hudu became a "market town" (*zhen* 镇), in 1159 a "market city" (*shi* 市), and in 1292 this town was given its current name Shanghai, and it became a county capital (Scheen, 2022). After this, the fishing harbor transformed gradually into a regional port with multiple functions.

In 1554, during the Ming Dynasty, a city wall with a moat was built as a fortification, with three water gates to enable ocean-going ships to dock within the urban core (Denison & Guang, 2006, p. 20). Dongjiadu, located outside the protective city walls, used to be the first urban extension outside the wall. A thriving bustling sailor's neighborhood arose here with trading houses, temples, and influences from all provinces and neighboring countries with trading posts, eateries, and culture. Each province or country was represented by a merchant guild or *huiguan*, a building that functioned as a meeting place for groups of migrants (Denison & Guang, 2006; Knyazeva, 2015; Moll-Murata, 2008). Ships moored along the Dongjiadu Canal and Huangpu River. Particularly during the late Qing Dynasty, the area started to attract international trade (communication with local historians). Due to the Opium Wars and the foundation of foreign concessions, the port function shifted north to the well-known Bund. As a result, international trade started to thrive again (after a period of border closure), with new mooring places and industries stretching in a longitudinal direction along both riverbanks (Figure 2), especially on the Puxi side. Dongjiadu quickly fell into disrepair, reinforced by wars and fires. In 1937 the Japanese bombed the area and Red Guards destroyed

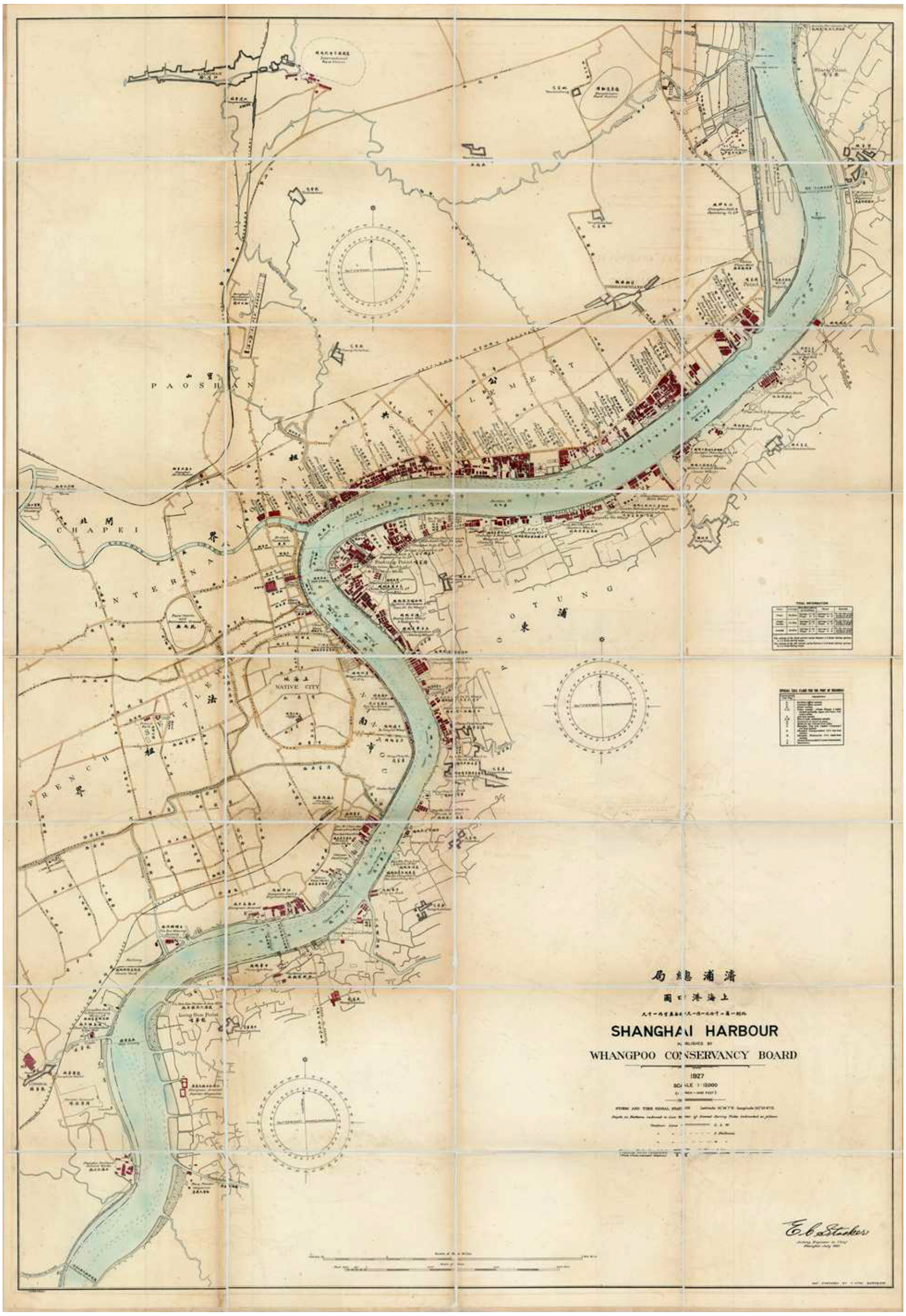

Figure 2. Huangpu River with embankments in a longitudinal direction. Source: Utne (1927).

most remaining cultural heritage during the Cultural Revolution (Denison & Guang, 2006; Knyazeva, 2015). Despite its historic and cultural relevance, Dongjiadu was not included on the municipal heritage list. This characteristic neighborhood recently has been wiped out in favor of commercial real estate with only two surviving buildings: a cathedral and a restored *huigan* (den Hartog & González Martínez, 2022).

2.2. Shifting Shipping Channels and the Birth of Shanghai

The large amount and density of water streams plus many changes over the years make it hard to identify ancient traces (Shi et al., 2022). Hence, the original course of the two main shipping channels, the Wusong River and Huangpu River, is not unambiguous.

There is even no clarity about where exactly the first inhabitants settled in this area, due to changing narratives (Scheen, 2022). Nowadays multiple streams are remembered in street naming. In the etymologically local Shanghai dialect, there was a distinction between waters in mainly north-south directions generally called Pu, Gang, and Jing, and in east-west directions Bang, He, and Tang (Lei, 2018). Many neighborhoods and street names contain these words still today. For example, the name of both city halves refers to this: *Pǔ Xi* (浦西)—in which *Xi* means west—on the west side of the Huang Pu River and *Pǔ Dōng* (浦东) on the east. The character *Pu* refers to an old creek in the north-south direction and Huang refers to the person Huang Xie (黄歇), better known as Chunshenjun (春申君), minister of state at the end of the Warring States Period (475–221 BCE) under whose leadership (according to folk tales and several historians) the river was excavated. During his reign, the river was renamed after him: Huangxiepu or Chunshenpu. Hydraulic interventions under his reign prevented floods and contributed to the prosperous development of agriculture (Lei, 2018). This fact is used as a strategy to stimulate local tourism by honoring him with a temple in Chunshen Village in the Songjiang District of Shanghai (Xinhua, 2002). From this village, the river branches from Suzhou (Jiangsu Province), Hangzhou, and Huzhou (Zhejiang Province) merge together. There is even a shrine for Chunshenjun and a Chunshen Hall with a museum on Huangpu's history. The importance of this former minister of state for Shanghai is emphasized mostly by borrowing the middle character from his name: the character *Shēn* (申) which is alternatively used as a nickname for the city of Shanghai. The city's full name Shanghai (上海) actually literally translates as (built) "upon the sea," since the coastline has been shifting eastwards (Figure 3). This naming reflects the importance of the coastal location and shipping channels.

2.3. Fighting Floods: Channeling, Dredging, and Diverting the River to Enable (International) Trade

Before the Huangpu River existed as the main drainage channel of Tai Hu Lake, the Wusong River had this function. Between 810–1042, the entire course from Tai Hu Lake to the sea was channeled to prevent silting, although dredging remains needed to enable merchant ships (coasters) to sail to Suzhou. During the Yuan Dynasty (1279–1368) the Huangpu became more important in use and was widened (Lei, 2018). It merged into the existing Wusong River at Huangpu *Kou*—"口'' *kou* means river mouth—a few hundred meters northeast of the current location (Denison & Guang, 2006). During

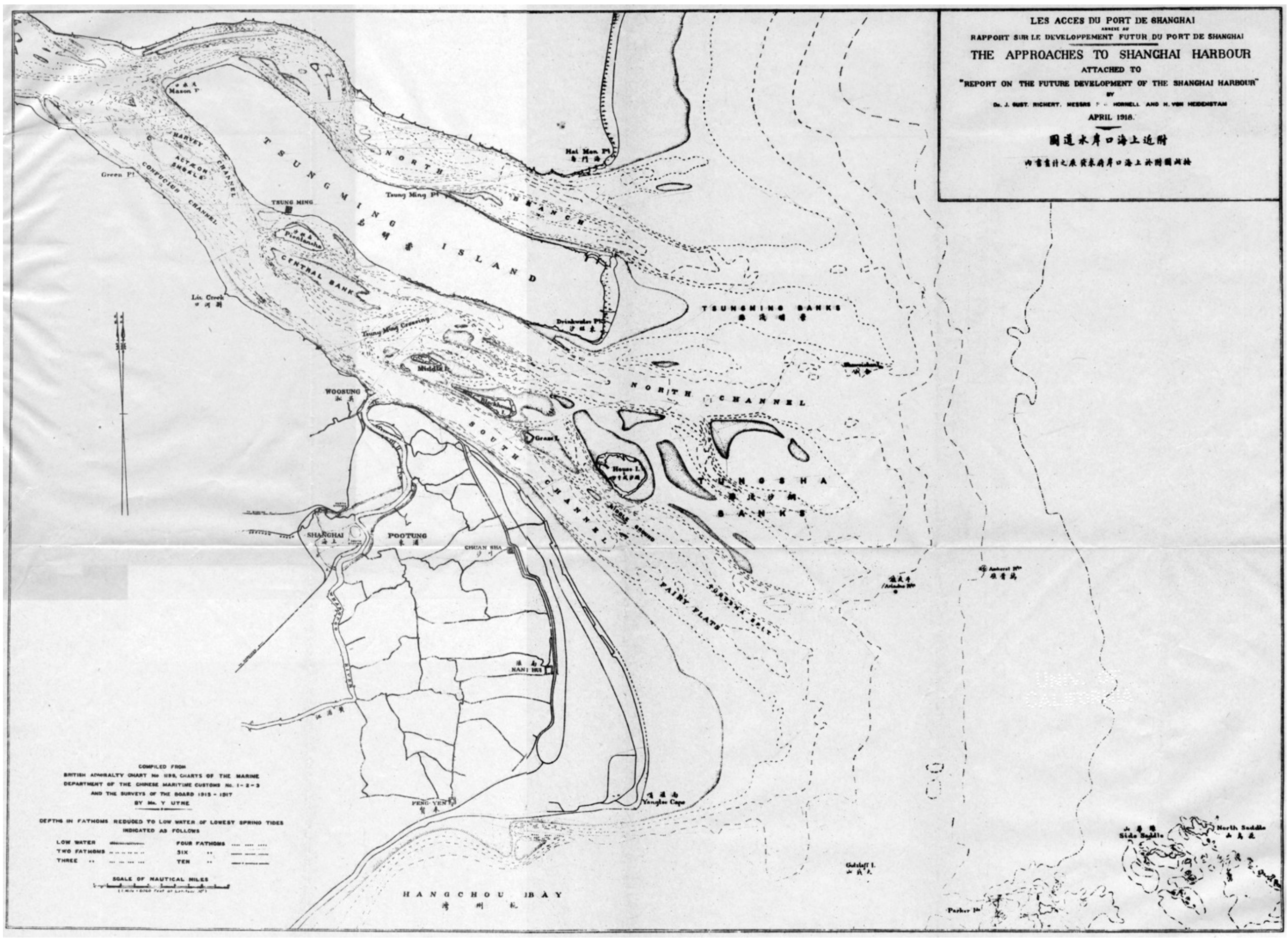

Figure 3. Yangtze River estuary with tidal landscape in 1918. Source: von Heidenstam (1920).

the Song dynasty, parts of the canalized creek system regularly silted up, leading to flooding during rainy seasons, with great damage to agriculture and the economy. This was exacerbated during the early Ming Dynasty (1368–1644)—at that time porcelain, cotton, and silk were the main export products of the region—when the lower reaches of the Wusong Creek River became silted up, and the Taihu Lake overflowed in July 1403 with a dramatic flood (Yang, 2022) resulting in the resettlement of many (Lei, 2018). Water engineer Ye Zongxing made a plan to dredge the Fanjiabang, which is the former name of the upstream Wusong River and is currently part of the Huangpu River between Waibaidu Bridge and Fuxing Island. The objective was to reduce flood risk downstream (Yang, 2022). This meant that outlet water from Tai Hu Lake was largely diverted via the new Huangpu course. As a result, the current Bund is located where it is. In addition to levees and other hydraulic works by Chunshenjun, these important engineering works by Ye Zongxing can be seen as equally essential in Shanghai's growth into a world port (according to interviewed historians). Yet only a modest memorial hall has been constructed for him in the periphery.

Another important water-control project was carried out a century afterward, resulting in the Huangpu River replacing Suzhou Creek as the prime transport artery. Due to the regular tidal waves from the East China Sea, the water level and flow of the Huangpu River changed three times a day (Yang, 2022), with still frequent flooding. To end this, Hai Rui—governor of Nanjing, then capital of the Ming Dynasty—ordered to build a dam east of the Jinhui River to redirect the Huangpu River to the north, giving the river its characteristic 90-degree angle in the southeast. This dam was replaced decades later with the excavation of the Dazhi Canal (*Dàzhì Hé*大治河) to the east and canalization of the Jinhui to the south, intended to further reduce flood risks but also to improve the saline and alkaline land conditions for agriculture east of the Huangpu River (Yang, 2022). The Dazhi Canal was dug by hand between 1977 and 1979—just after the Cultural Revolution (1966–1976)—by some 300,000 workers over a length of 39.5 km. Dazhi River makes a shortcut with the East China Sea and the same goes for the Jinhui Canal heading south, both are navigable by barges and even small coasters, but not intensively used (personal observations) and mainly serve for water management purposes.

2.4. Economic Reopening: Accelerated Industrialization, Agricultural Production, and Urbanization

After the Opium Wars, when the Treaty of Nanjing (1842) was signed and international trade was forced upon China, Shanghai grew in less than a century into the third largest financial center in the world after London and New York. After the international reopening, the Port of Shanghai began to function as a hub port and economic link for the wider Yangtze River Basin (Dai, 2019). The economic reopening also had a vast impact on the development of the direct hinterland within the delta region, especially on agriculture (with advanced irrigation systems), the rise of small and medium industries, new trends in handicraft industries, and population growth (Dai, 2019). After the Treaty of Nanjing, the city of Shanghai was subdivided into three main sections that operated under their own laws and regulations: the International Concession (before the British and American), the French Concession, and the Chinese city (Scheen, 2022). Each part had its own port or mooring places and institutions. Since the late 19th century, the Qing government expanded the port in Wusong for domestic activity (Hao & Li, 2018), while international, especially Western powers, operated from their concessions. At the beginning of the Qing Dynasty (1644–1911), Wusong was already a port town for the transshipments of goods, but it always played an important military strategic role, especially after the Opium War (Hao & Li, 2018). During the Qing government, a plan was raised to open new harbor basins for larger ships here at Wusong Town—the point where the original Wusong Creek (now Huangpu River) enters the Yangtze—to compete with the Shanghai Port that was run by foreign powers around the Bund. This was part of a larger plan—The Greater Shanghai Plan in 1927 (MacPherson, 1990)—to create a whole new city center outside of the foreign concessions. In reaction Western powers started dredging the Huangpu River in their concession areas. During the Second World War, a fierce battle with Japanese invaders took place here, memorialized with a monument and museum. Today this estuary is still called "Mouth of the Wusong" (吴淞口) with still a significant naval base.

The headwaters and middle part of the 125-km long Wusong River have been renamed Suzhou Creek since the mid-19th century by Westerners at the time of the foreign concessions since it connects to the formerly important port city of Suzhou. This channel played a crucial role in domestic trade and strongly influenced the spatial development of Shanghai, Suzhou, Songjiang, and the whole Yangtze River Delta region (Dai, 2019). The lower reaches of the Wusong River are now an integral part of the Huangpu and the name Wusong disappeared officially, although it is still the most important element of Shanghai's main shipping channel(s)—serving both the Huangpu and former Wusong River. Old Shanghainese know this and still use the original name in daily life.

After the foundation of the People's Republic in 1949 there came an end to "all kinds of sovereignty of imperialism and illegal occupation of our country, including ship diversion, navigation administration and channel dredging, which ended the chaos in the management of Wusong Port, which was caused by the imperialism for decades" (Hao & Li, 2018, p. 337). International trade was limited during Mao's rule (1949–1976). Under the communist rule of the People's Republic of China, Wusong Port gradually turned into an industrial port, in conjunction with the establishment of heavy industry-oriented in Baoshan District. Simultaneously, several satellite cities were built under, intended to strengthen ties with the rural hinterland with decentralized industries clusters. Agricultural production was meant to realize self-sufficiency, first with rice and grain, and since the 1960s also with aquaculture, pigs, poultry, and multiple crops.

2.5. Shanghai's Unprecedented Urban Growth as Economic "Head of the Dragon"

During the recent three decades, the world's economic center of gravity has shifted eastward, accompanied by extremely fast and large-scale urbanization. In 1992, revolutionary and former statesman Deng Xiaoping named Shanghai "Head of the Dragon" (Foster et al., 1998), i.e., China's economic gateway to the world. After a period of economic decline and a shrinking of the urban population, China's urbanization (Hsing, 2010) accelerated in an unprecedented way with the opening of the economy. The service sector began to grow, as did large-scale real estate developments. New cities and economic and technological development zones were established in the region (den Hartog, 2010), in conjunction with an export-oriented economy. In 2001 China joined the WTO and became increasingly influenced by globalization. Since the mid-1990s a massive scale jump of port and city took place, resulting in the spatial decentralization of the port (Figure 4) and city and the creation of multiple new towns (den Hartog, 2010). In 1986, Shanghai's Master Plan was approved by the state council, in which the local government proposed to build the container terminal Yangshan Deepwater Port in the southeast of Pudong District, and the Shanghai Wusongkou Cruise Port in Baoshan, with the aim to become the busiest international cruise port for the Asia Pacific region. In 1998, the depth of the Huangpu went from 7.5 to 12.5 m (according to communication with the Shanghai Dredging Company). Early this century, Shanghai started to move its ports to locations far outside the urban core to accommodate the expected urban growth and allow the new ports to develop further. Port decentralization accelerated under the influence of the new Port Law of 2004 (Notteboom & Yang, 2017). In 2013, a pilot Free Trade Zone was established in the new ports along Pudong's coastline.

Early 1990s deindustrialization of the Huangpu riverbanks started with the redevelopment of parts of the Pudong New Area as a Special Economic Zone and the construction of the Lujiazui financial district. Interestingly, in most European world ports such as Hamburg, Liverpool, London, and Rotterdam, ships usually moor in docklands or basins, while in North American ports such as New York and Boston, mooring takes place at piers. In Shanghai, however, cargo ships—and cruise ships and navy ships—moor at Bunds or embankments, in a longitudinal direction in the river. Hence, Shanghai has a unique port typology. As a result, over time, the port area with related industries and transshipment with moorings for loading and unloading along the Huangpu stretched for km, over a length of 60 km on both sides of the river. The outplacement of the port and related industries created space for the renewal of the previously inaccessible and polluted riverbanks.

The revitalization of the Huangpu River and Suzhou Creek (Shanghai Municipal People's Government, 2018) are central elements in Shanghai's current master plan (Shanghai Municipal People's Government, 2016), which has the subtitle: "Striving for an Excellent Global City." Shanghai wants to compete with other world cities such as New York, London, Singapore, and Tokyo in terms of economy, appearance, quality of life, sustainability, and inclusiveness. This master plan introduces a shift in the development of Shanghai from a (sprawling) urban extension model to one of densification and urban renewal. The main reason is to save agricultural land and nature as a compact city within newly introduced red lines (Shanghai Municipal People's Government, 2016).

All polluting industries must disappear over a bank length of no less than 120 km, thereby greatly reducing CO_2 emissions (den Hartog, 2021b). To further reduce Shanghai's CO_2 emissions (Yi, 2021), emissions from shipping (Zhao et al., 2020) must also be limited. The large-scale urban regeneration accelerated after the 2010 World Expo, with a long ribbon of public urban space along the former industrial riverbanks with reused industrial heritage for cultural purposes. Simultaneously, large-scale ecological corridors have been proposed (Shanghai Municipal People's Government, 2016, 2018). A significant portion of the stated ambitions has been realized with great success within less than five years, including significant amounts of public space and urban greenery, an achievement that makes riverbank developments in other world cities pale in comparison. However, there are also serious shortcomings, such as unprecedentedly high real estate prices and increasing unaffordability, accelerated by the demolition of old neighborhoods and outplacement of lower income groups (den Hartog, 2019), and arguably environmental and social injustice by transposing polluting industries to elsewhere to please the new wealthy who can afford to live here.

Yet with its classic Bund promenade full of colonial buildings and the Lujiazui skyline with ultra-modern skyscrapers, and extensions with "new bunds" (den Hartog, 2021a), the Huangpu River remains the artery and name card of Shanghai. Shanghai became again China's most progressive and innovative city, thanks to its port. This position of China (and Shanghai) on the world stage is further strengthened by the 2013 proposed 21st Century Maritime Silk Road, under China's Belt and Road Initiative (Xinhua, 2013).

2.6. Contemporary Challenges and Course Changes: From Industrial (Production) Landscape to Urban Consumption Landscape

China's rapid urban transition (Hsing, 2010) has had a global economic impact. There are significant

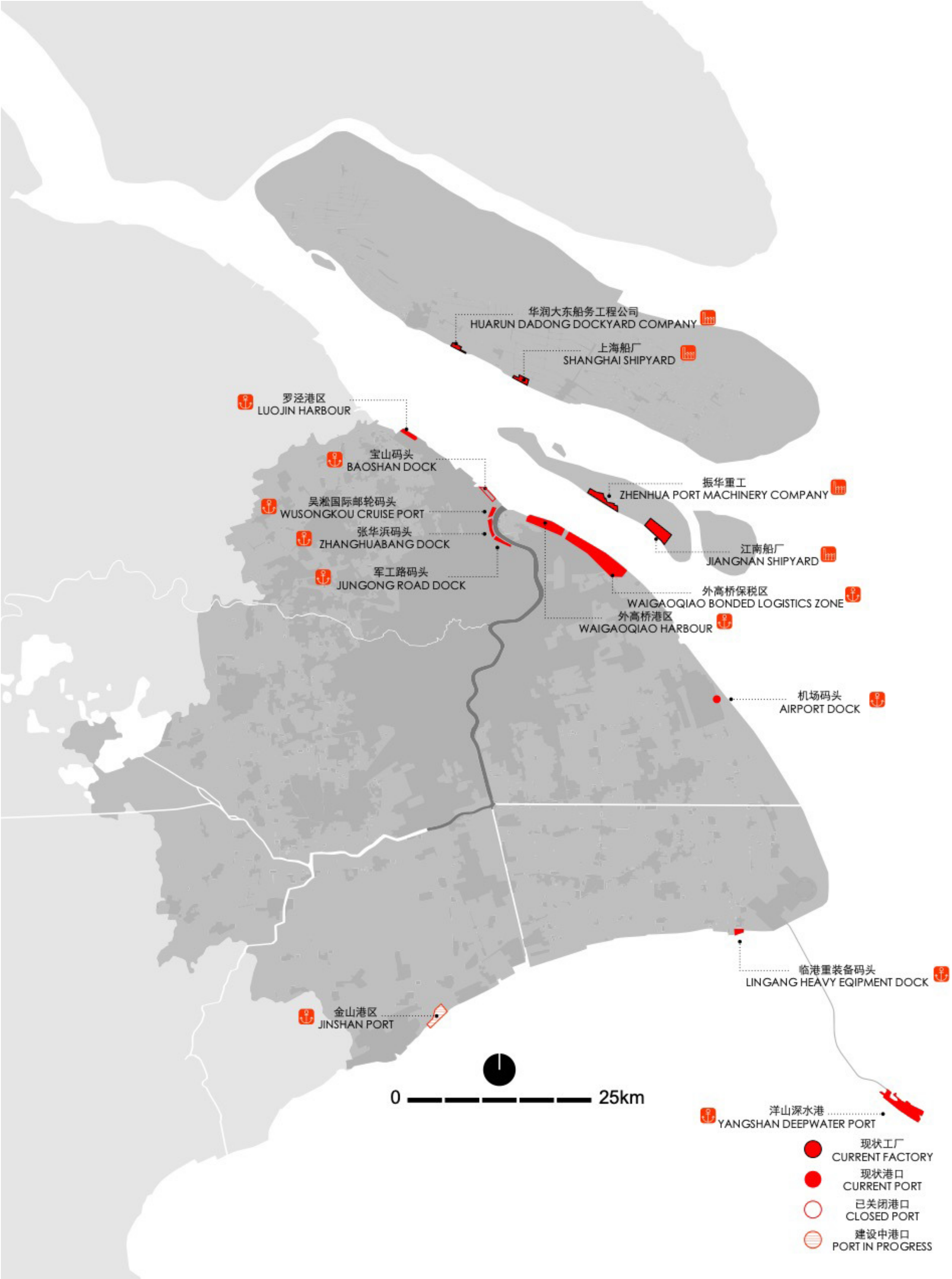

Figure 4. Ongoing decentralization of the port of Shanghai. Map by den Hartog and Hu in 2023.

improvements in the quality of life for many, but there is also serious collateral damage, both socio-economical (a growing gap between urban and rural) as well as environmentally. A range of local environmental clashes illustrates this, such as the agricultural drama with floating pigs (Jourdan, 2013). Tai Hu Lake and the upper stream of the Huangpu River are protected sources for drinking water (Wang et al., 2015), although their quality has been negatively influenced by industries (Bai et al., 2016), and nowadays most water is collected and stored in basins in the Yangtze River, though there are issues with saltwater intrusion into reservoirs ("Contamination report sparks Shanghai rush for bottled water," 2022).

Shanghai's location along the Huangpu brought prosperity, especially due to port activities, but also brought exposure to vulnerabilities due to the scarcity of fertile lands (Brown, 1995), increasing flood risk (Balica et al., 2012; Hanson et al., 2011; Ke, 2014; Ke et al., 2018;

Quan, 2014), and endangered wetlands (Li et al., 2020; Wang, 2012)—although these flood-risk related studies are based on data prior to the substantial improvements which have been made along the waterfronts since 2017 as integral part of beforementioned waterfront regeneration along the Huangpu River. In 1911, 1931, and 1935, flooding of the Yangtze River caused much damage and casualties (Carmichael, 2017). Also, during the first two decades of this century, floodwalls along the Huangpu River failed several times, most notably during typhoons in 1997, 2000, 2005, and 2013 (Ke et al., 2018). However, during the last 10 years, significant improvements have been made along the entire stretch of the Huangpu River, by combining improved retaining walls, embankments, and other civil engineering measures with large-scale urban regeneration and waterfront renewal, in addition to large-scale public spaces reconnecting city and river, ecological improvements, and real estate clusters to boost the economy and improve global competitiveness (den Hartog, 2021a, 2021b). New studies must inform us if these measures are sufficient to reduce flood risk.

Many physical references disappeared as a result of the reckless urban expansion of Shanghai over the past three decades, based on a tabula rasa planning approach, including many waterways (Shi et al., 2022). A shift in appreciation of the waterside (den Hartog, 2019) is causing tensions such as old working-class neighborhoods with cheap housing being bulldozed to make way for modern life with shopping malls, office and hotel towers, and luxury apartment complexes, which causes stress on the housing market with towering prices. The newly designed waterfront became a scene for large-scale and speculative real estate projects while affordable working-class neighborhoods are razed to the ground.

Moreover, despite green promises in the master plan and impressive amounts of new greenery, there are still environmental tensions, such as in fishery (Ning, 2020). In China "from the 1950s to 2000s, 53% of temperate coastal ecosystems, 73% of mangroves and 80% of coral reefs have been lost mostly due to economic development" (Paulson Institute, 2016). Along Shanghai's coastline, this was mainly due to massive land reclamations for urbanization, ports, agriculture, infrastructures, and a new airport. Natural wetlands are decreasing rapidly, but at the same time, new ones are being constructed. Due to sedimentation in the Yangtze estuary, several shoals began forming since the late 1940s. A Deep Navigation Waterway project through the Yangtze Estuary has been under construction since 2000: With the help of jetties and spur dikes the main navigation channel has been improved which meanwhile adds an average of 4.1 square km of newly constructed wetland yearly (Li et al., 2016). This adds to the Jiuduansha Wetland Nature Reserve in the middle of the Yangtze estuary, which geographically makes up part of the Chongming island formation of shoals but administratively belongs to Pudong District. This fast-growing new wetland has been constructed as compensation for the wetlands that were lost due to the construction of Pudong International Airport during the 1990s. Today, Jiuduansha is a nationally protected reserve and consists of four major shoals. Buildings and other constructions are not allowed here. However, there is an exception for the construction of a wetland museum here. The shoal just north of Jiuduansha contains Hengsha island—of which the part above sea level is inhabited mainly by farmers and is almost car-free; the elongated eastern part consists of constructed wetlands. This island, which administratively belongs to Chongming District, has been appointed recently by the Municipally to become a 158 square km "world-class pilot zone for ecological agriculture" (according to local officials). This will surely result in construction activities. Strict enforcement of a building-free area here, as with wetlands elsewhere along the Shanghai coastline, seems difficult to achieve even in a centrally controlled context. According to Tang et al. (2022), the channel in the south of the Yangtze Estuary—across the Jiuduansha shoals—transformed from erosive to depositional between 1983 and 2018. However, in another research by partly the same authors it is claimed that since the Three Gorges Dam was finished in 2003 and sedimentation ended, and this is resulting in serious channel erosion downstream, "potentially threatening the long-term stability of this large alluvial river and its deltaic and continental shelf development" (Zheng et al., 2018, p. 9).

The waterside in canal cities within the Yangtze River Delta used to be the dynamic backdrop for a multitude of activities, living, working, trading, washing, cooking, transportation, etc., all aspects of life took place along the water. Due to industrial development, the banks of the Suzhou Creek and Huangpu River became increasingly industrialized, and the water and the banks became so polluted that living there became unattractive. According to Wu (1979), the water quality used to be good before the 1920s, when industrialization began along the embankments of the Suzhou River. However, the water quality decreased quickly and life along the creek became nasty; the creek became like a sewer (personal conversation with local people and experts). This has all changed during the last two decades, and the waterfront is a prime real estate location now (den Hartog, 2019). Although the Huangpu is still intensively used by barges and coasters for hinterland connections, shipping no longer exists on Suzhou Creek since it is blocked at the river mouth to prevent currents.

The Huangpu River and Suzhou Creek became important demarcation lines in the collective memory of residents not only as physical but also as mental borders, with different lifestyles, and even different dialects and weather reports on either side. Both shipping channels are a symbol of Shanghai, as a cosmopolitan metropolis, culminating in the Bund and futuristic skyline of Lujiazui. The importance of the Huangpu River even goes to outer space since a small planet was officially named after this river (Schmadel, 2003).

3. Discussion and Conclusion: Changing Relationship and Priorities in Land Use

City, port, nature, and agriculture all compete for space. In previous paragraphs, it was explained how the course of shipping channels changed continuously in Shanghai. Inherently related to this is also the location of the port and Central Business District (CBD) as economic centers of gravity shifted. Port and city moved from Suzhou to Songjiang—now part of the direct-controlled Municipality of Shanghai—then within the (expanding) administrative boundaries of Shanghai itself; to the fortified old city and to Dongjiadu, then northwards along the Bund, almost to Wujiaochang (in the Greater Shanghai Plan), then to Lujiazui across the river in Pudong, and eventually dispersed in various sub-centers, and new cities (den Hartog, 2010), and even new bunds as new CBDs (den Hartog, 2021a). Most port functions are dispersed into regional clusters in the wider Yangtze Delta Region such as in neighboring Nantong (Jiangsu Province) and Ningbo (Zhejiang Province). The Port of Ningbo, a mere 100 km away from Shanghai, even is a direct competitor at the top of global port rankings and has more shipping movements than Shanghai. This regional competition and new hinterland relations bring new challenges, e.g., cooperation that crosses administrative boundaries, and also regarding integrated management of the ecological environment (Hou & Geerlings, 2016; Li et al., 2022).

In a relatively short period, the economic structure and the society of Shanghai (and China) changed from a dominant agricultural into an industrial and post-industrial phase in which the tertiary (service) sector became the leading sector. Shanghai and other Chinese cities were until recently self-sufficient in their food supply (Jacobson, 2012). In peripheral parts of Shanghai still a lot of rice fields can be found, although it is a fragment of the amount that existed two decades ago due to rapid urban expansion. However, China is still self-sufficient in rice (Deng et al., 2019), thanks to land use compensation programs.

During the brutal lockdown in the Spring of 2022, it became clear how far urban society is disconnected from the port, and also from the agricultural countryside: the urban food supply came to a standstill (den Hartog, 2023; James, 2022; Kuo et al., 2022). Opposed to official reports of sufficient food supplies (Ministry of Agricultural and Rural Affairs, 2020), the entire city of Shanghai was without food and other supplies (even medicines) for more than 10 days (den Hartog, 2023; James, 2022; Kuo et al., 2022), while there were abundant supplies in the nearby port (Ang, 2022). Even the global supply chain was disrupted considerably (Figure 5), with substantial effects on the world's major ports (Ang, 2022). In more than a few neighborhoods the supply was disturbed for a much longer time, such as in university campuses. After the lockdown, it took months to get effectively restarted. At one point, many citizens in one of the world's most modern and sophisticated cities started growing crops on their balconies.

This illustrates an extreme disconnection between city and port, and also between urban and rural. Although this was temporary, it underlines a need to reconsider connections between the city, port, and

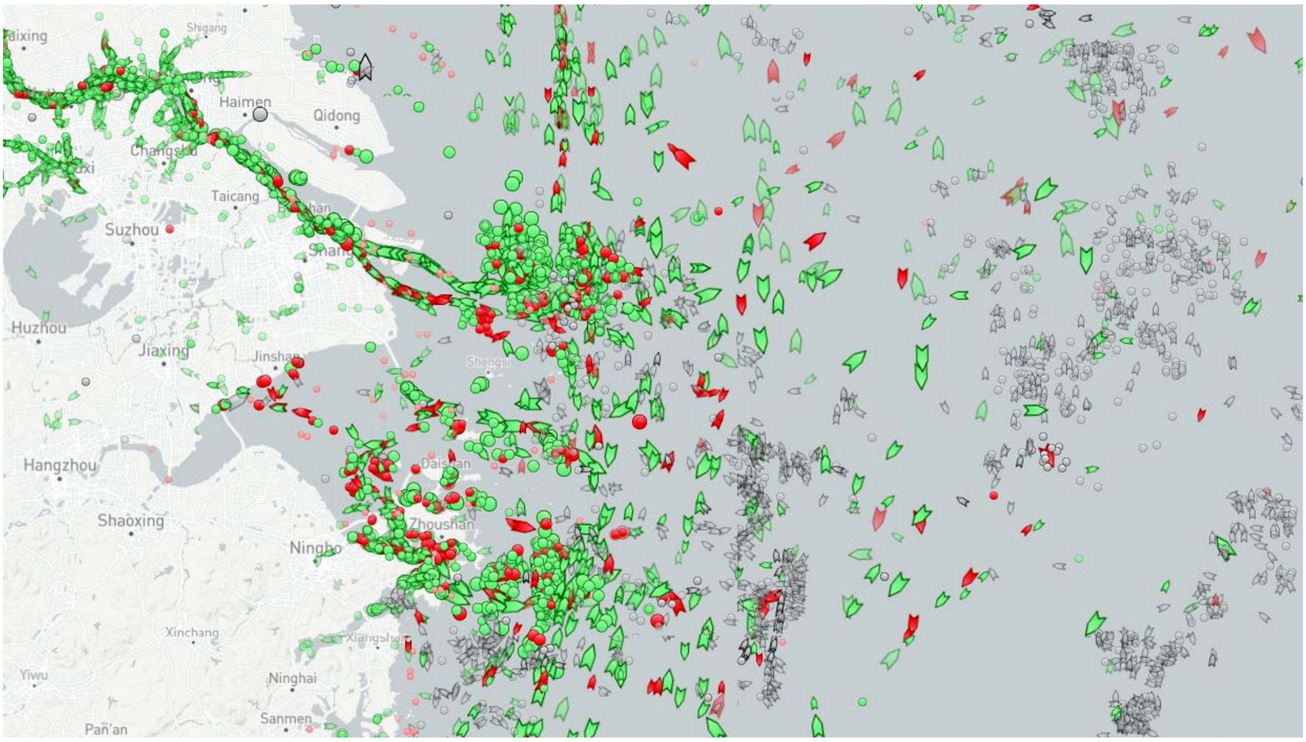

Figure 5. Vessels waiting off the coast off Shanghai during lockdown. Source: Enokido-Lineham (2022).

(rural) hinterland. Urban and rural are fundamentally interconnected, as explained by King (1911) for East Asian cases, and later notably also by Cronon (1991) for Chicago, and can be expanded for metropolitan regions in general. First of all, local, regional, and even global cooperation needs to be grounded in daily life reality, starting with the people. This is also promised in ecological civilization policies (Hansen et al., 2018), but not in practice. The lockdown shows there is a disconnection with the former advantages of Shanghai's strategic location (Dai, 2004). This is caused by a growing gap between the promises and expectations from the central government and the reality of daily life. Besides known governance priorities—the restoration of the ecosystem, water management, energy transition, and improvement of regional spatial structure (Shanghai Municipal People's Government, 2016)—a reevaluation of logistic chains is needed, especially the grocery on the streetcorner, and informal (wet) markets, all of which have been increasingly disappearing in the last few years in Shanghai. Above all, mutual communication between citizens and decision-makers is needed, as increasingly underlined and promoted by various local experts in Shanghai, but not yet practiced citywide.

Meanwhile, the construction of large-scale green structures as compensation and buffer (Shanghai Municipal People's Government, 2016) continues, as do other impressive measures in the field of quality-of-life improvement (den Hartog, 2021b). At the time of writing, a big question remains: whether major social and economic shocks caused by the pandemic—in particular the brutal lockdown—in combination with geopolitical changes (Kandhari, 2023) will change the path of globalization, especially for Shanghai and China. Long-term consequences for the port (Notteboom & Haralambides, 2020) and also for urban development remain uncertain. Yet this is in the pattern of a historical legacy, in which the closure and reopening of China and its ports are recurring (Wang & Ducruet, 2013).

Finally, in line with its ambition to become an "excellent global city" (Shanghai Municipal People's Government, 2016) Shanghai should take the lead in searching for reconnection and rebalance between urban development (city and port) and rural vulnerabilities (including agriculture, rural communities, and ecological vulnerabilities), and between global aspirations and local daily life realities.

Acknowledgments

Many thanks to Isaac Lawless for proofreading this article. Thanks to all interviewees willing to share their experiences and insights. Thanks also to the peer reviewers for their constructive remarks. The author received no financial support for the research and authorship of this article. An institutional agreement between the publisher and Delft University of Technology made this publication possible.

Conflict of Interests

The author declares no conflict of interests.

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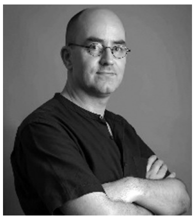

Harry den Hartog is an urban designer, researcher, and critic. In 2004 he founded the think tank-style studio Urban Language (https://www.urbanlanguage.org), which focuses on research and design solutions for urban and rural spaces. In 2012 he joined Tongji University in Shanghai as a faculty member. Since 2023 he also has a research position at Delft University of Technology, focussed on rural and urban revitalization strategies.

Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 319–329
https://doi.org/10.17645/up.v8i3.6757

Article

Flows as Makers and Breakers of Port-Territory Metabolic Relations: The Case of the Loire Estuary

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Submitted: 3 February 2023 | Accepted: 28 April 2023 | Published: 26 September 2023

Abstract
Ports worldwide are shifting from their original locations, and the reasons behind these patterns of port development are multifaceted. Reasons for locational changes may include local factors such as natural conditions, or global trends like containerisation. This article argues that flows play a significant role in making and breaking metabolic relations between spaces. The authors use a combination of qualitative and quantitative approaches to characterise the evolution of port and territory interactions. A historical sequencing illustrates the successive phases of connection and disconnection between port and non-port spaces over the years. Drawing from the urban metabolism framework, the analysis of a port's traffic structure demonstrates how flows influence a port's extraterritoriality. For this research, the case of the Loire estuary was chosen: the Grand Maritime Port of Nantes Saint-Nazaire is a polycentric port that originated in Nantes and extended coastward in Saint-Nazaire. The case study reveals that a port reaching an urban area does not necessarily mean it will engage or support metropolitan development. Moreover, it concludes that flows are active drivers of territorial development in port regions. The research more broadly discusses the extraterritoriality of large logistics and transport infrastructure, like that of ports.

Keywords
flows; port; port-city; territoriality; urban metabolism

Issue
This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

Seaports are strong logistic and industrial nodes in global supply chains that position port cities as entry points to globalisation and its effects (Hall, 2002). The irruption of global influences, exacerbated by technological advances such as containerisation, has in many ways disconnected ports from their local realities and ultimately transformed their relationship to their territory: physically, culturally, and spatially. Despite ongoing developments, most of the world's major container ports remain urban (Hall & Jacobs, 2012). An analysis of the successive connection and disconnection phases allows us to understand the renewed metabolic relations between port and urban spaces and reveal the sociotechnical processes that shape the territory (Hein, 2014, 2016).

The Urban Metabolism (UM) framework understands spaces as made up of flows whose interactions are determinants for territorial development. Logistics is a driving force that shapes the relation between spaces and flows and can thus influence the territorial structure (Hesse, 2020). Port regions, in particular, represent points of intersection between global and local flows, where the two often overlap and momentarily merge. Such flows inevitably have an impact on the metabolic relations that shape the territories they reach. Ultimately, ports' raison d'être is to convey flows (Lévêque, 2014). As such, they continuously transform their infrastructure and model to accommodate international trade and trends (Mat et al., 2016). As a result, ports tend to distance themselves from their birth territories and become extraterritorial to their host environment. Ironically, while bridging spaces, flows also deepen the alienation of critical infrastructure like ports. For this research, while we understand territories are made up of a variety of flows that are not quantified in port traffic reports (such as consumption and emissions), we have chosen to focus on import and export flows solely.

In what ways do flows shape territorial development and the metabolic relation between port and territory? Through a mixed methods approach, the article sheds light on several aspects of the relation and its evolution: A historical sequencing of port territory development illustrates the successive (dis)connection phases, while an in-depth analysis of the evolution of the regional port's traffic structure demonstrates the links between urban development and port operations. This encourages a discussion on flows as makers and breakers of metabolic relations (Clark, 1958) and drivers of territorial development.

The evolution of the relations between ports and cities, be it inland ports like Brussels, Strasbourg, or Paris (Beyer & Debrie, 2011; Hall & Jacobs, 2012; Masy, 2020) or seaports like Antwerp, Rotterdam, or Hamburg (Hein & van Mil, 2019; van den Berghe, 2015) has been investigated many times over. This study instead concerns the case of the Nantes Saint-Nazaire port. The Loire estuary offers a particularly insightful context to explore the dynamics between a port and its host territory because its polycentric nature stretches from one city to another. Nantes is located up the Loire River, while St Nazaire is 63 km away at the very mouth of the river on the Atlantic coast. Until their reunion in 1966, the two cities hosted an inland port and a seaport. Granted the Grand Maritime Port status in 2008, along with seven other major ones, it is France's fourth port and the leading one of the Atlantic façade. The decisions to implement a set of dominating industrial activities and accommodate global flows through specific infrastructures within the port land have greatly impacted the relations between the port and its territory.

2. Theoretical Framework: Metabolic Flows Through the Port–Territory Relationship

2.1. The Evolution of the Port-Territory Dynamic

Port and city have long influenced each other and their relations and coevolution are the subject of extensive academic literature (Hall & Jacobs, 2012; Monios et al., 2018). Some scholars argue that the city entered the port and built around it (Norcliffe et al., 1996; Zheng et al., 2020), while for others, the port represents an addition or equipment to the city, part of a development strategy that faces issues of territorial insertion from the start (Foulquier, 2019). In many cases, history has blurred the distinction between the two entities and merged them into coherent wholes (van den Berghe, 2015). "Portuality," theorised by Moretti (2021), is a territorial quality that denotes those cities born and developed through strong historic/symbolic and economic/functional relations with their port. Territoriality expresses, in addition to a legal content of appropriation, a feeling of belonging but also of exclusion and a mode of behaviour within an entity, whatever its size and the social group that manages it (Steinberg, 1994). The concept has been applied to ports to understand the link between their traffic preferences and global positioning (Bridge & Bradshaw, 2017).

As cities urbanised and ports expanded, their co-development and co-existence extended to a larger geographical perimeter. Just as cities have found less need to be ports, ports have found good reasons not to be in cities (Norcliffe et al., 1996). The notion of the port-city interface has helped understand spaces where port and city interests overlap and often conflict (Aouissi et al., 2021; Daamen & Louw, 2016; Daamen & Vries, 2013; Hayuth, 1982; Hein & van Mil, 2019; Hesse, 2018; Hoyle, 1989; Hoyle et al., 1988). Many factors, across scales, have ultimately transformed the multi-faceted relationship between port and territory (Marcadon, 1999). While natural conditions at the individual level have driven ports out of their birth territory, so have human-enacted global trends. The downstream migration of port facilities is the most obvious physical manifestation of the disconnection between seaports and port cities (Hall, 2007). Starting in the 19th century with the industrial revolution, new port logics have structurally impacted port infrastructure and location (Bretagnolle, 2015; Hein, 2011, 2016; Olivier & Slack, 2006). The organisational and spatial revolution brought by containerisation since the 1960s radically changed the meaning of the flow/territory paradigm in the port sector (Lavaud-Letilleul, 2005). This applies to most large and medium-range ports, whether fluvial or seaside ones, older installations that remain in urban areas, or newer ones built in their periphery. This research addresses commercial ports and their industrial zones, disregarding ones that are marinas exclusively.

Consequently, new interfaces between the port and non-port developments are created (Hein, 2014). International examples illustrate the mushrooming of port infrastructures across the landscape, whether towards the sea or outward in the hinterland. In most cases, new hubs in the form of inland terminals or "dry ports" that guarantee critical volumes and more fluid flows appear (Cullinane et al., 2012; van der Horst & van der Lugt, 2011). As a consequence of the globalisation of the world economy, particularly the intensification of material and energy flows and the restructuring of production and distribution, ports are challenged to reassess their role in a system that is increasingly conceived of as global, not regional (Hesse, 2013). As they become pivotal nodes in these international chains (Hayuth, 1989; Hesse & Rodrigue, 2004; Slack, 1993), oriented around global logistics requirements rather than local ambitions, the port-city split has accentuated (Hall & Jacobs, 2012), leading to a loss of connection between the port and public local and regional institutions (Hein & van de Laar, 2020; Hesse, 2013; Moretti, 2017). Here, the concept of territoriality examines the management of equipment in and of itself, cut off from the territory (Collin, 2005). As the fracture deepens, ports have become extraterritorial to their local environs.

One critique of the Bird (1963), Hoyle (2000), and Norcliffe et al. (1996) models is that they are highly generic and non-situational. They attempt to explain the port-city interface based on supposed all-encompassing drives, with clear-cut geographic-economic models, concepts, and phases succeeding in time (Mazy, 2015). Although these models are helpful in comparing ports, they only justify general trends while ignoring divergent and singular scenarios. Based on abstract space, these models struggle to detect the processes behind the continued urban attachment of ports and the geographical scales at which this connection occurs (Hall & Jacobs, 2012). We argue that the connection or disconnection can be assessed through additional criteria beyond physical infrastructure. New methods must be developed to define the changing relationship between ports and their territory. Through the innovative use of UM, this research aims to contribute to the vast literature on ports' territorial insertion.

2.2. Metabolic Flows of Transit

This research presents a "follow the flow" approach to trace the historical development of a port region. The relations between territories and their environments are diverse and complex, with multiple impacts on various geographical and temporal scales. However, the physical dimension of these relations is often overlooked. The UM framework provides a comprehensive analysis of the interactions between a city and its local region by examining the energy and material flows within a nested and interconnected system. While traditional UM studies quantify energy and material flows, recent studies explore the qualitative aspects of the relationship between an entity and its environment through an analysis of the social processes that produce space. The current challenge to the UM framework is to integrate political, demographic, economic, and geographic factors that influence a region's metabolism and to examine the relations between material flows and their urban systems.

At the center of the UM methodology are the flows. Conveniently, the port's primary function is to transport flows in import/export traffic. While numerous studies have examined shipping cargo in relation to regional development (Notteboom & Rodrigue, 2005) and ecological transitions (Mat et al., 2016), there has been a lack of research specifically focused on port metabolism as a concept. We argue the concept's application to ports supports an innovative exploration of the metabolic processes that shape a territory and help tell the story of a port's territorial integration. This research aims not to investigate the initial relation between port and city. It comes after the erosion of the long-standing symbiosis that once bridged the two (Norcliffe et al., 1996). It is to demonstrate the determinant role that flows play in the successive waves of connection and disconnection between port and territory.

3. Methodology: Historical Approach and Metabolic Traffic

By using the UM framework to analyse traffic flows, this research reveals different aspects of port-territory interactions beyond traditional economic analysis. It considers a more holistic understanding of the relations between a port and its surrounding region, taking into account social, environmental, and political factors. The mixed-methods approach advocated by Hein and van Mil (2019) also helps to bridge the gap between qualitative and quantitative approaches, providing a more nuanced understanding of the complex dynamics at play in port-territory relations.

3.1. Historical Sequencing Analysis

Historical sequencing provides a framework to illustrate the evolution of the relations between port and territory (Hein & van Mil, 2019; Masy, 2020). This methodology borrows from path dependency in that it identifies critical junctures (Tasan-Kok, 2015) as pivotal turning points that mark phases of continuities and ruptures. By examining historical maps and public policy documents, it is possible to trace the successive developments that provoked connection and disconnection phases, which are linked to port flows and infrastructure accommodations. This approach provides a chronological account of how the port-territory relation has evolved over time.

3.2. Metabolic Port Traffic Analysis

The typology of ports proposed by Dooms and Haezendonck (2004) was originally developed to study inland ports: We enrich the method by using it to study a polycentric port that presents both inland and seaside features. The approach distinguishes between two types of ports based on their location characteristics and the presence of adjacent industrial clusters: "metropolitan-supporting" and "industry-supporting" ports. The former has a more urban and regional logistics functionality and is dominated by the distribution of construction materials by road, while the latter is less tied to its neighbouring urban centers and is characterised by a traffic structure dominated by oil products, coal, ores, and steel products. The application of this framework to the Grand Maritime Port of Nantes Saint-Nazaire (GPMNSN) case study permits an exploration of the interaction between traffic flows and port infrastructure location, contributing to the overall development of the typology.

Following UM studies, we mobilised the Physical Trade Balance (PTB) indicator, which corresponds to imports minus exports. This is a key component of material flow analysis, one of the most robust tools used to measure the metabolism of a territory. The PTB is the physical equivalent of the monetary trade balance and measures the materials and energy that remain in the port before being consumed, shipped, or transformed. Understanding the material and energy flows transiting through and being consumed within a territory is crucial, and the PTB can facilitate the analysis of a territory's relation with its supply hinterland (Athanassiadis et al., 2018; Bahers et al., 2020). In this respect, the PTB is a first step in studying the material footprint of a territory (Eisenmenger et al., 2016; Wiedmann et al., 2015).

Imports and exports were measured using data from the port's statistical service (Nantes Saint-Nazaire Port, 2023) and from the archives of the regional statistical institute (for the data between 1955 and 2000), which were cross-referenced with Eurostat data on maritime transport. We developed a typology of merchandise per flow type:

- Oil/petroleum products: fossil fuels such as petrol, oil, and liquefied gas;
- Construction materials and minerals: building materials including sand, aggregates, cement, and wood;
- Biomass and agricultural products: fertilisers, animal feed, and human foodstuffs;
- Metals and manufactured products: metallurgical and manufactured articles made of ferrous or non-ferrous metals.

This typology draws from material flow analysis recognises these four major flows to be the most structuring for UM analysis (Bahers et al., 2018; Eurostat, 2018; Voskamp et al., 2017).

4. Results: The Territorial Development of Port–City Relations

4.1. Historical Sequencing

4.1.1. Preamble: A Historic Port-City

Nantes was considered the leading port in Europe as of 1704, with a tragically notable history in the slave trade. However, the estuary's silting up made it challenging for large vessels to reach Nantes. Consequently, outposts were developed where the cargo was received, loaded onto lighter boats, and transported to Nantes. The natural conditions are extensively documented as the estuary's morphology directed all decisions (Vigarié, 1977). The territory's primary economic advantages are its central position on the Atlantic seaboard and the availability of vast areas of industrial land. These assets form the basis of the territory's economic ambitions, complemented by a deep-water port project.

4.1.2. 1850s: Saint-Nazaire Penhoët Dock

Thereafter, Nantes was gradually linked to the smaller town of Saint-Nazaire, conveniently located at the mouth of the estuary, through daily steamboats and the extension of the Orléans railway. The building of the Penhoët Dock in 1881 confirmed the coastal city's role as the forward port facility. The relationship between the two municipalities requires closer examination. Le Bras (1932) says the history of the relationship between Nantes and Saint-Nazaire is always evoked with diplomatic frankness. He frames the opposition as the classical one between an old and new city, in this case, the sea and estuary ports. Saint-Nazaire is wanted as an "annexe" or transit space to support the other's growth. Despite substantial blockage from Nantes, the Saint-Nazaire Chambre of Commerce was inaugurated, shifting from a relation of subordination to one of independence. Upon the end of the First World War, a regional study committee was created to develop and ensure the planning of works of common interest. A period of connection and integration succeeded one of strong opposition: While the old city modernised, the new one became centenary (Le Bras, 1932). The Loire estuary bore the promise of a western metropolis that spread from Nantes to Saint-Nazaire. Yet the two do not have a natural tendency to come together: They are separated by vast unurbanised spaces that can remain so without jeopardising metropolitan construction, provided that the two centers find functional links (Cabanne, 1972).

4.1.3. 1966: One Port Authority

From the start of the project, the port served as the center of the new two-headed metropolis device (Place publique Nantes/Saint-Nazaire, 2007). In 1966, the once-distinct ports were merged under a single public enterprise: the Autonomous Port Authority of Nantes Saint-Nazaire. The first challenge posed by the creation of the autonomous port was to find ways of balancing the two different heads. To strengthen Saint-Nazaire's potential to play the role, it needed to raise the "critical mass" from which it could assume new responsibilities (Vigarié, 1980). Two development strategies were proposed for the "Atlantic façade" project: one entirely oriented towards export by sea regardless of the hinterland, and the other advocated for the region's development as an ocean frontage of a French and even European entity. The first justified the establishment of industries that did not appear profitable given the conditions of the regional and national consumer markets, but which would be if they are destined for overseas markets. These would include basic industrial forms of production such as coal, steel, and petrochemicals. The second direction sought to rely initially on existing medium and light industries, in particular food industries favoured by an important agricultural potential, and high-tech industries, to create a growing demand for basic products which would eventually call for, in later stages of development, the establishment of heavy industries. As if to seal the deal, the master plan for the development by 1985 of the Autonomous Port stated that the port offer would "be mainly oriented towards industry" (Cabanne, 1972).

4.1.4. 1970s Onwards: Montoir and the Exponential Industrialisation of the Estuary

Natural conditions determined the locations of industrial-port zones near medium and large seaports in France (Vigarié, 1977). Montoir and Donges (see Figure 1) were selected due to their greater accessibility for large ships and the available space for the development of heavy industrial production (Marcadon, 2021). A liquefied natural gas terminal and a container terminal opened in the following decade (Noyer & Patillon, 2012). The development of the poly-industrial port in Montoir, alongside the expansion of Donges through the interplay of created jobs, would bring Saint-Nazaire to the urban level from which a higher tertiary role could be established on solid foundations. Thus, in its initial conception, Montoir and its port appeared as instruments to serve regional development in the metropolitan sense. International shipping was a means, not an end (Vigarié, 1980).

Despite benefiting its immediate urban areas, the industrial hub became disconnected from them (Marcadon, 2021). The transfer of port activity downstream did not spur urbanisation. Instead, the town of Saint-Nazaire (with a population of 68,300 in 1982, in an agglomeration of 130,000) developed around a dominant industrial activity—shipbuilding and aeronautics—that had originally operated in Nantes. As part of the national deindustrialisation trend starting in the mid-1970s, this city gradually dropped its industrial function (Cabanne, 1990). Historians distinguish one estuary, two cities, and three maritime hubs, with Donges-Montoir as its leading powerhouse. In 1983, the quays of Nantes loaded or unloaded only 1.6 million tons of goods, compared to 10.4 million tons at Donges and nearly 7.5 million at Montoir. As a result, over 85% of the traffic of the Loire port took place downstream in the estuary. However, Saint-Nazaire did not benefit from this traffic: Since its docks did not meet modern conditions for maritime traffic, everything was concentrated in Donges and Montoir, where polyfunctional port installations had been established for several years (Cabanne, 1985).

On the other hand, Nantes retains full control of its port tool, which is located mostly outside the urban space. The Autonomous Port's headquarters were

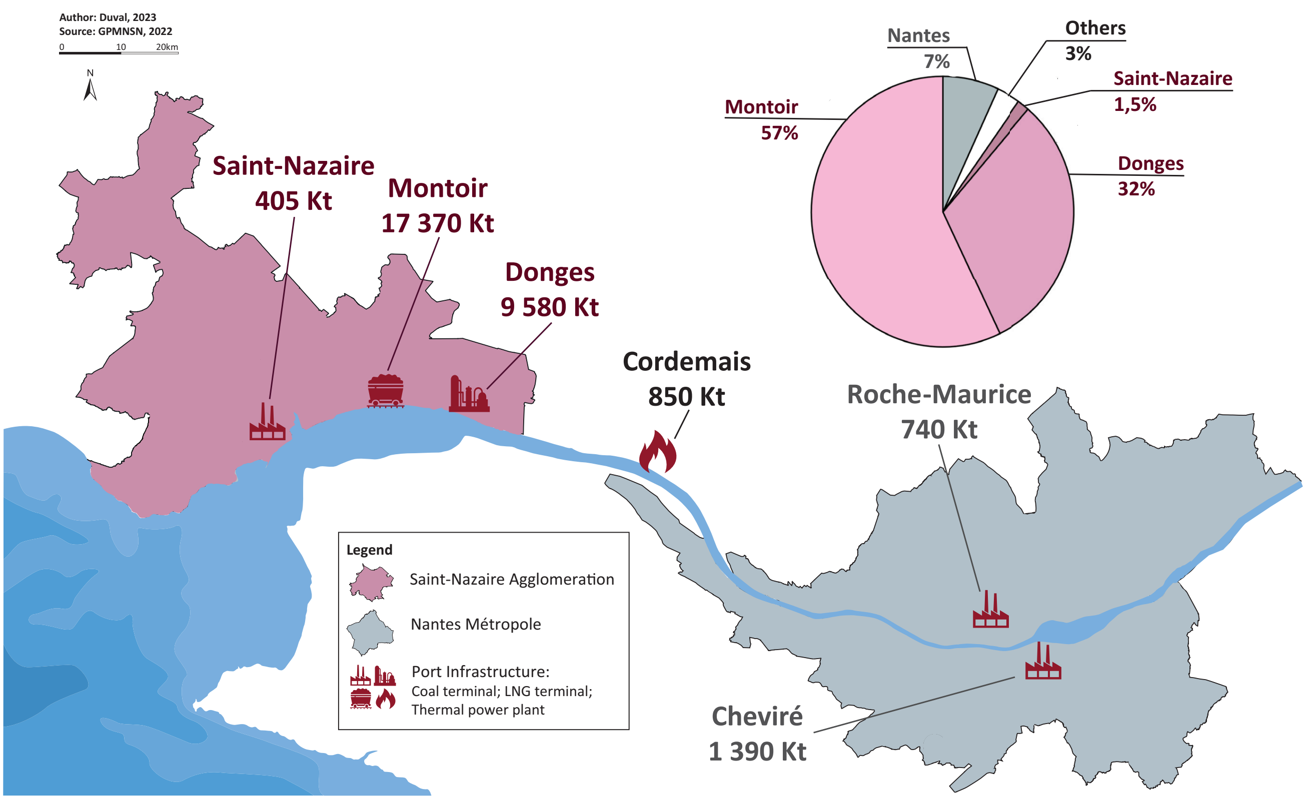

Figure 1. GPMNSN infrastructure and traffic structure. Source: Adapted from Nantes Saint-Nazaire Port (2023).

moved from the center of Nantes to a suburban area, symbolising the spatial separation of the port from the city. However, this move anchored the management of the port in Nantes rather than in the new technical installations of Montoir, which was also a possibility at the time (Cabanne, 1985).

4.1.5. 2008: Port Reform

The 2008 national port reform aimed to enhance the competitiveness of the metropolitan autonomous ports and transform them into major seaport authorities at the European level. As part of this reform, the GPMNSN was established, which marked a significant turning point in regional governance. The GPMNSN gained greater independence from local government, while also extending the representation of local governments in the port's governance bodies. In 2019, Christelle Morançais, the chair of the region, was elected as the head of the Supervisor Board, reflecting a renewed collaboration between the economic and territorial stakeholders of the estuary. This indicates a desire to reconnect the port with its territory, rather than just the two municipal governments of the two cities as was once needed.

In practice, today the polycentric port reveals an unequal distribution of activities across its infrastructure. The diagram in the previous section (Figure 1) displays the percentage of the overall GPMNSN traffic per location, highlighting that most cargo is handled outside of the two core urban centers. However, this alone does not suffice to indicate a disconnection between the port and metropolitan areas.

The qualitative analysis of the port's territorial development indicates a trajectory of successive (dis)connections between the two urban agglomerations and their port. Ironically, while the port originally served as a catalyst for the cities' merging, it has since grown as an independent center. Much of the existing case studies and theoretical models in the academic literature theorise and demonstrate a disconnection between city and port through simple notions of geographical distancing. We argue that geographic proximity is insufficient and that the study of flows helps to reveal further the nature of the links between the port and its territory. The analysis of the traffic flows, in the next section, informs the evolution of the metabolic relations between urban and port elements of the Loire estuary.

4.2. Traffic Structure Analysis

In practice, the GPMNSN's contemporary facilities are scattered along the estuary with a growing presence on the coast, encompassing twenty-two communes and five intercommunal structures. Figure 1 illustrates the location of the port infrastructure, and distinguishes which belong to the Nantes and Saint-Nazaire metropolitan areas. At the global level, ports are ranked per their annual tonnage. Figure 1 also details the tonnage each infrastructure handles (for the year 2022). The Nantes Métropole area operates 10% of the overall traffic, comparable to smaller ports like that of Brest or Lorient. While the two most significant facilities, Donges and Montoir, belonging to the Saint-Nazaire Agglomeration area, amount to 57% and 32%, respectively (Nantes Saint-Nazaire Port, 2023). Drawing from this first analysis, one can infer that port operations are more closely associated with Saint-Nazaire than they are with Nantes.

The following analysis aims to investigate the traffic structure to characterise the nature of the relation between the city/territory and the port. Figure 2 displays the evolution of the GPMNSN traffic structure between 1955 and 2022. The data used to produce the graph and analysis were obtained from the port's statistical service (Nantes Saint-Nazaire Port, 2023) and the archives of the regional statistical institute for the period between 1955 and 2000. The data is divided into four

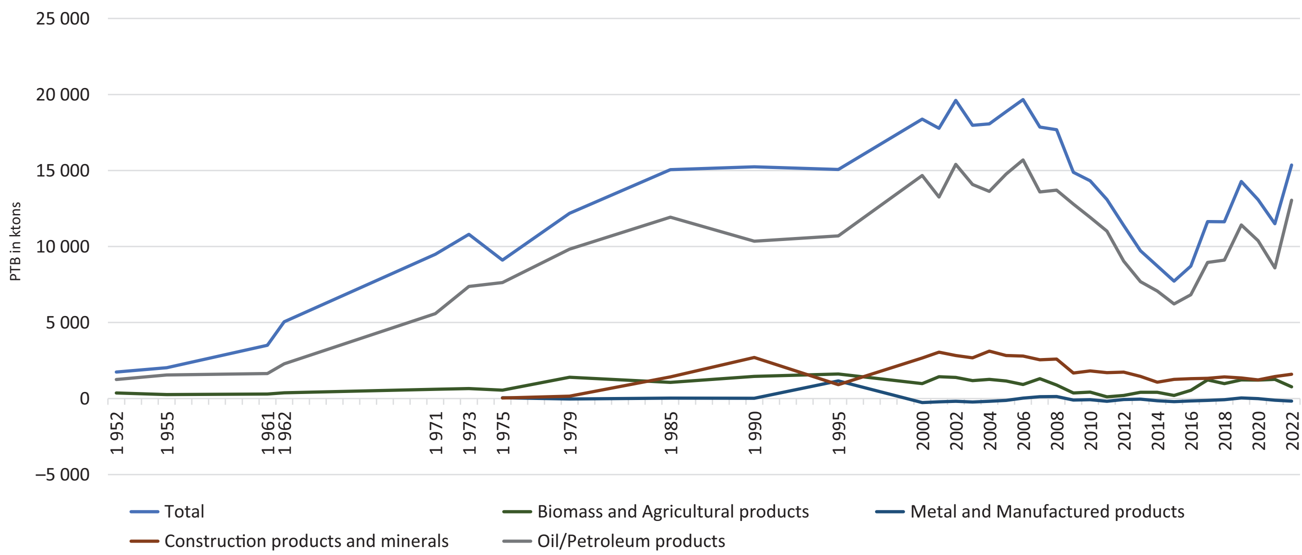

Figure 2. PTB (Traffic) of GPMNSN.

major categories of merchandise. The PTB corresponds to imports minus exports.

Figure 2 makes legible three important factors of port activity. First, imports exceed exports. For example, in 2022, the traffic of the port of Nantes Saint-Nazaire amounted to more than 29.7 million tons, of which 76% were imports (Nantes Saint-Nazaire Port, 2023). Therefore, the port primarily serves as an import hub for the consumption of goods and raw materials, rather than an export hub for hinterland products.

Secondly, most of the PTB is in the form of liquid bulk, such as crude oil, refined products, and natural gas. This is characteristic of an industry-supporting port, according to the established typology of flows. The planning and building of the Montoir-Donges port hub are intimately tied to the development of petroleum exploitation. In 1953, hydrocarbon traffic was already the main item in most major French ports, but its share represented less than two-thirds of entries and exits (2.1 out of 3.4 million tons). In fact, the prioritisation of petroleum/oil products in the Loire estuary port was an effort by local port authorities to adapt to global traffic needs (Cabanne, 1984). In 2022, the share of energy flows exceeded two-thirds of total traffic (69%) compared to just over half in 2021 (55%). This increase was partly due to the global energy crisis resulting from Putin's invasion of Ukraine. Like many European countries, France needed to secure its energy supplies in anticipation of winter 2022/2023 (Nantes Saint-Nazaire Port, 2023).

Thirdly, the other three main flow types (biomass, metal, and construction products) have remained relatively constant in tonnage over the years. This indicates that the port model has stabilised, despite spikes caused by global economic crises. It also implies that the metabolic relations between the port and the territory have remained unchanged. In other words, the port has continued to serve and grow its industry base, maintaining a coherent role in the territory.

Based on the hypothesis of Dooms et al. (2013), the traffic structure of GPMNSN suggests that it was intended to be an extraterritorial port, primarily serving industrial activities rather than directly catering to urban and regional economies and their populations. Consequently, we can infer that while the port has grown physically separating from the metropolitan area, it has also become disconnected from the urban system. The industrial zone of the port has expanded to the point where it dominates the overall port operations, at the expense of developing metropolitan-oriented activities.

5. Discussion: Territoriality of Metabolic Interactions

The worldwide-observed phenomenon of ports moving outside their birthplaces served as a starting point for this research: Scientific models account for their joint development, gradual disconnection, and other causes of the geographic and economic disarticulation of ports and cities. Global trends such as industrialisation and globalisation, in addition to local factors (such as changing ecological conditions), explain the choices made relating to port infrastructure. As ports become more deeply embedded in global supply chains, their administrative bodies undertook transformations to accommodate further global connection and commerce. In doing so, ports grew separate from their local realities, including that of surrounding urban areas, and ultimately became extraterritorial to their environment.

This article discusses the attenuation of the attachment of ports to their neighbouring urban areas and the changing metabolic relations between the port and non-port territorial elements. The history discussed above illustrates the strong ties that the city of Nantes initially had with the regional port. Early on, however, the difficulty of navigation on the Loire and accessibility were put forward as motives to forsake Nantes for a more coast-ward location. As water transport was cheaper than rail, port infrastructure was continuously relocated and built towards the ocean. Nantes and the port operated successfully and profitably until the orchestrated rise of Saint-Nazaire as the primary platform for maritime goods. For example, according to our results from the analysis of archival data, the port of Nantes accounted for 52% of traffic in 1952, whereas it represented only 30% in 1961 (70% for Saint-Nazaire and Donges). After a sequence of connections, the construction and operation of the Saint-Nazaire docks began to disconnect the birth city and port resulting in a trajectory of disarticulation that has continued until today. A century later, the port served as a medium through which to merge the two cities within a joint port authority; a brief connection interlude that may have had more to do with regional power relations than accommodating material flows. While the relationship between Nantes and the port was final, one could have expected the port to interweave with the urban fabric of Saint-Nazaire. Yet, historical and qualitative analysis reveals the migration of port facilities westward, and the construction of newer ones closer to Saint-Nazaire did not bring the city and port "closer together." Coincidentally, the next phase (of disconnection) unfolded as the port grew a center of its own, separate from the urban ones nearby, with the rise of the Montoir and Donges facilities. Today, the port appears disconnected from both metropolitan areas, and more closely associated with global flows of commodities than local and regional economies. The GPMNSN is neither a bridge nor a break between the two cities of Nantes and Saint-Nazaire. Instead, it is a third entity to acknowledge, an industrial enclave: both geographically and in its model's orientation.

The study of flows provides significant insight into the interactions between ports and territories, as well as their evolution. Clark (1958) discussed the ambivalent role of transport as both makers and breakers of cities. Here, we demonstrate the role of flows in port infrastructure planning. This article defines flows as the essence of the metabolic relation between port and non-port. Thus, they can potentially break port-territory relations and drive a port's developmental trajectory towards extraterritoriality. We determined the port's territorial integration by analysing the (dis)connection between the port and the territory. While flows do not have the agency to concretely take part in decision-making, their vital importance to port growth manifests in the numerous port infrastructure modifications that were made to accommodate them. The traffic of energy flows increased for 30 years, between 1975 and 2006. Despite experiencing several successive crises, it remains the most significant share of the port's overall traffic. The GPMNSN has thus become a vital energy installation at both local and national levels. It, therefore, comes as no surprise that transformations are carried out to ensure the successful handling of (fossil) energy flows in the port. Our methodology, drawn from Dooms and Haezendonck's framework (2004), identifies the preponderance of oil and petroleum products in the port's traffic share as factors in a port's extraterritoriality because it favours the development of the industry rather than metropolitan-oriented activities. The presence of an industrial zone adjacent to or within an urban area can be considered a benefit to the nearby metropolis. Although each fuel the others, industrial operations are in many ways separate from metropolitan-supporting ones. Indirect benefits may not justify the continued presence of industrial activities within metropolitan areas. Much like industrial areas within urban ones do not necessarily indicate a connection or joint development. Our analysis of the GPMNSN's traffic structure revealed it to be an industry-supporting port. Moreover, our case study supports our claim that flows are drivers of territorial development, as the decisions made to accommodate them can be directly tied to sequences of connection and disconnection between port and territory.

Numerous scholars have examined the disconnection of ports from cities/territories through abstract models (Bird, 1963; Hoyle, 1989) and others through historical sequencing (Hein & van Mil, 2019; Masy, 2020). Flows in ports have been extensively studied in exploring the globalisation of port cities (Ghiara & Sillig, 2008) and the search for increased competitiveness (Hein, 2016). However, flows have rarely been investigated as bridges or obstacles to territorial integration. This article proposed a mixed-methods approach to shed light on the role that flows play in port-territory dynamics. It foregrounds the central role flows play in creating and disrupting metabolic relations between spaces and in causing the parallel development of port and non-port. Throughout this research, the term "port" is used to contrast with "non-port," "territory," "city," and "metropolitan area" to emphasise a comprehensive distinction. This research demonstrated the disconnection between the two in the Loire estuary despite the continued presence of port infrastructure in metropolitan areas. We believe this innovative approach, inspired by methodologies derived from the UM framework, to be insightful in informing another facet of port-territory relations. One that most models overlook.

6. Conclusion

This article explored the role of flows in influencing the territorial development of port regions and metabolic relations between port and host territory. The study was conducted in two stages. First, the historical evolution of the port in its region and its relations with neighbouring urban areas were revealed through an analysis of historical sequencing. Significant events related to port growth and flow accommodation were identified as transitions from connection to disconnection phases. Second, contemporary port-territory interactions were analysed through a thorough traffic structure analysis. The case of the Loire port of Nantes Saint-Nazaire proved particularly insightful as it presents a polycentric port that has expanded over the years from one city to another. Until the mid-twentieth century, the main concern was the (dis)connection between Nantes and Saint-Nazaire. In contemporary times, the article examined the (dis)connection of the port from its territory. The dominant oil and petroleum flow type is directly identified as a factor of this disconnection, indicating a preference for industry over metropolitan activities. The authors deem this port type to be extraterritorial. The use of mixed methods provided a comprehensive understanding of the nature of the metabolic relations between port and territory. Both the geographical relocation assessment and the in-depth study of port traffic structure corroborated the hypothesis that the Loire estuary port was disconnected from its territory, despite its infrastructure remaining located within two large metropolitan areas. We believe that UM is an innovative tool for studying territorial development that can help reveal the multifaceted interactions that shape spaces.

Considering the extraterritoriality of ports, the industrial enclave it represents can be an obstacle to the implementation of regional development strategies. As ecological challenges reaffirm their urgency, the necessity to collaborate with the port in the Loire estuary grows. While the energy transition and circular economy gain momentum, one can assume their implementation might rekindle dialogue between the port and territorial actors while weaving energy and material flows of the port and urban systems together, thus enabling a new connection phase. This article calls for future research on the role of ports in setting up ecological transitions.

Acknowledgments

We would like to thank Gaetan Levillain, PhD student at Nantes University, who scanned and collected data from the archives of the regional statistical institute. We would like to thank the NExt program as well at Nantes University, in particular Jeremy Pruvost, the project coordinator, and Anne Ventura, the PhD supervisor.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 330–345
https://doi.org/10.17645/up.v8i3.6783

Article

The Texas Coast: Ship Channel Network of the Petroleum Age

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Submitted: 31 January 2023 | Accepted: 1 June 2023 | Published: 26 September 2023

Abstract
This article provides an overview of the Texas Gulf Coast as a port city region dedicated above all to oil and gas. By the late 1800s, the same trends in transportation and industry that encouraged ship channel construction around the world drew attention to schemes to transform the Gulf Coast's shallow bays and estuaries into inland deep-water harbors. An added factor in Texas was the vulnerability of Galveston and other coastal locations to hurricanes. Between 1902, when construction began on the 52-mile Houston Ship Channel, and the 1950s–60s, when a deep-water channel opened at Matagorda Bay along the mid-Texas coast, various levels of government—local, state, and national—combined to engineer one of the world's most elaborate navigation networks. Six deep-water channels were woven together by Gulf Intracoastal Waterway, which connected Texas to the Mississippi and beyond. During the years when these ports were taking shape, the Texas oil industry had begun to burgeon. In a reflection of the pre-Spindletop origins of Texas's deep-water movement, policy and planning continued to assume, until oil's dominance had become clear, that even the massive ship channels at Houston and Corpus Christi would serve mainly as outlets for agricultural commodities. It was the organizers of the state's petroleum sector who came to understand the Texas ship channels as exemplary locations for aggregating their diverse operations. This interplay between civil engineering and the energy sector made coastal Texas into a dynamic urban port region. Petroleum and petrochemicals, however, so thoroughly imprinted themselves on the landscape, economy, and life of Texas's oil port region that the region's post-oil future remained difficult to envision.

Keywords
Beaumont; climate change; Corpus Christi; Houston; petroleum industry; Port Arthur; port cities; ship channels; Texas cities

Issue
This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

This article offers an overview of the Texas Gulf Coast as a port city region that developed in tandem with the oil and gas industry, that came to thrive, as Carola Hein (2020, p. 194) puts it, on "the mix of oil and water." The aggregation of ship channels, pipelines, storage terminals, refineries, and petrochemical plants from Louisiana's Chemical Corridor down to Corpus Christi in South Texas exemplifies how port city regions came during the twentieth century to function, again in Hein's words, "as nodes in the global petroleumscape" (Hein, 2020, p. 193).

Between 1902, when construction began on the Houston Ship Channel, and the 1950s–60s, when a deep-water channel opened at Matagorda Bay along the mid-Texas coast, the various levels of US government—local, state, and federal—combined to provide coastal Texas with six deep-water channels, dredged to between 40 and 50 feet, supplemented by feeder canals, and woven together by the Gulf Intracoastal Waterway (GIWW), which connected Texas to the Mississippi and the Atlantic seaboard (Figure 1). As the article points out, the movement to remake the Texas Gulf Coast for ocean shipping preceded the Spindletop discovery of

1901, which revealed the oil reserves on which Texas's energy wealth would be built. The remaking of the Texas coast began as an episode in the transnational movement that took shape over the nineteenth century to reconstruct rivers, coasts, harbors, and waterfronts and, when deemed necessary, to engineer new navigation channels to accommodate new forms of shipping and the new scale and scope of commerce. In their conception, the great ship channels at Houston or Corpus Christi shared the impulse behind such ventures as the Manchester Ship Canal, the Chicago Sanitary and Ship Canal, the St. Lawrence Seaway, or the channelizing of the Rhine and Elbe in tandem with creation of Imperial Germany's network of inland ports and ship canals.

Promoters initially envisioned both the Houston and Corpus Christi ship channels as outlets for cotton, grain, and other agricultural commodities shipped into those cities via railroad from rural Texas and other southwestern states. Key organizers of the state's oil and gas sector, however, came to Texas with experience in Pennsylvania or Ohio. They already grasped the dependence of their business on port cities. Petroleum entrepreneurs identified the nascent ship channels as first-rate locations for concentrating refining, storage, and tanker terminals. Providers of specialized services to the energy sector—drill equipment manufacturers, rig fabricators, and so on—concentrated along the ship channels as well. By the 1930s–40s, geographers and economists analyzing Houston and other Texas ports—as well as photographers attempting to convey their appearance and atmosphere—were fascinated by the port landscape they saw taking shape, characterized by refineries and petrochemical plants, mazes of pipelines, fields of storage tanks, and tanker loading docks, the "landscape of oil and water," again in Hein's words (2020, p. 195).

As the citations reveal, the article builds upon the author's own research about Corpus Christi, while drawing upon contemporary as well as historical studies of Houston and elsewhere. The goal is to introduce the Texas coast altogether as a port city region, while

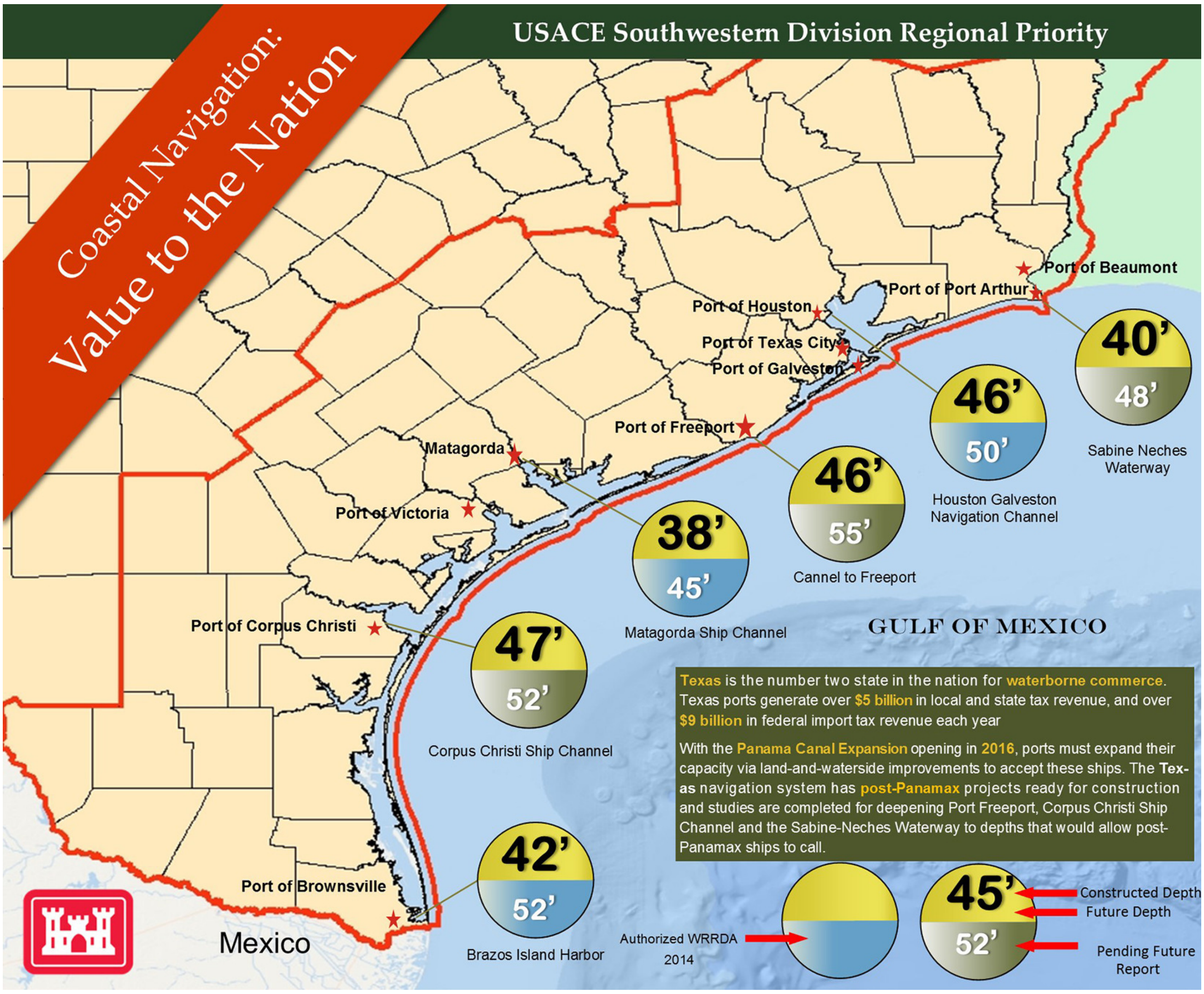

Figure 1. Texas's six deep-water ship channels, connected by the GIWW. The upper figures in the circles reflected current depth, c. 2014. The lower figures reflected authorized or proposed depths. Courtesy of Galveston District, US Army Corps of Engineers.

pointing readers toward how researchers have examined the various ship channels and their cities.

The first section of the article sketches the nineteenth-century background of schemes to reconstruct the Texas coast. It briefly considers the rise and stagnation of Galveston, the site initially identified as suitable for a major port, according to the saltwater understanding of port location that Texas's Anglo American colonizers brought with them. Even before the Great Storm of 1900 devastated Galveston, the shortcomings of a modern port city on a barrier island two miles from the mainland were feeding arguments for a deep-water channel dozens of miles inland to Houston.

The second section recounts Texas's half-century era of ship channel construction and considers how these ports became intertwined with the oil industry and became the epitome of diversified industrial petroleumscape. In the concluding section, the author reflects upon the ambivalent commitment that Texas's oil port cities have shown toward diversifying away from the industry that brought this region prosperity and prominence. In the aftermath of crises that dramatized the economic and environmental hazards of continued dependence on oil and gas, these cities have engaged in searching discussions of possible new commercial directions. But such discussions repeatedly proved fleeting and their results sporadic.

The transnational project of which this thematic issue is a component seeks to understand the history of modern port cities, their industrial heritage, and their social and cultural character in order to assist in sketching out a range of possible futures. This includes a "post-oil future," to quote Hein (2020, p. 218) one more time, for port city regions that coalesced, as the Texas coast did, around oil and gas. A practical route toward taking "much of the oil out of the water and the port city regions," while essential, is daunting to imagine, as the case of what is probably the world's premier oil port region dramatizes (Hein, 2020, p. 218).

2. Texas, the Gulf, and Port Development Before Oil

The Gulf Coast of Texas extends approximately 375 miles from the Sabine Pass to the Rio Grande. The coast's estuaries empty into eight bays. The mainland is separated from the Gulf of Mexico by a string of seven barrier islands from Galveston Island in the north to Padre Island, the world's longest barrier island, in the south. An extensive plain, 100 miles wide, stretches inland from the shore, with humid forests toward the north and arid shrubland toward the south. Not far off Texas, the gulf is quite deep in places, but Texas's lagoons and bays are uniformly shallow, with drafts of eight or ten feet at best and passes that silt or form sandbars. The Laguna Madre, a delicate ecosystem which extends from Corpus Christi Bay down behind Padre Island to the Rio Grande and then in another segment to Tamaulipas, Mexico, averages under four feet deep (Tunnel, 2002, pp. 7–9). "The ports of Texas," explains Jim Blackburn (2017, p. 37), the Houston environmental lawyer and policy expert, are "suitable in their natural state for only the shallowest draft commercial vessels."

Another noteworthy feature of the Texas coast—indeed of the Gulf Coast from Florida into Mexico—is how low-lying it is. The reputed highest point, the Corpus Christi Bluff south of the Nueces River, is 40 feet high. The salt dome at High Island on the Bolivar Peninsula northeast of Galveston is 38 feet. Only in a few other places does the shoreline rise more than five feet above sea level (Kosovich, 2008). Taken together, these features—the shallow bays, lagoons, and marshes, the low-lying shore, and the relative protection from Gulf of Mexico storms provided by barrier islands—explain most of the waterscape's history since Anglo American conquest and of course before that.

As elsewhere in the Americas, colonizers initially sought ports close to the ocean, in places accessible with minimal dredging, The port of Galveston originated in the 1810s in the activities of French privateers Louis Aury and Jean Lafitte. In the 1820s, newly independent Mexico tried to establish Galveston as an authorized port. Anglo Americans made it their port of entry to Texas and then a naval center during the Texas Revolution of 1835–36. Beyond taking control of Galveston, the Texas Republic in 1837 incorporated Houston and briefly used this new settlement as a capital. Houston's promoters sited their town where White Oak Bayou flowed into Buffalo Bayou, 18 miles upstream from where Buffalo Bayou flowed into with the San Jacinto River, which in turn connects to Galveston Bay. The town's developers insisted that Buffalo Bayou was reliably navigable. In reality, only light steamboats could make their way to early Houston (Bradley, 2020, pp. 9–12; McComb, 1969, pp. 13–14).

From a nineteenth-century perspective, Galveston qualified as "the sea Port…for this province" (Edward Lovelace quoted in McComb, 1986, p. 8). Goods and people unloaded at Galveston for transhipment up and down the coast or upstream to Houston and beyond. Galveston became the leading export point for Texas commodities, especially cotton, grain, and hides. Among its imports, Galveston maintained a trade in enslaved people, shipped mainly from US ports but at times smuggled from the Caribbean or Africa. With 4,177 people in 1850, Galveston ranked as Texas's largest city and by most measures its richest, a status maintained off and on into the 1880s (McComb, 1986, pp. 66–68, 85–86).

Galveston's location at the northern edge of a barrier island, two miles from the mainland, encouraged it to start fast but soon came to hamper it. As elsewhere along the Gulf Coast, the more protected, bay side of the island was shallow and obstructed by sand bars. Galveston Bay averages seven-nine feet deep. The island itself rises less than nine feet about sea level. A long series of hurricanes, with their devastating winds and surges, made clear the hazards of such a low-lying island town even before 6,000–8,000 people died there in the

Great Storm of 1900, still the deadliest natural disaster in US history. Galveston Island, moreover, offered minimal supplies of fresh water, as well as limited space for warehouses, freight yards, and industry. Under the Texas Republic and then during the US period, government as well as private investors endeavored to make Galveston as secure and functional as feasible. Shipping lines devised specialized shallow-hull sailing and steam ships to accommodate Galveston and the Texas coast more generally (Alperin, 1967, pp. 37–58; Barnett, 2007, pp. 185–192; McComb, 1986, pp. 42–49).

Railroads further exposed Galveston's limitations. As rail lines spread across Texas starting in the 1850s, Houston, with its broad, flat, well-watered site, became their Gulf Coast hub. In 1859, a rail line opened between Houston and Virginia Point, on the shore opposite Galveston. A trestle bridge was completed in 1860. This survived the US Civil War only to be wiped out in an 1867 hurricane. Railroads rebuilt it and added two more bridges over the next decades, all of which were wiped out again in the Great Storm of 1900 (Barnett, 2007, pp. 192–193; Bradley, 2020, pp. 37–38; McComb, 1969, pp. 34–40, 1986, pp. 49–58).

Nevertheless, Galveston still ranked in 1900 as the largest US cotton port, as well as the country's third leading port for wheat exports. The city seemed so indispensable that in 1880, the federal government established a Galveston District of the US Army Corps of Engineers, which oversaw a harbor-deepening program. By 1897, the harbor reached a depth of over 25 feet. After the 1900 hurricane, the Army Corps worked with local and Texas authorities on reconstruction and improvement, including a 17-foot seawall, eventually extended to ten miles long. By 1912, the island city was again the country's leading cotton port. While later coming to specialize in tourism and cruise ships, Galveston would remain a significant port for grain, fruits, and other commodities. Galveston's population reached a high in 1960 of 67,175 (Bixel & Turner, 2000, pp. 89–161; McComb, 1986, pp. 84–149). But this summary of Galveston's twentieth-century trajectory underscores how thoroughly it had fallen into the shadow of Houston, while falling behind Corpus Christi and Beaumont–Port Arthur as well. Both of these had been minor places before ship channels reached them.

Corpus Christi, two hundred miles south of Galveston and Houston, likewise illustrates geographic and economic factors that led Texas and US officials to contemplate deep-water channels to inland harbors even before petroleum began to affect navigation planning. The town originated in the late 1830s as an Anglo-American trading post on the western edge of Corpus Christi Bay, about 20 miles inland from Aransas Pass on the Gulf of Mexico. Corpus Christi's most picturesque feature was its sweeping crescent bay. More significant for the site's potential was the 40-foot bluff several hundred feet behind the shoreline. As already noted, this was reputed to be the highest point on the storm-ridden Texas coast.

The chain of events that led to the town's transformation began in the South Texas countryside. After the US Civil War, Anglo-American land operators—founders of the South Texas ranches that play a huge role in US western lore—accumulated land grants, often at the expense of Mexican landholders, who found themselves pressed financially and isolated politically. From annexation into the 1870s, the borderlands region remained loosely controlled, disputed territory, periodically wracked by raids and reprisals involving Mexican and Anglo and sometimes mixed-ethnic bands. Aided by the Texas Rangers, the ranch families determined to pacify the countryside, a cycle that culminated in a deadly 1875 raid by a gang with connections to northern Mexican military figures on a trading post northwest of Corpus Christi. In the aftermath, Anglo posses and vigilantes fanned out across the countryside carrying out "indiscriminate" reprisals, murdering "not only the outlaws, but also innocent Mexican settlers, ranchers and traders," as the city's Works Progress Administration guide put it (Works Progress Administration in Lessoff, 2015, p. 92). These events secured the Anglo cattle operations, while making possible the subdivision of ranchland for agriculture. Ranch families worked with investors and engineers to extend railroads, found satellite towns, and promote the migration of Anglo farmers. When in the early twentieth century oil deposits were discovered on these lands, ranch families already had experience as diversified entrepreneurs.

South Texas ranch families identified Corpus Christi as their site for a port where railroads would converge. They built townhouses atop the bluff and underwrote a range of business and civic institutions. The silted passes and shallow harbor posed an obvious obstacle. In the 1870s, packing plants along the bay and on Padre Island stripped hides, tallow, horns, and bones from cattle and threw the meat into the bay or left it to rot on the shore. With Texas cattle so abundant and prices low, it did not pay even to pickle the beef for shipment through such a difficult port. Richard King, founder of the famous King Ranch, responded by underwriting an eight-foot channel through Corpus Christi Bay. When in May 1874, a Morgan Line freighter reached the town's Central Wharf, over 2,000 people turned out to greet it. After a decade, the channel silted again (Givens & Moloney, 2011, pp. 122–123; O'Rear, 2009, p. 18, 2022, pp. 59–62). In the 1890s, a former Union colonel from New Jersey lined up New York investors for another attempt to construct a shipping channel. The dredge for this project ended up abandoned, buried in the silt. Still, this undertaking drew attention to Corpus Christi's potential for both large-scale commerce and oceanside tourism: a combined "Southern Newport" and "Chicago of the Southwest" as a contemporary promotional pamphlet stated the aim (Lessoff, 2015, pp. 99–100; Figure 2). Regional interests in South Texas were coming together behind a deep-water channel. Yet Corpus Christi, with a 1900 population under 5,000, still seemed to the

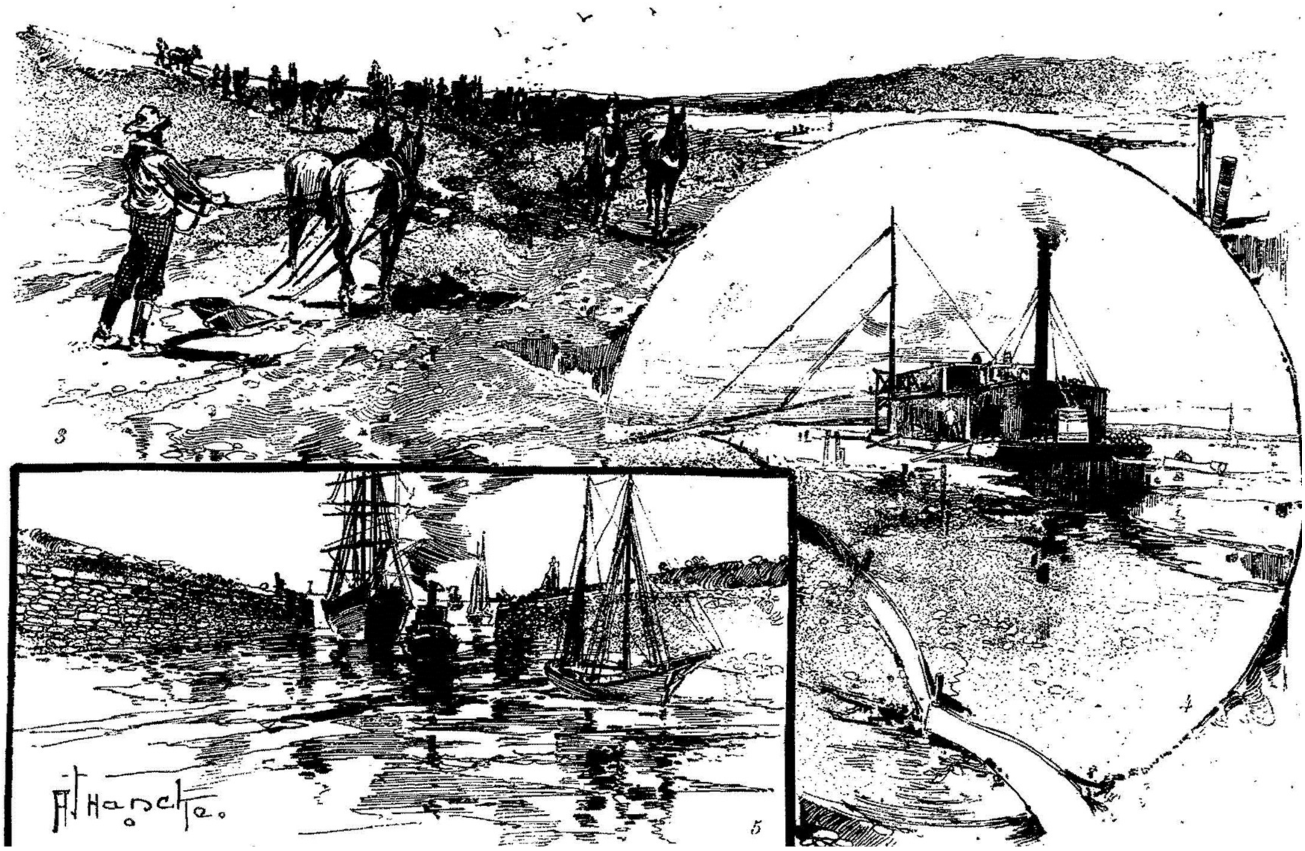

Figure 2. Print from *Engineering Magazine*, June 1892, of that decade's failed attempt to dredge "Ropes Pass" through the barrier islands and across Corpus Christi Bay. Courtesy of Kilgore Collection, Special Collections and Archives, Texas A&M University—Corpus Christi.

Army Corps of Engineers too insignificant and remote to justify more than minor efforts to open it to shipping, by comparison to the money and effort then being devoted to both Galveston and Houston (Alperin, 1967, pp. 126–133).

3. A Coast Remade for Petroleum

In 1904, Robert Kleberg Sr., Richard King's son-in-law and successor as operator of King Ranch, recruited a young Houston journalist named Roy Miller, a Kansas native with a business degree from the University of Chicago, as publicist for a rail project to the Rio Grande Valley. By age 24, Miller edited the *Corpus Christi Caller*, the region's main newspaper, another local institution underwritten by ranching interests. The newspaper provided Miller a platform for election as mayor in 1913, where he oversaw infrastructure and beautification projects intended to make Corpus Christi up-to-date and attractive. After three terms, Miller lost re-election in spring 1919 and returned to his newspaper. "The future of Corpus Christi" hinged, Miller proclaimed, "upon ONE THING ALONE—DEEP WATER" (Miller quoted in O'Rear, 2009, p. 89). In September 1919, Corpus Christi was struck by a hurricane in which as many as 600 died. The editor organized a Deep Water Association to lobby federal and state officials at last to construct a ship channel. The US Army Corps of Engineers continued to express skepticism that South Texas needed an elaborate port to match Galveston and Houston. Nearly all the effort that the Corps had expended to date had focused on Aransas Pass on the Gulf Coast. Rail connections there or to nearby Harbor Island would suffice, the Corps argued. Yet for all the damage wrought by the 1919 storm in Corpus Christi, these coastal sites were "practically swept clean," as an official port history later explained (Port of Corpus Christi, 1976, p. 15). "A safe harbor," Miller argued "should be established against" the Corpus Christi Bluff, many of whose residents made it comfortably through the September 1919 storm, unaware until the morning of the scale of destruction in the lower town and along the beaches (Miller quoted in Walraven, 1997, p. 7). When the Corpus Christi Ship Channel opened in September 1926, the seventh anniversary of the deadly storm, the official commemorative booklet stressed that "engineering ingenuity" had indeed provided South Texas with "*a safe port*" (Port of Corpus Christi, 1926, p. 6, italics original; Figure 3).

Massively expensive, dependent on public funds, navigation improvements are products of politics as well as economics, geography, and technology. Texas's ship channels manifest the strength in the state of

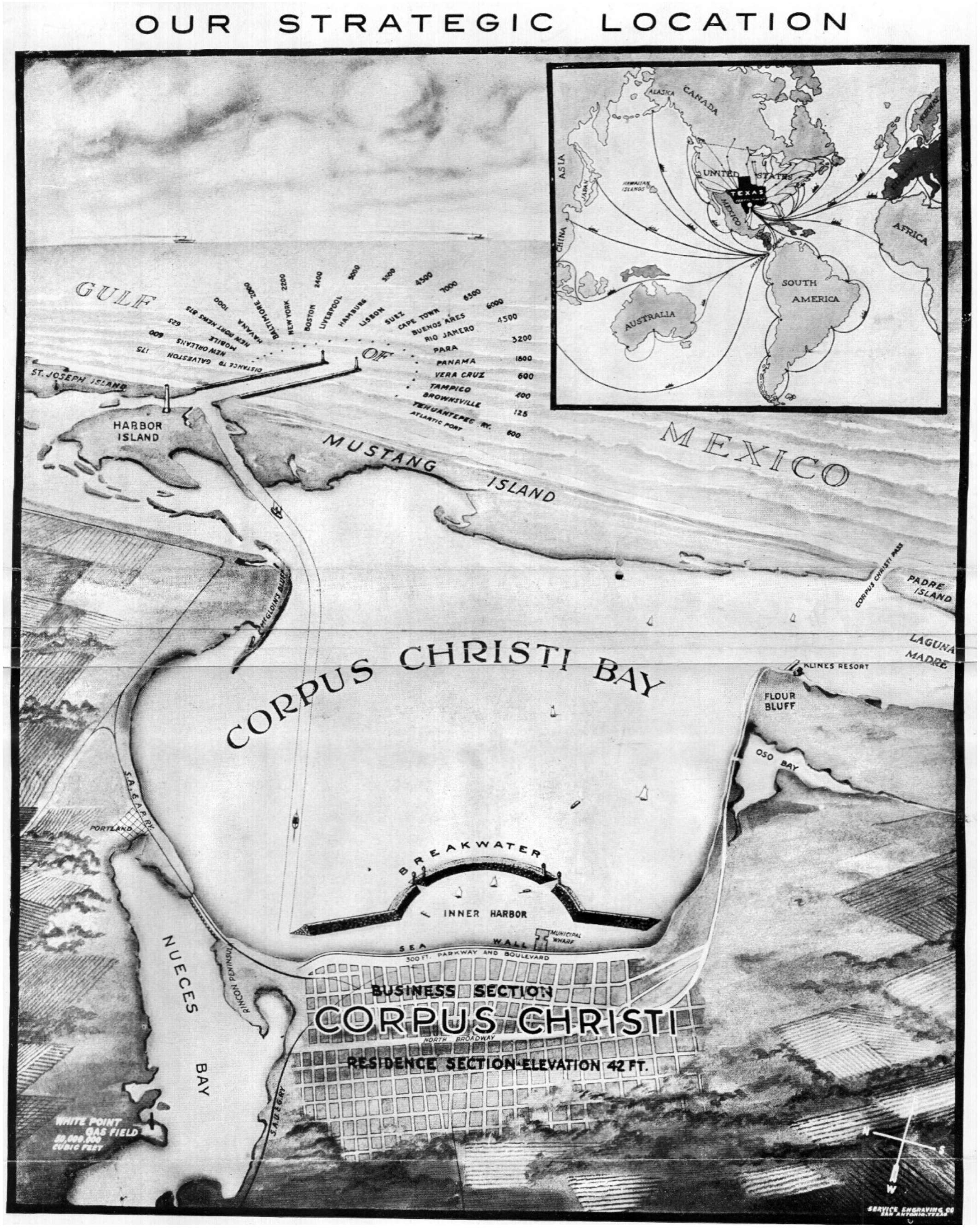

Figure 3. South Texas commercial and civic interests promoted the Corpus Christi Ship Channel as a strategic location for shipping to Europe and Latin America as well as through the Panama Canal. From a brief submitted to a hearing held by the US Army Corps of Engineers. September 1920. Courtesy of Kilgore Collection, Special Collections and Archives, Bell Library, Texas A&M University—Corpus Christi.

what historians label "commercial-civic" or "pro-growth" coalitions, which brought together development-minded politicians with business interests intent on linking the region to national and international networks of finance and commerce. At Corpus Christi, this was epitomized by Kleberg and Miller's alliance with South Texas congressman John Nance Garner, who had worked to direct funds to South Texas navigation projects since the early 1900s. After the Corpus Christi Ship Channel won authorization, Miller and Garner turned to integrating the Texas coast into the GIWW, authorized between Galveston and New Orleans in 1905. In 1929, Miller moved to Washington to lobby for Texas navigation projects, a task faciliated by Garner's elevation that year to speaker of the US House of Representatives and then in 1933 to vice-president under Franklin Roosevelt. Miller managed the 1931 election to Congress of his mentor's son, Richard M. Kleberg, and had a role in selecting Lyndon Johnson, then a young South Texas schoolteacher, as Kleberg's congressional assistant. Completed in 1949, three years after Miller's death, the GIWW provided a shipping artery 12 feet deep and up to 125 feet wide from the Rio Grande to Florida (Judd, 2021; Lessoff, 2015, pp. 101–103; O'Rear, 2009, pp. 67–79). The Texas coast, in sum, emerged as a key node in the global petroleumscape largely because the petroleum business was able to build on pre-existing commercial-civic alliances and on navigation projects set in motion before the extent of oil reserves in the state and the US Southwest became evident.

Houston's historians have understandably devoted much attention to events that led to construction of that city's immense ship channel and then to how the port became the basis for Houston's emergence as the self-proclaimed energy capital of the United States and even the world. As noted earlier, US and Texas officials as well as shipping interests remained committed to Galveston even after the Great Storm of 1900. Following a traditional saltwater strategy, Galveston's backers "deepened its harbor to permit increasingly larger ships to enter," explains William Barnett (2007, p. 191), a historian of US port development. Houston interests, by contrast, had for decades prioritized the site's value to railroads and industry, whose concentration at Houston in turn became a rationale for opening Buffalo Bayou to shipping. Already in 1871, the first Army Corps survey noted that the advantages of opening a channel to this emerging railroad center were "obvious" (Alperin, 1967, p. 96). By the early 1900s, 17 railroads met at four separate depots, justifying Houston's promotional nickname, "Iron-Ribbed City." The city served as eastern hub for the Southern Pacific system, whose Houston shops and yards employed over 1,200 by the early 1890s. Railroad construction and repair provided Houston with an industrial base in metals and machinery that later proved attractive to the oil industry (McComb, 1969, pp. 92–110; Platt, 1983, pp. 80–83). Against this background, Congress in 1896, five years before Spindletop, authorized a 25-foot channel all the way from Galveston Bay (by 1950, this would be deepened to 34 feet). In this way, Barnett (2007, p. 191) remarks, Houston become "the site where Texas railroads met the sea" (Figure 4).

Congress waited until 1902 to begin funding the project, which the city and its banks also underwrote through bond sales. Opened in 1914, the Houston Ship Channel had an origin separate from the Texas oil boom. Even so, the potential mutual benefit of these contemporary events became evident even as the ship channel was being built. At first, investors in the East Texas fields envisioned moving oil by train or pipeline to nearby Beaumont and Port Arthur. But Houston's comprehensive railroad network, its diverse, highly skilled industry, and its vibrant financial and commercial sectors made it an attractive base for oil operations. Motives to concentrate around Houston increased as reserves

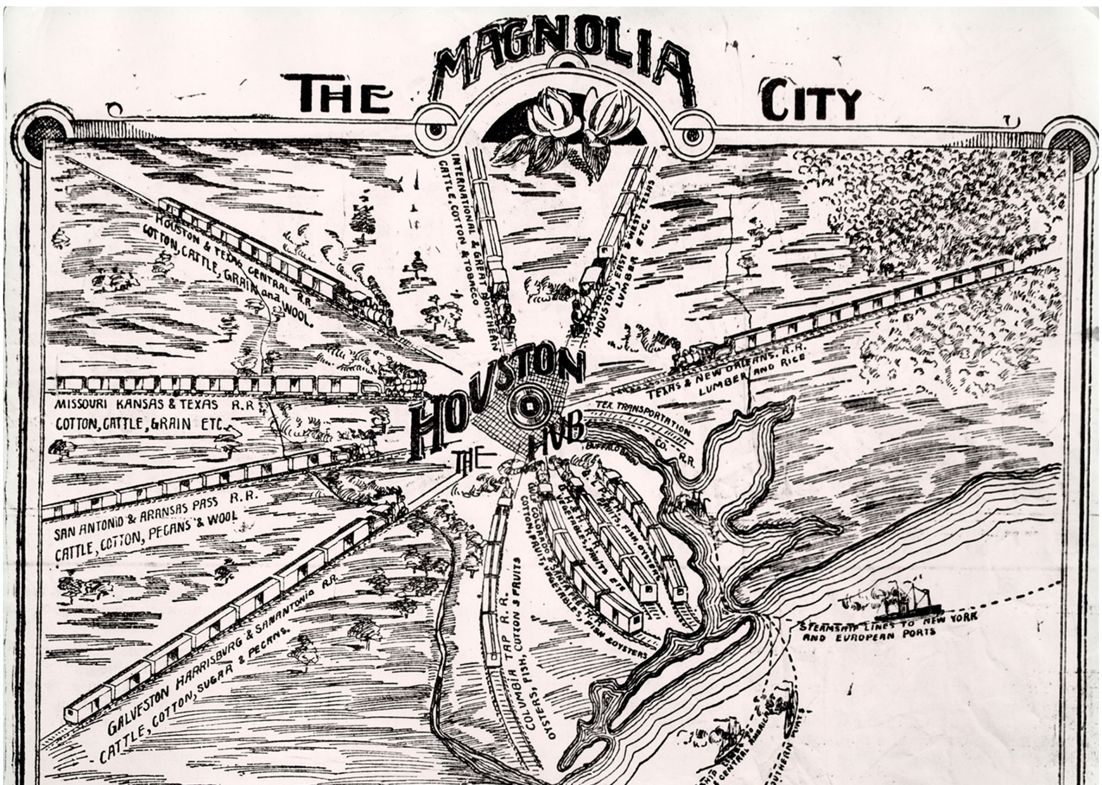

Figure 4. An 1898 print publicizing Houston as the railroad and industrial hub of the Texas coast. Courtesy of University of Houston Libraries Special Collections (https://id.lib.uh.edu/ark:/84475/do06149p703).

were discovered near the city, starting in 1905 with the Humble Oilfield 18 miles to the northeast.

Texas oil evokes swaggering, independent personalities, the industrial-era frontiersmen of the novel and movie *Giant*. While this stereotype had a reality behind it, experienced investors, managers, and technicians exerted a presence from the start. The founders of three major companies to emerge from the early Texas boom—Gulf, Texaco, and Sun—all had backgrounds in Pennsylvania and understood how indispensable Pittsburgh, Cleveland, and Philadelphia had been to the industry's growth. Texas Company (Texaco) founder Joseph Cullinan, who started with Standard Oil and who had run an oil equipment business in Pennsylvania before turning to Texas, moved his headquarters to Houston by 1908. Gulf Oil, organized by Pittsburgh's Mellon banking family, moved its headquarters to Houston in 1916. In 1919, Standard Oil of New Jersey (ESSO, forerunner of Exxon) acquired the majority share of Texas-based Humble Oil, which then began construction of its own Houston headquarters. Houston also became a locus for the American operations of foreign interests, such as Royal Dutch Shell, which starting in the 1920s built a refinery in the area, along regional offices and research facilities (Hein & Lessoff, 2022, pp. 28–31).

Even as petroleum's managerial and technical functions concentrated in Houston's offices, entrepreneurs such as Cullinan pointed to the Houston Ship Channel as ideal for transportation and processing. The Port Authority of Houston controlled expanses of land along the channel suitable for refineries, storage, pipelines, and much else. The port could ensure the industry a steady supply of fresh water (McComb, 1969, pp. 115–116; Sibley, 1968, p. 152). By 1930, the Port of Houston's nine refineries processed up to 194,000 barrels daily. Refineries spread around the region, for example to Texas City on the mainland side of Galveston Bay. Baytown, near the juncture of the San Jacinto River and Buffalo Bayou, took shape as a company town for the ESSO affiliate Humble after the opening of an oil field along the creek that ran through the town site. By World War II, Humble's Baytown operation was the largest US refinery, a status retained into the twenty-first century, when the refinery, by now renamed after Exxon/Mobil, employed 7,000 people processing 584,000 barrels/day (Bradley, 2020, pp. 152–153; Figure 5).

Oil firms located storage terminals at the Houston Ship Channel, fed by pipeline networks for crude and refined oil and, eventually, natural gas. Equipment and rig manufacturers and industrial construction companies also clustered around the Port of Houston. The most

Figure 5. The Humble Oil Refinery at Baytown along the Houston Ship Channel, 1944, already the country's largest refinery. Reprinted by permission, Bob Bailey Studios Photographic Archives, e_bb_2078, The Dolph Briscoe Center for American History, The University of Texas at Austin.

renowned of these—Hughes Tool—began in 1908 with a Spindletop contractor, Howard Hughes Sr., who allegedly bought an idea for a specialized drill bit from a millwright he met in a bar. By World War II, the Hughes plant, now under the leadership of the founder's son, aviator and adventurer Howard Hughes Jr., had branched into aircraft construction and military contracting. The construction firm Brown & Root made a fortune in public works contracting and shipbuilding before moving into chemical plant construction, pipelines, and offshore platforms. Brown & Root's 1962 merger with the oil field services firm Halliburton reinforced Houston's role as a provider of facilities and logistics to the multinational petroleum industry (Pratt & Castaneda, 1999, pp. 223–226).

This infrastructure drew manufacturers of petrochemicals, synthetic materials, and fertilizers. Cement works, metals producers, and inorganic chemical plants also located along the ship channel and up and down the coast. Such industries used high-energy manufacturing processes that benefited from reliable supplies of natural gas. By 1950, 27 chemical plants lined the ship channel, "future chemical capital of the world," as an analysis in the *Geographic Review* proclaimed. Products ranged from alkalies and chlorine to "synthetic glyercin, sodium silicate, industrial alcohols, insecticides, plastic resins, sulphuric glycering, ammonium sulphate, and ammonium phosphate" (Parsons, 1950, p. 77) This study's prediction seemed fulfilled by the 1980s when coastal Texas from Beaumont–Port Arthur area to metropolitan Houston accounted for half of US petrochemical capacity (Figure 6).

The hope that the Houston Ship Channel would serve Texas agriculture did come to fruition. A study from 1931 noted that in 1925 about a third of the US cotton crop moved through Texas ports. Cotton staple and cotton seed products remained more valuable—in dollar terms—than petroleum products, though in tonnage terms, petroleum already accounted for two-thirds

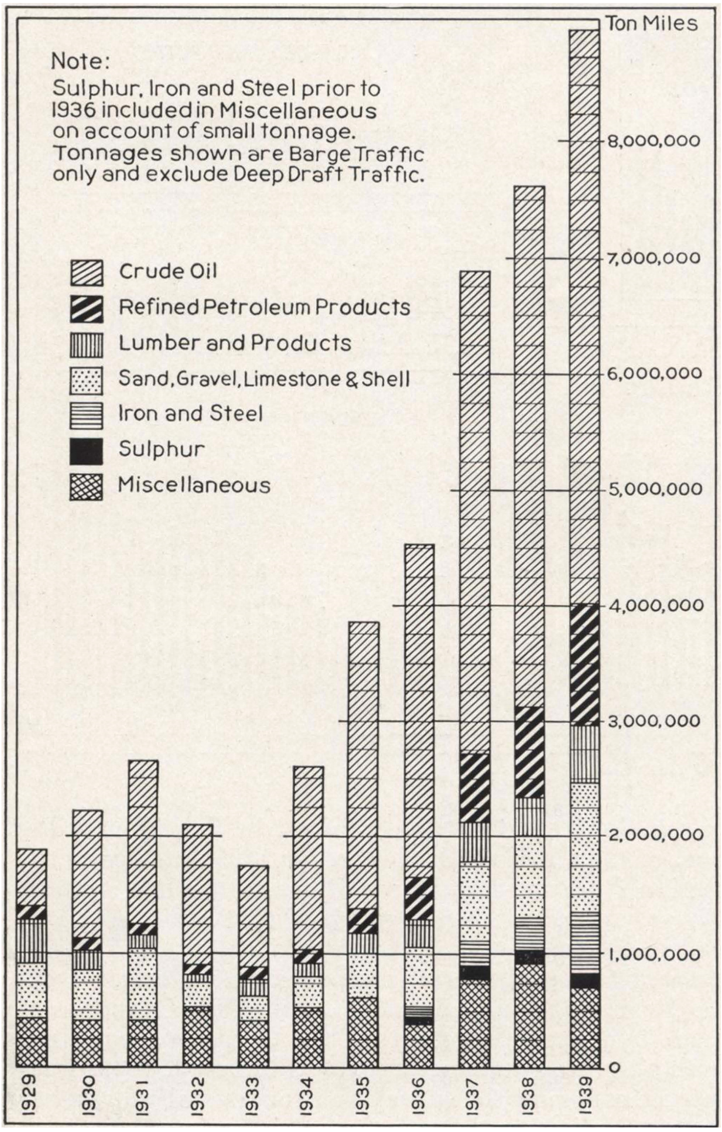

Figure 6. Chart tracing the speed with which crude and refined oil came to dominate traffic on the GIWW between 1929 and 1939. From Odom (1941, p. 204). Courtesy of JSTOR.

of the Texas coast's trade. Galveston and, to a lesser degree, Houston handled grain on a scale comparable to cotton. Nonetheless, what stood out to contemporaries was the scope, scale, and complexity of the petroleum industry landscape at Houston and nearby ports. "Pipelines, ranging from six to twelve inches in diameter, converge upon this port region; and pumping stations keep petroleum pulsating through them from all the great centers of production," the 1931 study remarked. "Thousands of acres of land adjacent to ship-channels at Port Arthur, Beaumont, Houston, and Texas City are used as storage-tank farms, as sites for petroleum refineries and by-product plants, and for wharf and terminal facilities by petroleum companies." Specialized factories, meanwhile, made and repaired "machinery, pipe equipment, and packages used in the industry" (Chambers, 1931, pp. 72–73). By mid-century, 80 percent of cargo shipped from the Port of Houston consisted of petroleum products (Odom, 1941, p. 202; Parsons, 1950, p. 72).

A similar shift in landscape and understanding took place in an even shorter time at the Corpus Christi Ship Channel after its 1926 opening. Already in 1916, the blowout of an exploratory well at White Point along Nueces Bay revealed substantial reserves within a few miles of the ship channel's eventual route. Corpus Christi's promoters likewise followed Houston's in stressing that an inland port offered synergies among railroads, shipping, freightyards, and industry. And as at Houston, the Port Authority of Corpus Christi controlled "ample room" for "all necessary piers, docks, and slips, and railway switches and terminals," along with "an unlimited quantity of fresh water" for industry (joint brief, City of Corpus Christi and the Corpus Christi Commercial Association, 1920, quoted in Lessoff, 2015, p. 67). Despite all this, oil and gas received hardly any mention in engineering studies, policy papers, promotional literature, and press accounts either during the campaign for the Corpus Christi channel or during its construction. Discussion focused on "a water outlet for [South Texas's] fabulous agricultural wealth" (Port of Corpus Christi, 1926, p. 6). Photos of cotton production illustrated brochures and pamphlets, with hardly an oil well in sight.

Farm products would remain a significant part of Corpus Christi's business. Yet petroleum-related activities soon overshadowed agricultural commodities. Corpus Christi gained the capacity to handle oil in 1930. By 1935, oil had surpassed cotton. By 1937, eight refineries lined the ship channel, processing 45,000 barrels daily. South Texas's commercial-civic leaders recognized fairly early natural gas's value in attracting diverse industries. In the early 1930s, business and civic leaders were so eager to win a $7 million inorganic chemical plant, a joint venture of American Cynamid and Pittsburgh Plate Glass, that they underwrote the deepening and extension of the channel, the construction of a second turning basin (of an eventual five), and the upgrading of the city's water supply. Local investors also underwrote the Southern Minerals Corporation (SOMICO), eventually a $100 million gas pipeline and supply company, intended to fulfill the "industrialist's dream" of "gas wells in sight of ship masts" (Industrial Banquet program, 1934, quoted in Lessoff, 2015, p. 103; Figure 7). By the 1960s, in addition to refineries, the Corpus Christi Ship Channel was lined by organic and inorganic chemical plants, aluminum and other metals operations, and a Halliburton cement factory, along with food processors and grain and cotton operations (Figure 8).

"Petroleum and natural gas," the *Geographic Review* summarized in 1950, formed "the basis for Gulf Coast's rapid urban and industrial growth" (Parsons, 1950, p. 73). Since Spindletop, the study explained, Texas by itself accounted for a third of US production and over 20 percent of world production. By mid-century, over one-third of US refining capacity was located in the coastal region of Texas and Louisiana, including the two largest refineries, at Baytown on the Houston Ship Channel and at Baton Rouge, Louisiana, along with six of the 12 largest (Parsons, 1950, pp. 73–80).

Unlike at Houston and Corpus Christi, proximity to oil fields explicitly influenced the deep-water system at Beaumont-Port Arthur from the start (Spindletop was about three miles south of Beaumont). The East Texas oil boom prompted Congress to assume control of privately funded navigation projects in the area and to underwrite a channel through the Sabine Pass on the Texas-Louisiana border, then 24 miles up the Sabine River to Port Arthur, and then about 20 more miles up the Neches River to Beaumont. Another branch of this project extended eastward to Orange on the GIWW. By the mid-twentieth century, the Y-pattern Sabine-Neches Waterway stretched 61 miles, with the channel over 30 feet deep. Beaumont, hitherto a railroad center and river port that mainly handled lumber, increased ten times from about 9,400 to about 94,000 people between 1900 and 1950. Port Arthur, founded as a land speculation in 1894, went from 900 people to over 57,000 in the same half-century. Clusters of refineries meant that the Beaumont–Port Arthur area at times produced nearly as much oil as Houston and sometimes exceeded Houston in cargo tonnage. Port Arthur employed 11,000 at two huge refineries adjacent to one another, "drawing oil by pipe line from East and West Texas, Oklahoma, Kansas, and Louisiana" (Parsons, 1950, pp. 72–74; see also Alperin, 1967, pp. 59–66).

By the 1940s, the discovery of more natural gas reserves encouraged further clusters of chemicals and metals operations along the mid-Texas coast. About 60 miles south of Houston, Freeport became a key example of the shorter harbor projects that supplemented Texas's major channels. There, starting in the 1920s, a three-mile, 32-foot channel was constructed at the Brazos River. During World War II, this became the site of a Dow Chemical complex underwritten by the US government. The centerpiece of this complex was a plant that extracted metallic magnesium, a lightweight alloy with strategic uses, from seawater. Dow's processes required

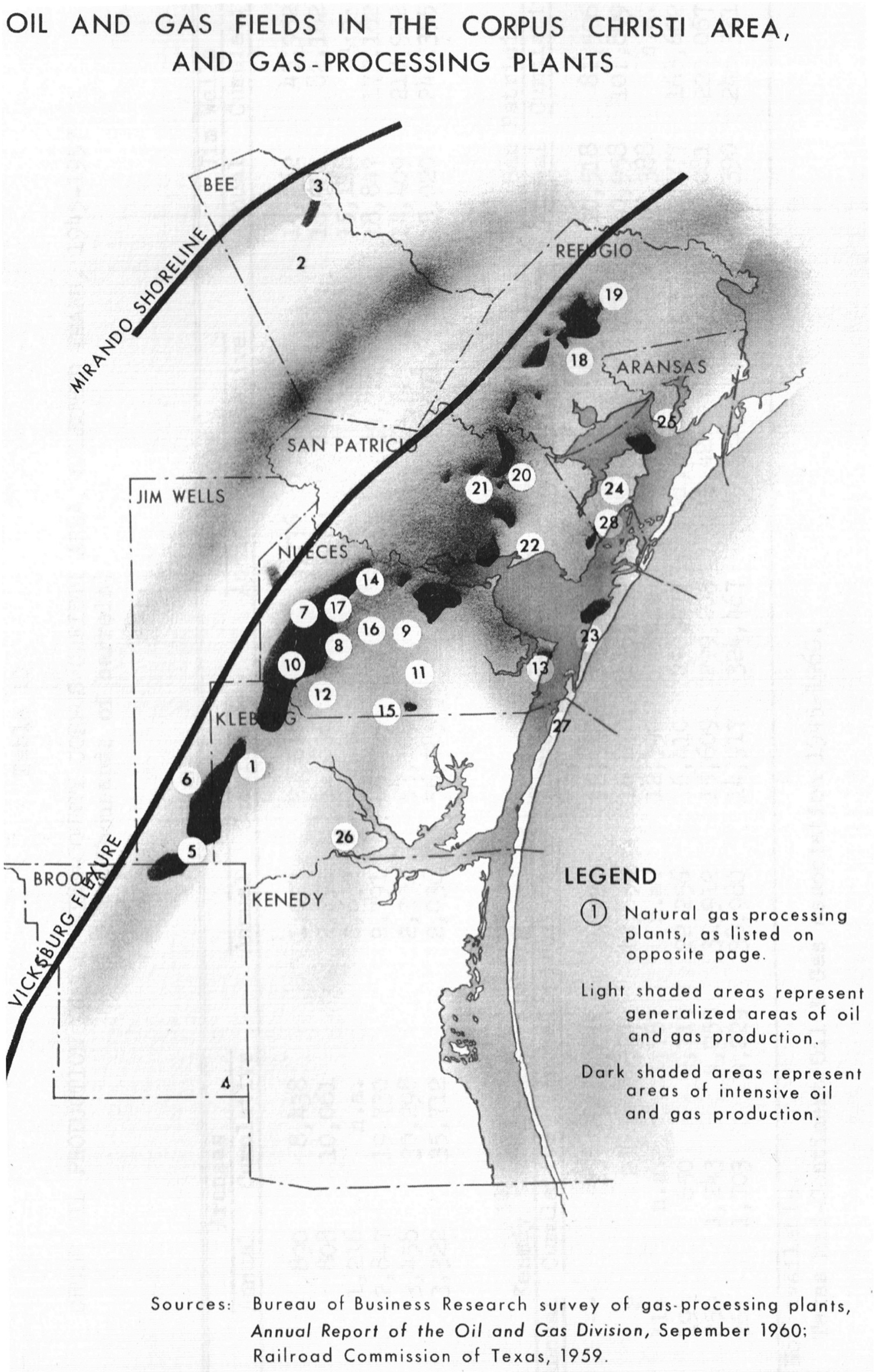

Figure 7. Oil and gas fields in the vicinity of the Port of Corpus Christi, 1960. Source: Ryan (1961, p. 113).

copious fuel, as did the aluminum plant that Alcoa built in the early 1950s at Point Comfort on Matagorda Bay. Union Carbide and Dupont likewise located in this area after World War II. In the 1950s–60s, federal and state officials pushed a deep water channel through Matagorda Bay (Foscue, 1950, pp. 12–13; Parsons, 1950, p. 76). The bay, with its agglomeration of chemicals plants, remained as vulnerable to gulf storms as in the 1870s–80s, when hurricanes forced abandonment of Indianola, for decades a staging ground for German and Anglo-American migration into central Texas. All that remains of Indianola is a historic marker.

4. The Weighty Heritage of Oil and Water

Hurricanes had loomed large in navigation planning for the Texas coast since the nineteenth century. By the early twenty-first century, climate change rendered disaster planning ever more urgent. Hurricane Harvey in August 2017 drew widespread attention to the region's

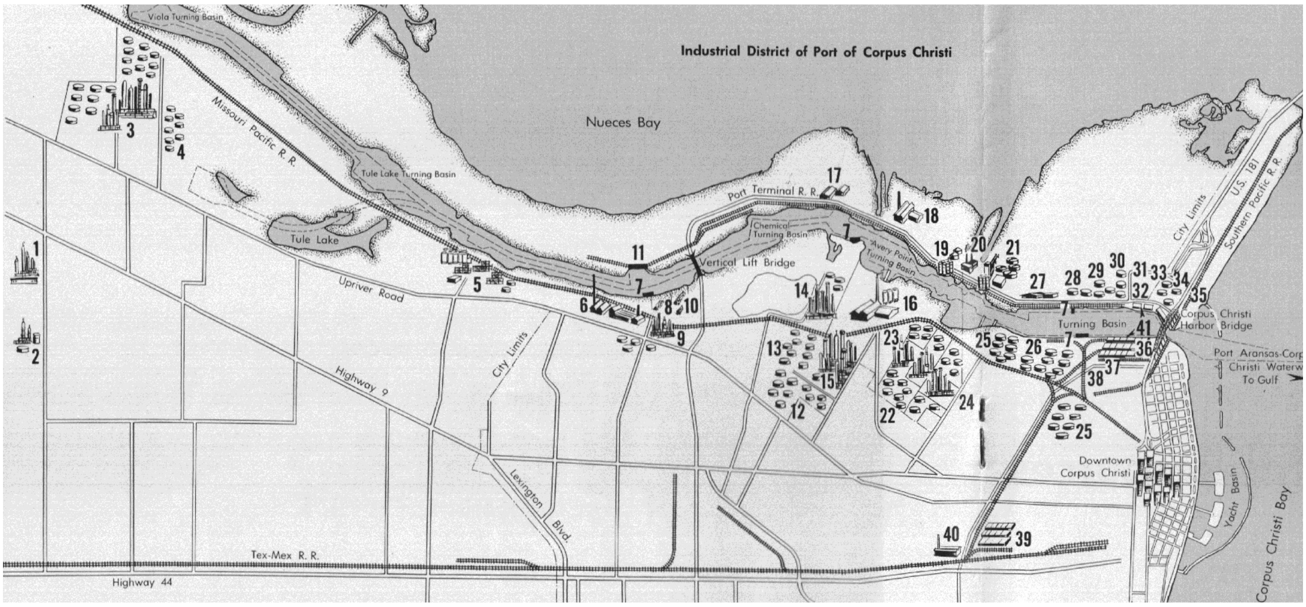

Figure 8. Industry along the Corpus Christi Ship Channel, 1958. Author's collection.

vulnerability. Yet Harvey's unprecedented flooding came mainly from rainfall when the storm stalled over the Houston area. That catastrophe had little *directly* to do with the Houston Ship Channel or the petroleum industry. As a reader remarked on an earlier draft, any city built in a comparable way amid metropolitan Houston's wetlands and bayous would have experienced similar flooding.

Experts concerned about the possible catastrophic interchange between the petroleum industry, ship channels, and Gulf of Mexico hurricanes had already been developing models and projections based on Hurricane Ike, which landed at Galveston as a category 2 storm on September 13, 2008. The 10–15-foot surge that hit Galveston could not surmount the 17-foot Galveston Seawall on the island's east side, but floods in excess of 12 feet inundated Galveston from the bayside to the west. A surge up to 20 feet submerged the Bolivar Peninsula northeast of Galveston. For all the damage inflicted on Galveston and the Bolivar Peninsula, observes the environmental lawyer Jim Blackburn (2017, p. 81), "the Houston region was spared the worst." Analysts at Rice University's Severe Storm Prediction, Education and Evacuation from Disaster Center calculated that if a similar storm—its intensity increased perhaps 15 percent—had made landfall a few dozen miles to the southwest, a storm surge plausibly estimated around 24 feet would submerge refineries and petrochemical plants at Texas City and Baytown before heading up the Houston Ship Channel. Storm water would crush storage tanks or lift them from their foundations, while breaking apart gas and oil pipelines. Over 2,220 oil or petrochemical storage tanks would experience flooding, as would "at least six refineries and well over a hundred chemical plants," Blackburn (2017, p. 84) notes. Up to 90 million gallons of oil and hazardous chemicals would flow into the urban area or into the rivers and bays. These projections did not even estimate the effect of rising sea levels and stronger storms related to climate change. Such scenarios prompted proposals for elaborate protection systems, such as the so-called Ike Dike, modeled in part on Rotterdam's Maeslant Barrier and the Eastern Scheldt Barrier in Zeeland (Blackburn, 2017, pp. 81–95; Figure 9).

Such scenarios added a new dimension to arguments made off and on since the 1960s that the Texas coast should look to de-emphasize petroleum. By the 2000s, this included schemes to shift the region toward renewable energy, fossil fuel's apparent successor. Those who saw Houston as potentially as formidable in renewables as it has been in fossil fuels pointed to the ship channel and its range of transportation and industrial facilities, but also to the technical and managerial skill that petroleum caused to accumulate in the metropolitan area. The energy industry explains why the Houston area is home to 57,000 engineers, as well as approximately 235,000 tech jobs and 8,800 tech firms (Medlock, 2021, pp. 2–3). Corporate headquarters, geological, technical, and financial services, energy-sector consultants, and specialized law firms concentrated in downtown skyscrapers or in the office parks of West Houston's Energy Corridor. By the 1980s, 34 of the 35 largest oil companies had a white collar as well as blue collar presence (Feagin, 1985, p. 1219). Such a broad base in corporate enterprise, finance, research, and the professions had already facilitated successful moves into aerospace after the founding in 1961 of what later became known as the Johnson Space Center and into medical services and biomedicine, with the step-by-step expansion of the Texas Medical Center in the decades after World War II.

By the early 2000s, meanwhile, the Port of Corpus Christi had become the preferred entry point for turbines

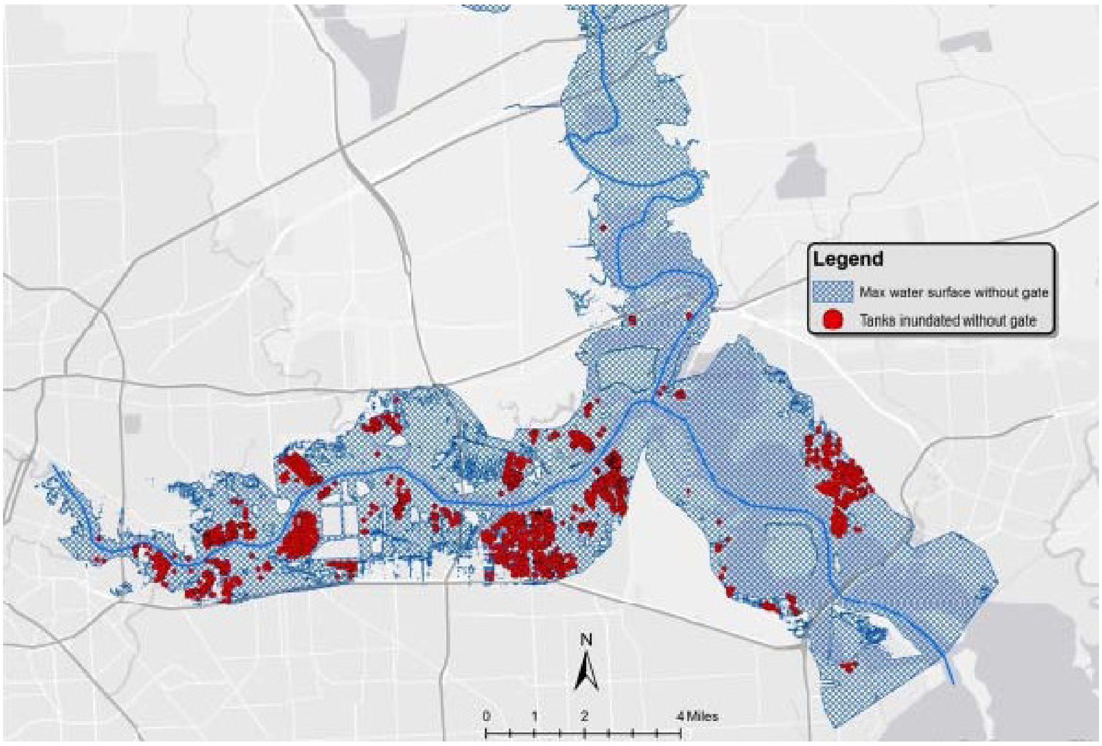

Figure 9. Projection of oil and hazardous substance tanks in the Houston area likely to be flooded by a 25-foot storm surge in the absence of a proposed coastal protection system. The Houston Ship Channel runs roughly west from Galveston Bay in the lower right. Source: Blackburn and Bedient (2018, p. 35).

for the vast wind farms on the Texas plains that in turn had made the state home of over a quarter of US wind energy capacity. Yet Corpus Christi's move into wind energy illustrates the tentative nature so far of any shift away from fossil fuels. Corpus Christi's investments in renewables amounted to a fraction of the billions invested in the Corpus Christi region to support South Texas's Eagle Ford shale oil field and to process and ship that field's output (Figure 10).

Likewise, despite a major expansion into container traffic, the Port of Houston still in the main meant oil and gas. By 2020 Houston handled 69 percent of container traffic along the US Gulf Coast. Yet 69 percent of Houston's cargo still consisted of liquid bulk, that is to say, oil and petrochemicals (Medlock, 2021, p. 3; Port Houston, 2020, pp. 7–9). Though usually outranked by Houston and Corpus Christi in terms of tonnage handled, Beaumont did manage to develop an identity apart from oil and gas, through its function as the largest cargo handling port for the US military.

Over the decades, for the most part, the energy sector's transitions and upheavals had tended to reinforce ties between Texas's ship channel network and the oil and gas industry. As the original Texas oil fields waned after World War II, Texas ports reoriented themselves toward offshore and multinational operations. More than the Texas Medical Center or anything else, the energy sector accounted for Houston's status as a global city, with Houston firms active everywhere oil was found, from the Americas to the North Sea across the Middle East and to Southeast Asia. Likewise, the Organization of Petroleum Exporting Countries (OPEC) embargoes and oil price shocks of the 1970s, functioned—counterintuitively, as Houston urbanist Joe Feagin noted at the time—to distract from the 1960s trend toward diversification that aerospace and biomedicine represented. The OPEC crisis encouraged Houston energy firms toward large new investment in "exploration, drilling, and machinery," employment in all of which increased in the 1970s (Feagin, 1985, p. 1220).

The most memorable crisis that illuminated the persistent hold that oil and gas exerted on Texas ports was the oil bust of the 1980s. The 1973 OPEC embargo caused prices to inflate from under $4/barrel to nearly $32/barrel early in the next decade. Then the recession of the early 1980s started a downward cycle that ended at around $12.50 in 1986. Bankruptcies spread through the energy sector, which had spent a decade investing based on continued high prices. From there, the crisis spread to banking, real estate, and other sectors of the regional economy. Houston unemployment peaked at around nine percent in 1987, when the energy sector began a slow recovery (Livingston, 2020).

Corpus Christi's unemployment peaked at 11.6 percent. That city's port authority responded with efforts to enter the tourist-and-convention sector that had thrived along the South Texas coast since the late 1800s. The port also established a foreign trade zone in an unsuccessful attempt to use tariff advantages to diversify manufacturing. It built a cold-storage warehouse in the hope

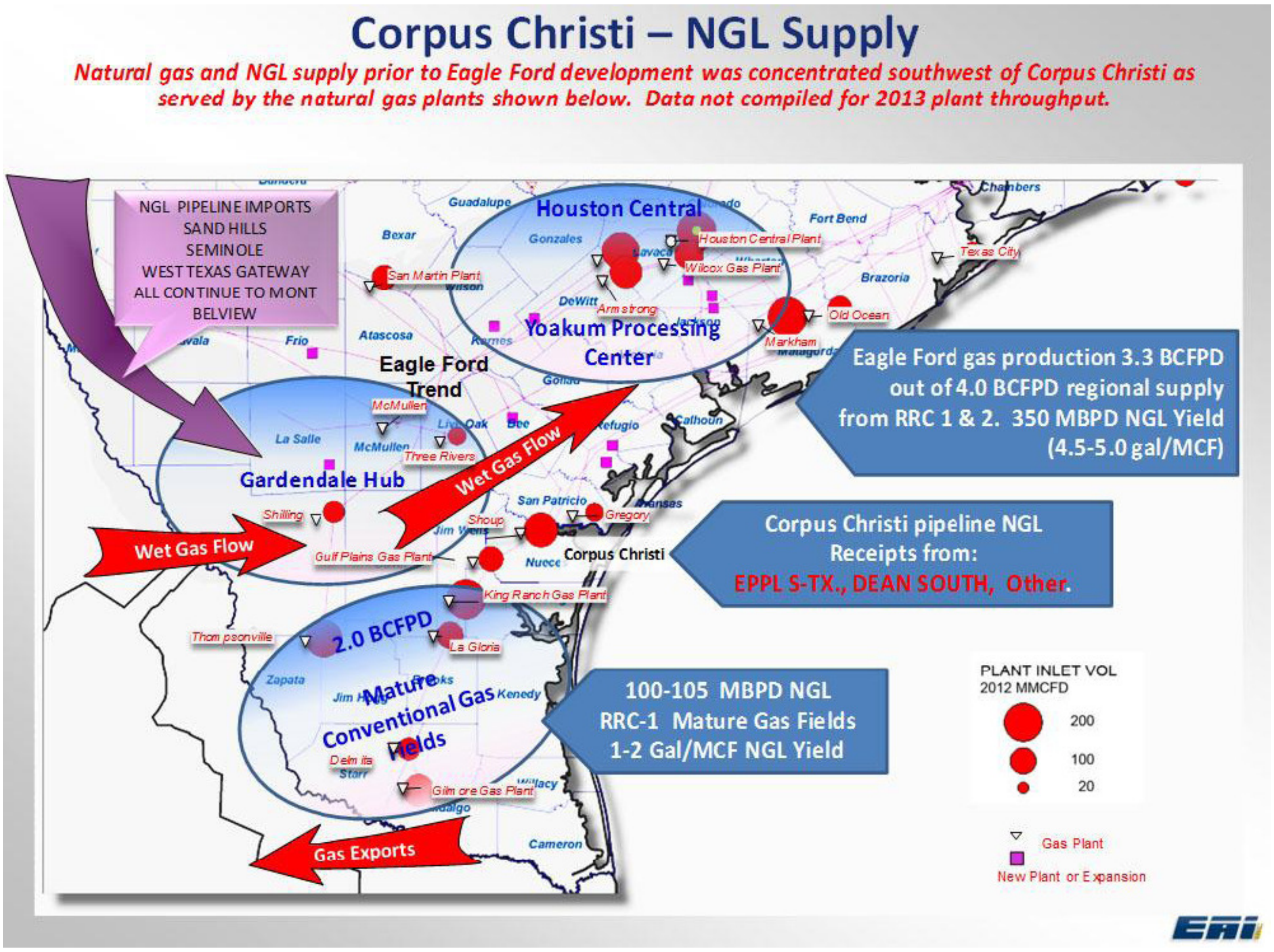

Figure 10. Accelerated production in the 2010s at the Eagle Ford shale oil field northwest of Corpus Christi—along with similar fields elsewhere in the state—spurred investment in facilities for handling natural gas and liquified natural gas (NGL) there and at other Texas ports. Source: Port of Corpus Christi Authority (2013, p. ES-13).

of attracting agricultural imports from Mexico under the NAFTA agreement. Yet the main reshuffling at Corpus Christi following the 1980s price collapse was within the oil and gas sector itself. Through the 1960s, the South Texas energy sector had mixed locally owned firms with branch operations of corporations headquartered elsewhere. By the 1990s, Corpus Christi—consistently ranked as one of the country's largest ports, often in the top five—basically functioned as a secondary or satellite center for national and multinational corporations. Through the 1980s crisis and then into the twenty-first century, petroleum and related activities accounted for around 70–80 percent of cargo tonnage at Corpus Christi. Most of this production and traffic was now managed from Houston, San Antonio, or Wichita, whose Koch Industries gained a major presence in Corpus Christi refining during these years. The 1980s crisis accelerated the decline of Corpus Christi's independent operators in exploration, drilling, pipelines, equipment, and geological services, all of which remained sluggish until the Eagle Ford boom of the 2010s (Lessoff, 2015, pp. 254–271).

In the 2010s, Houston, Corpus Christi, and other Texas ports envisioned the widening of the Panama Canal as another opportunity to shift away from petroleum. In Corpus Christi, the possibility of serving as a gateway to the south amounted to an older vision overshadowed by the shift to petroleum, which had tied the South Texas port more firmly into North American business networks (Lessoff, 2015, pp. 260–266). The price turmoil that accompanied the 2020 coronavirus pandemic briefly invigorated these sorts of arguments and ideas for finding new directions. But similar to earlier episodes, the price spike that followed the 2022 Russian invasion of Ukraine quelled such discussions.

The research group that put together this thematic issue has documented path dependence in port city regions and the consequent difficulties ports can have adapting to new circumstances (Hein & Schubert, 2021). The Texas Gulf Coast may stand as a strong instance of this pattern. Despite its pre-oil origins, Texas's port city region coalesced in a way that bound it deeply and broadly to oil and gas. A post-oil future now implies a level of deindustrialization and related disruption to the regional political economy that neither Texas nor the United States is prepared to manage. Little wonder, then, that civic and business interests in Texas's oil port cities—

and the residents of this region more generally—have to date responded unenthusiastically to arguments for removing oil from their water.

Acknowledgments

The author thanks Professor Carola Hein for helping to arrange the Nederlandse Organizatie voor Wetenschappelijk Onderzoek (NWO) grant that supported this research and for welcoming him as a visiting researcher at the TU-Delft through the coronavirus pandemic and beyond. The author also thanks Professor Stephen Ramos and the journal's anonymous peer reviewers for thoughtful and thorough comments on earlier drafts.

Conflict of Interests

The author declares no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 346–362
https://doi.org/10.17645/up.v8i3.6832

Article

How the Depths of the Danish Straits Shape Gdańsk's Port and City Spatial Development

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Submitted: 13 February 2023 | Accepted: 7 June 2023 | Published: 26 September 2023

Abstract

The depths of the Danish Straits limit the drafts of ships entering the Baltic Sea. The largest ships calling the Baltic in a laden condition are called Baltimax. The article presents how the dredging works carried out in the Danish Straits in the 1970s enabled the development of the Port of Gdańsk and consequently also influenced the city, being a residential base for employees of the new port and shipyards. The analysed case proves that, for port cities, overcoming a distant navigational bottleneck by dredging the existing passage or constructing a new channel might lead to a significant change in their development. The article also raises a question on the current development opportunities of the Port of Gdańsk, which is again increasingly limited by the depths of the Danish Straits, as large tankers and bulk carriers have already been entering Gdańsk not fully loaded for some time, and recently the largest container ships also reached the maximum permissible drafts.

Keywords

Danish Straits; development thresholds; port economic growth; port industry; port infrastructure; Port of Gdańsk

Issue

This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

The aim of the article is to show the relationship between the limitations caused by the depth of the Danish Straits and the Kiel Canal and the spatial development of the Port of Gdańsk. The article shows how the dredging works carried out in the Danish Straits in the 1970s enabled the development of the Port of Gdańsk and consequently also influenced the city. The work also presents an inverse relationship, which is taking place today, where the increase in the size of container ships calls into question the possibility of servicing ocean-going ships in the Baltic ports, limited by the depths of the Danish Straits.

The Port of Gdańsk is located in Poland on the southern coast of the Baltic Sea. The Port and the City of Gdańsk have been developing by interacting with each other for about 1,000 years already (Breś & Krośnicka, 2021). The spatial structure of the port currently consists of four areas (Figure 1b): the Old Port in the historic centre of Gdańsk, which is no longer in use; the Inner Port, stretching along the Dead Vistula River, capable of receiving conventional ships with a draft of up to 10.6 m (Gdańsk Harbour Master's Office, 2023); the still developing deep-water North Port, capable of handling ships with drafts up to 15.0 m; and the Central Port, which is in the pre-design phase. The handling capacity of the Inner Port is currently 13.7 million tonnes of cargo annually, while the North Port is 65.5 million tonnes annually (Port Gdańsk, 2023).

For the purpose of analysing the changes in planning decisions and their effects on the shape of the Port of Gdańsk, the authors traced the archival navigational charts of the Hydrographic Office of the Navy from the years 1967, 1974, 1996, and 2018 with subsequent corrections. They also studied archival materials from the times of the creation of the North Port and its development, which at that time were not available for public use (Andruszkiewicz, 1976; Central Board of Polish Sea Ports, 1974; Society of Polish Town Planners, 1977). The authors also reviewed archival professional journals from the researched period (Gruszkowski & Holc, 1963; Kochanowski, 1963). As a next step, the authors analysed selected plans for the development of the City of Gdańsk: historical (Stankiewicz & Szermer, 1959) and contemporary (Gdańsk Development Office, 2023; Gdynia Maritime Office, 2023) and statistical data from the years 1945–2020 (Białecki, 2011; Gaworecki, 1976; Główny Urząd Statystyczny, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1978, 1983a, 1996, 2000, 2004, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022) in terms of the impact the decision to build the North Port had on the city structure. The contemporary bathymetric situation in the Danish Straits and the Kiel Canal has been described mainly on the basis of navigational charts and sailing directions (Danish Geodata Agency, 2023; DanPilot, 2023; National Geospatial-Intelligence Agency, 2022).

2. Sea Access to the Port of Gdańsk: The Danish Straits and the Kiel Canal

The Baltic Sea is almost a closed water area, which is naturally connected to the Atlantic Ocean only by the Danish Straits. Thus, each ship entering Baltic ports until 1895, when the Kiel Canal was built, had to pass through one of the Danish Straits, being currently a part of Danish territorial waters, shared partially with Germany (Fehrman Belt) and Sweden (Øresund). There are two basic water routes via the Danish Straits (The Danish Maritime Authority, 2022, p. 37). Smaller ships, with a draught up to 7.7 m, might pass through the shorter route via Øresund—The distance between Skagen and Bornholm along this route is 252 nautical miles (DanPilot, 2023). The route for the biggest ships entering the Baltic Sea, with a draught up to 15.0 m, leads through the Great Belt (Storebælt) and Fehmarn Belt (Figure 1a). The total length of this passage from Skagen to Bornholm Island (so-called Route T) is 377 nautical miles. Currently, the drafts of vessels entering the Baltic Sea are limited by the shallowest sections of the T Route, leading through the Great Belt, which is about 17.0 m deep (The Danish Maritime Authority, 2022, p. 37). Moreover, the depth of the Danish Straits sometimes decreases significantly due to sand accumulation or a temporary low sea level caused by the negative stow (Nissen, 1991). Therefore, the recommended under-keel clearance is around 2.0 m (PIANC, 2014).

The water connections via the Danish Straits were and still are extremely strategic for the functioning of all the Baltic ports. Since 1429, Denmark has controlled the movement of vessels and cargo, when the King of Denmark—Eric of Pomerania—established the Sound Tolls (Carneiro & Nilsson, 2013). The dues played an important political role in limiting the development of particular port cities while allowing the others to grow (Froese, 2007). The semi-closed character of the Baltic Sea and lack of the right of free passage made the Baltic Sea *mare clausum* (International Court of Justice, 1991, pp. 16–18; Theutenberg, 1984). After the rejection of the idea of *dominium maris Baltici* and the abolition of the Sound Tolls, the straits became open to international commercial shipping in 1857, pursuant to the provisions of the Copenhagen Convention (Elferink, 2000, pp. 555–566; Law of the Sea Institute, 1983, p. 600).

In the years 1887–1895, the German Empire built an artificial channel across the Jutland Peninsula in order to shorten the way and avoid passing through

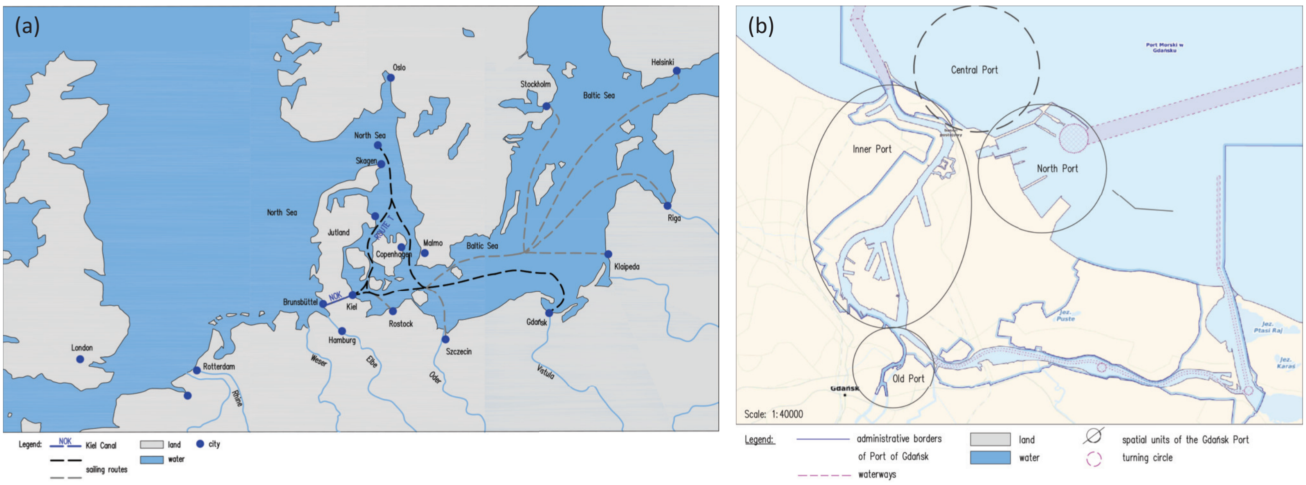

Figure 1. Location and structure of the Port of Gdańsk: (a) Access to the Port of Gdańsk by sea routes and (b) spatial structure of today's Port of Gdańsk. Source: Authors' work based on Spatial Information System of the Polish Maritime Administration (2023); Wasserstraßen- und Schifffahrtsverwaltung des Bundes (2023).

Danish waters in case of war. The Kiel Canal (in German, Nord-Ostsee Kanal) opened the new connection between the North Sea and the Baltic Sea (in German, Ostsee) and shortened the route by about 250 nautical miles (about 463 km) in comparison to the route via the Danish Straits (Wasserstraßen- und Schifffahrtsverwaltung des Bundes, 2023). In the years 1907–1914, the Kiel Canal was for the first time widened and deepened to 11.0 m. A further expansion of the canal began in 1965 and was carried out step-by-step until 2002. In 2010, a building permit was issued for the construction of a fifth canal chamber, enabling the deepening of it to 14.0 m. The construction works are expected to be finished by the year 2026 (Wasserstraßen- und Schifffahrtsverwaltung des Bundes, 2023). Currently, the maximum length (L) of ships passing through the Kiel Canal is 235.0 m, the maximum beam (B) is 32.5 m, and the draught (T) is up to 7.0 m. However, ships with a length of up to 160.0 m can have a draught of up to 9.5 m. The clearance under the bridges crossing the canal is 42.0 m (UCA, 2023).

Although the time of passage from the North Sea to the Baltic was shortened by the construction of the Kiel Canal, the Danish Straits were and still are deeper, even after the current modernisation works of the Kiel Canal. Therefore, from about 1960, when the drafts of ships increased significantly above 7.0 m, more and more of them started to use the Danish Straits again. This has slowly led to decreasing the economic importance of the Kiel Canal. Soon after, in early 1970, along with the further growth of ships' parameters, the Great Belt, which accepts maximum drafts of 13.0 m, became a bottleneck for many vessels entering the Baltic (International Court of Justice, 1991, p. 14).

The most problematic areas of the passage via the Great Belt were the vicinity of Gedser (The Danish Maritime Authority, 2014, p. 4) and today's Storebælt bridge (Braestrup, 2016). In the year 1975, as a consequence of a long international discussion, the shallows in between Gedser and the Darss Peninsula were dredged down to 17.0 m, and the Danish government opened an international waterway under the Storebælt: Route T (International Court of Justice, 1991, p. 12). At that time, this triggered entirely new development opportunities for the Baltic countries and ports, including Gdańsk.

3. Designing the North Port in Gdańsk

Until the 1960s, the core of the Polish merchant fleet consisted of ships with a carrying capacity of up to 10,000 deadweight tonnage (DWT; Andruszkiewicz, 1976, p. 5). Also, ships entering the Inner Port of Gdańsk were relatively small, having on average only 3,171 DWT in 1960 and 3,254 DWT in 1965 (Główny Urząd Satystyczny, 1969, p. 80). The sizes of the two largest ships that were called at Gdańsk in 1965 were in the range of 20,000–30,000 DWT (Główny Urząd Satystyczny, 1969, p. 85). During this period, the first ships of the Aframax (1954) and Suezmax (1956) classes appeared in the world, followed by the very large crude carriers (VLCC) in 1966 and ultra large crude carriers (ULCC) in 1968. To survive, the Port of Gdańsk had to start adapting to this technological change, as ships over 30,000 DWT started to call in the year 1966 (three ships in 1966, nine ships in 1967, and 40 ships in 1968). Still, the development thresholds were the depths of the Vistula River, Kiel Canal, and the Danish Straits.

Initially, around 1960, the entrance to the Port of Gdańsk, as well as a fragment of the port fairway in the mouth section of the Dead Vistula, were widened and deepened to 11.5 m (Andruszkiewicz, 1976, p. 4). Later, however, the expansion of the port with new water basins began to be considered. The original designs, resulting from the need to increase the port's capacity, were based on engineering ideas originating from the interwar period and the situation where numerous mooring berths were needed for vessels with a carrying capacity of about 10,000 ÷ 30,000 DWT, which were typical at that time. These solutions referred to the concept of a basin-pier layout and the river character of the Port of Gdańsk. These designs assumed digging a new canal across the bend of the Dead Vistula and using the existing narrow entrance to the port (Figure 2a) or building a channel connecting the Dead Vistula directly with the sea (Figure 2b). The berths along the new canal would increase the transhipment potential of the Port of Gdańsk to about 20–30 million tonnes per year (Andruszkiewicz, 1976, p. 9).

The window of further development opportunities for the Port of Gdańsk opened with the process of preparations for the dredging of the Danish Straits. At that time, Poland had started to consider building a deep-water port. The chosen location was Gdańsk, as having both a convenient bathymetric situation and demographic potential. In 1973, Poland ordered a fleet of modern Baltimax tankers, the parameters of which were defined by Route T opened in 1975. They were three tankers with a capacity of over 145,000 t (L = 293.0 m, B = 48.1 m, T = 15.3 m) and three tankers with a capacity of 137,000 t (L = 284.0 m, B = 43.4 m, T = 15.2 m). In addition, for the redistribution of fuels to the shallower Baltic ports and the delivery of cargo to the Inner Port in Gdańsk, three much smaller feeder tankers (L = 170.7 m, B = 25.9 m, T = 11.1 m) with a deadweight of 31,000 DWT were ordered (InteriaHistoria, 2014). These ships entered service at the beginning of 1975.

The preparatory works related to building the deep-water port in Gdańsk were formalised in 1968 (Szwankowska, 2018, p. 58). The designs of the Gdańsk port development created after 1968 were mostly a radical innovation compared to the previous proposals. Taking into account accessibility for the Baltimax ships, the location of a new port was proposed directly on the open seashore (Figures 2c and 2d). The design selected for implementation (Figure 2d) best responded to the growing turnover of the port (Table 1) and the

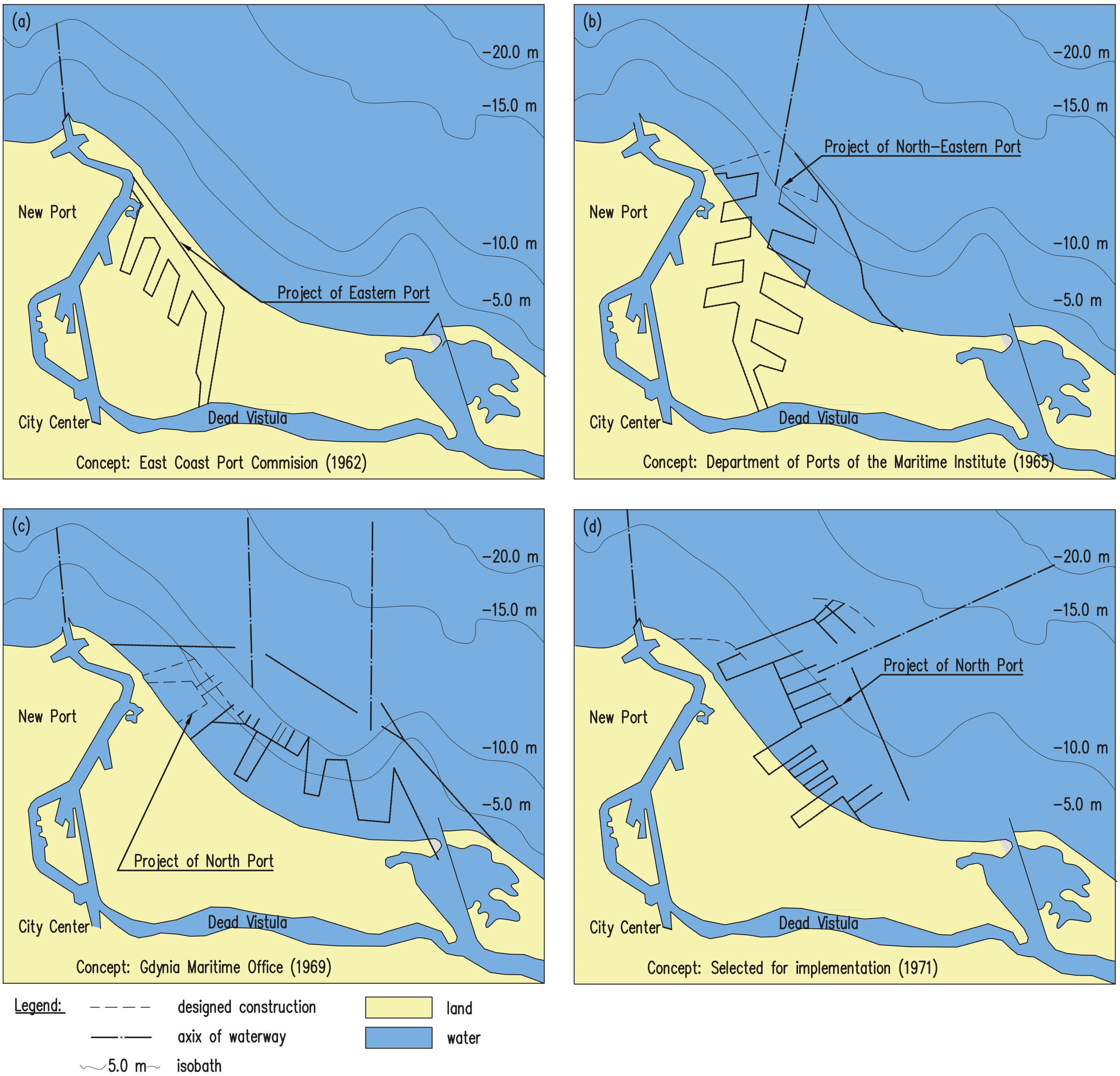

Figure 2. Port of Gdańsk development concepts: (a) Concept of Eastern Coast Port Commission (1962), (b) concept of Gdynia Maritime Office (1965), (c) concept of Department of Ports of the Maritime Institute (1969), and (d) concept selected for implementation (1971). Source: Authors' work based on Białecki (2011).

local hydrological conditions and was characterised by a more favourable soil-water balance (it required the displacement of smaller earth masses both during dredging works and landfilling of the water area). The design of the North Port also covered the access from the waterside. The planned port demanded a new approaching channel via the Gdańsk Gulf and new vast anchorage areas, both with depths responding to the needs of the Baltimax ships.

4. Building the North Port in Gdańsk

The construction of the North Port was planned to be divided into three stages. The first stage of the development of the North Port included the construction of coal, crude oil, and ore terminals (Figure 3). For this reason, this complex of terminals (then referred to as the transhipment depots) was initially called the Bulk Transhipment Area (in Polish, Rejon Przeładunków Towarów Masowych). Its construction began in 1970 (Andruszkiewicz, 1976, p. 17). The second stage of the construction of the North Port assumed the construction of a repair and a production shipyard to the east of the Bulk Transhipment Area. The next stage assumed the use of the land reserve located to the east of both shipyards for the development of the port's future cargo handling functions. Initially, the project assumed that it would be an area for the transhipment of crude oil products

Table 1. Turnover of the Port of Gdańsk divided into the turnover of the Inner Port and the Northern Port, and the gross handling time in the years 1945–2020.

Year	Total Gdańsk Port turnover (1,000 tons/year)	Gdańsk Inner Port turnover (1,000 tons/year)	Gdańsk North Port turnover (1,000 tons/year)	Gross handling time of 1,000 tons of cargo in Polish ports (hours/1,000 tons of cargo)		
				Average	Coal handling	General cargo handling
1945	354	354	n.a.	n.d.	n.d.	n.d.
1950	4,819	4,819	n.a.	n.d.	n.d.	n.d.
1955	5,244	5,244	n.a.	19.84*	13.5*	33*
1960	5,914	5,914	n.a.	22.5* (20.7)	15.5* (13.7)	42.1* (43.3)
1965	6,318	6,318	n.a.	18.1	10.5	35.4
1970	10,199.5	10,199.5	n.a.	16.8	8.1	41.2
1971	10,047	10,047	n.a.	15.5	6.9	39.8
1972	11,404	11,404	n.a.	14.6	6	36.8
1973	12,778	12,778	n.a.	14.8	5.6	41.4
1974	**15,892.1**	**14,018.9**	**1,873.2**	13.6	5.1	47.6
1975	18,558.1	11,255.4	7,302.7	**12.2**	**3.6**	**44.4**
1976	22,940.3	11,947.7	10,965.6	12.2	3.3	46.2
1977	25,153.4	**12,204.9**	**12,948.5**	11.3	3.6	42.5
1978	28,247.7	13,033.3	15,214.4	11	3.1	41.3
1979	27,008	12,305.8	14,702.2	11	3.4	46.1
1980	23,005.6	11,261	11,744.6	10.6	3.3	44.3
1981	12,375.4	8,872.3	3,503.1	12	2.3	44
1982	13,178.8	7,651	5,527.8	11.1	2.7	42.7
1983	17,972.8	7,737.8	10,235	6.6*	1.8*	57.8*
1984	21,333.4	8,926	12,407.4	n.d.	n.d.	n.d.
1985	17,830.1	8,349.1	9,481	n.d.	n.d.	n.d.
1990	18,283.6	7,760.7	10,522.9	n.d.	3.97*	34.2*
1995	18,261.8	**6,048.1**	**12,213.7**	n.d.	n.d.	n.d.
2000	16,080.6	5,210.1	10,870.5	n.d.	n.d.	n.d.
2005	23,341.4	5,875.1	17,484.3	n.d.	n.d.	n.d.
2010	27,182.1	6,513.7	20,668.4	n.d.	n.d.	n.d.
2015	31,684.9	n.d.	n.d.	n.d.	n.d.	n.d.
2020	40,574.7	n.d.	n.d.	n.d.	n.d.	n.d.

Notes: In the years marked with an asterisk (*), the statistical yearbooks specify data for the Gdańsk Port Authority only together with the other Polish Ports Authority; n.a.—not applicable; n.d.—no data available. Source: Authors' work based on Główny Urząd Statystyczny (1969, 1970, 1971, 1972, 1973, 1974, 1975, 1978, 1983a, 1996, 2000, 2004, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022).

(Figure 3). The last two stages of the construction of the North Port were not implemented in the form described by the project.

As the first investment while building the Bulk Transhipment Area (the first stage of the construction of the North Port), the coal handling and storage base was opened in 1974. Its storage yards had a capacity of 600,000 t and a daily efficiency of 50,000 t. The depot was equipped with modern railway infrastructure, including a wagon tippler (Andruszkiewicz, 1976, p. 19; Podgórski, 1997, p. 82). It was equipped with one mooring berth with a depth of 16.5 m (Andruszkiewicz, 1976, p. 26). Equipping the pier with highly efficient loading devices and belt conveyors with a capacity of 1,800 t/h meant that the time of handling and transport of coal in the terminal was significantly shortened compared to the service time in the inner port, where the stations were operated with grapple cranes with a capacity of 700 t/h (Table 1).

In 1975, a crude oil terminal was launched. It was connected by pipelines with the newly built refinery in Gdańsk (located south of the Dead Vistula, east of the city centre of Gdańsk), the refinery oil base (located on Stogi Island), and the "Friendship" Pipeline, running through Russia, Belarus, Poland, and Eastern Germany (Andruszkiewicz, 1976, pp. 19–20; Piskozub, 1986, p. 190).

Another reloading pier was dedicated to serving the ore terminal. It was 600 m long and 16.5 m deep at the mooring. The ore terminal was designed on an area of 40 ha, of which about 14 ha was newly refilled land (Piskozub, 1986, p. 227) and planned for serving five

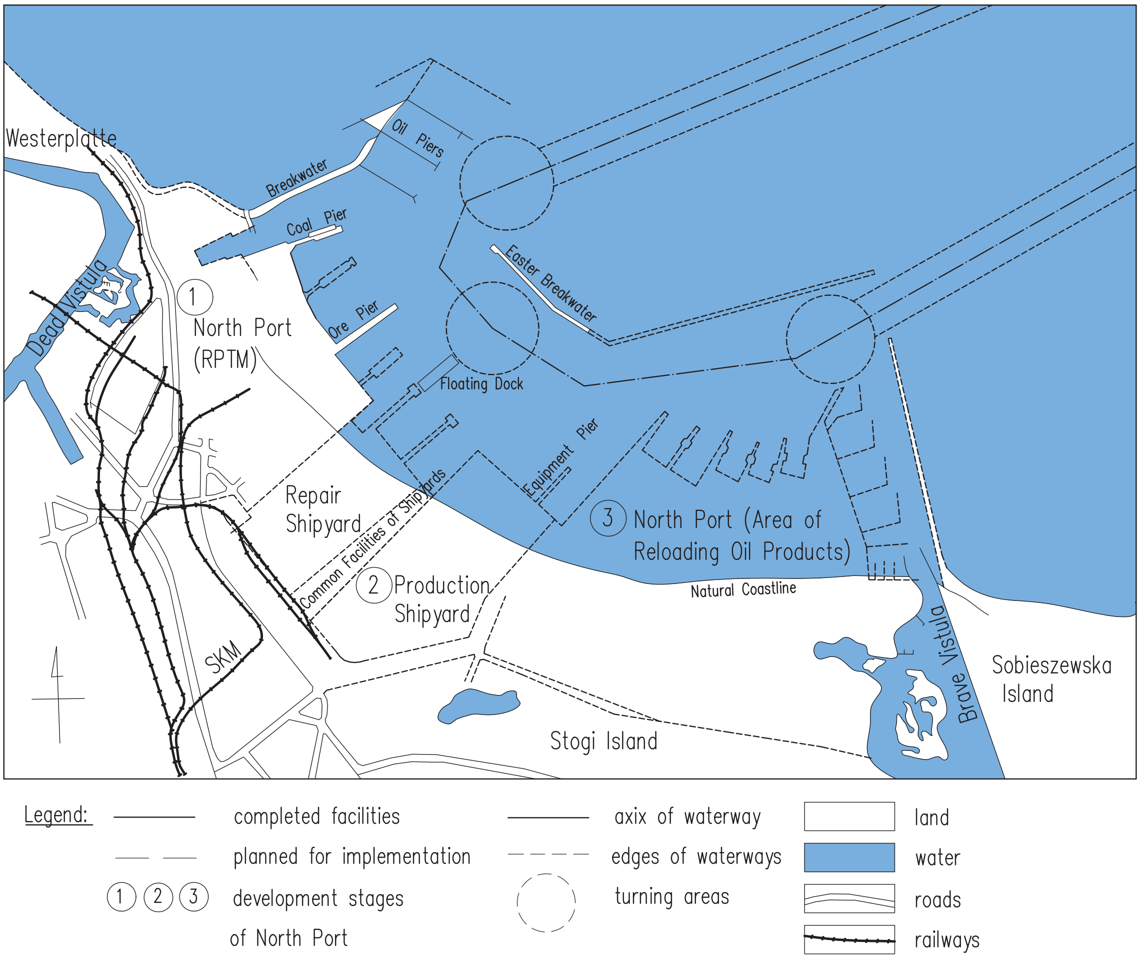

Figure 3. Functional structure of the North Port: The agreed division of land. Notes: The existing parts are marked with a solid line; RPTM indicates the Bulk Transhipment Area; SKM stands for fast commuters railway line (in Polish, Szybka Kolej Miejska). Source: Authors' work based on Society of Polish Town Planners (1977, p. 31).

million tonnes per year (Białecki, 2011, p. 171). The terminal was served its first ship in 1979 (Białecki, 2011, p. 171), but, in 1981, as a result of the declaration of martial law in Poland, the construction of the pier was stopped with the project implementation at the level of about 50%.

The concept of the North Port assumed, in a second stage, the construction of two shipyards: one for production and one for repairs (Białecki, 1977, p. 11) and industry related to the work of these shipyards (Figure 3). The repair shipyard, requiring a long mooring line, was to cover an area of 100 ha, and the production shipyard was 150 ha (Szymański, 1977, p. 27). Both shipyards were to produce and repair Baltimax and Panamax vessels (Szymański, 1977, p. 31). Due to the fuel crises of 1973 and 1979–1982 and the period of political transformation of the Polish state in 1989–1991, the shipyards were not built. Shipbuilding activity is still concentrated in Gdańsk in the Inner Port on the Dead Vistula.

Changing the structure of the Port of Gdańsk from having a fragmented spatial mosaic and served by conventional methods in the Inner Port to covering large areas in the deep-water North Port required a change in the way of thinking about transport links. The design of the North Port assumed connecting Stogi Island from the south with railway and road bridges. However, at that time, a tunnel connection between Stogi Island and the western bank of the Dead Vistula was already planned (Society of Polish Town Planners, 1977, pp. 11, 28). A new railway freight station, Gdańsk North Port, was also built in the central part of Stogi Island for cargo handling of the port. An SKM commuter railway line was also planned to transport employees from other districts of the city to the port (Figure 3). Communication of the North Port project was developed simultaneously with the Development Plan of the Stogi Island and was correlated with the Plan of the Communication System of the Gdańsk Agglomeration and the Development Plan of the Gdańsk Urban Area (Society of Polish Town Planners, 1977, p. 28).

Although the vision of development of the North Port was not fully realised then, after its launch, Gdańsk joined the small group of about 10 European ports that could accommodate ships with a draft of up to 15.0 m (Society of Polish Town Planners, 1977, p. 18). According to the concept, after only the first stage of development, the North Port was planned to enable transshipments at the level of 70–100 million tonnes per year (Central Board of Polish Sea Ports, 1974, p. 6) and even up to 200 million tonnes per year after further stages of development (Andruszkiewicz, 1976, p. 9). Hence, the handling capacity of the first phase of the North Port was already at least three times more than the capacity provided by the concepts of the Eastern Port from 1962 and 1965 (Figure 2). Moreover, most of the assumptions of the first phase of the plan (except building the commuter railway line) were fulfilled up to the year 2012.

Gradually, the Inner Port, located on the Dead Vistula, lost its importance, and the North Port became increasingly significant in terms of cargo handling. In 1974, when the first coal base was launched, the North Port handled 1,873,000 t of cargo, while the Inner Port handled 14,019,000 t of cargo. As quickly as 1977, the North Port slightly exceeded the turnover of the Inner Port (Table 1).

5. Influence of the Construction of the North Port in Gdańsk City in the Years 1974–1989

Both the Port and the City of Gdańsk were completely destroyed during the Second World War (Tölle, 2008). Re-activation of the port and the process of rebuilding the basic housing substance lasted until 1955 and took place simultaneously with the re-population of the city. Created just after the Second World War, in 1947, the Development Plan for Gdańsk (GD Plan) provided for the nodal-strip development of the Tri-City agglomeration, where the hubs were the downtowns of Gdańsk, Gdynia, and Sopot (Stankiewicz & Szermer, 1959, p. 331). The crucial centres of development of this urban layout were the seaports of Gdańsk and Gdynia (Figure 4). The development of the Port of Gdańsk was at that time planned as the construction of a new port canal, i.e., the so-called

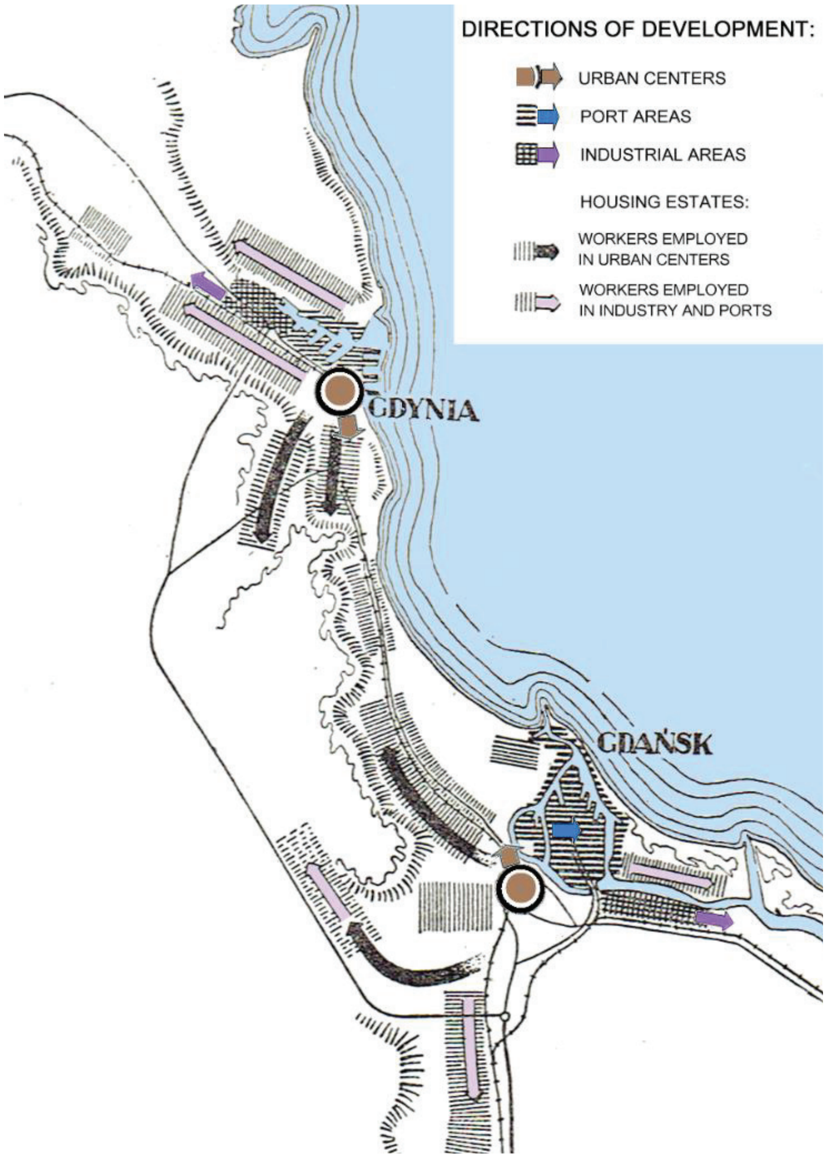

Figure 4. GD Plan for the development of the Tri-City agglomeration of Gdańsk, Gdynia, and Sopot from the year 1947 with new housing estates introduced to the plan after its revision in 1962. Source: Authors' work based on Stankiewicz and Szermer (1959, p. 331).

"Eastern Port" (Figure 2a). In accordance with the modernist principle of separation of functions, the authors of the plan assumed the development of an industrial and port district along the Dead Vistula (industrial district "East"). In parallel, they proposed bands of residential development dedicated to workers employed both in industry and the Port of Gdańsk (Figure 4).

In the years 1956–1981, of a centrally planned economy, due to intensive industrialisation and one of the highest birth rates in Europe taking place, Poland experienced massive urbanisation. The population growth in Poland in this period was so rapid that the cities experienced constant shortages of housing and urban infrastructure (Parysek, 2006). Therefore, the GD Plan was revised in 1962 (Szermer, 1977, p. 63) in order to enlarge the housing capacity of the quickly growing city (Table 2). The plan introduced new housing estates along the seashore, easily accessible in terms of daily commuting due to the vicinity of railway infrastructure (Figure 4). As stated by Kochanowski (1963, p. 455) and Gruszkowski and Holc (1963, p. 453), the needs of the maritime economy were one of the two main causes (apart from war damage) of the housing crisis in the 1960s in the urban area of Gdańsk. To support the housing needs of employees, the national companies established their own housing funds and sometimes were even opening their own housing associations. In Gdańsk, based on a maritime economy, such large companies as shipyards and the port authority played a significant role in developing new housing districts (Table 2). Often, the construction of housing estates in Gdańsk was carried out with funds obtained through loan agreements concluded with enterprises holding housing funds, e.g., with the Gdańsk Shipyard (Kochanowski, 1963, p. 455) or Port of Gdańsk Authority.

Intensive development of the maritime economy based on the development of shipyards existing in the Inner Port, refinery and the North Port (Figure 5), as well as industry based on their activities and banded in technological chains (Aftanas et al., 1974), required an appropriate population potential and intellectual capital. In parallel to employing local residents in the newly

Table 2. Number of inhabitants of Gdańsk city in the years 1945–2020, employment in the Gdańsk Port Authority, and the corporate housing fund of the Port of Gdańsk Authority in the years 1960–1975.

Year	Number of inhabitants in Gdańsk (thousands of persons)	Employment in the Gdańsk Port Authority (persons)	Corporate housing fund of the Port of Gdańsk Authority—Expenditure on financing cooperative and company housing construction (thousands of PLN)
1945	139.09	*	n.a.
1950	172.7	*	n.a.
1955	242.9	4,431	n.a.
1960	286.9	4,554	6,002
1965	321.3	5,776	1,356
1966			1,497
1967			1,561
1968			2,424
1969			2,500
1970	365.6	5,946	3,581
1971			773
1972			**19,133**
1973			0
1974			109
1975	414.2	n.d.	154
1980	456.7	6,947	*
1985	468.6	6,338	*
1990	**465.1**	5,050	n.a.
1995	463	*	n.a.
2000	456.6	*	n.a.
2005	458.05	*	n.a.
2010	460.5	*	n.a.
2015	461.79	*	n.a.
2020	471.52	*	n.a.

Notes: In the years marked with an asterisk (*), the statistical yearbooks specify data for the Gdańsk Port Authority only together with the other Polish Ports Authority; n.a.—not applicable; n.d.—no data available. Source: Authors' work based on Główny Urząd Statystyczny (1969, 1970, 1971, 1972, 1973, 1974, 1975, 1978, 1983b, 1996, 2000, 2004, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022).

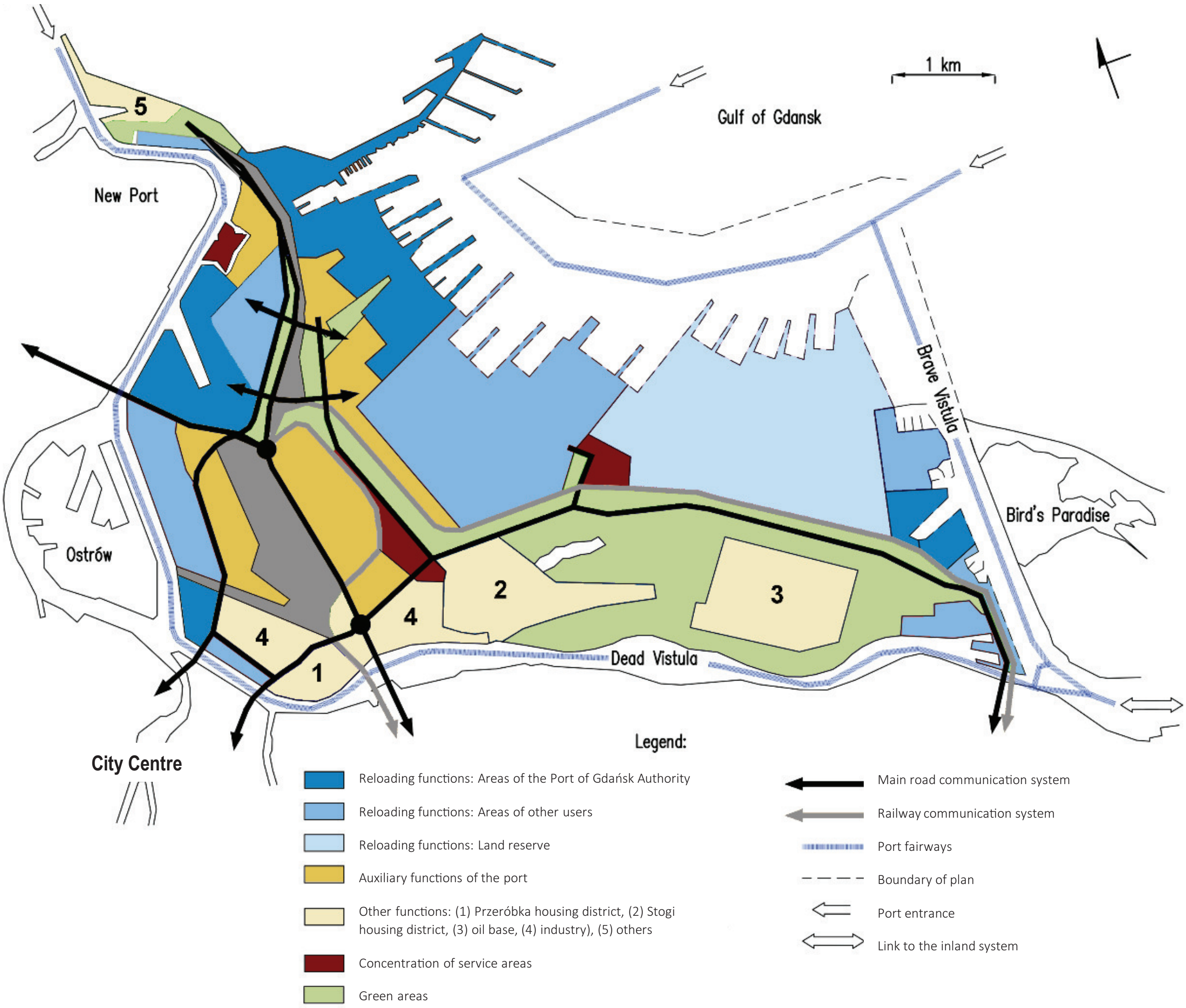

Figure 5. Planned functional and spatial structure of the North Port and the port-industrial district developed by the Spatial Planning Bureau of the Gdynia Maritime Office and approved by the president of Gdańsk in 1978. Source: Authors' work based on Białecki (2011, p. 135).

planned maritime cluster, workers and specialists representing various industries from all over the country were brought to Gdańsk. In turn, along with the newly employed workers, their families came to the city and settled permanently, occupying indirect and induced jobs. According to Gaworecki (1976, p. 72), the number of people employed in the maritime economy in the years 1965–1973 in the urban area of Gdańsk accounted for more than 8% of the total population, with approximately 50% of the population being professionally inactive at that time. It was planned to employ about 25,000 people to service the North Port and the East Industrial District (Tubielewicz, 1977, p. 46). The increase in the housing needs of future employees of the Port of Gdańsk related to the construction of the Northern Port was planned to be satisfied by a significant increase in expenditure on the construction of new apartments in 1972 (Table 2). The development of maritime industries and transportation, including planning and construction of the North Port was therefore without a doubt one of the triggers for the rise of the Gdańsk population, which increased from 286,940 inhabitants in 1960 to 365,600 in 1970 and 456,707 in 1980 (Table 2).

Simultaneously with the plan of the port district, the Development Plan of Gdańsk Urban Area was released (Gruszkowski, 1977, p. 55). The plan continued the idea of the GD Plan from the year 1962 by building Gdańsk's new residential districts based on a fast commuter railway network called SKM (Gruszkowski, 1977, p. 58; Tarkowski et al., 2022). Soon, on the strip of coastal lowlands north of the centre of Gdańsk, large modernist housing estates began to gradually emerge (Młyniec in 1965, Małe Przymorze in 1965, Wielkie Przymorze in 1970, Zaspa in 1973–1975, and Żabianka in 1972–1975; Gruszkowski & Holc, 1963; Kochanowski, 1963; Rembarz, 2009). These mono-functional housing districts accommodated among other inhabitants the new employees of Gdańsk's industry with their families, including those servicing the North Port and the East Industrial District.

6. Developing the North Port After 1989

After the declaration of martial law in Poland in 1981, the process of industrial and housing development proceeded very irregularly until 1989. In the period 1981–1983, the Port of Gdańsk experienced a significant decrease in transshipments due to an embargo of Poland (Table 1). The fall of the socialist system in 1989 and the introduction of a free-market economy necessitated the restructuring of the country's economy. In the 1990s, the process of industrialisation stopped and, as a consequence, migration to the urban centres declined (Parysek, 2006). In Gdańsk, the biggest shipyard went bankrupt, causing sudden and large unemployment in the city and region. Big national companies (including those serving the maritime economy of the Port of Gdańsk) went through the process of privatisation by creating many smaller subsidiary companies. In many cases, this process led to companies closing down (Gomułka, 2016; Kolodko, 2009, 2011) or to the reorientation of companies' profiles towards small and medium private enterprises, as well as a large wave of economic emigration from Poland to Western Europe. The number of inhabitants of Gdańsk decreased (Table 2). The Act on Privatization of Port Enterprises of 1990 made it possible to commercialise the Port of Gdańsk (Szwankowska, 2018, p. 63) and separate the sphere of technical infrastructure from the sphere of operations.

After these deep economic and technological transformations took place in the Port of Gdańsk in the years 1994–1996, the Port of Gdańsk Authority SA in consultation with the Gdańsk Development Office of the City of Gdańsk initiated elaboration of the Masterplan of Gdańsk Port and Industrial Areas (Szwankowska, 2016). The masterplan reduced the area planned for the transhipment and storage function in relation to the original plan of the North Port—The maximum eastern border of the investment was now placed almost in the middle of the shoreline of Stogi Island (Figure 6). This shift was the result of a social discussion and took into account the recreational needs of the inhabitants of the Stogi housing estate and the protection of the city beach (Szwankowska, 2018, p. 65). The masterplan also

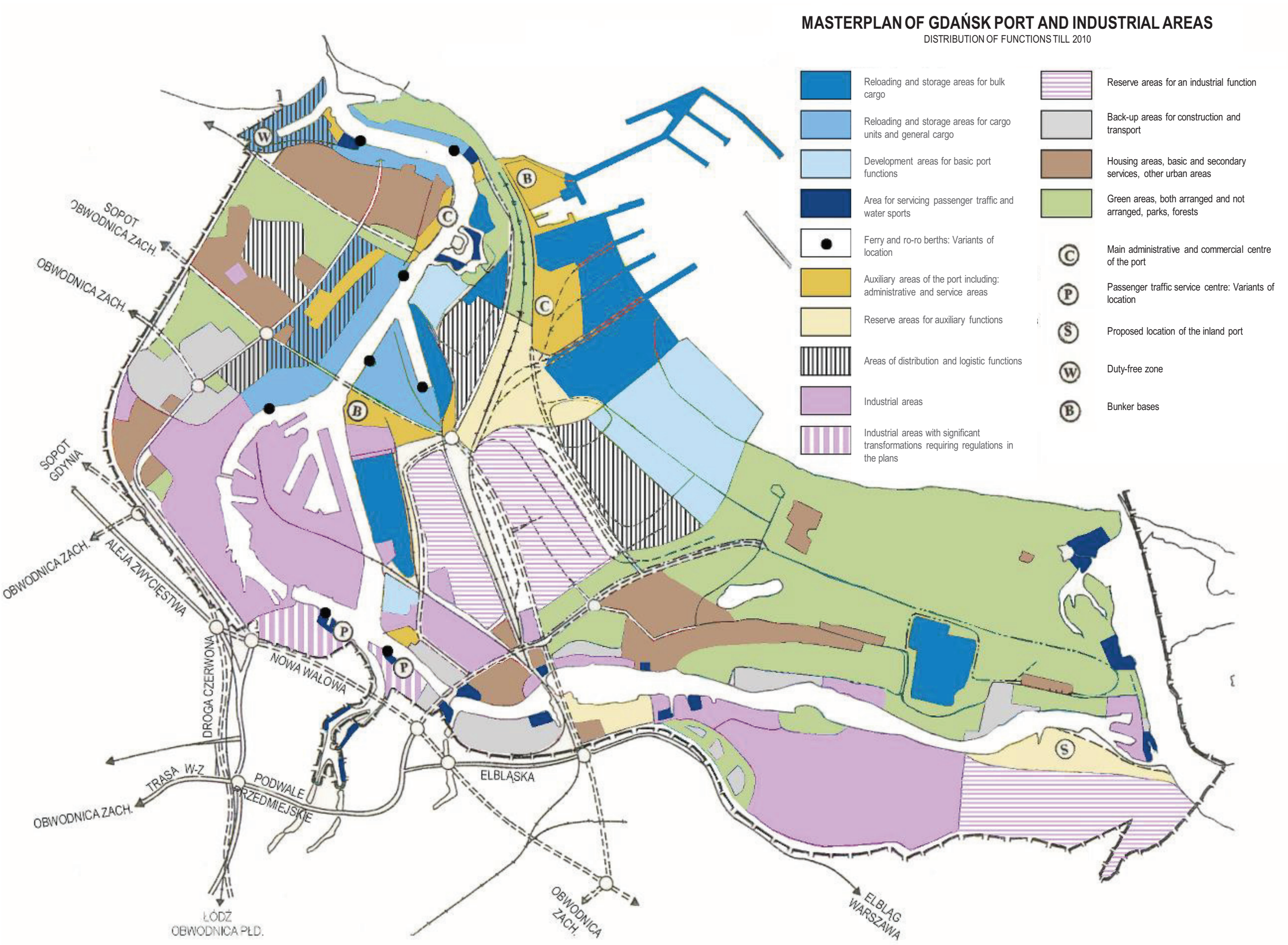

Figure 6. Masterplan of Gdańsk port and industrial areas (1996): Spatial distribution of functions until 2010. Source: Authors' work based on Szwankowska (2018, p. 66).

indicated the approximate locations of the future logistics functions and the container terminal (Kondratowicz, 2003; Szwankowska, 2018, p. 64).

In this period, the investments ending the first phase of the North Port development plan from 1968 were finally implemented. At the end of 1992, the next berth in the crude oil terminal in the North Port was commissioned, and in the following years, two additional ones (Podgórski, 1997, p. 87). In 1998, an LPG gas terminal was launched in the North Port between the coal and ore piers, serving gas tankers with a length of 280 m, a draft of 9.5 m, and a capacity of up to 20,000 DWT (Szwankowska, 2018, p. 64). Around 1995, the approach fairway to the North Port was widened and equipped with new communication and signalling systems (Szwankowska, 2018, p. 64). In 2001, the North Port was connected to the south across the Dead Vistula by a new road bridge and a modernised railway bridge. Therefore, also the transportation system planned in 1978 was almost finished (Szwankowska, 2018, p. 65).

In 2004, Poland joined the EU and, with the support of national and EU funds, the country rebuilt the basic infrastructure (Havel, 2022; Rachwał, 2011) enabling the activation and further development of enterprises. In 2002, a local spatial development plan was adopted by the City of Gdańsk for the area of the North Port. The plan took into account the possibility of building a deep-water container terminal (MATROS, 2001), in the area foreseen in the masterplan from the year 1996 as an extension of the North Port (Figure 6) and in the previous plan from 1968 as an area of two shipyards (Figure 2). Finally, in 2007, a wide pier (800 × 315 m) of a deep-water container terminal (DCT) was launched (Figure 1b). At that time, the DCT terminal had 650 m of mooring line and a depth of 16.5 m (Buca & Mitrosz, 2016). The area of the terminal was 44 ha (Szwankowska, 2018, p. 65). The DCT was built to increase the economic growth of its hinterland and transport connectivity of the Port of Gdańsk. However, without a decision on dredging the Danish Straits several decades before and building the deep-water North Port, the Port of Gdańsk would not be able to serve large ocean container ships and become a container hub, as the Inner Port was and still is able to serve only the feeder vessels. Currently, the terminal can handle ultra-large-container-ships-type container ships (caring more than 20,000 twenty foot equivalent unit). As a consequence of building the DCT, the Pomeranian Logistics Centre began construction in its vicinity in 2012. In 2016, a tunnel under the Dead Vistula joined the Stogi Island transportation system (along with the DCT and Pomeranian Logistics Centre) with Gdańsk from the west direction. In the years 2015–2016, due to the rapid increase in container turnover, another 650.0-m-long section of the quay was added to the DCT. The area of the terminal also increased by another 27 ha (Szwankowska, 2018, p. 65). Currently, the DCT has changed its name to Baltic Hub and is undergoing the next expansion phase, this time by reclaiming new water areas (Baltic Hub, 2023).

The development of the North Port and the collapse of the Gdańsk shipyard rendered the areas located on the west bank of the Dead Vistula obsolete. The development strategy of 2014 for the Port of Gdańsk until 2027 envisaged a gradual deepening of this process, and ultimately the release of the left-bank side of the river from port functions (Szwankowska, 2018, p. 68). A similar situation occurred in the post-shipyard areas (Lorens & Bugalski, 2021; Nyka & Szczepański, 2008; Szmytkowska, 2022), where new housing estates and cultural services have slowly appeared within the last 10 years. In the case of the Inner Port, this process was however stopped due to the deepening and modernisation of the Inner Port in the years 2016–2022.

The plan of the North Port assumed development to the east—In the most ambitious assumptions, it was to reach as far as the Brave Vistula and Sobieszewska Island (Andruszkiewicz, 1976, p. 46). After the gradual transfer of transhipment functions from the Inner Port to the North Port, as well as limiting the eastern direction of the North Port development by the masterplan from 1996, the concept of the Central Port was elaborated in 2019 (Czermański et al., 2021; Postoła, 2019). The location of the Central Port (Figure 1b) between two already existing port complexes (Inner and North Ports) might allow for the development of the Port of Gdańsk in a more compact way. The concept of the Central Port provides for further entry into the sea and the creation of new piers by landfill of the sea in order to build deeper reloading berths. The concept of the Central Port is included in both the current Study of Conditions and Directions for the Development of the City of Gdańsk from 2019 and the Plan of Maritime Areas of the Port of Gdańsk, currently being prepared by the Gdynia Maritime Office (Maritime Office in Gdynia, 2021).

7. Depth Limitations in Designing the Central Port

The assumptions for the design of marine structures of the Central Port currently require the adoption of basic guidelines regarding, above all, the depth of approach channels and the mooring berths. To define these, the maximum parameters of ships that will be served in the Central Port are needed (PIANC, 2014; Thoresen, 2018, p. 9). Typically, port design takes into account a long-term perspective of several decades, taking into account ships that are very often still in the design concept stage. Currently, the North Port is accessible for fully loaded ships of Baltimax class. However, according to the recommendations of the Harbour Master's Office in Gdańsk, the largest ships that could currently be handled in the North Port are vessels with a carrying capacity of 300,000 t and a draft of 15 m (Gdańsk Harbour Master's Office, 2023). The biggest ships that have entered the North Port of Gdańsk so far are the crude oil tanker Atlantas (International Maritime Organisation [IMO] number: 9389899) in 2016 with a capacity of 321,300 DWT, length of 290.0 m, breadth of

60.0 m, and a draught of 16.7 m ("Gigantyczny tankowiec niedługo w Gdańsku," 2016); container ship MSC Gülsün (IMO: 9839430) in 2019 with a capacity of 23,756 TEU, length of 399.9 m, breadth of 61.5 m, and a draught of 16.5 m (Baltic Hub, 2023); and the bulk carrier Agia Trias (IMO: 9241657) in 2020 with a capacity of 185,820 DWT, length of 290.0 m, breadth of 47.0 m, and a draught of 17.9 m (Portal Morski, 2020). All of them were, however, not fully loaded.

In the case of Atlantas (Portal Morski, 2016), before entering the Baltic, she had to be partially discharged by ship-to-ship transfer to another tanker and came to Gdańsk along with the feeder tanker to discharge. Therefore, serving such large ships in Gdańsk demands either that the ship is not fully loaded with cargo on the ocean route or that it is partially discharged before passing through the Danish Straits (in a port or by ship-to-ship transfer). Both solutions increase transportation costs. While the size of ULCC crude tankers and bulk carriers has not increased since the late 1970s, the parameters (including drafts) of container ships are still increasing to benefit from economies of scale. Prokopowicz and Berg-Andreassen (2016) defined the "very large container ships" class with a capacity of 10,000–20,000 TEU and the ultra-large container ships, which could carry over 20,000 TEU. The largest recently built container ships are Ever Alot (IMO: 9893955), built in 2022 with a capacity of 24,004 TEU, and MSC Irina (IMO: 9929429), with a capacity of 24,346 TEU, having drafts that increasingly call further into question the possibilities of Gdańsk and other ports of the Baltic Sea as ports serving ocean connections and being container hubs. And here again, after almost 60 years, the question arises about the possibility of further deepening the Danish Straits.

The Port of Gdańsk and all ports of the Baltic Sea are thus in a situation where the further increase in the size of ocean-going vessels (especially their drafts) will limit the possibility of their passage via the Danish Straits. In the process of planning the Central Port, the question becomes extremely important: What parameters should be used when planning its layout? The assumption of designing depths typical of Baltimax will, by definition, eliminate the possibility of servicing the next generation of ocean-going ships. So, in the longer term, is there a possibility of another deepening of the Danish Straits and maintaining the development perspectives for Baltic ports as ocean hubs? Is a more likely scenario a return to the situation known in Gdańsk from around the mid-16th century, when the bottleneck for ships entering the Port of Gdańsk was the depth of the river passing the Old Port? The waterways of the port were too shallow at that time to serve ocean-going galleons, and this fact reoriented the system of sailing routes starting in Gdańsk into a network of feeder connections served by much smaller vessels (Krośnicka, 2005, p. 30).

8. Conclusions

The deepening of the Danish Straits and the opening of the T Route to the Baltic Sea in 1975 opened a development window for the Port of Gdańsk (Figure 7). Overcoming this single development threshold (which, it is important to point out, is very distant from Gdańsk itself) allowed for the construction of a deep-water North Port, able to serve modern ships of Baltimax class. This investment was crucial for the continued existence of the Port of Gdańsk as an important ocean transportation node, as the old Inner Port, even after its deepening,

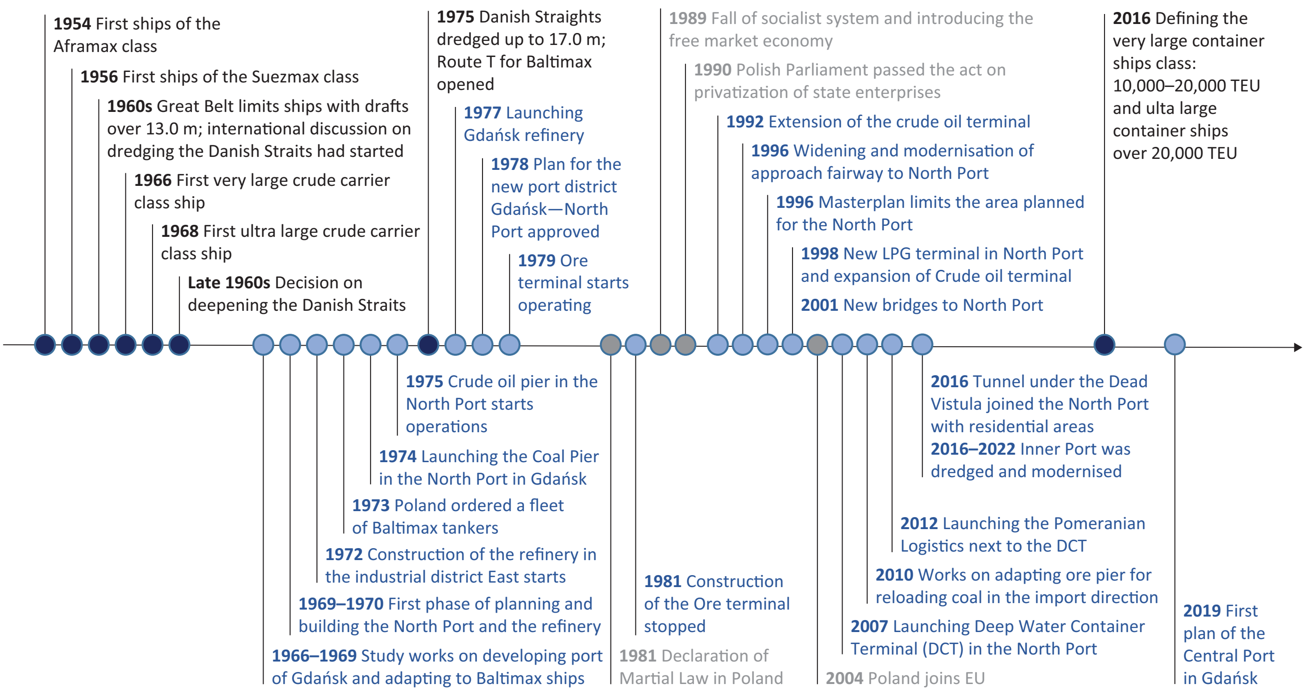

Figure 7. Timeline of the evolution of the North Port in Gdańsk.

would not be able to serve ships larger than 30,000 DWT. As quickly as 1977 (after four years of operations), the North Port slightly exceeded the turnover of the Inner Port, and in 1995 (after the difficult period of marshal law and politica l transformation for the Polish economy), the North Port's turnover was twice as big as the Inner Port's (the Inner Port served 6,048,100 t, while the North Port 12,213,700 t of cargo).

Launching the North Port along with the port's industry (crude oil refinery, oil bases), as well as plans for building two new shipyards in its vicinity re-orientated the economy of the Port of Gdańsk, but it also strongly influenced the development of the city. During the times of the centrally planned economy, the plan was to employ about 25,000 people to service the North Port and the East Industrial District. Such a high number of potential employees required the development of residential districts along with the servicing of urban infrastructure. Therefore, both the authorities of the Port of Gdańsk, the Gdańsk Refinery, and of shipyards still located in the Inner Port established their own housing funds, in which expenditure on financing cooperative and company housing significantly increased while constructing the North Port (Table 2). As a consequence, these maritime economy entities participated in building the new, modernistic residential districts in Gdańsk.

The suitability of a given water body in a port, and therefore also its closest region, for cargo handling and storage usually depends on the depth of the water body. The decision to carry out dredging works in a given water area, as was the case in the area of the Inner Port in Gdańsk in the years 2016–2022, therefore not only leads to the maintenance of transhipment functions but also slows down the process of moving port functions towards deeper waters—described by Bird (1971) as "down-stream" movement—and results in delaying the process of urban recycling. From the point of view of reducing the environmental impact, it is a beneficial process. Also, from the point of view of the city's development, it is a positive phenomenon, giving both the authorities, city, and port time to react and rethink the investment and transformation process.

Reducing the land reserves for the development of the Northern Port by the masterplan from 1996 made it possible to rationally use the port space and preserve coastal recreational areas, but at the same time, it forced today's reorientation of the development of the Gdańsk port towards deeper waters and the emergence of the concept of the Central Port. The design of the Central Port needs careful consideration of the parameters of ships that might enter the Baltic, even if not fully loaded. At present, the draughts of ultra-large container ships approach the limits of permissible depths enabling passage through the Danish Straits, thus various far-reaching economic and spatial effects can be expected for Gdańsk and other ports of the Baltic Sea.

To sum up, for port cities, overcoming even a very distant development threshold by dredging the existing navigational passage (Danish Straits) or by constructing a new channel (Kiel Canal) results in a significant change in the development conditions (in positive or negative terms) through the reorientation of maritime routes. The case study of the North Port in Gdańsk confirms, therefore, that the port-city relations are among those shaped by accessibility to the global sea routes (Ducruet et al., 2018; Ducruet & Lee, 2006; Russo & Musolino, 2023).

Acknowledgments

The authors are grateful to the reviewers for their in-depth and very insightful reviews and remarks, which significantly helped to improve the manuscript. The authors also would like to thank Prof. Anna Styszyńska for her help in preparation of some historical plans. This work was partially supported by the Gdańsk University of Technology research project WA/DS/036393 and by the Gdynia Maritime University research project WN/2023/PZ/10.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 363–375
https://doi.org/10.17645/up.v8i3.6770

Article

The (Re)Industrialised Waterfront as a "Fluid Territory": The Case of Lisbon and the Tagus Estuary

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Submitted: 31 January 2023 | Accepted: 17 June 2023 | Published: 26 September 2023

Abstract
If delta and estuary areas are observed under the perspective of a double system of dynamic infrastructures, the object of parallel "water/urbanisation" processes, the interface spaces become key nodes. In this perspective, port and waterfront areas can be described as spaces of mediation. The article argues that in the case of Lisbon and the Tagus, as possibly in several other port cities, these edge spaces can be described as "fluid territories." The pre-eminent characteristic of "fluid territories" is that they are not permanent, neither in space nor time. These areas present accelerated transformations, less defined boundaries, and an increased spatial and management complexity. Moreover, "fluid territories" also mediate (a) the culture-natural environment, with human action appropriating the natural system through infrastructure and urbanisation, and (b) the industrialised economic estuary, with its continuous updating. To demonstrate this hypothesis, two samples of Lisbon's riverfront are observed, recording its constant variability over the last 200 years of industrialisation, emphasising the "fluidity" of the mediating spaces. The understanding of the "fluid" characteristic of water/land mediation spaces is relevant for the present. Being dynamic and regularly reinventing spaces, spatial planning, public space, and architectural design processes in "fluid territories" should increasingly seek adaptability, flexibility, and openness to change. In the climatic context of continuous uncertainty combined with the need to make room for infrastructure, rethinking mediation areas through the lens of the theoretical concept of the "fluid territory" enables the implementation of urban transformation processes consistent with contemporary challenges.

Keywords
fluid territory; Lisbon; mediation spaces; port city; Tagus; urban deltas; waterfront

Issue
This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

1.1. Lisbon and the Tagus: Are the Mediation Spaces a Fluid Territory?

Throughout history, the development of water and land infrastructures and the resulting new spatial demands have led to changes in the territory, with governance structures influencing land use (Pagés Sánchez & Daamen, 2020). Among water-related activities, the importance of the port in economic development has allowed its infrastructures to drive spatial transformations (Grindlay Moreno, 2017; Hoyle, 2000; Munim & Schramm, 2018). This relationship continues to be an important paradigm for waterfront contemporary cities, as it combines a close spatial association with maximum functional interdependence, as Akhavan (2020), Hoyle (1996), and Meyer (1999) point out. In the specific case of delta regions, Meyer et al. (2016) argue that these have functioned as magnets for economic development and urbanisation for many centuries but, at the same time, these regions are the most vulnerable, where floods, drought, salinisation, and pollution represent major risks for millions of people, economic development, and the environment.

The Lisbon Region and the Tagus Estuary, in particular, have been intrinsically connected throughout history, as the natural system has been shaped to support land appropriation and economic activities. The infrastructure construction has been continuous over time, both on water and land, as if a parallel history could be written, as these infrastructures have been updated to adapt to the new demands of each technological cycle.

The development of the river's accessibilities has taken place through a continuous process of dredging, progressively adapting to the evolution of the boat's characteristics, and building a system of "fluvial roads" hidden beneath the water of the large estuary. The water-based activities responded to the technological characteristics of each cycle, dictating what, by analogy, could be defined as a process of "waterisation"—the water utilisation and infrastructure process.

A parallel development can be observed in the different generations of the land accessibility system, which evolved from the reuse of preindustrial roads to a new mobility system, built on landfill areas, with the new railway and roads side-by-side. Land occupation and use also responded to the technological characteristics of each cycle, confirming the process (established in literature) of (re)urbanisation.

In the perspective of a dual system of dynamic infrastructures and of a parallel process of "water/urbanisation,'' interfaces become key nodes. As such, the port and waterfront areas can be understood as spaces of mediation.

The article argues that, in Lisbon and the Tagus, as well as probably in several other port cities, these edge spaces can be understood as "fluid territories" and present a double dimension. They articulate aquatic and terrestrial surfaces, whose main spatial characteristic is that they are not stable, neither in space nor in time, being reshaped between technological cycles and responding to new needs. These areas tend to be spatially dynamic and less stable, presenting accelerated transformations, less-defined boundaries, and increased territorial and management complexity, combining transversal approaches (Hein, 2021). This port cityscape is administered and planned by multiple institutions and rarely as part of a shared vision. Given the spatial instability and fluidity of its boundaries, buy-in from local stakeholders is needed to facilitate a common approach (Hein, 2021). As Moretti (2019) indicates in her concept of threshold, the border between the city and the port is often perceived as a space of separation and contention. However, it is a dynamic interface capable of responsive potentialities and disposed to technological changes and structural updating. In this perspective, the article proposes to address mediation spaces as "fluid territories" to accentuate the dynamic characteristic of the interface situation, connecting the water and land systems. It is as if the argued "fluidity" was symbolically announced by the daily tide.

Moreover, these fluid territories are the mediation spaces between (a) the culture-natural environment, understood as the "man-made nature," with the anthropic action appropriating the natural system through infrastructure and urbanisation, and (b) the industrialised economic estuary, with its continuous upgrading, answering to the technological and economic cycles (Meyer & Nijhuis, 2014). The article registers the constant variability of this relationship over time, emphasising how the mediation spaces are "fluid territories" if observed from a broader perspective.

The main argument of the article is supported by the observation of this double dimension: the dynamic mediation between the water and land and the dynamic mediation between the culture–natural system and the economic evolution of each technological cycle. The association of physical and spatial dimensions with the sociocultural dimension is the hypothesis from which the article derives, methodologically using geo-historical spatial mapping and description as an analytical tool (Hein & Van Mil, 2020). Mapping and description allow the initial hypothesis to be corroborated (Schubert, 2017) and affirm how the water and land interface have changed over time as a "fluid territory."

However, the term "fluid territories" is not a new concept and has several applications. In the literature, it has been used as a metaphor in soft planning, following Allmendinger and Haughton's (2007a, 2007b) studies, referring to "a growing number of practices that occur at the margins of statutory planning systems" and "planning solutions that go beyond traditional administrative boundaries and introduce new governance processes between formal and informal structures and institutions," developed "at different scales, ranging from the European level…to regional approaches…and local community-led initiatives" (Cavaco et al., 2023, p. 2). The idea of spatial and administrative flexibility prevails, pointing out "the fluid areas between formal [planning] processes where implementation through bargaining, flexibility, discretion and interpretation dominate" (Allmendinger & Haughton, 2007b, p. 306). In this context, fluidity is also associated with the non-Euclidian notion of relational and multidimensional space, with variable geometry, overlapping the planning scales, shifting "from being 'hard-edged' containers to flexible and less-defined spaces" (Galland & Elinbaum, 2015, p. 69). Along the same line, in their study on the regional development zones in Finland, Jauhiainen and Moilanen (2011, p. 728) define the term fluid territories as being "characterised by flexible boundaries, policy integration, and 'governance of governance.' "

The concept of "fluid territories" is also applied in association with water issues to highlight its dynamic characteristics, e.g., the recent exhibition on the Danube Region mapping (Slovak National Gallery, 2022). It is often used in the scope of creative activities, such as landscape, urbanism, architecture design studios, or symposiums, associated with the idea of an unresolved space, also unstable or located in the connection between systems (Khosravi & Issaias, 2022; OWMF Architecture, 2023). Khosravi (2020) referred to it, pointing to the "changing inertia and relationships between the port, the city and territory" (Hamed Khosravi Studio, n.d.). It is also used in arts, referring to the interconnection between experiences and transition (argos, 2022), or in interdisciplinary studies (Reading Landscape, 2022).

Nevertheless, it is important to mention that the theoretical concept of "fluid territories" does not refer only to a contemporary phenomenon, considering, for example, the case of the Nile Delta and the cyclical floods that over time allowed for the development of agriculture and the settlement of the population. The contemporary understanding is the recognition that identifying vague parameters in the relationship between the natural system (water/land) and the city can provide new perspectives for interpreting urban transformations.

In this perspective, the article adopts the term "fluid territory" to refer to the mediating characteristic between active systems (water/land, culture-nature/economy, city/estuary), their permanent dynamics, and their regular variability in space and in time, deepening the concept of porosity in the study of port-city territories (Hein, 2021).

To support this approach, interface spaces were selected in Lisbon and the Tagus Estuary. The aim is to discuss the situation of spatial mediation between water and land, as well as between the culture–natural system and the economic cycle demands, highlighting the dynamics and transitory characteristics of these territories. It argues that especially since industrialisation, the evolution of these spaces over time justifies the regular reinvention of the existing structures and the creation of new ones in response to socioeconomic changes. Moreover, in recent decades, with the acceleration of technological and societal transformations, this fluid relationship between the river and the city has intensified: The cycles of reinvention are getting shorter, dictating a succession of new paradigms. New problems loom on the horizon, such as climate change adaptation, reminding us that even the recent upgrades to those spaces may not be definitive and exhaustive.

1.2. Methodology

To explore how waterfront areas, as water/land mediation spaces, can be understood as "fluid territories," the article focuses on Lisbon and the Tagus Estuary and develops a case study approach. Two key exemplary samples are selected, the Boavista and Alcântara riversides, analysing their evolution within the framework of the hypothesis. This empirical observation seeks to highlight the constant variability of the occupation of these mediating spaces over the last 200 years of the industrialisation process, emphasising their "fluidity" characteristics.

It should be mentioned that the large Tagus Estuary is the centre of the Lisbon Region and that industrialisation has found preferable riverfronts at different moments in time, moving from Lisbon Municipality's western waterfront to the eastern one, to the southern banks and Alhandra upriver. In Lisbon, the:

> Development and transformation of different areas of the riverbank was not simultaneous, nor were the growth dynamics on the banks of the Tagus, initially more north-centred, close to the city and, in the 20th century, progressively advancing towards a metropolitan dimension—also integrate the southern shore. (Costa, 2007, p. 55)

Since Lisbon is not considered one of the major industrial riverfronts in Europe, the selected case studies focus on the western riverfront of Lisbon Municipality. This area experienced the first industrial and port occupation in the 19th century and has undergone urban regeneration dynamics since the 1940s. Consequently, this location provides a more extensive historical development and better illustrates the argument presented in the article.

The analytical work is supported by primary sources, namely historical cartography and literature that ensures the correct interpretation of the charts. As proof of the argument provided, the text presents maps hand-drawn by one of the authors, depicting the relevant aspects of the urban transformation that took place over time in the port space. The approach is supported by established empirical research on the evolution of the waterfront case study (Costa, 2007, 2013), and the understanding of the redevelopment of these interface spaces accordingly to three moments: the waterfront of the first industrialisation, the waterfront of the second industrialisation, and the contemporary one (Andrade & Costa, 2020; Costa, 2013).

The use of the author's interpretative hand-drawn maps of the two cases makes it possible to highlight the evolution in space and time of the mediation spaces, addressing each moment with the article's hypothesis: Can these areas be understood as "fluid territories" that regularly (re)shape the industrialised culture-nature estuary?

The morphologic evidence of the urban transformations is reinforced with the presentation of realised or unrealised plans and projects for these areas. The objective is to emphasise that the "fluidity" of these territories is not only revealed in their physical expression but also in the domain of the ideas and approaches to their spatial transformation, justifying their qualification as spaces with an accelerated dynamic, in continuous reinvention.

It should be noted that this dual approach (evidence of urban morphology and ideas of spatial transformation) does not undervalue the existence of relevant technological, political, and socio-economic processes that conduct and justify it. Nevertheless, the methodology focuses on evidencing the argument, the "fluidity" characteristic of these territories, leaving the door open for further publications on the discussion of the "whys," which could certainly vary in each territory and city.

Thereby, the article's hypothesis on the dual perspective of the "fluid territories" is discussed "in practice." The article is completed with a broader discussion of the hypothesis, justifying why Lisbon and the Tagus can be considered as a "fluid territory" and why this definition is relevant to the discipline.

The theoretical concept of "fluid territories" is a provable argument for the Lisbon case study. But as happens with several concepts in urbanism, typological representativeness becomes a hypothesis for other cases. Consequently, the article suggests that it might be possible to extrapolate the results, particularly to other industrialised waterfronts with more intense dynamics of (re)urbanisation. As a hypothesis, might they also be understood as "fluid territories"?

2. Case Study Observation and Discussion: Two Samples of Mediation Spaces Between Lisbon and the Tagus

The morphologic interpretation of the evolution of the Boavista and Alcântara riverfronts allows us to observe five different moments, common to both cases, although they occurred at slightly different moments in time: (a) the first industrial occupation of former preindustrial territories; (b) the first initiatives of landfills and occupation of water areas for industrial uses, associated to the first industrialisation dynamics; (c) the large port and railroad landfill at the end of the 19th century; (d) the waterfront occupation in the 1960s, observing the intense port and industrial occupation of space, although several of the buildings were already unoccupied, as the second industrialisation resulted in the migration of these activities to the east and south riverfronts of the Tagus Estuary; (e) the contemporary situation, highlighting the ongoing urban regeneration processes.

The discussion of the physical evidence of accelerated land transformation is reinforced by the approaches and concepts that underpinned them, evidencing how the "fluidity" of both cases also extended to the domain of the ideas, in a continuous process of evolution, also on the perspectives of how the riverfront areas should evolve. Both arguments converge to justify the article's argument, that these can be understood as "fluid territories.''

2.1. The Boavista Riverfront as a Fluid Territory: Five Moments of an Industrial District Permanently in Question

The Boavista riverfront is a testament to how, during the approximately 200 years of industrialisation, the mediating space between the water and land presents characteristics of "fluidity." Not only has the water/land mediation space undergone five generations of spatial configuration, but it has also been constantly challenged, with the succession of unrealised spatial plans and projects, (re)urbanisation works, and renovation of functional and building tissues. This process has been accompanied by an evolution in the conceptual approaches to the territory, regulating the balance between the culture-nature system and the economy, in a continuous "fluid'' dynamic.

This territory's evolutionary process can be initially referred to as the preindustrial Boavista Street and Beach, as seen in the concave riverfront in Figure 1a. The beach was described by Silva (1993, p. 8) in the early decades of the 19th century as an "implausible deserted space" which was progressively occupied by industry and the subject of failed public attempts to reorganise the informal urban configuration of plots with a very short street, water facades, and a deep, perpendicular extension. The cholera epidemics of 1854 and 1855, followed by the yellow fever epidemic of 1857, which focused on the infectious emanations of mud from the site, were the final arguments to justify the works of the Boavista riverfront (Silva, 1993).

After an initial unsuccessful project to build a closed harbour in the 1840s, a new landfill and the deep-water dock were built between 1858 and 1865, combining industrial expansion, harbour improvement, sanitisation intervention, and urban reform (Figure 1b). The following decades were marked by an improvement and the establishment of new industries and by the urban reform plan of the 1860s, which reprofiled the transverse streets and proposed the opening of a middle longitudinal one (Figure 2a). This reform was fully implemented several decades later, at the beginning of the 20th century (Costa, 2007, pp. 78–86), and can be observed undergoing in 1911 (Figure 1c).

As observed, if we can argue that during the 19th century, there was not a single decade of stability in the Boavista riverfront, both in its physical transformation and in the evolution of the ideas to address it, the 20th century was not different. Proposals for a large longitudinal landfill for the Port of Lisbon had been developed since the 1870s, but it was not until 1886 that a project was stabilised by João Joaquim de Matos and Adolfo Loureiro. The project was realised between 1887 and 1905, allowing the implementation of the port's modern infrastructure, with the opening of the new longitudinal border road and rail corridor. As a result, a new waterfront layout was created, separating the former Boavista Landfill from the water, as can be seen in Figure 1c.

The first decades of the new century were marked by the intensive and heterogeneous occupation of the new port riverfront extension with facilities of the first industrialisation, such as the fishing docks, shipping companies, the electrical installations of the train company and the port's sanitary facilities (Sousa, 1926). Again, the dynamics of change did not take long and the emergence of the second industrialisation, with the consequent change in the energy source and technologic paradigms, justified the rapid obsolescence and abandonment of the dense industrial and port facilities occupation from the 1950s onwards, as can be observed in Figure 1d.

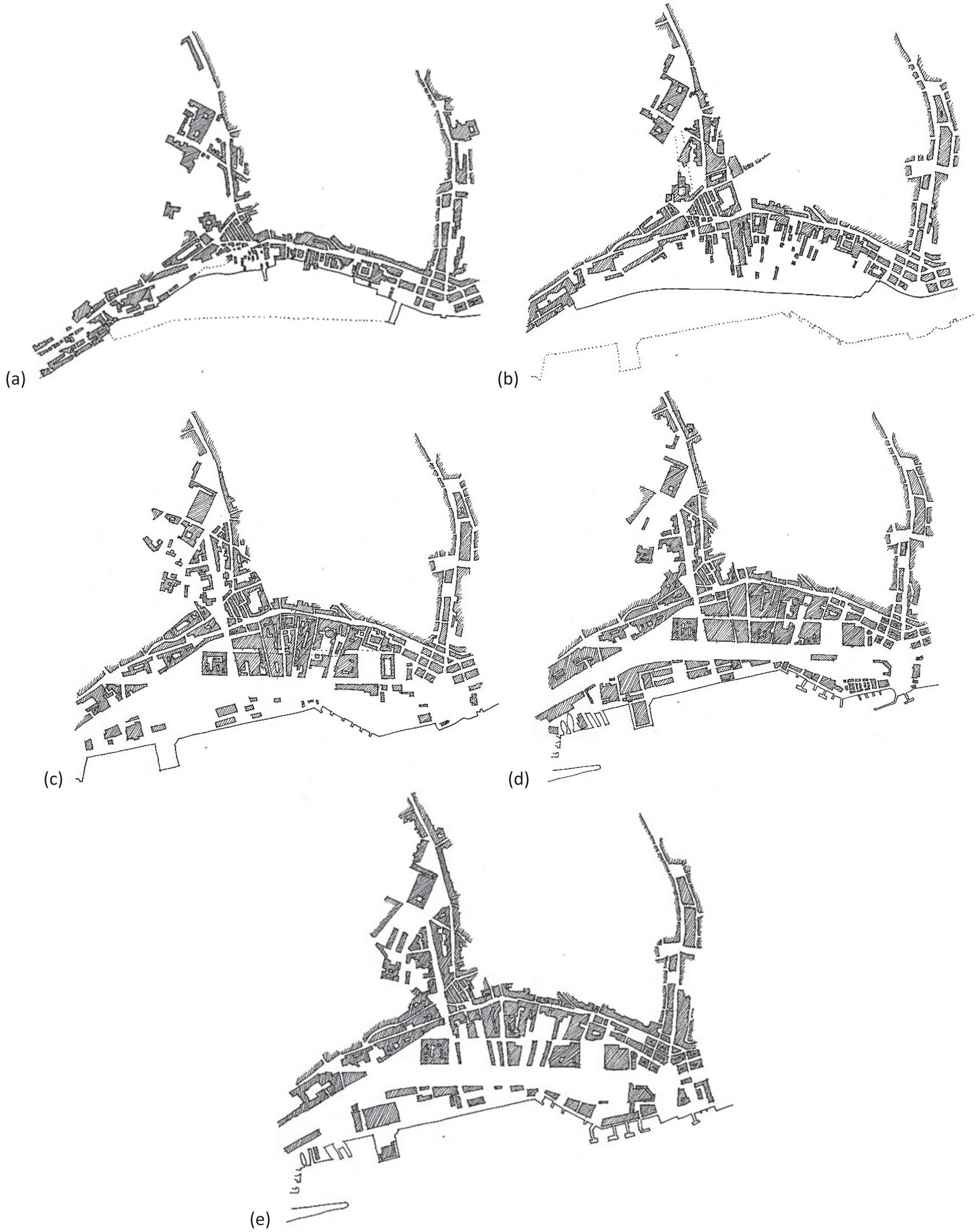


Figure 1. The Boavista riverfront evolution in maps: 1807, 1865, 1911, 1963, and 2023. Drawings by João Pedro Costa, 2023.

In the second half of the 20th century, unimplemented plans for the redevelopment of Boavista's decaying urban fabric succeeded one another. The first known reference dates to the 1960s and proposed the redevelopment of the site through the complete demolition of the industrial urban fabric and the construction of three large new blocks, according to a conceptual approach that attributed a negative value to the former industrial heritage, thus proposing its complete replacement with a new urban fabric (Figure 2b).

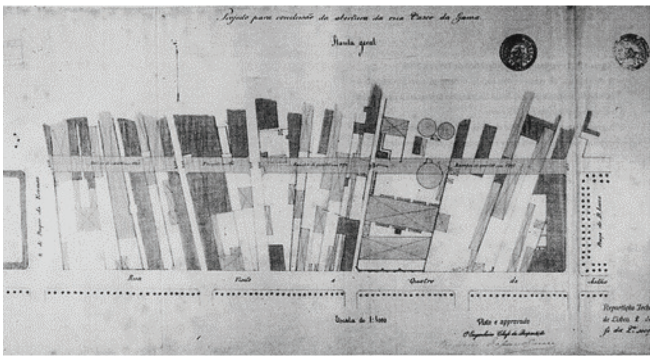
The 1980s made an important contribution to the emergence, in public opinion, of the need for riverfront regeneration with a new conceptual approach. Referring to a shift that took place in this decade, Ferreira (1997, p. 151) argues for the need to "bring out a collective awareness that recognises the past of the riverfronts linked to economical uses and its present linked to a sensitivity of an environmental, aesthetic and playful nature." The results of the 1988 public competition promoted by the Architects Association for the redevelopment of the western and central riverfront of Lisbon were significant for this change, establishing the new cultural approach to the regeneration process and emphasising the need to reconnect the city with the riverfront.

The 1990s was a decade of controversy. The 1994's Spatial Plan for the Riverside of Lisbon proposed by the Port Authority tried to replicate, in the 20th century port landfill, a London Docklands "real estate" dense regeneration model, generating an intense public reaction that stopped this process. In 1993, Lamas carried out a preliminary study for the redevelopment of the Boavista area, exploring a different cultural approach. However, the regeneration process only began in the 2000s. The process adopted a medium-term approach that would respect the "spirit of the site," mixing a new urban fabric that follows the transversal orientation of the historical building with some rehabilitated pre-existing structures. Since the 2010s, the Boavista urban fabric has been undergoing intense regeneration, nowadays supported by two approved detailed plans (Figures 3a and 3b). This ongoing process (Figure 1e) represents the maturation of a regeneration process that took 50 years to see the light of day.

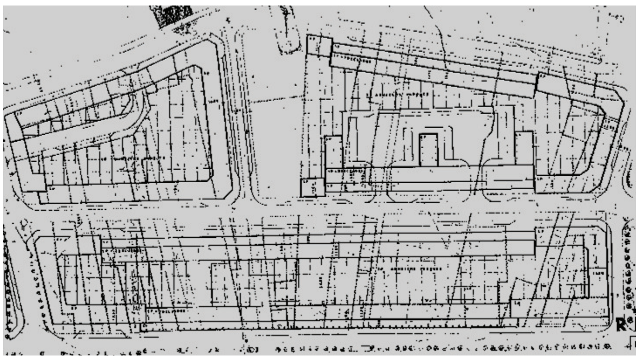
Although incomplete, the brief story presented on the Boavista riverfront clearly demonstrates the accelerated dynamics of an urban space of mediation between water and land. It evidences a permanent pressure for spatial change, accompanying a transformation dictated by the evolution of technology and the economy, to which the man-made environment has had to adapt. Since the beginning of the 19th century, this space has verified a continuous process of reinvention, with several non-realised projects and plans that have contributed to the maturation of changes that later ended up taking place.

It can be argued that, as a space of water/land mediation, the Boavista riverfront has been a fluid territory, in space and in time. Permanence has been rare during the last 200 years, and although a regeneration process is underway, new agendas emerge for the future. Climate change adaptation is one of these agendas, obliging these spaces to face new problems, such as sea level rise, increased flash floods and changes in the patterns of extreme weather events.

The relationship between the culture–natural system of the territory and the economy and its cycles has been as intense as the sequence of dominant agendas demonstrates. Informal industrialisation, urban reorder attempts, sanitation, formal industrialisation, regeneration of formal industrialisation, port expansion, reindustrialisation, urban renovation approaches, heritage approach to urban regeneration, urban regeneration focused on new economies and environment, and climate change adaptation, were eleven successive main cultural approaches to the riverfront spaces, in accordance with the needs of the economic cycle and the societal priorities. Under this perspective, the transformation of the natural system of mediation between water and land was also a continuously "fluid" changing process.



(a)



(b)

Figure 2. The Boavista riverfront. (a) Project for the conclusion of the opening of Vasco da Gama Street, general plan, connecting Duque de Terceira Street on the left with D. Luis I on the right, the City of Lisbon, unreadable date (1867?). Source: Silva (1993). (b) Revision study of the blocks, a municipal plan developed for the Boavista area, City of Lisbon, 1962. Source: City of Lisbon (2017, p. 13).

(a) (b)

Figure 3. The Boavista riverfront: Assembled extracts of the two implementation plans. Both plans support the ongoing urban regeneration of the former industrial area. (a) The Boavista Landfill Detail Plan West. Source: City of Lisbon (2017). (b) the Boavista Landfill Detail Plan East. Source: City of Lisbon (2021).

2.2. The Alcântara Riverfront as a Fluid Territory: Five Different Moments of the Industrial Port-City in Question

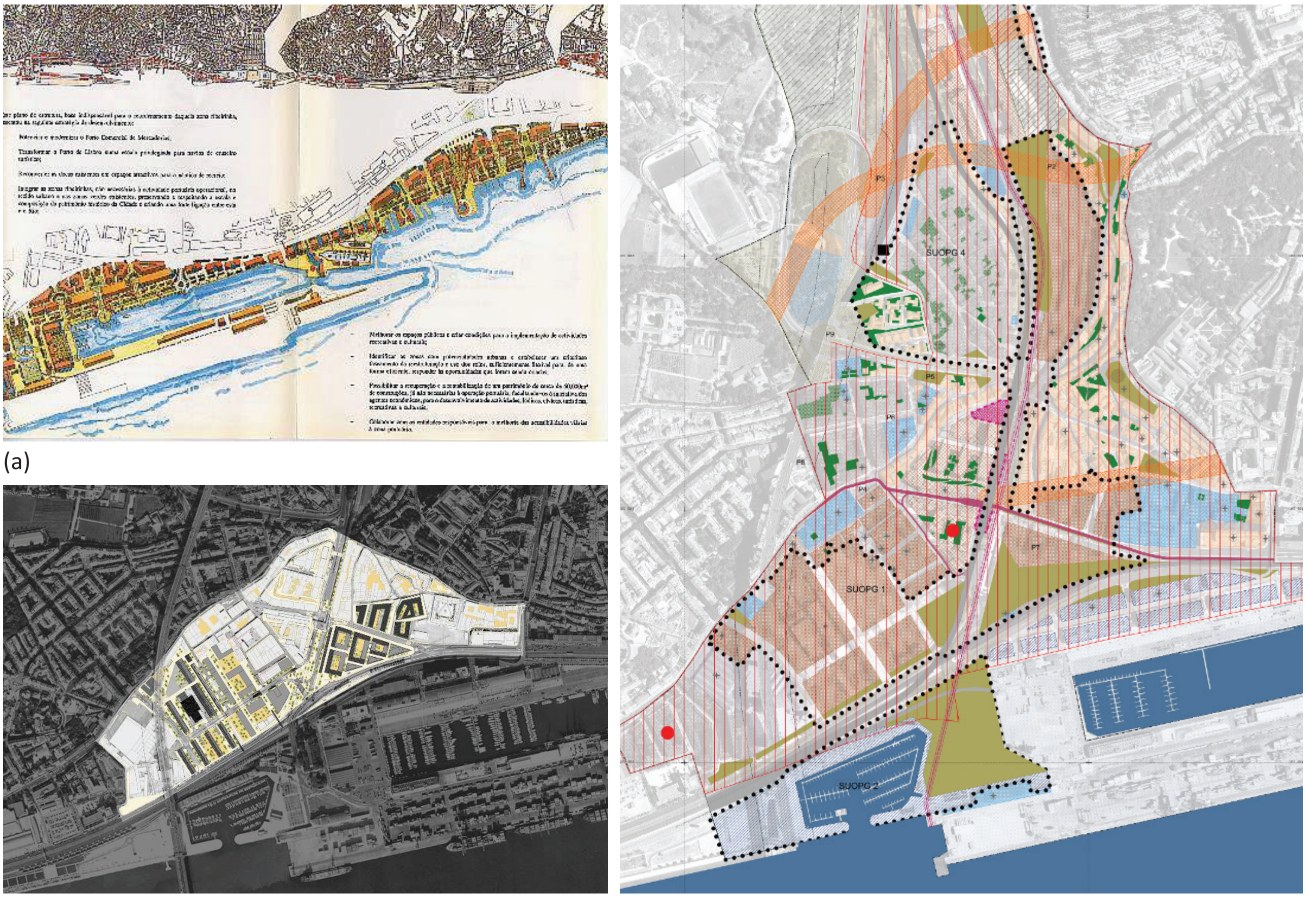
The Alcântara riverfront reinforces the evidence of how, in the last 200 years of industrialisation, the mediating space between water and land presents characteristics of "fluidity." Being one of the birthplaces of Lisbon's industrialisation, it has also experienced at least five different generations of spatial configuration, although not exactly corresponding to those of the Boavista riverfront. Not having had a stabilised industrial configuration, the Alcântara redevelopment has been constantly questioned, especially since the mid-20th century. The succession of unrealised plans and projects and the public debate on the conceptual options can be understood as a maturating process that anticipated the most recent approved versions and urban regeneration works. The evolution of conceptual approaches also reveals "fluidity" characteristics, in a delicate balance between the culture–nature system and the economic demands.

The industrial transformation of the Alcântara riverfront can initially be referred to as the preindustrial occupation of a large tidal mill and lime kilns, as can be seen in Figure 4a. The second half of the 18th century saw one of the first industrial transformations of the city, with the regularisation of the Alcântara riverside and the occupation of the mill's former water area by a new Tagus landfill (Figure 4b). The first industries located on the landfill were replaced in 1865 by the large União Fabril company, which expanded its site facilities in 1898 (Faria, 2001). At the end of the 19th century, the construction of the large port landfill radically changed the Alcântara riverfront. Not only was a significant territory conquered from the river, but also two new docks were built, Santo Amaro, on the left, and the large Alcântara Dock on the right (Figure 4c). These new areas were intensively occupied by port and industrial facilities in the first decades of the new century (Figure 4d).

In the 1926 description, the Alcântara Dock landscape was marked by warehouses, depots, and various factories, the port disinfection, and by the Colonial Navigation Company; the Alcântara riverfront pier was dedicated to intensive passenger traffic; and the Santo Amaro Dock to the railroad goods deposits and the Vacuum Oil Company facilities (Sousa, 1926). With the improvements made by the port in 1946, the Alcântara occupation was enhanced, with the construction of several standardised industrial or storage buildings measuring, 65 × 13 to 15 m, along five wharf corridors, and the two new maritime stations on the riverfront piers (Figure 4d). In line with the observation of the Boavista riverfront, the mid-century transition to the second industrialisation was accompanied by the rapid obsolescence and abandonment of former industrial and port facilities. The transformation of the industrial area of Alcântara on the former tidal mill was envisaged at least by the Lisbon Master Plan of 1967, approved in 1977, which classified it as an area of tertiary activity to be reconverted through territorial spatial planning instruments. On the contrary, the area under the jurisdiction of the port authority was mainly maintained for port activity.

This was a very intense period of public discussion on the regeneration process. The controversy over the 1994 Spatial Plan for the Riverside of Lisbon's "docklands redevelopment model" also reached Alcântara (Figure 5a), freezing the transformation ambitions for the Alcântara Seaside. In opposition, several versions for

Figure 4. The Alcântara riverfront evolution in maps: The first half of the 18th century, 1807, 1909, 1963, and 2023. Drawings by João Pedro Costa, 2007 and 2023.



(a) (b) (c)

Figure 5. The Alcântara riverfront spatial planning. (a) Spatial Plan for the Riverside of Lisbon, elements of the exhibition held at the Alcântara Maritime Station, extract of the brochure. Source: Port of Lisbon (1995). (b) Urban study for Alcântara Río. Source: Valssassina et al. (2005). (c) Alcântara Urbanisation Plan, extract of the Zoning Plan II, Fernandes de Sá. Source: City of Lisbon (2015).

the redevelopment of Alcântara Land were proposed, such as the 1996 Alcântara River Urbanisation Plan by Margarido Pires, which supported the first realised landmark in Alcântara: the reconversion of the former União Fabril company facilities, by Valssassina, in the transition of the century. Furthermore, the Alcântara Land side has also known proposals that never got off the ground, such as the 2003 Three Towers project by Siza Vieira or the 2004 Two Towers project by Sua Kay.

The complexity of the Alcântara area contributed to the slow advancement of the redevelopment process, once it was obliged to make the urban proposal compatible with the new key railroad, port, and road nodes, all overlapping in the same space at the mouth of the Alcântara riverside, a water line known for its intensive flash flood events. Consequently, the debate on spatial planning in Alcântara has also been very intense. Promoted by the municipal agency Ambelis, the 2005 urban study Alcântara XII, by Valssassina, Mateus, and Nunes answered the initiative of five major landowners and articulated common intervention principles with the municipality (Figure 5b). For the Alcântara riverside, the 2008 Integrated Plan for Interventions in the Riverfront of Lisbon identified Alcântara as an area of study carried out by the Municipality and the Port Authority, pointing out the promotion of a common green redevelopment project.

In tandem with the discussion on the “hard” redevelopment of Alcântara, the rehabilitation of the two hectares of the former Lisbonense spinning and fabric company marked an opposite approach to the old industrial structures. Applying the Rs policy to spatial planning and architecture, it utilised the existent structures in an “aesthetic of reuse,” evoking the principles of sustainability. The LX Factory space has been, since then, a mixed-use area combining offices with culture, creative industries, art, restoration, and leisure, being a must-visit site in the city.

The spatial planning definitions for Alcântara were finally stabilised with the approval of the 2015 urbanisation plan, by Fernandes de Sá, after seven years of elaboration and discussion (Figure 5c). It is with this instrument that recent advances in the regeneration process have been implemented, such as the Hospital CUF Tejo, developed between 2015 and 2020, or the two frontline office buildings, by Saraiva, built between 2020 and 2023.

In a common dynamic with the Boavista riverfront, the Alcântara Sea areas also continue to be under the port's authority management responsibility, although in this case, the port remains active. Alcântara has the deepest pier in the estuary, adequate for container exploration, although its location within the city does not allow for logistical space and makes rail and road connections with the hinterland difficult.

Finally, the climate change adaptation agenda has recently emerged on the Alcântara riverfront. Tackled since the 2010s, the "what if" agendas and the ethical responsibilities of spatial planning are on the table nowadays (Costa et al., 2013), reminding us that the emergence of new agendas on the urban transformation processes did not end in the past, but, on the contrary, are perhaps part of the genetic heritage of "fluid territories."

Representing a fast overview of a denser transformation process, the brief history synthesised for the Alcântara riverfront again demonstrates the dynamics of an urban space of mediation between water and land. Since the early industrialisation stages, Alcântara has been under pressure for spatial change, moving, in each cycle, between new ideas, unrealised plans and projects, public discussions, and finally realised plans and projects. Alcântara has lived under a regular process of industrial, port, and urban reinvention, questioning the culture-nature environment in the scope of the evolutive technology and economic perspectives. Informal industrialisation, industrial infrastructure, industrial regeneration, port expansion, port industrialisation, city reindustrialisation, urban renovation approaches, heritage approach to urban regeneration, urban regeneration focused on new economies and environment, and climate change adaptation were 10 cultural approaches observed. As in the Boavista riverfront, it can be argued that, as a space of mediation, the Alcântara riverfront has been a fluid territory, also balancing the culture–natural system approaches with the economic cycles.

3. Discussion: Urban Waterfronts as Fluid Territories?

As has been demonstrated, Lisbon and the Tagus have had a dynamic relationship throughout history. The nexus between the territory's culture–natural system and the economy and its cycles has been dynamic, inducing the transformation of the natural system of mediation between water and land as a continuous process of "fluid" change. The observation of the specific cases of Boavista and Alcântara was fundamental to understanding this "fluid territory" condition.

Although the concept of "fluid territory" has been discussed focusing on the two case samples, it is considered to be a first step towards, firstly, understanding the mutability of spaces between land and water, and the subsequent application of the study to other geographical contexts. A study that provides insight into how it is necessary, in the face of future challenges posed by the effects of climate change, not to consider these spaces as having a rigid and fixed boundary, but rather as fuzzy-edged areas, where the first characteristic is spatial, temporal, and conceptual "fluidity." Therefore, the concept of "fluid territory" allows to describe the coexistence of different systems in time and the space, reinforcing the variability that defines the territories between land and water.

Understanding this specific characteristic of the water/land mediating spaces is relevant for the present. As dynamic and regularly reinvented spaces, spatial planning, public space, and architectural design processes on "fluid territories" should increasingly seek adaptability, flexibility, and openness to change. In times of extensive urbanisation, when infrastructure is addressed as a socio-culture object, "fluid territories" have transition as a continuous feature and reinvention as a permanent challenge. Furthermore, the present-day transformations might be only one more short-term step in the evolution of these very dynamic territories.

Questioning the broader representativeness of the Lisbon case, the different urban realities naturally observe their own specific characteristics and moments, but the hypothesis that can be open at this point is that those waterfronts might also be fluid territories, observing, in their own forms and times, a continuous dynamic of accelerated reinvention until the present day.

As argued, the exploration of the characteristics of physical waterfront spaces, at different temporal and spatial scales, helps to understand the cycles and agents that operate there (Hein & Schubert, 2021). Increasingly, the challenges are on a larger scale in shorter times, and "fluid territories" have the adaptive capacity to absorb these changes.

The special condition of the waterfront as a mediating space, in sections where urban and port land are significantly valuable, confers a particular pressure on the waterfront, justifying its permanent rethinking. As Hein (2021) explains, in port-city territories, the port and the city engage in multiple ways, not just along a single thin line as historically, physically, and governmentally defined. The study of the port-city interface space is useful for understanding the different urban and spatial dynamics that occur in the waterfront space. Related to the concept of porosity that Hein (2021) deals with, Moretti's (2019) definition of these spaces can be framed as thresholds. Intimately linked to these concepts of porosity and threshold is the reflection on these mediation spaces as "fluid territories," which requires rethinking the limits between them and the planning of ports and cities. As dynamic spaces that are periodically reinvented, spatial planning, public space, and architectural design processes in "fluid territories" must increasingly seek adaptability, flexibility, and openness to change. It is in this dynamic of changing spaces that the permanent elements must be flexible, if not physically or morphologically, then through adaptive reuse. Therefore, this concept of fluid territory reopens the debate on the flexibility, adaptability, and resilience of these spaces of mediation that must respond to the demands of different realities that coexist in this interface. These are exceptional spaces, with greater public exposure, and this gives greater relevance to the article's argument. As Gehl (2010) states, soft edges are privileged areas where citizens can safely observe and enjoy the landscape and enjoy the city's best climate.

Indeed, the spatial form of urban interfaces demonstrates its most relevant attribute, namely being mutable, not stable, to respond to the needs of the two systems that connect. Dynamism, both spatial and temporal, becomes increasingly important in a present time characterised by the effects of climate change, as it allows the system to adapt to change. As Hein argues (2021), at a time of climate change, sea-level rise, and shifting coastlines, it is especially important to understand how porosity, or its absence, affects port cities' functioning over time. Boundaries are built, torn down, and rebuilt, continuously creating new patterns of engagement between port, city, and territory.

The proven adaptability of these "fluid territories" throughout history (Costa, 2007; Schubert, 2017) guarantees its reinvention and flexibility in the face of future challenges. Therefore, present and future development opportunities lie in the adaptability established in a dynamic boundary between water and land. Research on the history of cities, ports, and waterfronts, including dimensions of resilience and path dependence, can help us to better grasp the relationship between spatial and social development (Garcia, 2021; Hein & Schubert, 2021).

As it has been possible to verify, "fluid territories" have demonstrated their resilient character, adapting not only their edges and their physical spaces but also the adaptive reuse of the industrial buildings themselves and the land use (Añibarro et al., 2023; Vizzareri et al., 2021). Thus, there is a resilience capacity in this territory both from a physical and functional perspective, adapting to the different economic cycles, as well as social, constituting representative spaces of the city of great historical, scenic, and environmental value. In fact, from a broader perspective, resilient thinking can find a useful application in "fluid territories." All the seven attributes of resilience are particularly adjusted to these areas: recovery, connectivity, capital building, adaptability, robustness, flexibility, and transformability (Pinho et al., 2012).

Nevertheless, the concentration and densification of urban and industrial land use have resulted in the disappearance of the natural resilience capacity of deltas (Meyer et al., 2016). These territories have an increasing flood risk that is reinforced by sea level rise caused by climate change. A fundamentally new approach is necessary, creating more room for natural and social processes which can contribute to increasing the resilience of these urbanising deltas. Meyer et al. (2016) propose that, in the long term, "building with nature" delivers the conditions for delta regions to adapt to climate change continuously, by using the formative power of nature as the strategy's foundation. He affirms that the role of urbanising deltas in the world's economy and ecology can change radically: From being the crucial hubs of the old fossil fuel-based economy, urbanising deltas can become the engines of a new, clean energy-based and circular economy.

Understanding the transitoriness of the occupation of these mediation spaces, historically, points out a characteristic that might continue in the present and the near future. By doing so, the contemporary intervention on the riverfront water and land mediation spaces can clearly assume it will not be definitive and that the changing dynamic continue to intensify. Adaptability, flexibility, and the incorporation of change become a criterion of sustainability in the transformation of the riverfront, both in the spatial planning and (re)design of the public space and urban fabric.

4. Conclusion: (Re)Shaping the Industrialised Culture-Nature Estuary in Fluid Territories

Presented as the main argument, the article discusses how the interface areas between water and land can be understood as a "fluid territory," having as a case study two samples from the Lisbon riverfront. In the approximately 200 years of industrialisation, the spaces mediating the city with the Tagus Estuary have regularly been the subject of processes of reinvention, through realised and unrealised plans and projects, and public discussions, as if a collective and continuous maturation process was undergoing. Furthermore, as this intrinsic water and land connection continues in the present, new agendas emerge, such as climate change adaptation, which oblige mediating spaces to address different problems.

It can be argued, by extrapolation, that the mediation spaces between water and land present "fluidity" characteristics. These edge spaces face permanent pressure to change, in space and in time, but also dynamic perspectives on how the man-made culture-nature system can answer the economic demands. These areas can be understood as "fluid territories" that regularly (re)shape the industrialised culture-nature estuary. As a result, a hypothesis emerges for the application of the concept to other waterfront cities, particularly the river and delta ones.

This argument can be relevant to the subject both with a theoretical and practical application. If the water and land interface spaces are "fluid territories," their dynamic, transitoriness, or reinvention characteristics can recommend attributes of adaptability, flexibility, or openness to change to the spatial planning, public space, or architecture design processes. The culture-nature water space (re)shaping is an ongoing continuous process that does not end in the present, permanently addressing the port and water economies, infrastructural scenarios, regional (re)structuring, cultural heritage, (re)urbanisation, ecosystems quality, nature reserves, agriculture, and all the activities related to the "fluid territories" between water and land.

In times of extended urbanisation, when infrastructure is seen as a sociocultural object, "fluid territories" are transitory and reinvention is a permanent challenge.

Acknowledgments

This work is financed by Portuguese national funds through Fundação para a Ciência e a Tecnologia (FCT) under the strategic project with Reference Nos. UIDB/04008/2020 and UIDP/04008/2020.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 376–389
https://doi.org/10.17645/up.v8i3.6848

Article

Prospective of an Inland Waterway System of Shipping Canals in Skikda (Algeria)

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Submitted: 16 February 2023 | Accepted: 20 June 2023 | Published: 26 September 2023

Abstract

Sustainable development projects require careful balancing of economic interests and ecological needs. The case of Skikda, a city in northeast Algeria, located on the Mediterranean coast, illustrates the challenges connected with such a development. The ancient city coexists with a young hydrocarbon port and industrial pole that serves as a transfer hub in the flow of petroleum between hinterland and sea. The installation of the port and petrochemical refining plants on the banks of the estuary of the Safsaf River presents many challenges to local citizens and the ecosystem, including pollution of the water system, groundwater, and river water, and damage to the area's ancient heritage. This study argues that we need new and less polluting forms of intermodality between hinterland and seaport to make urban mobility more sustainable. It asks whether and how the existing rivers and wadis (river channels that are dry except during rainy periods) can be transformed into artificial canals for river navigation to improve the transport fluidity and sustainability of Skikda. To answer this question, the study adopts a prospective approach using the MICMAC scenario method. This approach entails, first, presenting and evaluating the potentialities of the existing rivers of Skikda using QGIS, and second, discussing and proposing scenarios for transforming these rivers into urban waterways, that is, artificial canals for inland navigation. The prospect of inland waterway transport in Skikda may be a radical scenario, yet, despite its hydraulic capacity and advantages, this system is not receiving attention in Algeria. We suggest that water transport can breathe sustainable blue life into a vulnerable industrial port city, transforming its challenges into opportunities.

Keywords

inland waterway system; MICMAC; prospective; scenario; shipping canals; Skikda

Issue

This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

Many contemporary port cities have grown over centuries or even millennia at places where rivers discharge into the sea, creating complex landscapes where shipping and industrial development create multiple challenges for historic sites, urban living, and ecological health. Skikda, an ancient port city located in the northeast of Algeria on the Mediterranean at the mouth of the Safsaf River, provides an example of such challenges. The second-most important port of the country, after Algiers, Skikda is considered the eastern gateway for the export of hydrocarbons to international and European markets by sea. Since the 1970s, Skikda has been a stronghold of the oil and gas industry (Ghennaï et al., 2022).

Skikda's economic advantage has led to deficiencies in terms of urban development. Apart from the pollution and vulnerability imposed by the oil industry, Skikda faces important challenges of urban mobility, due to the location of the city between two natural barriers, the sea on one side and the mountains on the other. Urban development is further constrained by a large industrial zone that is close to the heart of Skikda's urban center. Since the 1990s, security measures taken to protect this sensitive state infrastructure have led to the restriction of access to the area and the closure of Skikda's airport. Furthermore, access to the boulevard that links Skikda and the tourist area, Filfia, has been limited. Restricted access to this boulevard adjacent to the port creates urban mobility problems. The boulevard is key to maritime and touristic activities, and citizens have demanded the reopening of this route (Ghennaï & Madani, 2022).

Traffic congestion and everyday traffic jams in Skikda are a serious problem for both the city and the industry. They require rethinking the transport systems in Skikda. The authors propose investigating the potential of the hydrological assets of Skikda by creating a waterway system that relies on existing channels and rivers, such as the Safsaf River (Figure 1), which links the port to the industrial area and the hinterland, as a new means of facilitating urban transport in Skikda and, indeed, Algeria. This waterway can be both internodal and intermodal, as it would connect the seaports to new inland shipping functions.

The use of such waterways for transport functions raises many questions about water quality because the Safsaf River connects several municipalities of Skikda located in the Safsaf valley, including the industrial zone, as well as the Safsaf River, feeding agricultural activities and biodiversity in Skikda's rural area. The Safsaf River basin is a vital watercourse because of its flora and fauna and it contributes to the irrigation of agricultural areas. It is controlled by four major dams, including Zerdaza Dam, and is home to some 460,000 inhabitants (Rouidi et al., 2022). The city of Skikda receives its water from the basin of the Safsaf River, which starts in the south of Algeria. This basin has an area of 1,158 km^2 (Rouidi et al., 2022). The Safsaf River derives its name from the willow trees that line its banks. It was along this river that the Phoenicians established one of the earliest cities, Skikda Thapsus. In fact, some historians suggest that the river mentioned as "Thapsus africae, juxta Rusicadem" is none other than the present-day Safsaf River (Tissot et al., 1884). Over the years, the river has experienced significant pollution due to its location as a population center and industrial hub (Rouidi et al., 2022).

Parts of the river are in fact a dumping ground for unpurified rainwater and wastewater, and from the river they flow directly into the sea, posing major threats to humans and non-humans. The source of the Safsaf River is the Djebel Taïa mountain, but the Safsaf River is fed by the dam of Zardza. This has contributed to contaminating these waters with dangerous toxic pollutants, mainly metals such as iron, cadmium, and manganese. The contaminated Safsaf River is equipped with only four wastewater treatment plants, with a treatment capacity of 42,000 m^3/day, holding a large volume of untreated wastewater, which extends to 16,153.2 m^3/day (Boubelli et al., 2018).

To develop more sustainable ways of living and working we need new approaches to industrial and urban mobility. This article explores the potential of new approaches to intermodal transportation through the development of artificial shipping canals in Skikda, while also considering the ecological implications of such transportation. Following a short introduction to the role of inland waterway transport (IWT), this article explores the potential of converting the Safsaf River into a new mobility system to improve urban flows, solve urban connectivity problems, and connect ports with the industrial zone and hinterland. Our plan for converting the Safsaf River to a canal involves integrating a sustainable river transport system in Skikda as an asset for promoting tourism and meeting urban and industrial challenges.

The objective of this study is to develop a prospective scenario for the recovery of the river and the development of a canal as an urban waterway. It aims to both absorb the negative effects of the oil industry and promote the role of water in improving the quality of life. To achieve this objective, the study suggests creating a hydraulic map of the Safsaf River using geographic information system. Subsequently, the researchers employ MICMAC, a tool that facilitates idea sharing by utilizing a matrix to analyze the interrelationships among variables assumed to influence the studied strategy's implementation.

1.1. Brief Introduction to Inland Waterway Transport

Canal shipping has long been the backbone of trade in many countries. IWT is one of the oldest inexpensive and reliable navigation systems (Bu & Nachtmann, 2021). The largest IWT systems are located in China, Russia, and Brazil (Wiegmans & Konings, 2016). IWTs have been constructed through the transformation or connection of rivers, as well as through excavation. Herodotus, for example, mentioned the restoration of the Great Canal of Babylon around 1700 B.C. The construction of the Suez Canal began around 600 B.C., connecting the Nile in Egypt and the Mediterranean to the Red Sea. The Great Canal of China was built in the 7th century to link the sea to the capital via Canton (Hepburn, 1909).

In the 12th century, European leaders started to develop a great canal system of Europe, including Charlemagne's connection of the Rhine and the Danube. One of the historic artificial navigable canals is the Canal du Midi in Toulouse, France. Built in the 17th century, it is an impressive piece of engineering, with flows provided by water collection in the test channel, water flow at Naurouze, and the Montagne Noire (Mukerji, 2021). The canal has been a success, even though it has been closed some summers for lack of water (De Wolff et al., 2021). IWT has been key to the development of the Netherlands, connecting the port facilities of Amsterdam

(a) (b)

Figure 1. (a) Zeramna River Branch of the Safsaf valley and (b) the estuary of the Safsaf River on the Mediterranean Sea.

to the hinterland in 1826 and again in 1876. Similarly, the port of Rotterdam was connected to the lower Rhine in remarkable feats of engineering (Hepburn, 1909). The Seine River canal, the Rhone River canal in France, and the Rhine–Scheldt canal respectively connect the Ports of Rotterdam and Antwerp, forming a major economic zone of Europe (Eski & Fiddelers, 2022).

IWT has made it possible to solve many of the navigation problems associated with land-based infrastructure, which suffer from poor surfacing, traffic congestion, environments unsuited to transport due to various risks, such as soil quality, which can cause landslides, and wadi flooding, leading to the blocking of roads built near this type of watercourse (Cheranchery et al., 2021). Canals and river restoration projects are recently gaining increased attention, both to improve the quality of life and to facilitate transportation. The capacity of such projects to enhance trade depends on several factors, such as governance and waterway characteristics, including navigability, operability, depth, and length, but also climate change (Caris et al., 2014; Jonkeren et al., 2014). Successful cases of canal revitalization can also provide factors for analysis; these experiments have become a model for sustainable development that will boost cultural and tourism values, improve climate and environmental conditions, and create a historic waterside landscape that is attractive, cost effective, and energy efficient.

River renewal projects are developing all over the world and help revive aquatic life in the ecological system, such as in the Cheonggyecheon River in Seoul, South Korea (Robinson & Ji, 2022). There, the restoration of a waterway of cultural and touristic value has improved the climate and environment, attracting millions of visitors each year with its historic waterside landscape (Yoon, 2022). This waterway has become a symbol of the transition of planning paradigms in the city of Seoul and a worldwide model of sustainable development (Lee & Jung, 2015). Opposing perspectives criticize the project's economic viability and sustainability, seeing it as a form of artificiality and superficiality that fails to protect nature in the city. Even in terms of ecological functionality, according to Kim et al. (2005), the renewal of animal and plant species has not been striking, raising questions about the quality of the water that feeds this watercourse (Kim et al., 2005; Kim & Jung, 2018).

Despite the critiques, Seoul's river rehabilitation project is often seen as a major driver for revitalizing the urban center while remaining it in contact with water and nature. This project can provide inspiration for converting existing rivers and wadis to artificial canals for river navigation. This will improve the mobility system to enhance urban flows and solve urban connectivity and sustainability problems in Skikda.

Indeed, Algeria is served by rivers that provide downstream communities with water for agriculture and industry, but they have not been used for transportation purposes, despite citizen interest in rehabilitating valleys, such as Bibi, Tanji, and others. The Safsaf River, along with its network of watercourses, holds historical significance and continues to serve as a source of irrigation (Hadef et al., 2022; Sakaa et al., 2022). Despite the growth of industries located near its estuary, where water flows directly into the Mediterranean Sea (Figure 2), the river remains in use.

Thus, the scenario to convert the Safsaf River to link the ports to the industrial zone and the hinterland could benefit from knowledge gained by a project approach that enables elements of prospective scenarios to be designed and organized from a vision of urban planning and mobility in the socio-ecological transition. This article uses the cartographic tool QGIS to collect information on the Safsaf River. QGIS will enable us to establish

(a) (b)

Figure 2. (a) Satellite view capturing the liquid discharges of the refinery in the estuary of the Safsaf River on the Mediterranean Sea and (b) industrial hydrocarbon installations on the banks of the Safsaf River.

scenarios for the prospective IWT for Safsaf River and to discuss them using MICMAC.

2. Material and Methods

To better understand the possibility of integrating an IWT in Skikda, we used the prospective method, defined as a strategic method to determine future probabilities (Abril Ortega & Arias Chávez, 2020). We have structured the research in two phases that complement each other: We first mapped the Safsaf valley, using the QGIS software. Then we processed the cartographic data to analyze the creation of an IWT using the MICMAC software. The hydraulic maps obtained by QGIS have allowed us to extract the characteristics of the Safsaf River and to envision revitalizing them, as well as to propose a range of scenarios to develop urban waterways in Skikda. On the basis of the results of the first step and of the scenarios proposed for the potential revitalization of the Safsaf River, we identified a series of variables for the IWT scenario in Skikda by using MICMAC.

QGIS and MICMAC are two very different but essential tools at each stage of this research. QGIS provided the foundation to perceive and understand the morphology and the geographical characteristics of the Safsaf valley. MICMAC helped us structurally analyze the potentialities of the river network of the Safsaf valley. However, MICMAC does not provide specific factors as a decision support tool; instead, it gives users the possibility of determining their own factors in relation to their project, thus giving more objectivity to the research. This is why the choice of factors must be part of a rigorous theoretical and practical framework, and in line with the objectives of the research. MICMAC's structural analysis is based on stimulating reflection within the group to facilitate the study of the performance of the various factors (variables).

Our research provides a theoretical framework for answering questions about the importance of waterways in urban planning, and the reasons for proposing an IWT in Skikda. The introductory review will influence the use of both research tools QGIS and MICMAC, whose use will be presented separately from each other, while their results will be complementary because part of defining the design variables for the MICMAC analysis will be based on the data from the theoretical framework and the QGIS mapping. Therefore, the latter two will directly influence the behavioral evaluation of each variable in the structure matrix, from which we will obtain a direct influence map (DIM) and a direct influence graph (DIG).

2.1. The Prospective Method With the MICMAC Tool

The MICMAC tool is used for prospective structural analysis, which consists of developing a series of factors likely to influence a prospective scenario under study, and then assessing their mutual interaction (Khan et al., 2020). These factors (as variables) will be introduced into the MICMAC database to form the study matrix. Open-source MICMAC software is used to examine the impact of relationships between the variables of the matrix (Venegas et al., 2022), identifying dependency and mobility relationships (Balouli, 2022) in order to classify the variables of the system according to their strong or weak impact on the prospective scenario (Benjumea-Arias et al., 2016), thus offering the opportunity to improve the urban strategy according to the contribution of the different factors.

Based on the three pillars of sustainable development—economy, society, and environment—we have selected a set of characteristics of the smart port-city and considered them factors influencing the scenario of the IWT for the Safsaf River. These factors include opening up the port to the city, competitiveness, optimization and digitalization, the creation of ecosystems, the reduction of greenhouse gas emissions, and self-sufficiency through the production of clean energy (Ghennaï et al., 2022). The analysis factors for MICMAC in this research are also designed according to the benefits mentioned in the literature review in this article, such as the improvement of housing and transportation, facilitation of trade, and an increase in e-governance, navigability, operability, accessibility, and security.

Thus, the analysis focuses on the impact of the revival of the Safsaf River, one of the most important rivers in Skikda (Boubelli et al., 2018), and the development of a new transport system in the city. Table 1 presents the key factors that need to be considered in the development of scenarios for the prospective of converting the Safsaf River into an artificial IWT. In line with the three pillars of sustainable development, we defined 21 variables that can influence the transition of the Safsaf River into a navigable waterway, and that also have an impact on the integration of river transport in Skikda.

By considering these factors as variables within the MICMAC database (La Prospective, n.d.), the software generated a matrix table that illustrated the interdependence between factors based on their mutual influences. This matrix allowed us to define the direct influence of the ranges indicated by a standard scale, provided by the MICMAC software, from 0 to P, where 0 = no influence, 1 = weak influence, 2 = moderate influence, 3 = strong influence, and P = potential influence. The influence of each factor on the other factors proposed for the scenarios of integration of the Safsaf IWT, will be evaluated by projecting its potential impacts on the rest of the factors of the DIM matrix, according to the rating scale provided by MICMAC, which ranks the influence of the study factors from 0 to P. In addition, the specificities of Skikda's context will be taken into consideration, particularly its status as a port city with an important cultural heritage and natural landscape on the one hand and an industrial-oil reality and petroleumscape on the other. In this study, we have limited the research to direct influences, which will be presented in a DIM, elaborated in four sections, where the variables of each section share influences with specific characters mentioned in Figure 3.

2.2. Direct Influence Map Zones

The result of the analysis of the influences of the factors developed and proposed in this article for the scenarios of integration of the Safsaf IWT, based on the dimensions of sustainable development, will be presented in matrix form in MICMAC, and then the software will generate this matrix in a DIG. Reading the graph is based on the legend provided by the software, which determines the degree of influence between the factors of the proposed scenario through the degradation of the line linking the factors together, from the most important influence, represented by a bolder line, to the weakest influence, represented by a finer line. The importance of the DIG resides in its ability to visually present the impact relationships between the factors of the scenario. The aim is to give an idea of which factors have a high or low impact, enabling the integration strategies of the prospective scenario Safsaf IWT to be improved, focusing on the success factors and enhancing the scenario's weakness factors.

3. Results

3.1. Results of Mapping of the Safsaf Valley by QGIS

Prospective scenarios for the integration and supply of the prospective Safsaf IWT require hydrological data,

Table 1. Table of variables for converting the Safsaf River into a canal.

Dimensions of Sustainable Development								
	Economy	Short label		Society	Short label		Environment	Short label
1	Wealth creation	1Wealthcra	8	Passengers shipping	8Psnrshipg	15	Energy efficiency	15Enrgyeff
2	Growth in port activity	2Grprtactv	9	Employment	9Employmnt	16	Development of the seascape	16Dvlpscpe
3	Maritime freight chain	3Mritfreit	10	Governance	10Govrnenc	17	Reducing pollution	17Rdcpolut
4	Competitiveness and attractiveness	4Cmptvatrc	11	Safety	11Safety	18	Ecosystem and biodiversity	18Ecos&bio
5	Sustainable investment	5Sustinvst	12	Water, identity, and culture	12Wtridnty	19	Climate change	19Climatch
6	Feasibility and viability of the project	6Feaviabty	13	Social equity	13Eqitysoc	20	Preservation of natural resources	20NturlSrc
7	Reconstruction costs	7Recnstcst	14	Social facilities	14Socfacil	21	Management of natural risks	21MngRisks

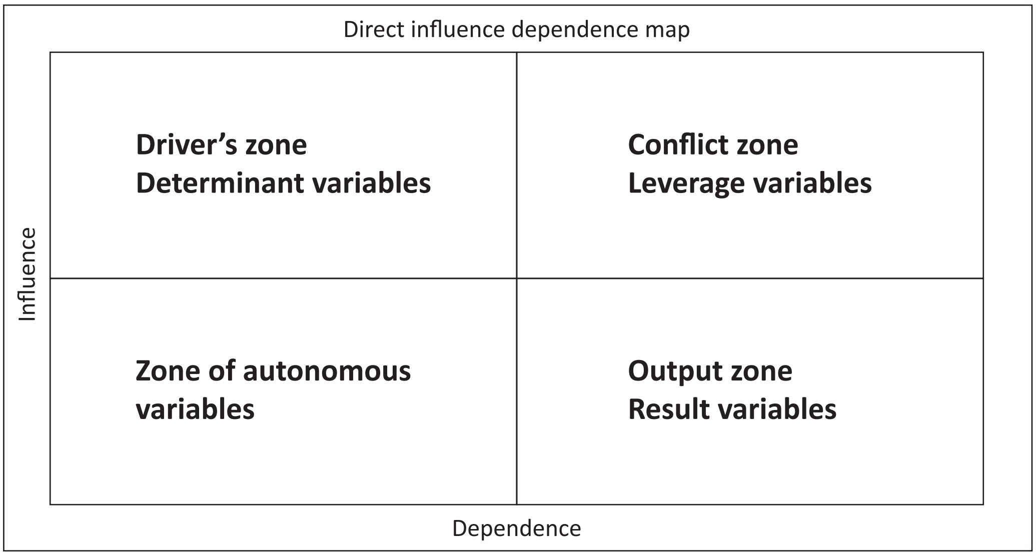

Figure 3. The specifics of the DIM zones that define the level of strength of the study variables in MICMAC.

which are obtained using mapping. The result is the map in Figure 4, generated by QGIS, which shows the morphology of the Safsaf River, its various courses and branches, its current supply from the Zerdaza Dam, and the estuary where the river flows into the Mediterranean Sea. Figure 6 projects the possible scenarios for the prospective canals, the maps also show the municipalities crossed by the Safsaf River, such as the municipalities of Al-Hadaiek, Ramdane Djamel, Salah Bouchaour, and El-Harrouch, in Zardaza to the south; Sidi Mezghiche, Bouchtâta, and Aïn Zouit in the west; and Hammadi Krouma, Beni Bechir, and Filfila in the east. The map in Figures 4 and 5 shows that the veins of this valley form a rich network capable of connecting many municipalities and urban and peri-urban areas of Skikda. It presents an attractive hydrodynamic landscape.

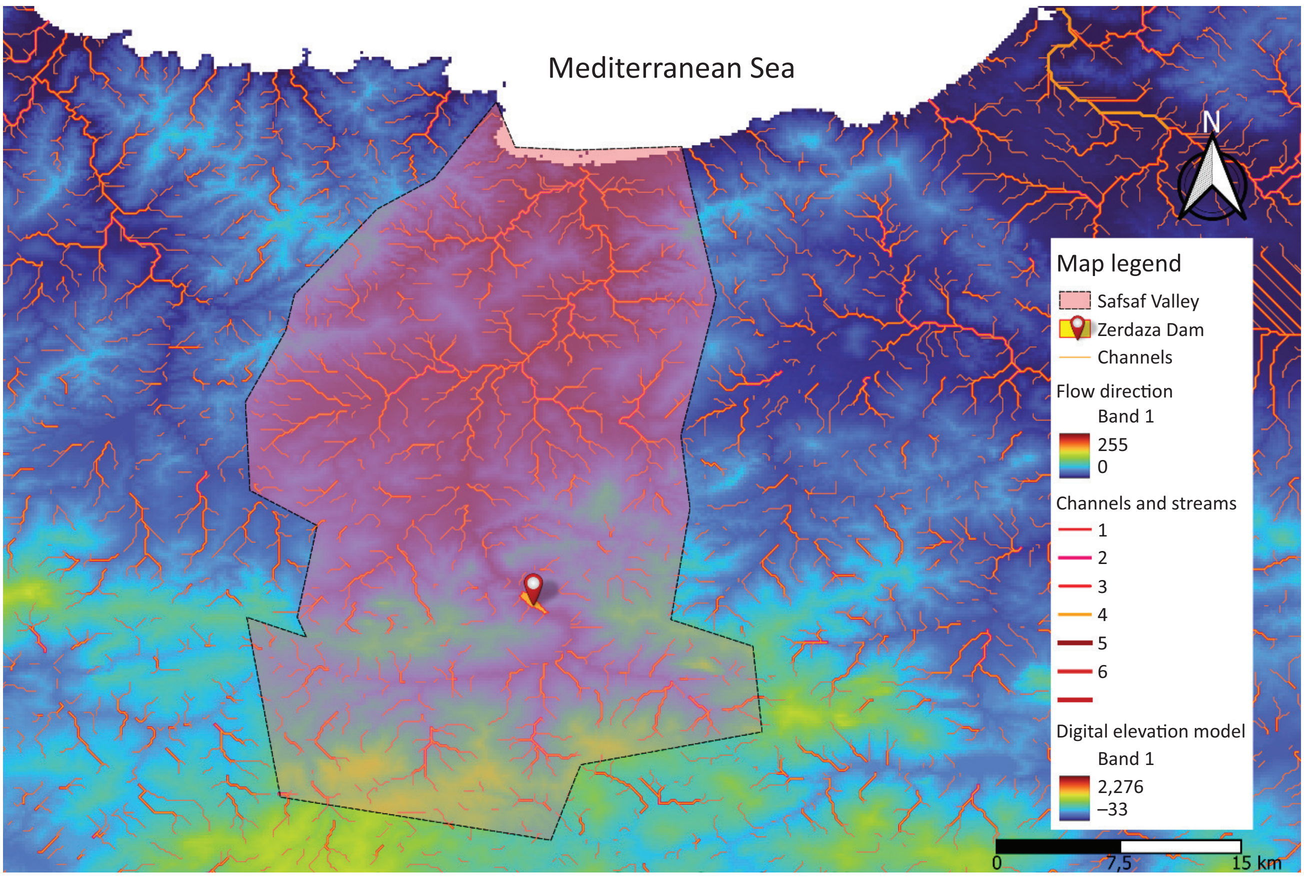

Figure 4. The trajectory of watercourses in Skikda's Safsaf valley.

Figure 5. Potential for the development of existing waterways into inland waterway shipping canals in the Safsaf River of Skikda.

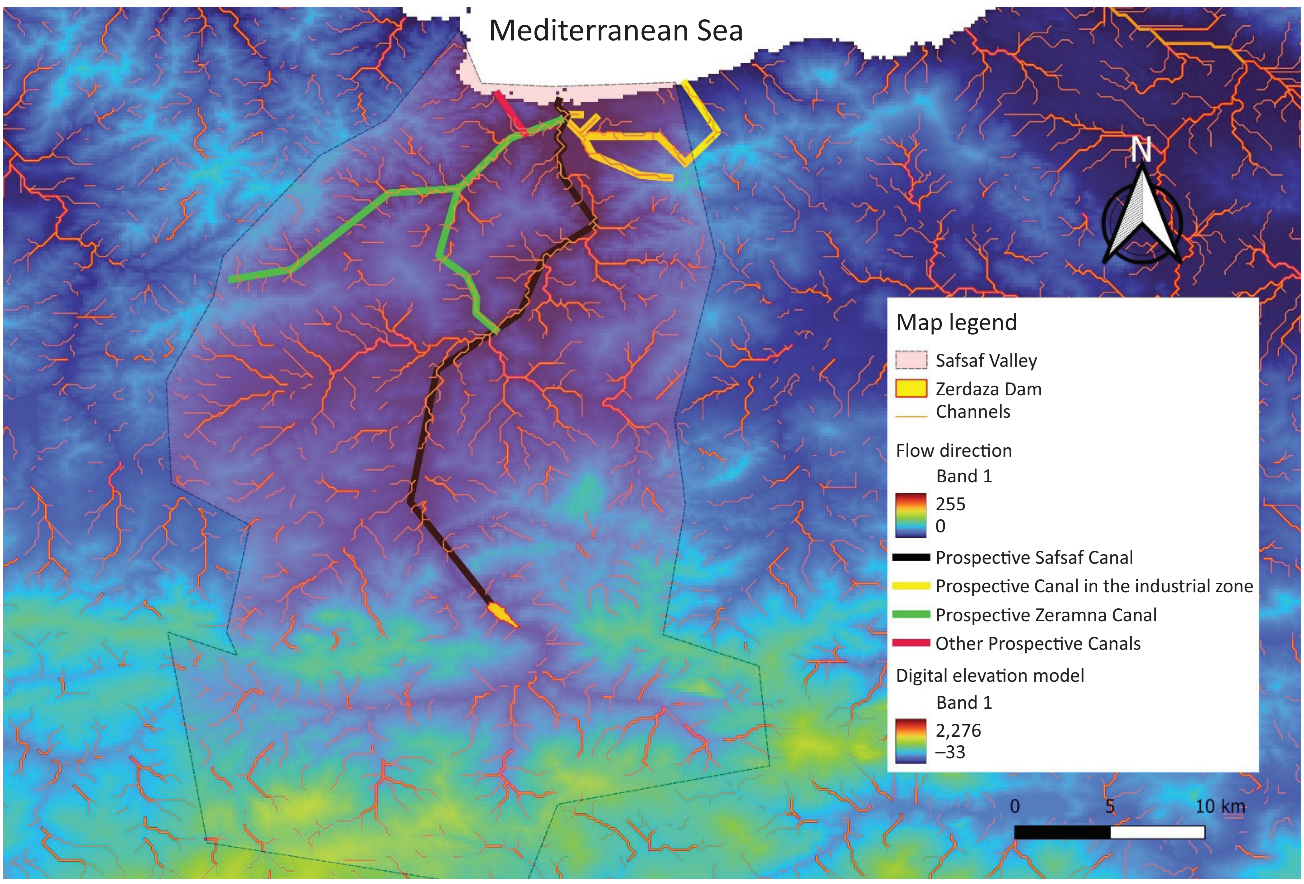

Figure 6. The trajectory of the prospective inland waterway shipping canals within the valey of Skikda.

The geographical characteristics of the Safsaf River would allow it to accommodate an artificial navigable canal. Upstream of the Safsaf River is the dam of Zerdaza; downstream is the Mediterranean Sea. In fact, the Zerdaza Dam and the Mediterranean Sea can constitute two sources of supply for the prospective Safsaf Canal, each with its own direction of water flow, opposite to the other. This makes it possible to feed the prospective Safsaf Canal, depending on the choice of the direction of the water source, where water can flow in one of the two directions, naturally or artificially. The choice of feed direction is based on several potential feed scenarios for the prospective Safsaf Canal. Salt water taken from the Mediterranean can be a source of supply for the prospective Safsaf Canal, which can be exploited either by levelling the canal at a certain depth for a certain distance, equipping it with systems that control the direction of flow, or by feeding the treatment plants that can supply fresh water to the canal.

As long as the Safsaf River is connected to the Zerdaza Dam, the latter can serve as an ideal source, ensuring an optimal flow to the prospective canal. However, the exploitation of water from Zerdaza to other destinations disrupts irrigation and the drinking water supply for the population of the municipalities of El-Harrouch, Aïn Bouziane, and Mjez-Edchiche, whose supply of potable water comes mostly from the Zerdaza Dam (Bomani, 2022). Thus, the fresh water from this dam is crucial for the stability of the local community and therefore it is essential to think about ensuring an artificial flow to the Safsaf River, without causing a shortage of supply problems. It is necessary to look for alternative ways of providing a water flow to the Safsaf River throughout the year, avoiding any possibility of water supply crises among local populations. In this context, several integrated proposals for the artificial supply of the prospective inland waterway can be provided, singly or in combination, to ensure the quantity required to feed the prospective Safsaf Canal:

- During some years in the rainy seasons the dam of Zerdaza has experienced a maximum increase in the water level, exceeding its technical capacity. The dam has had to be emptied, and water was wasted. Due to the age of the dam, built between 1929 and 1945, rehabilitating and extending this hydraulic infrastructure could contribute to increasing the capacity of the dam. Collecting this larger volume of water would make it possible to feed the prospective canal without disrupting the population's water supply.
- Almost every rainy season, the Safsaf River and the Zeramna River flood neighboring districts. A significant amount of rainwater could be collected in collinear reservoirs, allowing it to be preserved for use during the dry seasons, when it could contribute to the water flow of the prospective canal in the Safsaf River.
- A new dam could be constructed that would be dedicated to irrigation and the local population's water supply, reserving Zerdaza Dam as the supply of the prospective inland shipping canal.
- Small valleys and gorges could be redirected to flow into the Safsaf River.
- Underground water could be exploited.
- It is possible to reverse the natural direction of the water flow, so that it would flow from the estuary of the Safsaf River instead of from the Zerdaza Dam by digging a channel obliquely under sea level. This would ensure the flow of salt water to a certain depth inside the canal, taking into account solutions for flood control.
- Operating Mediterranean water desalination plants could ensure a flow of fresh water in the future inland waterway and thus preserve the ecosystem and local agriculture.

3.2. Results of the Analysis of the Prospective Scenario of Integration of the Inland Waterway Transport Safsaf in Skikda by MICMAC

Table 2 presents a matrix of the authors' evaluation, according to the level of impact of each of the variants on the others, for the scenario of integration of the Safsaf IWT in Skikda.

The factors developed in this article for the prospective scenarios of integration of the Safsaf IWT will be considered as study variables and will be entered into the MICMAC database in matrix form. With this MDI composed of 21 × 21 variables, MICMAC proceeds to analyze the influence of each variable on the other variables of the MDI, which describes the relationships between the variables and their strengths through two main graphs generated by MICMAC: the DIM (Figure 7) and the DIG (Figure 8). The DIM defines the strength of variables, classifying them in a plane divided into four sections: strong influence zone, conflict zone, exit zone, and autonomous zone. The DIG can be the result of processing data by MICMAC, in different percentages: 5%, 25%, 50%, 75%, or 100%. The DIG translates the relationship between variables into a gradient line, in size and color, aiding understanding of the relationship and influence of key factors in the prospective scenario.

4. Discussion

The first section, located at the top right of the DIM, presents the zone containing the variables of strong influence, defined as the driving variables that have a significant impact on the other factors involved in the scenario. Most variables in this zone are related to the economic pillars of sustainable development, such as wealth creation. However, the feasibility and viability of the canal strongly influence the transition of the mode of transport in Skikda through the growth of port activities and inland waterways freight. The improved qualities of

Table 2. Table of matrix of direct influences (MDI), for a prospective structural analysis by MICMAC of the factors developed in this article on the basis of smart port-city and sustainable dimensions, and which influence the scenario of integration of the Safsaf IWT.

	1: 1Wealthcra	2: 2Grprtactv	3: 3Mritfreit	4: 4Cmptvatrc	5: 5Sustinvst	6: 6Feaviabty	7: 7Recnstcst	8: 8Psnrshipg	9: 9Employmnt	10: 10Govrnenc	11: 11Safety	12: 12Wtridnty	13: 13Eqitysoc	14: 14Socfacil	15: 15Enrgyeff	16: 16Dvlpscpe	17: 17Rdcpolut	18: 18Ecos&bio	19: 19Climatch	20: 20NturlSrc	21: 21MngRisks
1: 1Wealthcra	0	3	3	3	3	3	2	3	4	3	2	2	3	3	2	3	2	2	1	2	2
2: 2Grprtactv	4	0	3	3	3	3	2	3	3	3	2	2	2	2	3	2	2	2	2	2	2
3: 3Mritfreit	4	3	0	3	3	3	3	4	3	3	3	2	2	3	3	3	3	2	2	3	3
4: 4Cmptvatrc	4	3	3	0	3	3	2	3	3	3	3	2	2	2	3	3	2	2	2	2	3
5: 5Sustinvst	4	3	3	3	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
6: 6Feaviabty	4	3	4	3	4	0	3	4	3	3	3	3	3	3	3	4	3	4	3	3	3
7: 7Recnstcst	2	2	3	2	4	3	0	3	0	2	3	1	3	3	0	3	2	3	2	4	4
8: 8Psnrshipg	4	3	4	3	3	3	2	0	3	3	3	4	3	3	3	4	3	2	3	3	3
9: 9Employmnt	2	2	2	2	3	2	0	2	0	2	0	1	4	2	2	2	0	0	0	0	2
10: 10Govrnenc	3	2	4	2	3	3	2	3	2	0	3	2	3	3	3	3	2	3	3	3	3
11: 11Safety	3	3	4	3	3	3	3	4	2	3	0	2	3	3	4	2	3	2	2	2	4
12: 12Wtridnty	4	3	3	3	3	3	2	4	3	3	3	0	3	3	2	4	3	3	3	3	3
13: 13Eqitysoc	2	2	3	2	3	3	2	3	3	3	2	2	0	3	2	2	1	1	1	3	3
14: 14Socfacil	2	2	3	2	3	3	3	3	2	3	2	0	3	0	3	3	2	2	2	2	2
15: 15Enrgyeff	3	3	3	3	4	3	2	3	3	3	3	3	3	3	0	3	3	3	4	3	4
16: 16Dvlpscpe	4	3	3	3	4	3	2	4	3	3	3	3	3	3	3	0	3	3	3	3	4
17: 17Rdcpolut	2	2	2	3	4	3	2	3	2	3	4	3	3	2	3	3	0	3	4	3	3
18: 18Ecos&bio	2	2	2	2	3	3	2	3	2	3	2	3	2	2	3	4	3	0	4	3	3
19: 19Climatch	2	1	3	2	3	3	2	2	2	3	2	2	2	2	3	2	0	3	0	3	3
20: 20NturlSrc	4	3	4	3	4	3	4	4	2	3	2	3	2	3	3	4	4	4	4	0	3
21: 21MngRisks	3	3	4	3	3	3	4	3	2	3	4	2	2	2	2	3	3	3	3	3	0

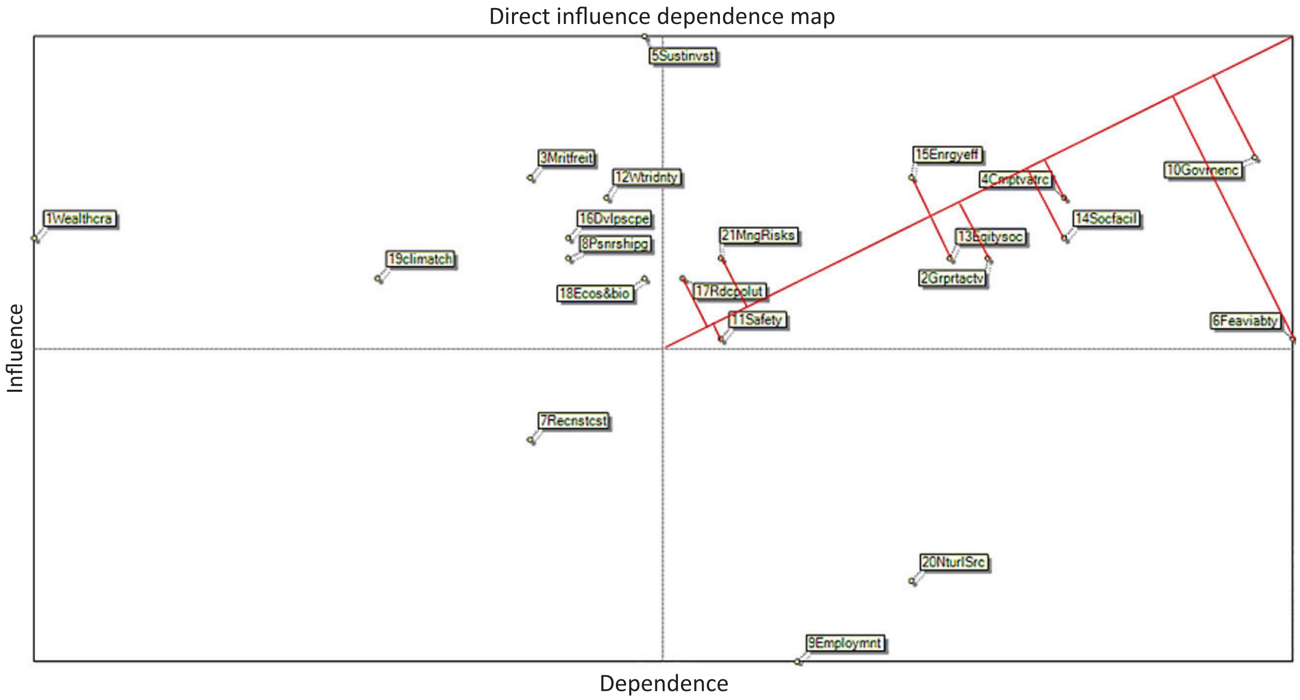

Figure 7. View of DIM for the prospective inland shipping canal the Safsaf River.

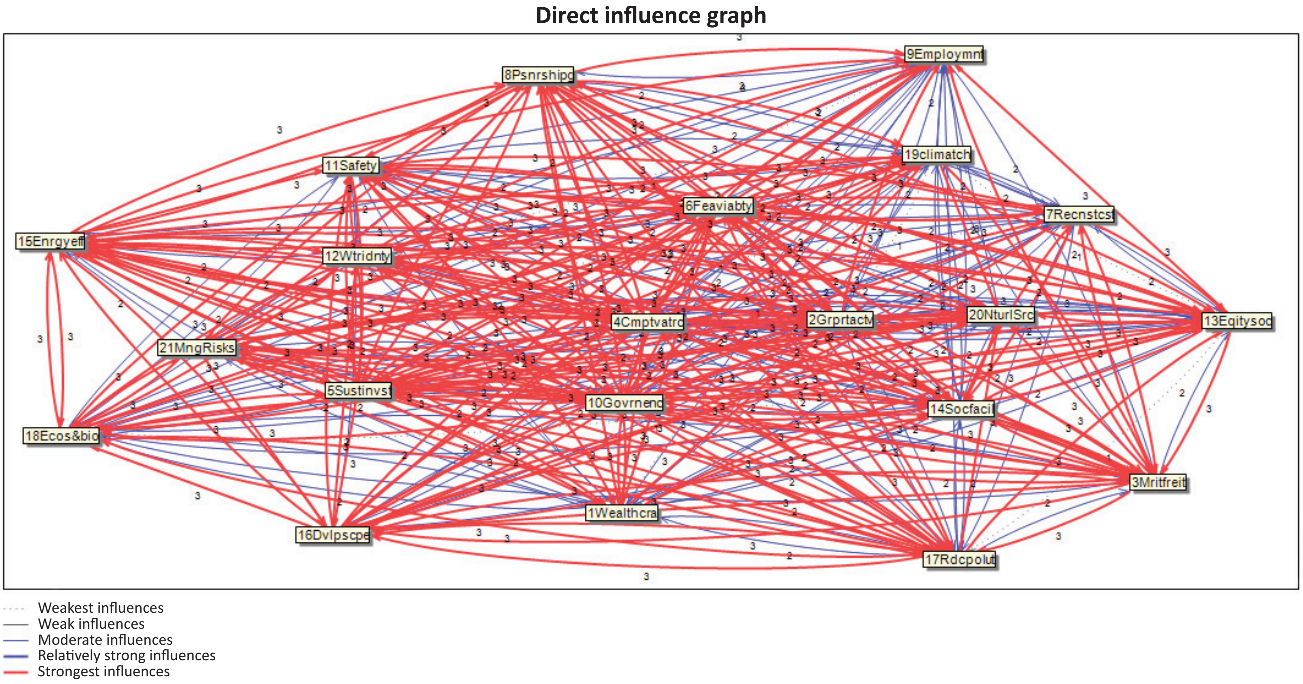

Figure 8. The analysis map of the study matrix MDI, generated by MICMAC, in the form of the DIG (at 100%) for the prospective inland shipping canal in the Safsaf River.

inland navigation strengthen the position of the prospective shipping canal, and will facilitate its integration in the socio-economic layer of Skikda. The quality of the water that will feed the canal will also be important to consider in the revitalization of the ecosystem, raising questions about the ability of these waters to continue to supply the agricultural regions inland of Skikda.

Moreover, the regeneration of waterways is a sustainable investment that will improve the attractiveness of Skikda through the recovery of the ecosystem and aquatic biodiversity, allowing the revival or introduction of activities related to water, such as fishing, walking, tourism, and swimming. Therefore, the new socio-cultural structure of the prospective Safsaf Canal would lead to a radical change of the current landscape, enhancing the area's water identity, absorbing oil industry pollution, and resolving the quadruple urban barrier in Skikda (Ghennaï et al., 2022).

The second section at the upper left of the DIM presents the conflict zone, the most important field for the prospective scenario, as it combines the variables, known as the relay variables, that are both the most influential and also dependent; hence the role of strategic factors, because they have the ability to strongly influence the other variables (Benjumea-Arias et al., 2016). Aiming to extract the most influential factors in this scenario, we use the strategic diagonal, which separates the conflict zone diagonally, and then the variables will be classified according to their location relative to the vector. The variables closest to the vector are the most strategic factors in the prospective scenario (Abril Ortega & Arias Chávez, 2020). As a result, we observe that the factors of competitiveness, security, reducing pollution, and improving energy efficiency have a direct influence on the scenario, as they provide the attractiveness of maritime transport of goods and passengers, thereby ensuring the continuity of port activities. Other factors appearing in the second zone, the conflict zone, are also strategic, such as the growth in port activities, social equity, social facilities, feasibility, and viability. Indeed, improved urban mobility, supported by the feasibility and viability of the new maritime functions of the inland shipping system, will reflect high standards for services and will improve access times to social facilities in ways that improve social equity in Skikda.

The lower left section of the DIM shows the variables known in the prospective MICMAC method as output or an excluded variables zone, which contains the low mobility but dependent outcome variables: employment and natural resources. These two factors influence the other factors of the scenario. Among them, employment is one of the indications of viability of the potential canals, while natural resources critically impact the system's feasibility, as the exploitation of water from Zerdaza Dam can negatively affect the irrigation flow and the population's drinking water supply. Therefore, the use of alternatives is recommended, such as a hillside basin, a seawater desalination program, and urban and industrial wastewater treatment. Those would be more reliable and sustainable methods of feeding the prospective Safsaf Canal.

The last area, located in the lower left part of the DIM, is the autonomous zone of dependent variables with low influence on the other variables in the MDI, where only one variable appears: the cost of reconstruction. This factor supports the feasibility of the prospective scenario by saving the costs of cleaning the flooded neighborhoods. This would be accomplished through the recovery of rainwater and redirecting it to feed the Safsaf River. However, this factor has little influence on the prospective Safsaf Canal, as the variable of the cost of reconstruction is potentially related to the inconstant Skikda pluviometry, which varies from one season to another.

The DIG divides the influence relationships between the variables in the MDI into two categories: strong and weak. Strong relationships are presented by red links, and weak relationships by blue links. According to this graph, it can be observed that there is a strong relationship of influence mainly between the competitiveness and attractiveness variables (development of the seascape, sustainable investment, water-related local identity, and culture), while the weak relationships of influence between the variables in the MDI are between employment and reconstruction costs. Thus, this graph provides an opportunity to examine the weak relationships and strengthen them to establish consolidated relationships between the different variables of the scenario matrix and determine the key variable that will contribute to the success of the prospective scenario, hence the prospect of a more dependable inland shipping system in Skikda.

The use of the prospective method with the MICMAC tool allowed us to develop a matrix made up of many factors involved in the prospective scenario. The software classifies these variables according to their influence and dependence in a DIM and translates them into a DIG. This method allows a deep vision of the importance of each variable and thus of the potential for integrating an inland navigation canal in Skikda. Consequently, the prospective method tools enable understanding of the role and influences of the key factors in a scenario and the achievement of the objectives of the prospective of the Safaf canal, under the aegis of the three pillars of sustainable development. This will help bring about a reliable transition in Skikda to a clean and smart inland shipping system.

5. Conclusion

According to this research, the prospective canal will be possible to integrate in Skikda, thanks to the adaptive hydrological characteristics of the natural watercourse of the Safsaf valley, and the maritime identity of the Mediterranean people, especially the inhabitants of Skikda, who have a historical link with water (Ghennaï & Madani, 2022). This research makes it possible to rethink not only the integration of an IWT in the Safsaf River, but also the integration of a large system of navigation by canals in Skikda, exploiting their natural potential as watercourses, and with respect to the Bibi and Tanji Rivers, which have a very attractive natural heritage, promoting a sustainable fluvial tourism economy.

This research combines two mapping methods. One is a geographical spatial mapping by QGIS to provide data necessary for the second method by building a matrix multiplication for a structural analysis by MICMAC, which in turn provides maps of direct and indirect influences. In this context, the prospect of an IWT in Skikda by the prospective method involves the exploitation of the mapping of the Safsaf valley, generated by QGIS, thus the prospecting and discussion of several possible paths to the integration and revival of the prospective Safsaf IWT, in accord with the characteristics of the valley and the municipalities of Skikda. Then, the choice of the factors, based on the three pillars of sustainable development—society, economy and environment. The influence of these factors, considered the variables of the study, will help determine the success or failure of the prospective scenario, according to the orientations of the smart port-city.

In examining the influential relationships between these factors, this study can give stakeholders a more detailed and clear view of a scenario's effectiveness, abilities, limitations, and its strengths and weaknesses. Decision centers can then work to address the weaknesses in order to minimize as much as possible the project's shortcomings and deficiencies. In this regard, the use of the foresight method in the case of Skikda has been able to provide results that allow us to form a better sense of the possibility and effectiveness of integrating of an IWT in the Safsaf River by extracting success factors and the ones that could lead to failure. This allows us to propose to the stakeholders efficient and sustainable orientations based on strategic foresight. Thus, this process is a form of smart thinking that encourages the promotion of collective thinking based on digitized methods, within the framework of sustainable development, through the digitalization of the planning process. It is part of the transition to a smart port-city.

An inland shipping canal in Skikda should promote the integration of an intermodal dynamic of maritime/canal transport system, linking the ports to the waterways in the industrial zone, as well as to the inaccessible sides of Skikda. Thus, the pressure on the city center will be reduced, and a fast flow to the university and the popular districts located in the valley of the Safsaf River will be ensured, connecting several of the municipalities of Skikda. In this way, the prospective canal will connect and homogenize the various urban entities, becoming a major factor in the development of Skikda. In addition, the integration of the Safsaf IWT Canal offers the potential to recover the ecological functions of the Safsaf River; the reactivation and regeneration of the watercourse will contribute to the improvement of the environment and help to moderate the temperature increases that result from the fumes of the refinery in Skikda. As a result, the canal will develop a dynamic aquatic landscape, promoting the porosity of the city and contributing to the creation of wealth in a sustainable manner.

In addition, safety is an attractive measure for risk management challenges associated with reclaiming a waterway in the heart of an urban fabric, especially since inland shipping is safer and cleaner than automobile transport (Fan et al., 2021). In addition, the plan to integrate a waterway in Skikda—a smart inland shipping system—should be adapted to the industrial and polluted context of the city, promoting the reduction of pollution and the creation of an energy autonomous navigation service.

Ever since this region was colonized by the French, engineers have focused on draining the rivers of Skikda rather than exploiting them for their beneficial effects. Since independence, urban strategy has encouraged the damming and coverage of Skikda's rivers. This research encourages decision-makers to adopt a different strategy, based on the prospect of a successful recovery of the Safsaf River. An integrated scenario of an inland shipping system in an industrial city like Skikda can change the fate of the city and make it a model for other Algerian cities. Ultimately, even if decision-makers have overlooked opportunities to harness the power of canals to revitalize the role of water, citizens still believe that the prospective Safsaf Canal can become an example of sustainable urban transition and a source of inspiration for a new urban thinking that aims to improve the livability of cities through water.

Acknowledgments

We would like to express our gratitude to the Laboratory PUViT (Projet Urbain, Ville et Territoire) at University F A Setif 1, Algeria, and the Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands, for their support.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 390–405
https://doi.org/10.17645/up.v8i3.6902

Article

Potential Impact of Waterway Development on Cultural Landscape Values: The Case of the Lower Vistula

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Submitted: 7 March 2023 | Accepted: 22 May 2023 | Published: 26 September 2023

Abstract

The northern ("lower") section of the Vistula is on the route of two international waterways—E70 and E40. However, the current condition of the riverbed prevents larger vessels from passing through. Plans for the waterway date back to the beginning of the 20th century. Following Poland's ratification of the European Agreement on Main Inland Waterways of International Importance in 2017, the general concept has been transformed into more concrete studies and has found its place in the national development policy. The scientific and political discourse primarily addresses the potential benefits of river regulation in the field of transport and energy. Against this background, studies on the impact of investments on the natural environment are published less frequently. Meanwhile, the Vistula has for centuries influenced the formation of a unique cultural landscape, which will be severely transformed if the river is regulated. On the other hand, insufficient transit depths of the waterway result in the loss of the function of the historic transport corridor, which also changes the character of parts of the area dependent on the river—in particular, the riverside areas of towns. This article aims to indicate the need for a qualitative landscape assessment of how the impact of investments is assessed and the best solution chosen. Using the assumptions of the historic urban landscape, the author analyses the potential impact of the planned investment in the lower Vistula on the surrounding cultural landscape. The potential scope for change in two dimensions is indicated at the scale of the lower Vistula and the individual towns. The possible impact of the investments on the panoramas is illustrated for selected cases.

Keywords

heritage; historic urban landscape; river regulation; UNESCO

Issue

This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

The Vistula is considered one of the last unregulated rivers in Europe (Angiel & Angiel, 2015), but this does not mean that its riverbed has not been transformed. Great floods have influenced the development of the dyke system since the Middle Ages. However, their entire system with sluices and pumping stations was not developed until the 19th century, perpetuating human interference in the functioning of the fluvial system (e.g., Makowski, 1997; Starkel, 2001). At the end of the 1840s, the old Vistula estuary in Gdansk was regulated (Samól et al., 2023). In the following decades, a ditch to the sea (1890) was built to protect Gdansk from the encroachment of flood waves. In the case of the main river, the Vistula, regulation mainly concerned the construction of dikes. This intervention has accelerated the flow of water and transport of debris and contributed to a decrease in retention (Starkel, 2001). The adverse effects of past transformations are raised as an argument for further regulation, the next stage of which is to be the Lower Vistula Cascade (LVC; Babiński, 2005; Babiński & Habel, 2013).

The concept of creating a system of water barrages on the Vistula was conceived in the interwar period by Tillinger (1919). The first barrage along the Vistula (Goczałkowskie Lake) was created in its upper reaches, on the border of Silesia in 1956. It was created based on Stalin's 6-year plan—the communist state's development strategy of 1950–1955. This plan also assumed the canalisation of the lower Vistula in the Warsaw-Gdansk section (Sejm of the Republic of Poland, 1950). The devastation of the war meant that the potential for constructing hydroelectric power plants was not yet recognised in this river. The approach to the Vistula changed in the late 1950s and early 60s when the Tellinger concept was revisited. This decision resulted in the construction of the Włoclawek barrage, which was put into operation in 1970. The erection of the barrage was accompanied by the creation of an extensive reservoir, which permanently transformed the landscape east of the city along a stretch of about 37 km. The concept of cascading returned as a political project in 1978. The resolution adopting so-called *Vistula Programme* included the pathetic declaration, in keeping with the era's spirit, "Let us make the Vistula a symbol of the blossoming of socialist Poland, a trail leading into the future" (Plenum of the Central Committee of the Polish United Workers' Party, 1978). Announced amid an unfolding economic crisis and already criticised by environmental circles, the project did not live to see its implementation (Jermaczek, 2017).

Over the following years, it was revisited with updated concepts for the LVC. The arguments in favour of the investment are primarily to restore the navigational potential of the river, which would provide a link between the two international waterways (IWWs) E40 and E70, providing inland waterway access to the ports of Gdansk and Gdynia, whose joint handling volume in 2022 was around 95 million T (Port of Gdansk, 2023; Port of Gdynia, 2023). The discussion has intensified following Poland's ratification of the European Agreement on Main Inland Waterways of International Importance (AGN) in 2017. Currently, most of the lower Vistula is characterised by Class I (up to 400T) or Class II (up to 650T) navigability. Only small sections meet the parameters of Class IV (up to 1,500T) and Class V (up to 3,000T) navigability (Council of Ministers, 2002, 2020). In order to meet the standards of an IWW, a minimum of Class IV navigability should be ensured, which means that the river could be navigated freely by vessels with a tonnage of 1,500T, a length of up to 85 m, a width of 9.5 m, and a draught of 2.5 m (Dziubińska & Weintrit, 2014). Indirect reference to the investment was made in the draft *National Shipping Programme till 2030* (NSP; Ministry of Infrastructure, 2022). The programme aims to restore the conditions for reliable and efficient transport on the main inland waterways in Poland. The programme does not hard-code the realisation of the entire LVC. However, it indicates "support in the preparation of the Vistula River Waterway Development Programme" and "continuation for the construction of the Siarzewo waterway degree" (Ministry of Infrastructure, 2022, p. 42). Although none of the water barrages is included in the indicative list of projects, the programme softly indicates raising the navigability class of the section from Nieszawa to Tczew to Class IV.

In addition to the anticipated logistical benefits, the energy argument is often cited (e.g., Kosiński & Zdulski, 2013; Woś et al., 2022). The LVC would be expected to enable an average annual energy production of between 3428.4 GWh and 4221.1 GWh (Szydłowski et al., 2015). In addition, the literature also argues for an alleged positive impact of the investment on tourism development (Brenda, 2013; Wojewódzka-Król, 2017) and flood prevention (Babiński & Habel, 2013).

Although the approach to environmental protection has changed dramatically since the first appearance of the concept of building reservoirs on the Vistula River, the scientific articles to date (including quite contemporary ones), as well as the studies conducted, mostly overlook the issue of numerous forms of nature conservation or classify them as an obstacle (e.g., Szymkiewicz, 2017). There needs to be more research on the impact of investments on heritage and landscape. Although a reference to landscape issues was included in the legally required environmental impact assessment for the NSP, no actual impact analysis was carried out there. The theme is very general and only two-dimensional. Even worse is the situation of cultural heritage, which has been reduced to listed monuments located in the area of the planned investment. Other forms of conservation, such as the register of monuments, protected landscape areas, etc., have been ignored.

Therefore, the presented article aims to analyse the impact of the LVC on the landscape and, in a broader sense, to show how the experience of the transformed waterways should influence the sensibility of the proposed engineering solutions.

2. Theoretical Framework

A planning condition that has become programmatically more important at the beginning of the 21st century is the context of landscape management. The European Landscape Convention introduces the notion of a "landscape policy," on which the concepts of "landscape management" and "landscape planning" appear alongside "landscape conservation." It was also groundbreaking in its stipulation that every landscape should be managed, and that the assessment of landscapes should take into account the specific values attributed to them by the parties and the population concerned (Council of Europe Landscape Convention, 2000). This was in response to a strand of anthropological work on the landscape as a cultural process (Hirsch & O'Hanlon, 1995). Starting from a heritage conservation perspective, the multifaceted importance of landscape was developed by UNESCO. In 2005, the Vienna Memorandum proclaimed that the evolving notion of cultural heritage required updated integrative approaches and methodologies for urban conservation and development in a territorial context that could respond to local cultural contexts and value systems (UNESCO, 2005). In 2011, UNESCO recommended the application of the historic urban landscape

(HUL) recommendation to historic urban areas and their wider geographical environment (UNESCO, 2011). Fundamental to this recommendation was an emphasis on landscape protection while treating the city as a whole and integrating heritage protection into the broader context of urban management—taking into account both cultural and natural features (Ginzarly et al., 2019; van Oers, 2014). In addition to assessing its physical characteristics, the urban landscape should be considered as a lived space that is infused with sociocultural values and is a subjective mental representation of the environment that changes over time and space (Thompson, 2018).

None of the above approaches assumes the immutability of the urban landscape; on the contrary, they assume the possibility of a certain transformation of the urban landscape if it aims at sustaining tangible and intangible cultural values as an element of sustainable development (van Oers, 2014).

This integral treatment of the landscape aligns with the European Landscape Convention. The HUL recommendation implies not only an integrative approach to the urban landscape but also to its wider context (UNESCO, 2011). Large rivers flowing through cities play an essential role in constructing their identity. This happens through factors that we can identify as resulting from the topography, which often determines the location of a city (wide vantage point and defensibility, location on a trade route, ability to locate a port, etc.) and the economic and cultural stratifications, the material and immaterial manifestations of which have developed based on a waterside identity. These factors changed according to the development of the art of war, transport technologies, and methods of manufacturing goods.

Large hydro projects have long been the subject of keen attention by UNESCO. In addition to their impact on the landscape of the valleys surrounding cascading rivers, they can affect the catchment landscape (Jo et al., 2022). The threat to the Abu Simbel temples in Egypt threatened by the construction of the Aswan Dam prompted a series of international campaigns in 1959 (Taylor, 2018). The World Heritage Committee has decided that the construction of dams with large reservoirs is never considered compatible with world heritage status (UNESCO World Heritage Committee, 2016).

In the development of the HUL methodology, it has been assumed that planning for recommendation-based development should involve six steps: mapping, consensus, vulnerability, integration, prioritisation, and partnership (Bandarin & van Oers, 2014; Gravagnuolo & Girard, 2017). Given that the official public discussion of the LVC has so far been reduced to a consultation on a general document such as the draft NSP and its Environmental Impact Assessment (Ministry of Infrastructure, 2022), there is still room to supplement the concept of the LVC with in-depth studies on the cultural landscape and its valorisation. In this text, I will focus on mapping and identifying potential spheres of vulnerability while identifying fields for further action in line with HUL's recommendation.

3. Methods

Taking into account the possibility of visually experiencing the cultural landscape, three dimensions of the potential impact of the development on the perception of the selected urban landscapes were assumed: disruption of the perception within the land part of the urban complex (Cullen, 2012), disruption of the possibility of water perception, and disruption of the perception of the skyline (Otero et al., 2009). Bearing in mind that the HUL also considers natural values, these will be indicated in the case studies. The presence of cultural and natural values is considered to be the occurrence of sites and spaces that, due to their quality, have been subject to various forms of legal protection. The limitation of this approach is that valuable elements not yet under such forms of protection are not taken into account, but it does allow a preliminary assessment to be made and areas particularly predisposed to further research of a qualitative nature to be identified.

The impact of cascading will first be simulated in the QGIS software using a numerical terrain model and data from the National Institute of Cultural Heritage (2022) and the General Directorate of Environmental Protection (2022). The foundations of heritage objects were assigned elevation data in the form of a centroid generated inside the polygon, which made it possible to locate them in relation to the water table (current water levels are presented in Table 1). In addition, the boundaries of the spatial forms of heritage and nature conservation in relation to the water table were verified. Changes in the perceptual possibilities of the city skylines were also identified. A numerical land cover model on a scale of 1:5000 was used as the basis for the simulations. The water barrage parameters and the water table's expected elevation were taken from an article by Szydłowski et al. (2014; Table 2).

The study mentions that water barrages will result in the creation of reservoirs, but their form is not specified. The concept of the Siarzewo water barrage, made available by the State Water Holding Polish Waters, assumes the construction of a damming threshold. The reservoir will be created only within the natural channel with embankments (State Water Holding Polish Waters, 2021). Therefore, the article considers the impact on the landscape if two scenarios for reservoir formation—spilling and capped by an embankment within the limits approximating the current river channel—are implemented. In the case of the spillway, the normal damming level was taken as the water table level after cascading (Table 2). In the case of embankment construction, the maximum damming level (Table 2) was taken as the minimum height of the embankment crest, adding 2 m for earth structures and 1.5 m for concrete structures (see Ministry of Environment, 2007, p. 5340). In both

Table 1. Current water level according to numerical terrain model.

Town	Gniew	Nowe	Grudziądz	Świecie	Chełmno	Fordon	Solec Kujawski	Toruń	Ciechocinek	Nieszawa
Water level (m a.s.l.)	9.0	13.5	17.9	21.4	22.3	28.6	30.8	36.6	39.4	41.3

Table 2. Parameters of water barrages in the LVC concept were adopted for analysis by Szydłowski et al. (2014).

Water barrage	River (km)	Normal damming level (m a.s.l.)	Maximum damming level (m a.s.l.)	Minimum damming level (m a.s.l.)
Tczew	903,500	11	12.5	10.5
Gniew	876,300	18.5	20	18
Grudziądz	829,500	25.5	27	25
Chełmno	801,500	32.5	34	32
Solec Kujawski	758,000	41	42.5	40.5
Siarzewo	707,900	46	46.5	45.3
Włocławek	674,850	57.3	58.5	56.5
Płock	618,000	64	65.5	63.5
Wyszogród	584,000	70.5	72	70
Warsaw	539,500	81	82.5	80.5

cases, the embankment system will need to be extended, with the former being lower. In the case of some of the towns in question, it may be that the height of the existing embankments or the natural elevations of the land means that raising the embankments will not be necessary. It should be borne in mind that due to the scale of the analysis, a simplified model has been used in this study. The actual height may vary and is calculated on a case-by-case basis at the design stage taking into account, among other things, the effect of wind and levelling between the water barrages. Thus, as the height of the embankments is assumed based on the less favourable variant (Ministry of Environment, 2007) it must be assumed that the target height of the embankment crest may be higher than that assumed based on the maximum damming level and the embankment material. In the descriptive layer, the results of the spatial analyses for individual cities will be supplemented with essential information on historical conditions based on literature research.

This simplified simulation of the spillway (taking into account the existing embankments) was carried out for the entire section from Tczew to Włocławek, while the variant of the construction of the embankments was simulated for selected localities with different characters, where the widening of the river would lead to the violation of important public spaces. In these cases, an additional qualitative analysis showing the likely impact of the investment on the skyline was applied. The water level in the illustrations was taken as the normal damming level. To illustrate the change more clearly, reference objects will be indicated in the analysed panoramas.

3.1. Study Area

The Vistula is the longest Polish river, whose course is divided into three main hydrological sections: Upper Vistula (from its sources in the Silesian Beskid to Zawichost), Middle Vistula (to the mouth of the Narew River) and Lower Vistula (to the Baltic Sea; Ceran et al., 2014). The lower section connects Warsaw with Gdansk and indirectly the port, flowing through several smaller industrial centres (Płock, Włocławek, Bydgoszcz, Toruń, Grudziądz, Świecie, Tczew). The E40 IWW is located along this section, which, from Bydgoszcz to the Vistula Delta, connects with the E70 IWW (Figure 1). There are numerous areas of natural value—most of the river's length is covered by the Natura 2000 system. However, other large-scale forms of nature conservation, such as landscape parks and protected landscape areas, are also present. There is also no shortage of sites of outstanding natural value in the river valley—reserves—which are concentrated mainly around Grudziądz and in the section between Włocławek and Płock (General Directorate of Environmental Protection, 2022; Figure 2).

The lower Vistula Valley area is also characterised by a great richness and diversity of forms of archaeological heritage and tangible cultural heritage. The latter group also includes two sites inscribed on the UNESCO World Heritage List. There are two ensembles inscribed on the UNESCO World Heritage List in the area in question—the Teutonic Castle in Malbork and the Medieval Urban Complex of Toruń (National Institute of Cultural Heritage, 2022; Figure 2). Both complexes were inscribed in 1997. The Malbork Teutonic Castle is located on the Nogat River in the Vistula delta. For strategic purposes, the site has an extensive exposure foreground, and its proposed

Figure 1. Vistula River divided into upper, middle, and lower courses and in conjunction with other IWWs.

extensive buffer zone (not yet approved) extends to the Vistula River in the section south of Tczew. Toruń, on the other hand, is located directly on the Vistula River, and the buffer zone of the medieval town covers both sides of the river.

In addition to the above-described ensembles on the UNESCO World Heritage List, the historic urban complexes of Tczew, Gniew, Nowe, Grudziądz, Świecie, Chełmno, Fordon (now part of Bydgoszcz), Toruń, Nieszawa, Włocławek, Dobrzyń on the Vistula, Płock, and Wyszogród are valuable and distinctive elements of the Vistula River landscape. A settlement of medium cultural value but directly linked to the river is Solec Kujawski. Further landscape linkage with the mainstream of the lower Vistula River also applies to Gdansk, Elbląg, Malbork, Kwidzyn, Bydgoszcz, and Ciechocinek.

Delimitation of the area involved several barrages. First, the area to be analysed was delimited primarily based on the boundaries of geomorphological units (Solon et al., 2018). Where an urban complex is placed directly behind a geomorphological unit boundary, which is also included in the analysis. In this area, a preliminary identification of the presence of natural and cultural values confirmed by the granting of forms of conservation was performed (Figure 2). An in-depth analysis with a simulation of water level rise was carried out for the section from Tczew (water barrage) to Włocławek, i.e., from the first of the planned barrages to the existing reservoir, including the water barrage in Siarzewo, treated as a priority. This section was considered to represent a significant variation in the valley's width while having the potential to impact the buffer zones of both UNESCO-listed communities. In addition, this section is identified as a priority for the restoration of navigation in the draft NSP. It is also noteworthy that the entire section of the river is included in the Natura 2000 bird area (Figure 2).

4. Results

For reasons of urban flood safety, the barrages have been located upstream of the settlements; however, the

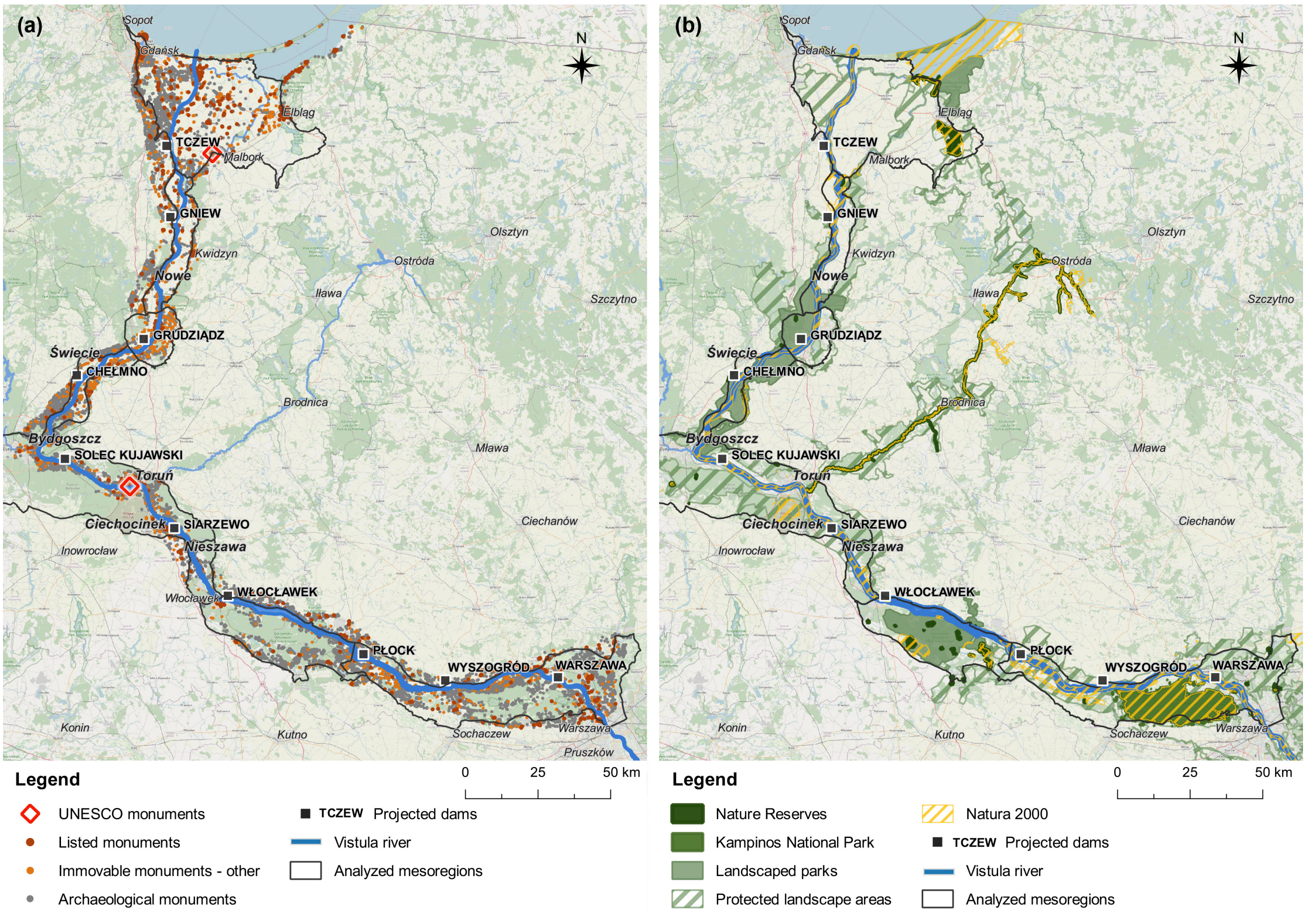

Figure 2. Forms of conservation: (a) monuments and historic sites and (b) nature.

water reservoirs may mostly affect landscapes located to the south of the site—including cities and tributaries of the Vistula River. Beginning with a general assessment of the section under consideration, it should be noted that the water barrages in Chełmno and Solec Kujawski will have the greatest impact on the landscape. The barrages in Tczew, Gniew, and Grudziądz, due to the shape of the valley and previously constructed embankments, will have little impact on the town's public spaces and panoramas (Figure 3). The more detailed contexts are described below.

Gniew: The steep slopes of the valley means that the Tczew water barrage will not have a significant impact on the skyline of the town nor its public spaces. It may have a minor impact on the Wierzyca River Protected Landscape Area, which is a tributary of the Vistula (Figure 4).

Nowe: A well-preserved medieval town layout at the foot of which, on the Vistula, are the remains of a Teutonic Castle. The tributary located at the foot of the castle—the Mątawa—is already separated from the Vistula by a system of pumping stations. Due to the possibility of containing new damming levels within the already existing embankments, the realisation of the LVC would not affect the landscape of the town or its exposure from the other bank (Figure 4).

Grudziadz: The narrowing of the Vistula riverbed facilitated the crossing, and this factor probably determined the development of the settlement. Between 1880 and 1892, the Vistula was regulated. A harbour was built on the river (Sieradzan & Kozieł, 1997). This was to open Grudziądz to the industrial era. During World War I, the Vistula slopes were the site of fortifications. The lay of the land means that the realisation of the investment will not affect the landscape of the town or its exposure from the other bank (Figure 4).

Świecie: The town is located at the confluence of the River Wda with the Vistula. Since the 1820s, as a result of regulatory works on the Vistula riverbed, the flood risk has increased significantly. The translocation plan submitted by the magistrate in 1830 envisaged the foundation of a new town in the suburbs between the Bydgoszcz–Gdansk road, built between 1825 and 1827, and the left bank of the Vistula. Between 1846 and 1857, a new district was established in the suburbs on the left bank of the Wda, called the New Town (Czaja, 2012).

The construction of the reservoir will encroach on the Vistula Landscape Park, which includes the town's suburbs, and the Chełmno Landscape Park on the opposite side of the river (Figure 4).

Chełmno: The area of the upland on which the town is situated has a form similar to a peninsula, bounded

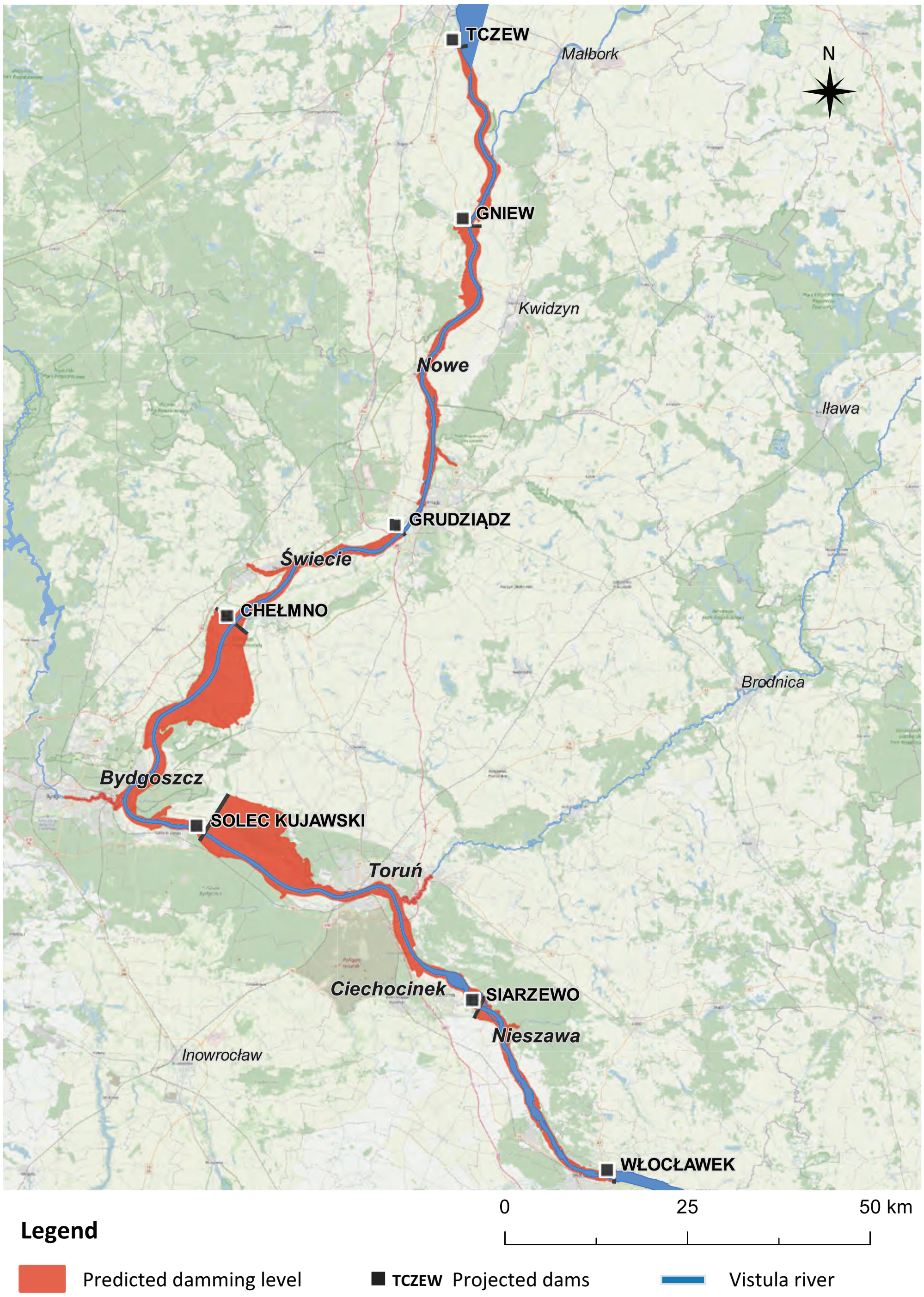

Figure 3. Spatial effects of the LVC: spillway variant.

from the west by the north slope of the Vistula River, from the south by the slope of the Browina River, and by a trough stretching from the south-east. A series of oxbow lakes form the floodplain beneath the town. The town was founded in the 13th century, initially to the north of the present town centre in the place of the later fishing suburb; it was probably moved to its present location in the middle of the 13th century, and the reasons for this decision are not known (Czacharowski, 1999). The picturesque location, however, contributed to the town's marginalisation in the age of industrialisation. The lack of a bridge crossing over the Vistula limited accessibility to the main transport routes and thus weakened the town's competitive position (Czacharowski, 1999). The implementation of the LVC would not affect the town's landscape or its exposure from the other bank (Figure 4).

Bydgoszcz: The analyses carried out indicate that the implementation will have no particular impact on the physical elements of the city's cultural landscape—with the exception of Fordon, described below, which was incorporated into the borders of Bydgoszcz in the 1970s.

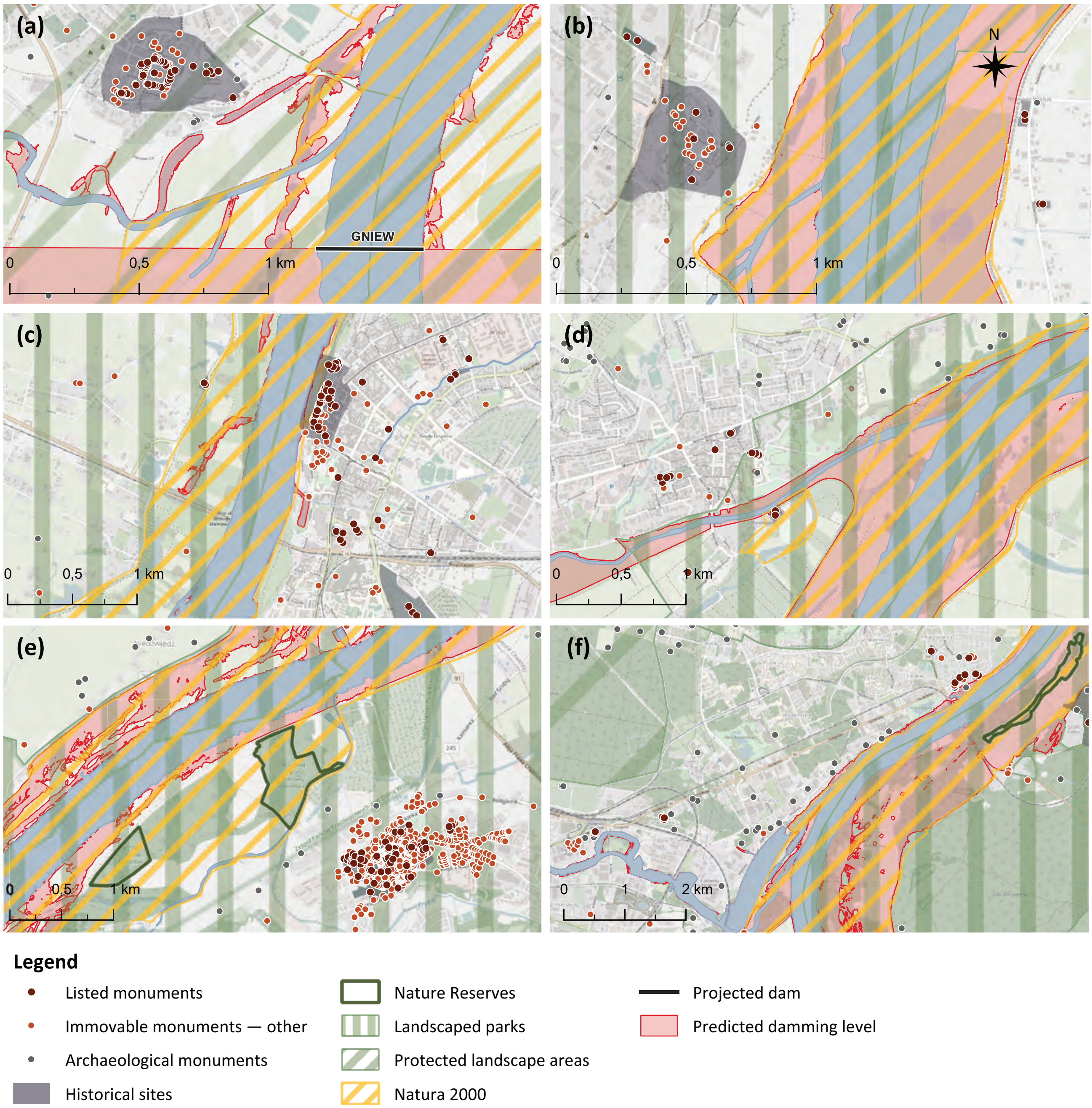

Figure 4. Impact of the LVC implementation (spillway variant): (a) Gniew, (b) Nowe, (c) Grudziądz, (d) Świecie, (e) Chełmno, and (f) Fordon.

Fordon: Located in the southern part of the Lower Vistula River Valley, known as the Fordon Valley. To the north-west, the edge of the valley is the Swiecko Upland, with slopes reaching almost 60 m in height. The medieval town lies on the bank of the Vistula, below the mouth of the Brda River, on a terrace rising about 10–15 m above the level of the Vistula (Okoń et al., 2016). The implementation of the LVC through the construction of embankments may slightly affect the access to the water from the side of the town. Here, the public spaces are elevated to between 34.1 and 35.8 m, with an assumed maximum accumulation level of 34 m a.s.l. However, the investment will affect the Nadwiślański Landscape Park on the opposite side. Once the project is implemented, the dike will separate the area from the water or water will absorb part of it resting on the upland. (Figure 4).

Solec Kujawski: The historic layout of the old town would not be compromised by the project. There is, however, a possible impact on the area at its foot containing remnants of a Dutch settlement (Figure 5)—similar to that in Żuławy.

Toruń: The city's structure now spans both banks of the river, with the UNESCO World Heritage-listed Old and New Town complex located on its northern bank. Toruń is an exceptionally well-preserved example of a medieval commercial and administrative centre

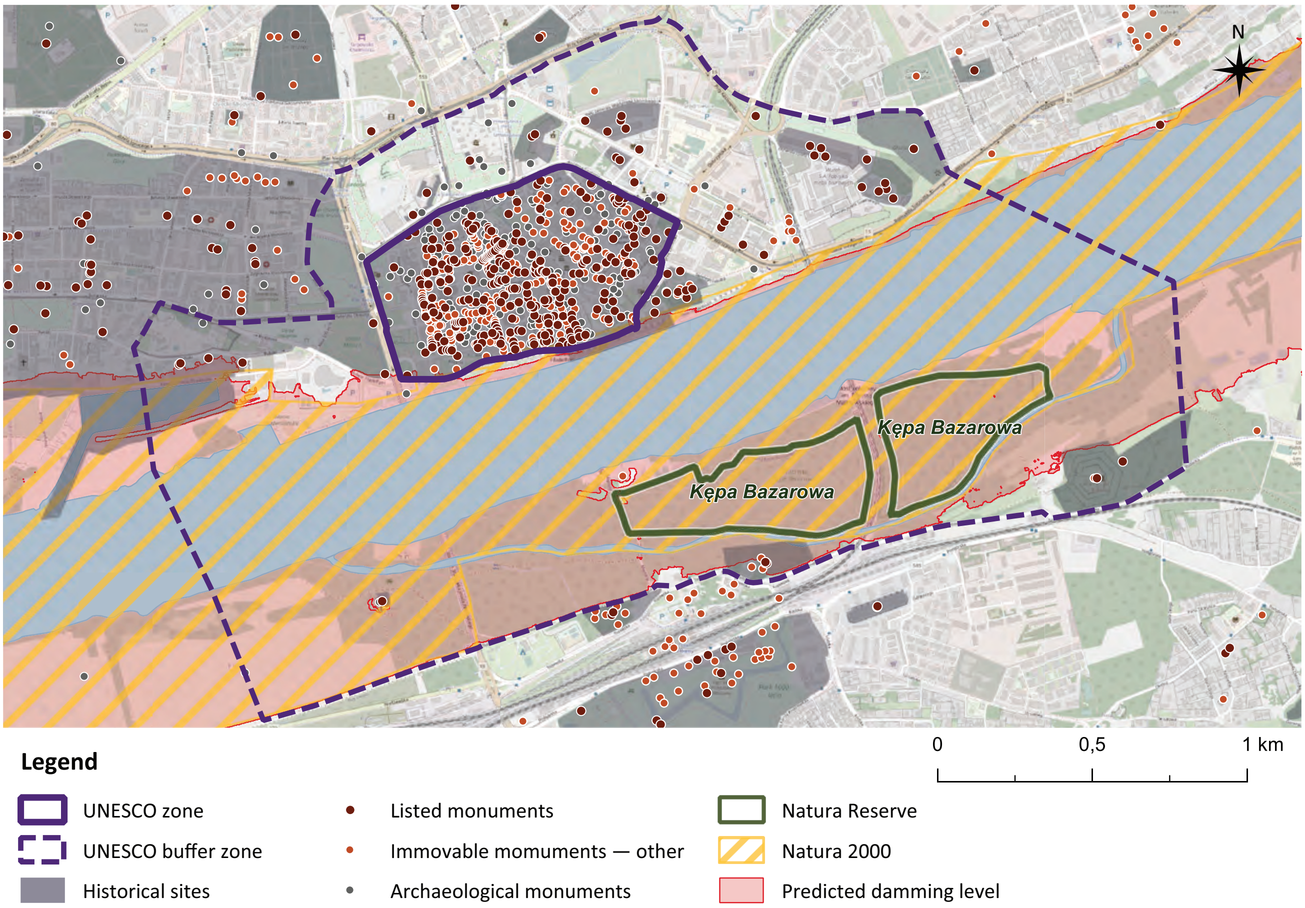

Figure 5. Impact of the LVC implementation (spillway variant): Toruń.

of European importance (UNESCO, n.d.). The layout reaches the river, creating a distinct and vibrant waterfront along its banks. On the opposite side, in the area of the former fortifications, there is the Kępa Bazarowa reserve and the remains of the relocated town of Nieszawa (Czaja et al., 2019). This valuable natural and cultural area offers an attractive panoramic view of the complex while at the same time acting as its buffer zone. The implementation of the LVC would raise the level of the Vistula at this location by 4–6 m. This would mean that the popular boulevards would have to be protected with embarkments, limiting the perception of the water. The perception of the skyline would also be altered—both assuming (here unlikely) a free spillway and the construction of embankments (Figure 5). The historic park on the old riverbed would also need to be protected.

In the context of the wider environment, it should be pointed out that the implementation of the LVC would affect the Drwęca valley, which marks the current southern boundary of the city. This meandering tributary of the Vistula is an area of very high natural value—it contains a reserve, a Natura 2000 habitat, and a Protected Landscape Area.

Ciechocinek: A historic health resort whose most valuable element is a complex of graduation towers. Due to the town's location in the highlands, it is not directly threatened by the implementation of the LVC. However, the investment would affect the Ciechocinek Lowlands Protected Landscape Area and the Natura 2000 areas located there (Lower Vistula Valley and Nieszawa Vistula Valley), in particular Kępa Dzikowska, located at the foot of the town (Figure 6).

Nieszawa: The town is located in the so-called Ciechocinek basin. It was founded in its present location in 1460, and the main axis of the present urban layout originates from that time (Czyżniewska, 1984). In the northern part of the town, in the quarter delimited by the streets and the Vistula escarpment, the Gothic St. Jadwiga Church is located. It is assumed that the construction of the Siarzewo water barrage will have a real impact on the public space in the area of the church by physically limiting or partially obscuring the view of the river, and with the spillway variant, on the possibility of viewing its panorama by significantly distancing the viewpoint on the opposite side of the Vistula (Figure 6).

Based on the previous identification, another qualitative analysis was carried out—a simulation of a perspective view of the skyline. Two settlements of different scales—Toruń and Nieszawa—were selected for this. In order to harmonise with the current character of the development, it was assumed that a concrete (north side) and earth (south side) embankment was used in the first case and an earth embankment in the second.

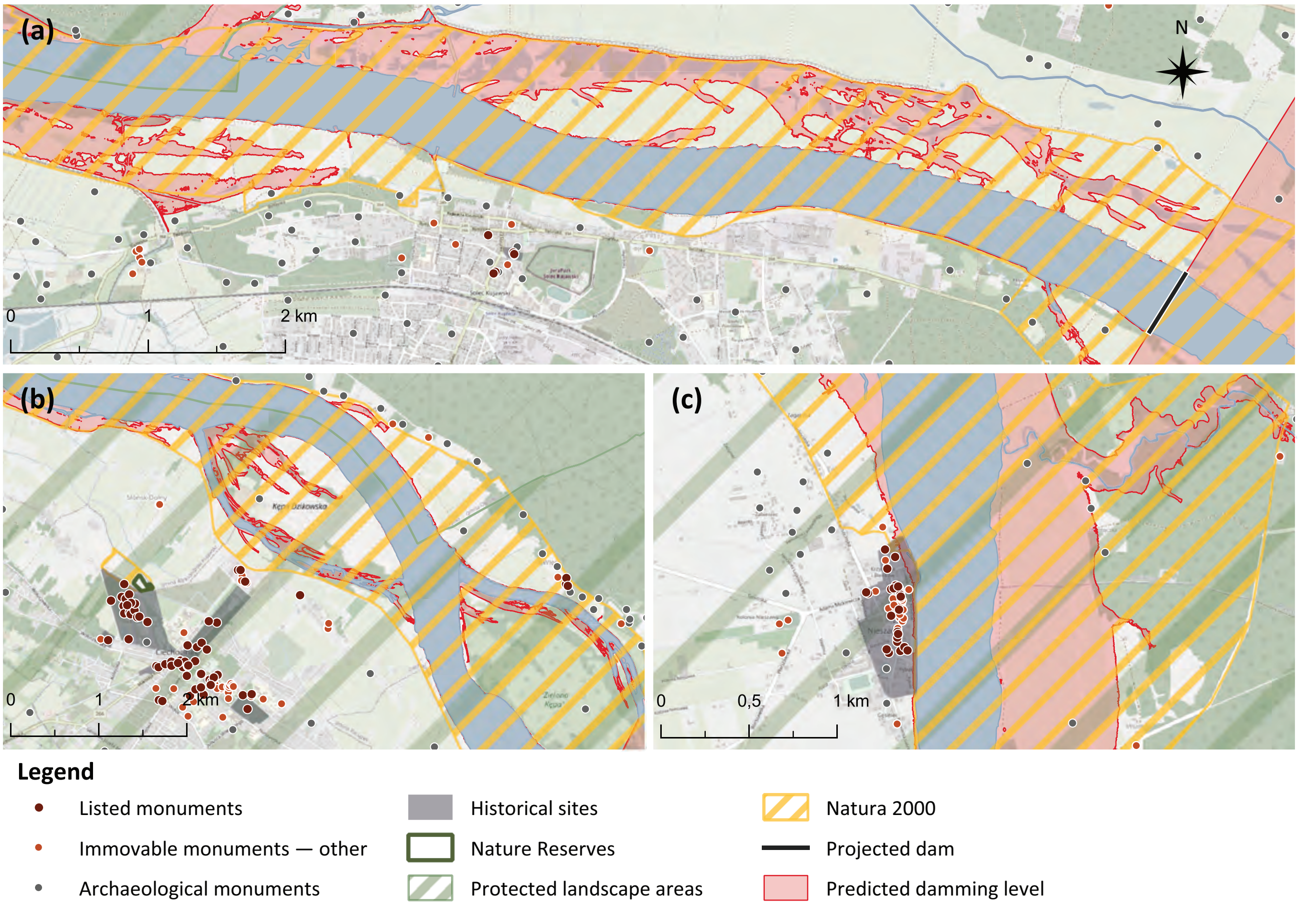

Figure 6. Impact of the LVC implementation (spillway variant): (a) Solec Kujawski, (b) Ciechocinek, and (c) Nieszawa.

In the case of Torun, the minimum height of the dike crest should be 44 m a.s.l. (north side) and 44.5 m a.s.l. (south side). The existing one by the historic Old and New Town is located 40–42 m a.s.l., while the embankments by Kępa Bazarowa reach 43 m a.s.l. This means that the crest would be a minimum of 2 m above the boulevard, while the existing embankment on the south side would have to be raised by a minimum of 1.5 m. The medieval Mostowa (Bridge) Gate was chosen as the reference site. It is located 41.47 m a.s.l., meaning it would be partially obscured if the embankment were built (Figure 7).

In the case of Nieszawa, the minimum height of the dike crest should be 48.5 m a.s.l. (both sides). At present, the boulevard is at a level of approximately 43 m a.s.l., while the old town buildings are located at approximately 46.5 m a.s.l. In this case, the medieval St. Hedwig's Church and the eyot on the Vistula were taken as reference sites. The building is at an elevation of 48 m a.s.l., meaning it would be partially covered if the embankment were built and the eyot would disappear (Figure 8).

5. Discussion

Against the background of the current plans for the LVC, it is worth noting that, with few exceptions, the construction phase of large hydro-engineering projects on rivers in developed countries ended in the 1970s. In addition to the saturation of this type of infrastructure, it should be noted that awareness of the impacts caused by river regulation on the natural environment (e.g., Hauer & Lorang, 2004; Nilsson & Dynesius, 1994), and the hydrological system (e.g., Grill et al., 2015; Kondolf, 1997), has increased significantly since then. The report of the World Commission on Dams (2000) also sent a strong signal pointing out the inadequacies of the existing approach. Currently, mainly in Europe and North America, the removal of barriers of various scales and the cessation of reservoir filling is occurring. The motives for such actions vary, but they are often economically motivated (Habel et al., 2020). The Water Framework Directive has identified restoration as a desirable direction for managing EU rivers (Directive 2000/60/EC, 2000). Looking at the cases of the heavily regulated rivers Danube and Rhine, it is noted that this is a very complex and challenging process to implement (e.g., Hohensinner et al., 2011; Muhar et al., 2016). In addition to the ecological and hydrological effects, studies also point to the negative impact of the strong conversion of river sections on the aesthetic quality of the landscape (Hermes et al., 2018). This raises the question of whether the arguments behind realising the LVC a century ago remain

Figure 7. Impact of the LVC on a panorama of Toruń: (a) before and (b) after.

valid in the face of contemporary conditions, knowledge, and experience.

Given that the draft NSP in the 2030 perspective talks about further documentation for the Vistula waterway, this article demonstrates the need to consider cultural landscape issues in subsequent works and in the strategic decision on whether and how to implement this project. The draft environmental impact assessment for the NSP cites the landscape valorisation of Poland by Śleszyński (2007), in which most of the landscapes of the

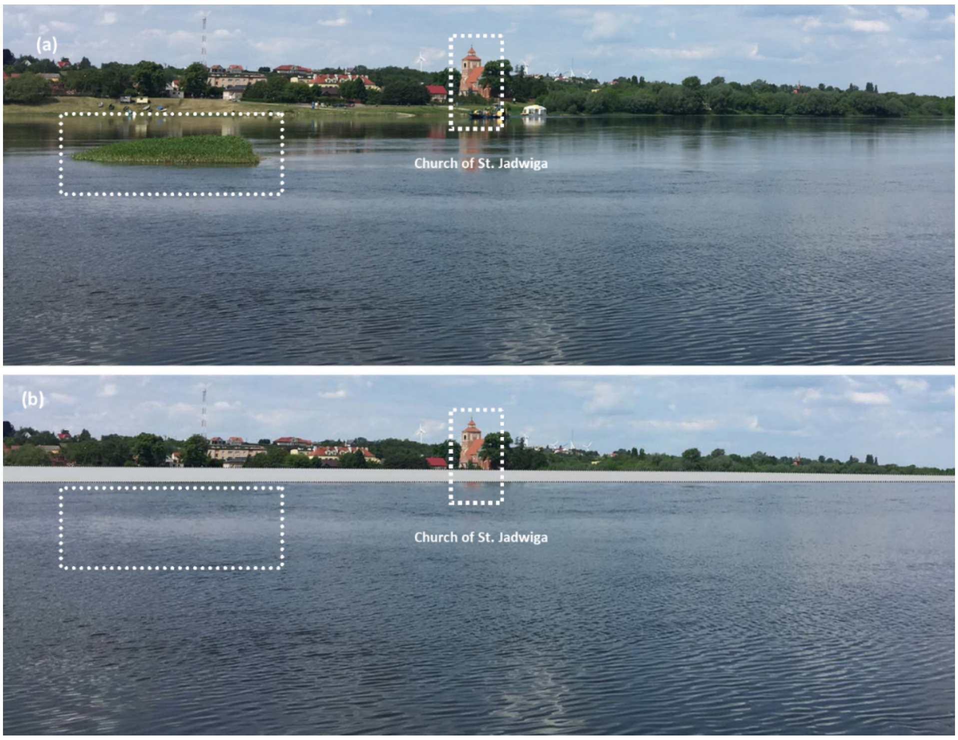

Figure 8. Impact of the LVC on a panorama of Nieszawa: (a) before and (b) after.

Lower Vistula were assessed as having average values, and the Vistula delta was assigned low values. It is worth noting that experts differ significantly in their assessment depending on the criteria adopted. For example, in the study by Kistowski et al. (2006), whose methodology emphasised the uniqueness and integrity of landscapes, the Vistula delta was indicated as a landscape of high value. It is a unique polder landscape in which the waterway provides the most interesting perspectives of layered and coexisting natural and cultural elements (Lipińska, 2012; Nowicka, 2022; Nyka, 2017). Moreover, the cited project lacks a visualisation of the impact of the investment on the landscape, not to mention considering the impact on specific riverside urban landscapes (see Cengiz, 2013).

The article primarily undertakes a general assessment of the visual impact of the construction of the core section of the LVC based on available assumptions. This does not exhaust the full spectrum of activities envisaged in the HUL recommendation, but as visual information has a 76% impact on urban environmental satisfaction (Jeon & Jo, 2020), it provides an important reference point for subsequent activities. Collisions of investments with areas considered of natural value, which are part of the urban landscapes analysed, are also presented for context. The analysis also cites the most relevant elements of the intangible waterfront heritage of these cities, for which the construction of the LVC could have a broader relational dimension.

The potential impact of the development on the latter element requires wider recognition. The draft NSP ascribes benefits resulting from the activation of the port function to the following localities: Gdansk, Elblag, Bydgoszcz, Warsaw; reloading: Włocławek, Płock, Chełmno, Korzeniewo (a suburb of Kwidzyn), and Tczew, while the greatest rationality of port development is indicated in the ports indicated in the AGN—Bydgoszcz-Solec Kujawski and Gdansk. However, the document does not specify the estimated amount of reloading, or the scale of economic activation triggered by the investment. In view of so many uncertainties, the implementation of the LVC may represent both an opportunity and a threat to intangible cultural heritage. On the one hand, the creation of conditions conducive to the restoration of economic links with the river may favour the maintenance of disappearing professions or traditions; on the other hand, the question arises whether current technical and organisational requirements will fit harmoniously into the historical context or become a threat to it.

The HUL recommendation does not provide a simple answer on how to resolve development dilemmas when they concern investments of supra-local importance. In the case of towns and cities whose brand is to be built on a site inscribed or aspiring to be inscribed on the UNESCO World Heritage List, an essential argument for giving high priority to the HUL recommendation is the risk of losing or not gaining the title. However, the decision itself is subject to the decision of the central authorities, who are the ones who direct the candidacy and are responsible for meeting the standards (UNESCO, 2021), which does not necessarily include the involvement and acceptance of the local community. A question worth developing is how to use the HUL in the context of both local and supra-local development plans—primarily regional and national. Here, the European Landscape Convention indicates the need for a common continental policy on the landscape that simultaneously respects the relationship with the landscape of its users (Olwig, 2019) but does not indicate specific multi-level management tools to help resolve conflicts. As the change in approach has come at a time when large-scale cascading projects are no longer taking place in Europe, it is difficult to identify good practices that could become a reference for the LVC. One current implementation is the Ilisu Dam in Turkey. However, the decision to implement it has been criticised due to the primacy of political and economic objectives over environmental criteria (Dinler & Özçakır, 2022).

6. Conclusions

The article discusses the potential impact of the LVC on HULs. This issue needs to be added to the academic and political discussion on the planning and implementation of the development in question. The landscape is formed by coexisting natural and cultural values. The extent of the protection to which it should be subjected derives from these two components. The implementation of large-scale developments must take an equally strong account of the impacts they have. Historically, this has not always been the case, but the awareness of the human impact on the environment today versus 70 years ago is obviously different.

The analysis presented here shows that, in terms of environmental impact assessment, the landscape must be studied both holistically (area-wise) and qualitatively (characteristic views, panoramas, etc.). A lack of awareness of the impact (or analysis of the landscape area-wise, i.e., two-dimensionally) may result in unawareness of a number of natural and cultural values that are present in the landscape. This may consequently mean their loss.

In this light, the impact of the LVC on the landscape of the Lower Vistula is beyond doubt. What is an open question, however, is the price that society and nature may pay for the implementation of the mega-investment. Answering this question is beyond the scope of this article.

Acknowledgments

Figures 2–6 were made by Krystian Leliwa based on the author's methodology.

Conflict of Interests

The author declares no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 406–424
https://doi.org/10.17645/up.v8i3.6866

Article

A Catalyst Approach for Smart Ecological Urban Corridors at Disused Waterways

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Submitted: 21 February 2023 | Accepted: 28 April 2023 | Published: 26 September 2023

Abstract

Green and blue infrastructures have always played a key role in shaping European cities, acting as drivers for urban and rural development and regeneration. There is a reawakening of consciousness by European cities towards their waterways following long periods of estrangement relating to (de)industrialisation and, consequently, the decline in industrial riverfronts. This article reviews the precedents relating to the regeneration of disused waterways in European cities, depicts the common threads that distinguish those locales, traces similarities with the Manchester Ship Canal, and develops a catalyst-based approach for future development. The catalyst-based approach is a well-established methodology in other disciplines but has not been tested in urban design. The article investigates the Deux-Rives in Strasbourg and similarities to, and possible scenarios for, future development of the Manchester Ship Canal. The catalyst-based approach focuses on connectedness, employment, health and well-being, affordable housing, and the challenge of governance in managing cross-border areas around waterways. The article explores the potential of a catalyst-based approach in developing a smart ecological urban corridor, applying possible scenarios alongside the Manchester Ship Canal. Through an investigation of the possible application of the distinctive innovative methodology, combining the catalyst-based approach with a community engagement process, the article examines possible scenarios of urban development with green and blue infrastructure linked by a linear mobility spine for a smart and sustainable urban corridor between Manchester and Liverpool alongside the Manchester Ship Canal.

Keywords

catalyst-based approach; disused waterways; European cities; Manchester Ship Canal; SPL Deux-Rives; urban ecology; urban waterways regeneration

Issue

This article is part of the issue “Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland” edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

Waterways are critically important for the health and well-being of their surrounding communities as well as the environment. They have been a foundation of material economic wealth worldwide. Waterways, in many European locales, have gone through different stages of development over the last two centuries. Many sites have seen the rise of industrialisation and, more recently, a decline in their banks. Such disused landscapes provide opportunities to develop smart urban corridors that could heal the rural–urban fabrics around waterways and provide an innovative model for future urban living, with access to the natural environment, innovative mobility modes, and the provision of contemporary economic activities.

Green and blue infrastructures have always played a key role in European cities. The overlaying patches of different rural and urban areas around waterways are complex and require different approaches and ways of thinking. The current ecological and societal challenges can no longer be overcome via current planning practices. The trends in cities' development are now established around economics, nature, the search for a new healthy urban lifestyle, and new approaches to governance that will serve the multitude of variables and everyday occurrences/disruptions that cities face.

This article investigates the possible adoption of a catalysts-based approach for the development of disused waterways. Through an extensive literature review on existing waterways' development, projects (Section 2), and a case study analysis of the Deux-Rives project in Strasburg (Section 3), key strands for development were identified and applied in a number of scenarios for the development of the Manchester Ship Canal (MSC) in the UK. The catalysts-based approach (Section 4) was applied using the identified strands in a similar development to the MSC (Section 5) to develop six scenarios for a smart ecological urban corridor between Liverpool and Manchester (Section 6). The article explores six scenarios of urban development with green and blue infrastructure linked by a linear mobility spine.

The concept of ecological urban corridors first appeared in the field of biology. With the increase in human demands and scarcity of resources, the concept has become central in rapid urbanisation and in regional integration in connecting green corridors in cities and intercities. The speed at which cities grow and the need to take over existing rural areas is increasing at a fast pace due to population growth and exodus to the urban areas (Seto et al., 2013; United Nations Department of Economic and Social Affairs, 2018; United Nations Economic and Social Council, 2018).

The rapid development of urban expansion leads to biodiversity loss and landscape fragmentation. Some argue that it is necessary to focus large scale on ecological corridors both within urban and rural areas and concern has begun to be raised on their ecological, social, cultural and other features (Che, 2001; Han et al., 2022; Peng et al., 2017; Rouget et al., 2006; Savard et al., 2000). An urban ecological corridor will meet the needs of residents in terms of creating an ecological green living open space. The term "urban ecological corridor" is usually defined by a linear or ribbon ecological landscape that provides the functions of an isolated natural habitat, green open space, or human habitat in the context of an artificial eco-environment of a city or urban area (Biscaya & Elkadi, 2021; Noss & Harris, 1986). With the paradigms of economic development and ecological protection, with the expansion of urban environmental problems and increasing human ecological demands, the efficient construction and management of urban ecological corridors are seen as a possible way to resolve the contradictions in the process of rapid urbanisation.

There are several classifications of urban ecological corridors which vary according to the structure or function of an urban ecological corridor. In terms of structural function, they can be identified as a river corridor (Han et al., 2022; Peng et al., 2017; Yan et al., 2021), a green transportation corridor (Yueguang et al., 2003), a biodiversity conservation corridor (Li et al., 2009), a heritage corridor (Yu et al., 2005), and, more recently, a recreation corridor (which is a response to urban residents' need for green open space and recreational space, i.e., walking and cycling). In terms of functional classification ecological urban corridors can be defined as a barrier corridor, impeding materials, energy, and information from flowing and, by doing so, protecting special species from external interference thus conserving biodiversity (Noss & Harris, 1986; Peng et al., 2017). These can cause natural habitat fragmentation, reduce landscape connectivity, and increase local species' extinction. Conversely, they can create ecological constraints to urban expansion and prevent urban sprawl such as London, Seoul, and Beijing greenbelt constructions (Gant et al., 2011; Munton, 2016; Yang & Jinxing, 2007). Additionally, there are communication corridors. These promote the flow of important channels for water, nutrients, energy, plants, and animals thus increasing the connectivity possibilities between important patches (Zhang et al., 2005). The two functions are not exclusive and can occur simultaneously in ecological urban corridors.

The idea behind urban development is interlinked with the way technology is shaping our present and dramatically impacting our future. The ubiquitous infrastructure is considered an enabler of smart urban development (Anthopoulos & Fitsilis, 2010; Anttiroiko, 2013; Kitchin, 2014). Technology has an impact on developing urban infrastructure, planning, water supplies, public transportation, and environmental protection (Anttiroiko, 2013; Kitchin, 2014). Complex information systems require an innovative approach to urban development (Anthopoulos & Fitsilis, 2010; Anttiroiko, 2013; Kitchin, 2014). Blue and green corridors are urban corridors developed around watercourses, flow paths, and surface water ponding along with the green infrastructure that typically accompanies urban blue corridors (Gaston et al., 2013; Kazmierczak & Carter, 2010; Li et al., 2017; Scott Wilson, 2011). The dynamic linkages and ecological relationships of both with the urban environment create areas of multifunctional use (Gaston et al., 2013; Li et al., 2017; Scott Wilson, 2011).

2. The Rise and Decline of Inland Waterways in Europe

2.1. European Waterways' Role and Relevance: Historical Catalysts for Development

At the beginning of the 21st century, European cities witnessed the phenomenon of shrinkage. The main factors attributed to causing shrinking cities include an increasingly ageing population and internal migration from underdeveloped to more competitive sustainable and healthy locations (Wolff & Wiechmann, 2018). These trends are associated with cities in North America and Europe (UN-Habitat, 2008, p. 40) that have experienced changing demographic and economic conditions that have led to spatial configurations (Haase et al., 2014; Wiechmann & Bontje, 2015). Cities in Central Europe have experienced a severe demographic shift relating to infertility, economic decline, and to selective out-migration (Haase et al., 2014). Urban shrinkage is now an issue within policies and planning strategies yet research on the cross-national comparative perspective is limited (Großmann et al., 2013). The changes in the spatial configuration of European cities present an opportunity for re-imagining their future in more environmentally sustainable and healthy contexts.

Cities are not studied as "isolated islands" but little research on urban histories has examined urban-rural links with environmental underpinnings (Castonguay & Evenden, 2012; McDonnell & Pickett, 1990). The rural landscape has been artificially shaped to meet social and economic needs, as have urban settlements. These are both shaped by the geographical, topographical, and spatial conditions of the landscapes they occupy. Spatial analysis of waterways has overlooked the varying patches of the rural and urban landscapes. Urban waterways' inter-relationships highlight the need for a spatial analysis of urban growth within a city including beyond its official boundaries (Pupier, 2020).

In many European locales, waterways have gone through different stages of development in the last two centuries. Many sites have seen the rise of industrialisation and, more recently, have seen a decline in their banks (Castonguay & Evenden, 2012). Many have witnessed the decline and disuse of their waters in parallel with the impoverishment of the communities alongside their banks (e.g., the River Mersey in the UK, Trancao in Portugal, and Alzette in Luxemburg). Ecologically, waterways have paid a high price for serving the needs of industries and their densely populated regions during the 1800s (Gollin et al., 2016). Urban growth as well as industrial wastes have contributed to a decline in the health of the waterways (Castonguay & Evenden, 2012; Knoll et al., 2017).

The fluvial power of waterways represents the collective product of not only geology, ecology, and climate but also economics, technology, politics, and human conceptions. They provide habitats, food, water, hydropower, and mobility and can also guarantee connectedness, the flow of commerce, as well as water. Their geological value is matched by their economic role; politics complement this role: Waterways connect and divide nations and regions. A source of identity, they have often become the symbol of the communities they cross and "flow over" instead, but they also present dangers.

Damming, channelisation, canalisation, water extraction, and contamination have ruined urban waterways. These factors have resulted in different levels of impoverishment: biological, loss of free-flowing waters, loss of wildness, and repercussions for adjacent floodplains and riparian lands. Flooding hazards have become more frequent and intense, impacting the urban environments surrounding the waterways. Many waterways are currently undergoing ecological rehabilitation and are cleaner at present than at any time since the late 18th century (e.g., MSC, UK; Iton River, France; Odderbæk in Jutland, Denmark).

2.2. Urbanisation and Waterways: Current Trends

UN-Habitat (2008, 2016) identified the global trends which are shaping urbanisation. Firstly, there is the merging of cities into mega-regions, corridors, and city regions. These new formations have increased interconnectivity, but have also increased imbalances. The second global trend is suburbanisation. This can take multiple forms, from informal settlements spreading to the urban periphery or more formal suburban and satellite development causing urban sprawl and suburbanisation. However, in both cases, city expansion needs to be carefully considered as it can create social, economic, environmental, and governance challenges. Nevertheless, cities are considered central to achieving the UN Sustainable Development Goals, recognised particularly by Sustainable Development Goal 11, regarding sustainable cities and communities. Hence, inclusive, safe, resilient, and sustainable approaches to city design are essential for sustainable infrastructure, urban mobility, and energy systems (UN-Habitat, 2016). The inherent complexity of urban challenges has been recognised by the EU with the Pact of Amsterdam feeding into policy initiatives such as the EU Cohesion Policy which intends to integrate urban policy initiatives and go beyond individual sector working (European Commission, 2019).

Flooding is one of the principal environmental hazards faced in Europe (European Environment Agency, 2010). The urbanisation of rivers which run through many of our cities has undermined the ecosystem services which riverine ecosystems can provide, leading some to call for restoration and regeneration schemes in order to restore the ecosystem services provided by rivers (Everard & Moggridge, 2012). As Spits et al. (2010) noted, many European cities and towns are located along rivers in former flood plains. Their analysis of national and municipal policies in cities in the Netherlands, France, and Germany showed a trend towards policies to maintain river discharge capacity and, specifically in the Netherlands, a further change in policy to allow space for rivers. Furthermore, each country is found to approach the issue of building on flood plains differently. With development pressures for urban expansion likely to maintain an interest in riverfront and floodplain development, finding ways to combine both, i.e., room for the river and urban expansion, requires creativity (Spits et al., 2010). Others have observed a shift in European policies on flooding away from traditional policies on protection towards risk management and adaptation (Hayes et al., 2014; Mostert & Junier, 2009; Roslan et al., 2021).

Deprived communities around (dis)used waterways in Europe present a real challenge to cities' expansion. Studies have pointed out the need for creativity in addressing them (Spits et al., 2010) and the priority is to establish a baseline through a cross-national database that can provide a thorough assessment of these blue-ways' current conditions. From the Oresund Lagoon (Copenhagen) to the salt marshes of Aveiro (Portugal), from the industrialised banks of the Meuse in Liège (Belgium) to the Teressa River in the Catalan Valles (Barcelona), existing case studies allow for the identification of urban development catalysts, relying on a partly forgotten hydrographic network, which can be absent from the imaginary and the metropolitan narrative.

Cities are rediscovering their neglected waterways after decades of industrialisation and economic growth (Biscaya & Elkadi, 2021; European Environment Agency, 2016; Knoll et al., 2017). Berlin and Liverpool have been cleaning their rivers and rethinking urban planning around them. While the relevance of water and waste in the industrialising city has long been a focus of urban environmental research, waterways have not received the same attention (Kaika, 2004; Koop & Van Leeuwen, 2017). The reintegration of blue ways into urban life has been mainly conducted through decreasing pollution, parks development, and pathway construction based on ecological restoration (Castonguay & Evenden, 2012; Coates, 2013).

Recent projects around waterways in Europe are country- or locale-specific, focusing on different facets of development. Some projects focus on assessing and promoting heritage and tourism around blue ways such as the project "European Waterways Heritage: Re-Evaluating European Minor Rivers and Canals as Cultural Landscapes," aiming at promoting the cultural heritage of minor waterways and historic canals in Europe, or the NIWE, a network of canal, river, and lake waterway operators and promoters of the economic, social, and environmental benefits of Europe's inland waterways (ongoing). With an emphasis on transportation, the European Commission funded the Waterways Forward project under the EU TRIMIS—Transport Research and Innovation Monitoring and Information System (2010–2012).

Projects focusing on specific locales or countries include: Waterways for Growth focused on the North Sea Region (2007–2013) under Keep.EU (European Commission), London Waterways (social enterprise, ongoing) aiming to support communities that live on London waterways with emphasis on small urban mooring sites, Galway 2020 (ongoing) focusing on promoting and on the development of waterways in Galway, and, more recently, EMMA, funded by the Interreg Baltic Sea Region Programme (2014–2020) supporting integrated territorial development and cooperation for a more innovative, accessible, and sustainable Baltic Sea region. Additionally, there is the Danube STREAM—Smart, Integrated and Harmonized Waterway Management, focusing on the clean growth of transport management around the Danube.

RiverWiki, funded through the Environment Agency and managed by the River Restoration Centre (UK), provides an interactive source of information on river restoration schemes from around Europe. The focus is on the environmental restoration (i.e., water and biodiversity) in European rivers.

The World Bank supported a few projects in the 1990s and early 2000s around ports and inland waterways but none since then. Examples of the redevelopment of river/canal sites include the Bradford-Shipley canal road corridor in the UK (Bradford Council, 2017), the Hafen City Hamburg project in Germany (Ministry of Urban Development and the Environment, 2014), and Cheonggyecheon stream as part of Seoul's urban regeneration plans (Cho, 2010; Lee & Anderson, 2013; Temperton et al., 2014). All projects are due to be completed by 2030 with the projects in Hamburg and Seoul being at the forefront of urban regeneration awareness.

The Bradford Metropolitan District Council has developed the Bradford corridor which stretches over 3.10 miles in length and looks at housing, job creation, and ideas to deal with the rapid population growth in the area (Bradford Council, 2017). The Hafen City has been in development since 2000 with the aim of integrating the inner city with the existing port and industrial area. Since 2010, a new proposal has been under development to deal with the increasing growth in population and consequent growth of Hamburg city, due to its status as a city-state, as a highly successful port, and also due to its strategic position at the crossroads of Eastern and Western Europe. The principles of the project are based on its relationship with the river, existing urban qualities, and the quality of its open spaces. The project focuses on inclusiveness, affordable homes, education, and improving the quality of life through public spaces and green and environmentally-friendly city development which intends to result in an improvement in the quality of life of its citizens, improved mobility, and integrating natural space in the city (which is facing the current and future climate changes' challenges through energy turnaround; Couch et al., 2011; Ministry of Urban Development and the Environment, 2014; Sepe, 2013).

More recent waterways-funded projects include Waterborne and MERLIN (Horizon Europe 2022). The first focuses on clean maritime transportation and the second on the ecological restoration of freshwater-related ecosystems. The projects include a workstream focusing on inland European waterways.

3. Urban Development of Waterways: The Deux-Rives Project, Strasbourg

The literature review on inland waterways in Europe enabled the identification of historical catalysts for urban development around waterways as well as current trends. The case of the Deux-Rives project in

Strasbourg captures many successful urban catalysts for the redevelopment of neglected European waterways and supports the catalysts-based approach applied to the MSC. The Rhine is a major European river, stretching from Switzerland, through France, Germany, and the Netherlands to the North Sea. Its length is over 1,320 km, of which 880 km are navigable. Its catchment area covers Italy, Austria, Liechtenstein, Luxembourg, and Belgium (Frijters & Leentvaar, 2003). Ecologically, the Rhine Valley is an alluvial reservoir containing the largest European groundwater resource (Longuevergne et al., 2007).

The river's geographical position has been considered as a conflictual border between France and Germany for decades (Febvre & Schöttler, 1997). Conversely, it has also been a strong symbol of international cooperation, for example when it was part of the Vienna Treaty (1815) and was opened to international traffic (Reitel, 2006). Strasbourg is part of this narrative; it has been claimed in different periods of history over the last five centuries by both France and Germany. It has been part of France since the end of the Second World War.

The Rhine river basin is made of four distinctive river ecosystems; the High Rhine (above Basel and mostly located within Switzerland's boundaries), the Upper Rhine (situated between Basel and Bingen), the Middle Rhine (in between Bingen and Cologne), and the Lower Rhine (the lower stretch of the river between Cologne and the German-Dutch border and the arms of the Netherlands delta; Frijters & Leentvaar, 2003; Mellor, 2021). The lower stream was subjected to major flood controls in the 20th century. The river historically has played a significant role as a safe border between antagonistic neighbouring states as well as being a major shipping route (Frijters & Leentvaar, 2003; Mellor, 2021). The more recent border change in the Rhine has been the one between France and Germany following the chemical disaster of 1986 (Van Dijk et al., 1995).

Due to its geographical position and cross-border cover, the Rhine has suffered from rapid industrialisation since 1850 (Reitel, 2006) causing water quality deterioration (i.e., wastewater discharges by industries, agriculture, etc.) with consequent high levels of pollution rates causing severe damage to its ecosystems. This was exacerbated by the fire at the Sandoz chemical factory near Basel for which the river water was used to extinguish the fire, and this used water then flowed back into the Rhine causing the extinguishing of nearly all the aquatic life downstream (Schiff, 2017). The Sandoz incident was the driver for the transboundary collaboration through the Rhine Action Programme of 1987 or the "Salmon 2000 Goal" (Frijters & Leentvaar, 2003) and the inception of the eco-city, Deux-Rives project in Strasbourg.

3.1. Strasbourg, Upper Rhine

A major port city with the second largest inland port in France, Strasbourg is situated in the traffic junction connecting the Atlantic to a wider Europe and Germany to Italy; it has always benefited from its transborder location (Bik, 2006; Pupier, 2020). As with the MSC, it has witnessed a decline in its use and its preeminent economic role and geographical position following the decline in shipping and the environmental crisis; this has caused a significant impact on the communities based around the two rivers.

The city sits between two rivers, the Ill and the Rhine, both contributing to its significance in the 19th century but also to its downfall due to three main factors: (a) increasing floods in the alter Rhine which affected Strasbourg's citadel, consequently being the focus of various projects for river regulations around the bridge between the Strasbourg and Kehl; (b) these and the rapid population growth and absence of appropriate sewage systems which have lowered the water table resulting in the ending of shipping and the decline of the rivers' water quality (Knoll et al., 2017; Reitel, 2006); and (c) issues with urban governance and water management changing its hydrological profile have also played a key role in its decline (Koop & Van Leeuwen, 2017). Another factor which has contributed to the rivers–city relationship and its consequences is due to the municipality of Strasburg being subject to the national water strategies of the foreign policy of France and Germany throughout its history (Knoll et al., 2017; Koop & Van Leeuwen, 2017).

Despite being located 3 km from the river, during the 17th and the 19th centuries Upper Rhine water management changes, both Strasbourg and Kehl became border cities giving way for a cross-border urban space to grow, with the main functions of a city and including the majority of the population (Reitel, 2006; Sohn, 2014). This area gave way to several new projects following the Sandoz ecological accident in 1986 with new cross-border cooperation initiated and developed by the European Union (Pupier, 2020; Schulte-Wülwer-Leidig et al., 2018).

3.2. EcoCités, "Deux-Rives/Zwei-Ufer"

Strasbourg's historical role and geographical position as a key border city and, subsequently, its development during the 20th century with its expansion to the north, south, and west at the cost of its border with Germany posed a number of challenges. The Grande Île of Strasbourg has had World Heritage status since 1988, the first urban area of France inscribed in UNESCO's World Heritage List (UNESCO, 2023). With the growing need for housing, and using the wastelands so as to avoid urban sprawl, the city turned to its neighbour across both the waterways, the Ill and the Rhine, from Strasbourg to Kehl in Germany (Mazzoni, et al., 2016). The aim was to be internationally recognised for its Franco-German identity through a vision of people-centred transboundary cooperation across states while retaining its human dimension and its connectedness with nature and green areas while preserving and respecting its heritage. With a vision to establish an economic and cultural centre in Strasbourg, the project focused on developing four districts: Citadelle, Starlette, Coop, Rives, and Port du Rhin (City and Eurometropolis of Strasbourg, 2009, 2010). The vision was pursued through car-free arteries and organically connected neighbourhoods with vegetation through to a high-quality environmental strategy that encompasses the transformation of 250 ha of port wasteland from the Ill to the Rhine (City and Eurometropolis of Strasbourg, 2010).

In response to the Ministry of Ecology's EcoCités initiative, both cities collaborated to promote several large-scale sustainable city projects in the urban, social, and energy areas based on the challenge of the expected demographic growth of 50,000 new inhabitants by 2030 (Almassy et al., 2018; City and Eurometropolis of Strasbourg, 2010). The project's rationale was based on the region's competitiveness, its exponential demographic growth, the increasing numbers of younger and most-deprived sectors of the population in the territory, an economy centred on creativity and innovation, and considerable land resources. The project is anchored on three interlinked layers: the blue, the green, and the public transport framework (Figure 1).

The blue layer preserves the visible and invisible (underground) water to secure the quality of the environment. The area's historical context made it the structuring element of the design. The green layer is made up of parks, forests, and valleys that run along the watercourses and agricultural land linking the territory. Its fundamental role is in establishing the spatial relationship of the city with the wider region, as with the water framework, but also to guarantee ecological continuity and biodiversity protection. A dedicated corridor of public transport, consisting mainly of tram and rail networks, links the two cities and the different areas (i.e., living, working, and leisure). It is also linked with the wider transport network outside Strasbourg. The aim is to remove car traffic from the area. The layers serve as

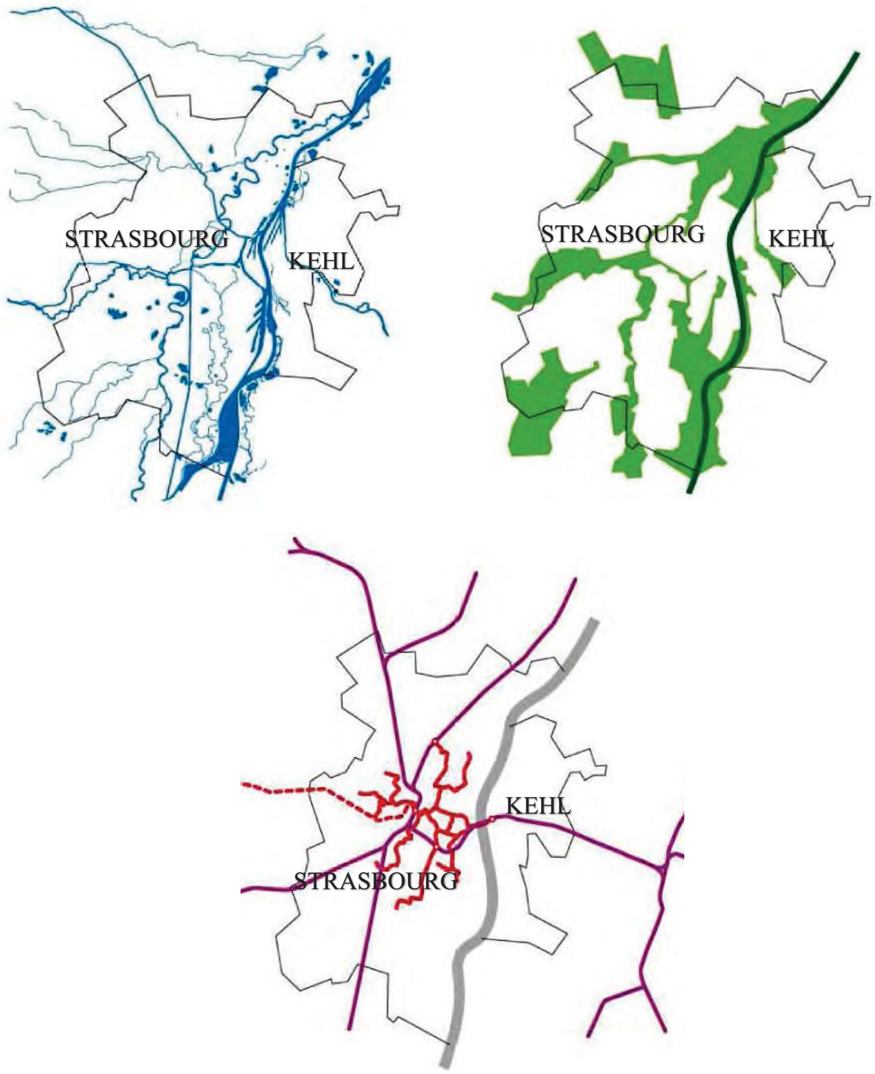

Figure 1. Strasbourg blue, green and public transport framework. Source: Authors' work based on City and Eurometropolis of Strasbourg (2009, p. 5).

an urban development framework and are to be read and interpreted in juxtaposition (City and Eurometropolis of Strasbourg, 2009, 2010, SPL Deux-Rives, 2023).

3.3. Identified Key Development Principles

Connectedness, a key principle of the project, is the continuous linkage with Germany through the tram line estalished in 2012, supporting the city's future urban development. The transport line plays a significant structuring role in lessening the effects of demographic growth in the Port du Rhin area. The tram network was complemented by an increase in transport bike infrastructure. Ecological connectivity is, therefore, one of the key project drivers.

In 2016, the project was extended to public-owned developers and the adopted strategy was based on urban development programming in a "non-static" manner which will allow the project to evolve and adapt according to the feedback received (Strasbourg, 2023). The key principle in the applied methodology is "iteration," the project unfolds and develops with time and through the different add-ons and their assessment. The stakeholders involved from both sides of the waterway include: the project owner and manager, elected representatives, current and future inhabitants and workers, local residents, and associations (Strasbourg, 2023), thus increasing the region's resilience through cross-cooperation in urban planning development. The project's other principles include *inclusivity and cultural diversity*, increasing *employment and high-grade technical job* opportunities, connectedness with nature to promote a *healthy living environment*, preservation of historical and cultural heritage, securing quality for the environment through an ecological balance, *social justice* and local democracy. These principles are translated into three project axes that aim to build the metropolis on the two banks of the river.

The first axis is to recycle urban spaces and open the metropolis to the river by highlighting the Grande-Ile, a World Heritage site, in urban policy and creating a metropolitan belt linking the historic city centre with the suburbs and different municipalities (Figure 2). The second aims at structuring the metropolitan district's poles and centres to encourage a social and functional mix, supporting the tram network's constant urban renewal (Figure 2) and the third axis focuses on nature in the city and the quality of the public spaces and also on preserving large areas for agriculture to supply the metropolis.

The strategy is driven by 24 projects with different timeframes and is spread across 23 municipalities with a vision for almost 17, 000 housing units thus increasing affordable housing in France by 40% with 80% situated near public transport, for the expected increase of 50,000 inhabitants by 2030 (Almassy et al., 2018).

4. Catalyst-Based Approach for Waterways' Urban Development

A catalyst-based approach is used in this article as a method that incorporates many urban designs' best practices—granularity, incrementalism, and the mixing of uses, scales, and people. The catalyst design approach has been used in both chemistry and biology to improve activity, selectivity, and the scope of a catalyst application (Abbasi et al., 2022). Initial catalyst identification is based on published literature with the goal of utilising already-existing catalysts as opposed to developing new ones (Abbasi et al., 2022; Imhof & Van der Waal, 2013). Catalysis-based research can be complex. Regardless of the catalyst development tools used, involving key stakeholders from the beginning and taking into account the overall impact of a catalyst on the process is the key to success (Imhof & Van der Waal, 2013; Moulijn et al., 2000). This approach/method might not be appropriate for all regeneration schemes. The application of a catalyst-based approach in this article focuses on areas abandoned because of deindustrialisation, in some

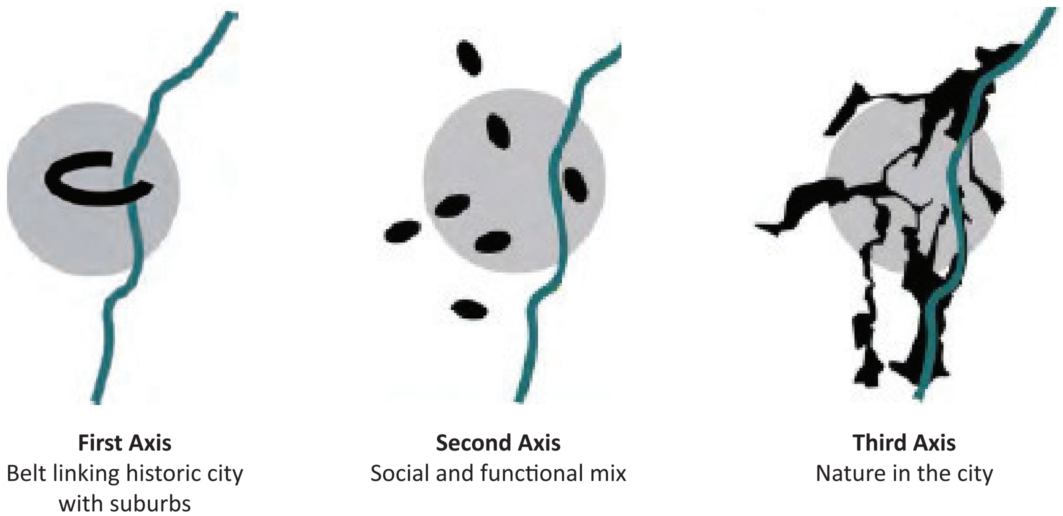

Figure 2. Deux-Rives project's axes. Source: City and Eurometropolis of Strasbourg (2009, p. 2).

cases recycling the properties of waterways cleared or left vacant by mid-20th century urban "renewal" programmes in neighbouring cities. The article presents a number of ecologically based scenarios for the MSC based on the identified catalysts from the literature review and Deux-Rives case study.

Identification of the initial catalysts was obtained based on Gough et al. (2017) guided literature review and thematic analysis of European disused waterways' catalysts for urban development (Vaismoradi et al., 2016). Springer, Science Direct, Google Scholar, IEEE Xplore, and ACM Library were extensively used. Articles, reviews, case studies reports, conference proceedings, and book chapters were reviewed. Significant research publications published between 1999 and 2019 were obtained on: (a) green and blue urban corridors' historic development and methodologies; (b) European cities' growth and the societal and ecological challenges it presents as well as applied catalysts; (c) European urban growth in relation to climate change, urban population, pollution, and depleted infrastructure; (d) new trends such as disruptive technologies, digital cities, and urban data analytics; and (e) contemporary catalysts for urban development and innovative ways to support ecological urban growth through blue infrastructures that consider natural risks as part of the urban systems' stability. This review and the Strasbourg case study analysis also identified general themes and catalysts to be applied to the MSC case study. The literature review and the waterway urban development precedents revealed five common threads: (a) connectedness, (b) employability, (c) health and wellbeing, (d) housing, and (e) governance.

4.1. Connectedness

Waterways could be, if not well integrated, a divided natural element as much as a connector feature. Maintaining and/or enhancing connectedness between the different rural and urban patches around waterways is, therefore, a key catalyst in the development of waterways' regions. Plans should aim for continuous linkage via sustainable mobility networks to deal with future urban development whilst preserving biodiversity corridors to lessen the effects of increased demographics. Sensitive ecological planning would ensure connectedness with nature to promote a healthy living environment.

4.2. Employability/Jobs

Communities around disused waterways are usually among the lowest-income groups in a region. Lack of infrastructure, a spread-out, usually isolated, population, and low education levels lead to high unemployment rates in these regions. The provision of meaningful jobs and high-grade technical/paid job opportunities is, therefore, a must in redevelopment efforts. Plans should aim to particularly support younger generations and the most deprived sectors of the population to establish a thriving economy based on creativity and innovation respectful of natural resources in order to increase the competitiveness of the region.

4.3. Health and Wellbeing

Waterways provide fantastic opportunities to promote a healthy living environment, preserve historical and cultural natural cultural heritage, and secure quality for the environment through an ecological balance. Successfully implemented projects would ensure accessibility to nature and blue and green infrastructure in order to promote wellbeing and health for work and leisure. Successful development, however, could lead to highly attractive propositions for urban developers with projects that could severely damage the ecosystem. Efforts should be made to maintain the natural ecosystem with clean fresh water and clean air in order to preserve and enhance a region's agricultural economy.

4.4. Housing

Land values are intrinsically linked to upgrades in its available infrastructure. This is particularly noticeable in waterfront locations. While this could be seen as a positive outcome of any development, a balance should be struck to ensure affordability and to avoid segregation of deprived local communities. Planning policies should aim at establishing a level of diversity through affordable housing with good living conditions supported by a good/accessible transport network.

4.5. Governance

It would be difficult to draw strict boundaries around development areas along waterways. Such regions are by nature fluid and seamlessly connected. Any development or regeneration efforts should, therefore, consider agile cross-borders or/and cross regions plans across various combined authorities or official groups which include different stakeholders, inhabitants (current and future), workers, local residents, and other actors in the areas that can support waterways' resilience (across areas/regions) by cross-cooperation in urban planning development.

The study of the Deux-Rives project traced the identified catalysts for waterways' projects in the literature, in what is believed to be a successful regeneration project across the Rhine in Strasbourg. The aim is to support the development of a catalyst-based approach that could be applied to develop smart blue and green urban corridors in the MSC region in the UK which could potentially be extrapolated to other inland European waterways' contexts. The catalysts-based approach presents an evolving methodology in urban development as well as an approach to transboundary collaboration in support of communities and urban ecologies. Through this approach, a number of ecological-based scenarios for the MSC were developed by applying an iterative process invention grounded on the development and application of the identified catalysts.

5. The Development of the Manchester Ship Canal

The literature review and the analysis of the existing EcoCité project linking Strasbourg (France) and Kehl (Germany) led to the foundation of the potential catalysts for the urban development of disused waterways. Efforts have been made below to apply those catalysts to the development of the MSC in the UK. The aim is to integrate the rural and urban landscapes in support of smart urban futures in the region. There are strong similarities between the two waterways' contexts of Strasbourg and Manchester. The two inland waterways have historic and ecological significance in their respective regions, both have been impacted by the industrial revolution with the increase of pollution and the subsequent decline in shipping and navigation in different ways. Both projects aim to interlink two cities in a more sustainable and ecological way. The identified catalysts in Strasbourg could, therefore, be used and applied to unlock the potential of the inland waterways in Manchester.

Based on the potential environmental, liveability, and economic catalysts and enablers identified, the MSC project enlisted academics, local governments, and industry partners to establish a set of principles that would guide the development of a smart urban corridor for the MSC. With a focus on creating potential scenarios (Pill, 1971) of what the smart ecological urban corridor along the MSC could be, the Delphi Technique was used in the iterative process to achieve consensus on real-world knowledge from experts in the fields of the identified catalysts on what to apply (Dalkey & Helmer, 1963; Hsu & Sandford, 2007). To determine the potential of the MSC corridor, to consider potential catalyst projects, and important drivers and enablers, a series of multidisciplinary meetings and iterative workshops with key experts from various fields (including urban design, ecology, engineering, environmental studies, transportation, health, and social science) were held (Dalkey & Helmer, 1963). As Pill (1971) and Oh (1974) suggested, participants were chosen based on their background and expertise rather than their familiarity with the topic.

Participants representing different stakeholders were presented with the most recent qualitative and quantitative data which were used to examine the socio-spatial traits of the MSC region. Participants in the workshop were also shown the analysis of key catalysts to help guide their discussion. To aid in the analysis and discussion at the workshops, data on the various existing layers of the MSC corridor were gathered and processed concurrently. Various institutions and local governments provided key data sets that the participants used to further define and identify the catalyst projects.

6. Manchester Ship Canal

The MSC, a symbol of the industrial revolution, could inspire a new smart ecological urban corridor that connects diverse communities, industries, and government agencies.

The 56-mile Liverpool to Manchester smart ecological urban corridor is a case study within the northwest region in the UK, but its conditions and characteristics can be extrapolated to other parts of the globe: Fast-paced population growth in both Liverpool and Manchester has increased human urban habitat demands. The buffer area along the MSC has the potential to develop into a smart ecological urban corridor that connects human needs, environmental infrastructure and scientific and economic development, biodiversity, and quality urban space for a growing population. Human-natural system integration is key.

The first major urban regeneration project along the MSC was MediaCity (2006) in Salford Quays, formerly Manchester Docks (Nevell & George, 2017). According to Biscaya and Elkadi's (2021) research, innovative technologies sparked Manchester's industrial revolution.

An iterative process was applied through two workshops that enabled the formation of a high level of consensus among various experts and interested parties in various sectors and activities (Hsu & Sandford, 2007; Pill, 1971). The workshops were supported by basic data analysis and the evaluation of the opinions gathered during the workshops in the catalyst-based iteration process. The themes and concepts were mapped based on the level of agreement reached, and the findings are presented here.

6.1. Catalysts and Scenarios

The scenarios were developed based on a number of iterations and on the different amalgamations of the key five catalysts previously explained.

6.1.1. Create a Digital Highway and Infrastructure to Support Business, Working, and Living Connectivity

The MSC is currently mainly used for freight transport and there are logistics hubs along its margins with some key industry infrastructures (Figure 3).

The canal can be transformed into a digital highway infrastructure, potentially with drones to attract innovative business investors and subsequent technological jobs for high-qualified professionals. The area can be developed along the digital infrastructure through the design of a connected working and living environment (Figure 4).

6.1.2. Green Space Creation and Natural Capital

The canal's environment and landscape are its key assets. Green areas promote healthy, collaborative living.

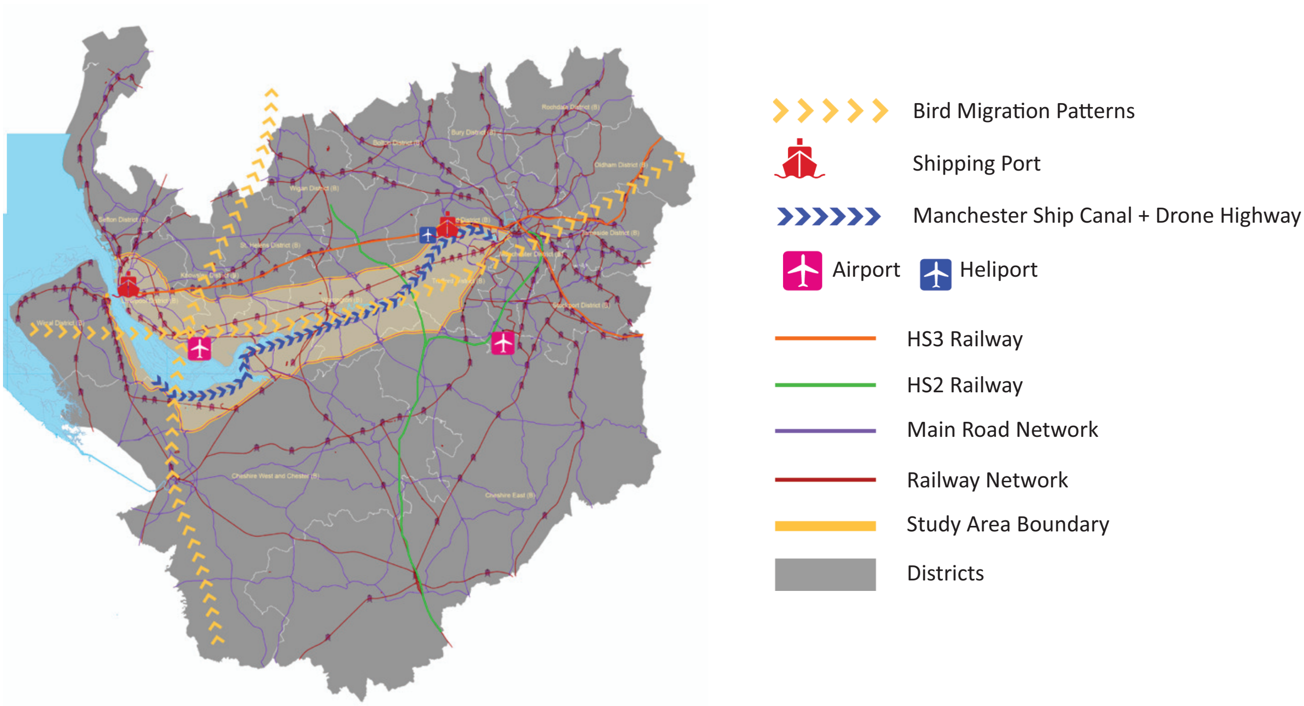

Figure 3. Transport networks, high-speed railways, airports and airfields, digital highways, and birds' migration paths. Source: Authors based on Digimap.

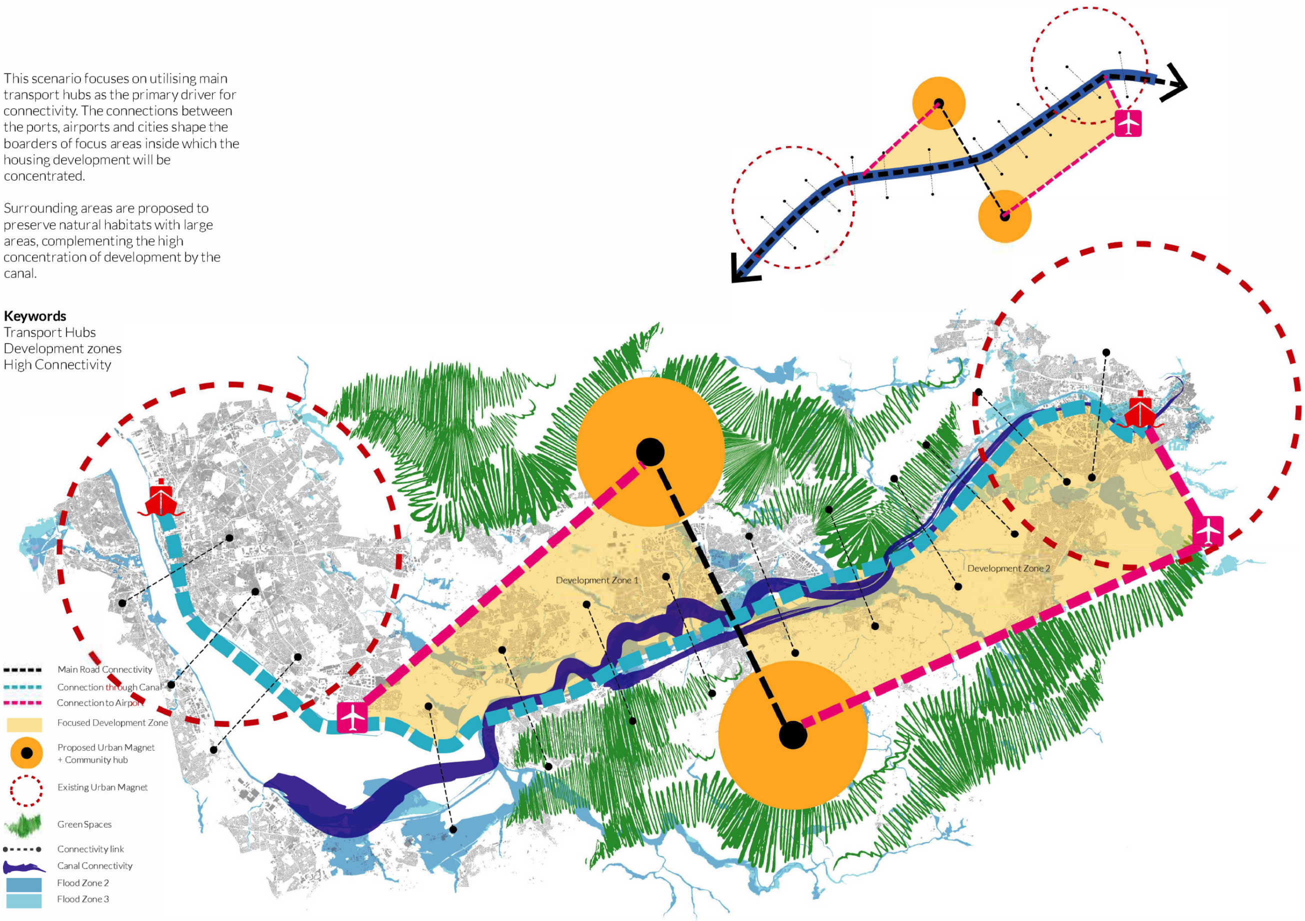

Figure 4. Scenario 1.

Urban/rural interconnections, urban agriculture on the urban fringe, and living and working hubs can support the flood-prone MSC margins (Figure 5). Green spaces and natural capital preservation improve air quality and residents' and tourists' livelihoods (Figure 6).

6.1.3. Creative and Innovative Jobs

Innovative jobs drive population fixation. Given that young people tend to settle in major cities despite data showing that housing and the quality of life are

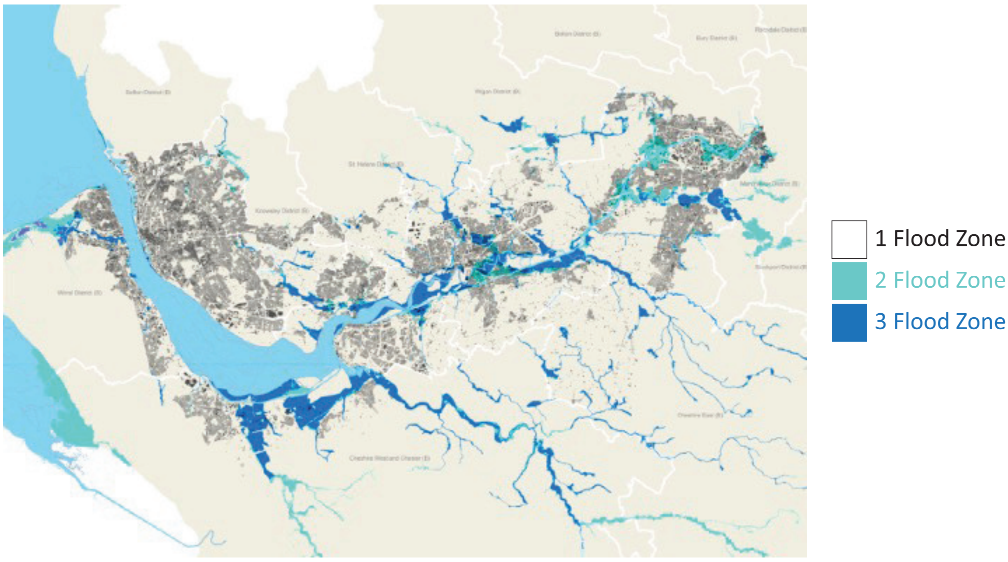

Figure 5. Flooding map. Source: Environment Agency (2016).

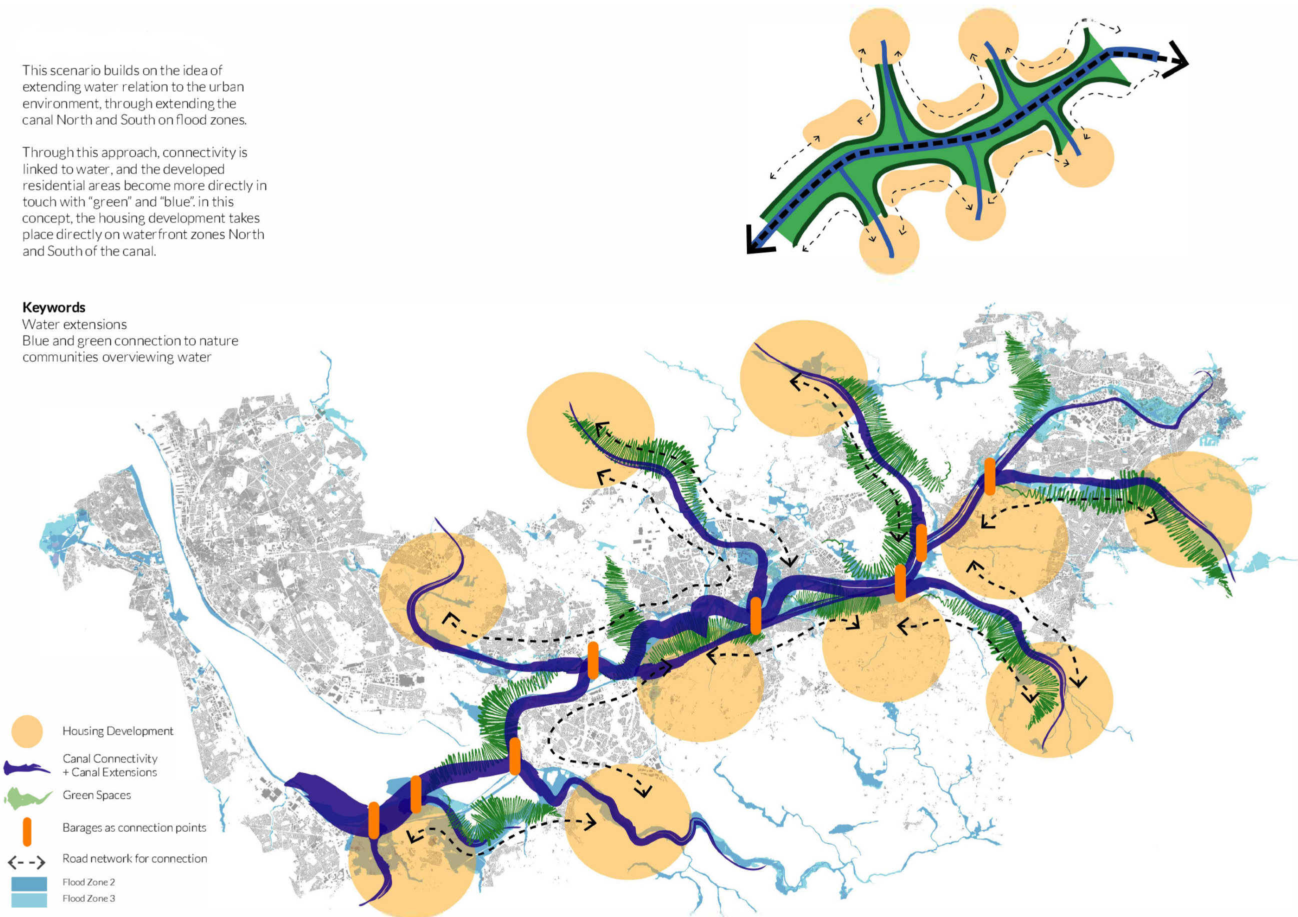

Figure 6. Scenario 2.

unsuitable, population growth trends along the corridor require special attention. The creation of innovative jobs along the corridor may attract highly skilled young people to work and live (Figure 7).

6.1.4. Linking the North With the South: Mobility and Active Transport Along the Corridor

Changing corridor use and mobility is necessary. Development depends on the canal's north–south connection. Local and government initiatives to improve the transport network and increase mobility can form the basis for a connected active transportation network along and through the MSC. This will support creative and innovative businesses to grow and create jobs. More bridges, cableways, or boats along the corridor in strategic locations near working/housing hubs and green spaces can enhance this (Figure 8).

6.1.5. Create High-Density Affordable Housing Integrated With the Natural Environment and Easy Access to Greenspaces

Creating innovative jobs is inextricably linked to this theme. Population and housing must be altered. Affordable housing is essential to attract youth. High-density housing that connects housing hubs, work hubs, and green spaces is considered the most effective way of creating liveable areas along the corridor (Figure 9).

6.1.6. Re-Designing the City Centres and the Urban Corridor to Improve Collaborative Living

With population growth, city centres will become more expensive places in which to live (Figure 10). The design of the corridor and the re-designing of the cities' centres can enhance connectivity along the urban corridor while providing a sustainable environment in which to live, work, and visit that is close to the city centres and provides easy access to them, as well as access to green spaces and outdoor spaces that can be enjoyed by all.

6.1.7. Education for the Future

Digital and disruptive technologies affect future education. Today's generation expects adaptability, not lifelong employment. Given education's strong presence in the Salford Quays area (the former Manchester Docks), more can be envisioned, including the establishment of relations between education and innovative business. Technology will play a major role in education in the future. Digital, media, creative industries, professional services, and new distribution and logistics business models can explore these relations.

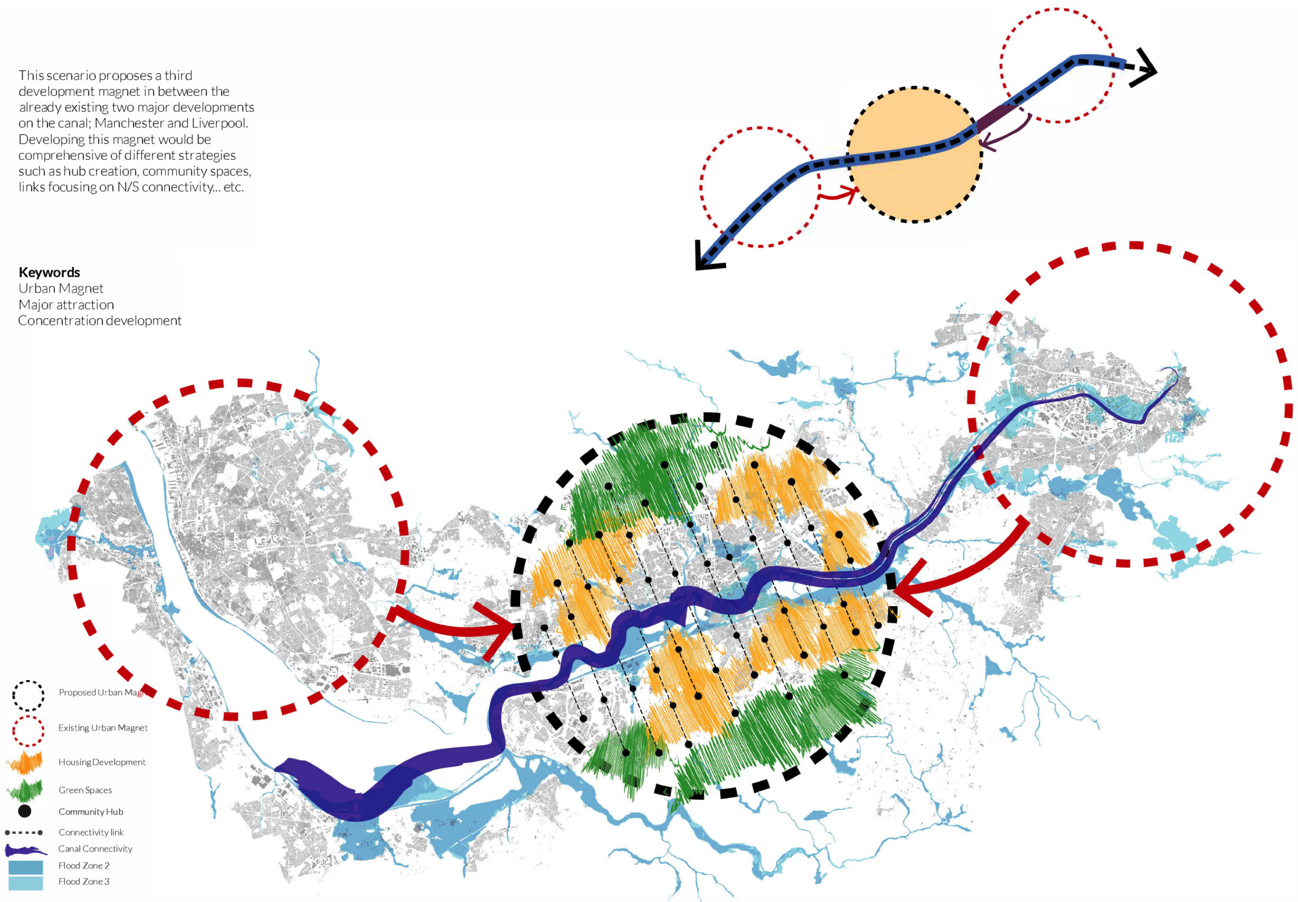

Figure 7. Scenario 3.

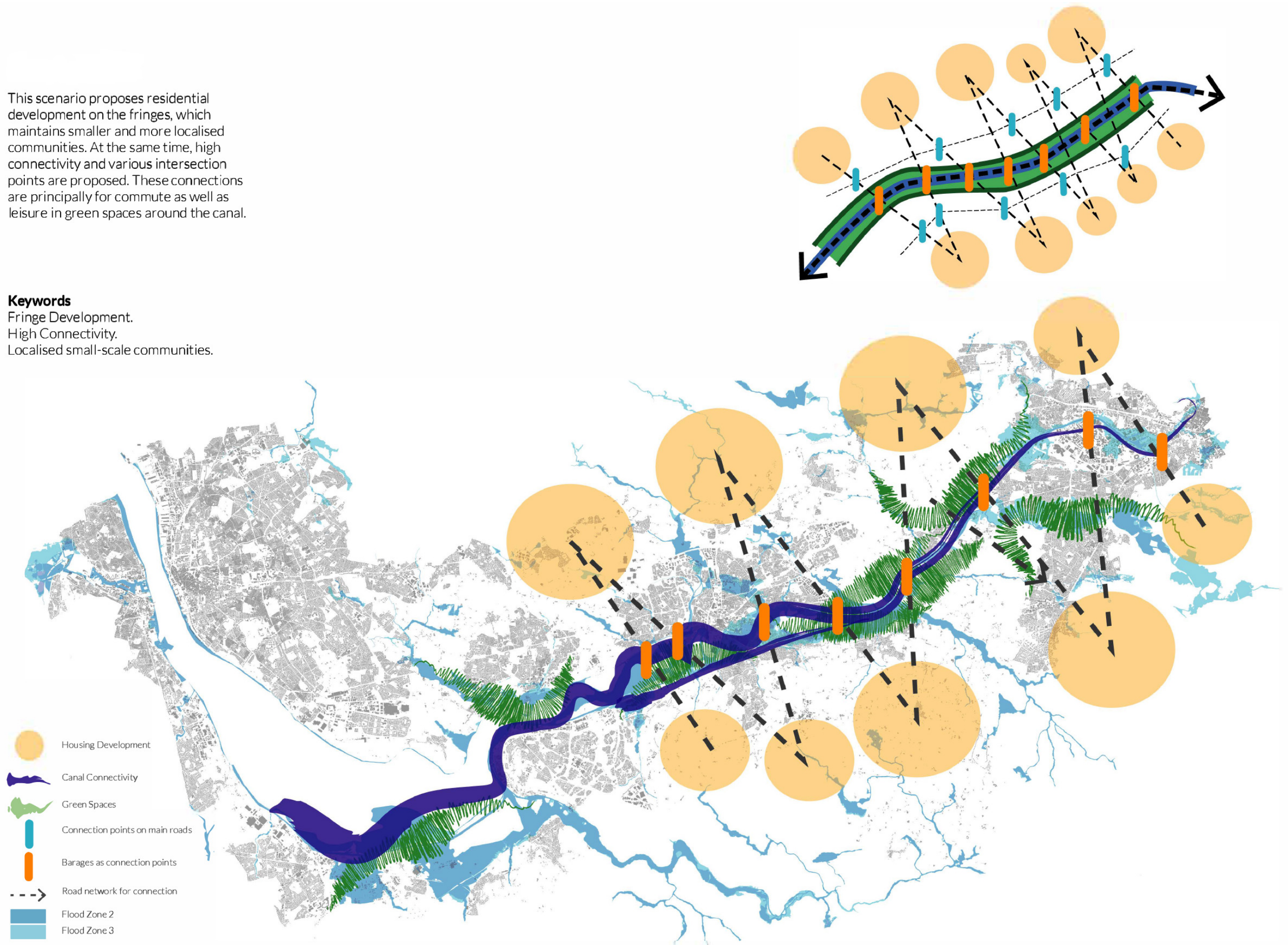

Figure 8. Scenario 4.

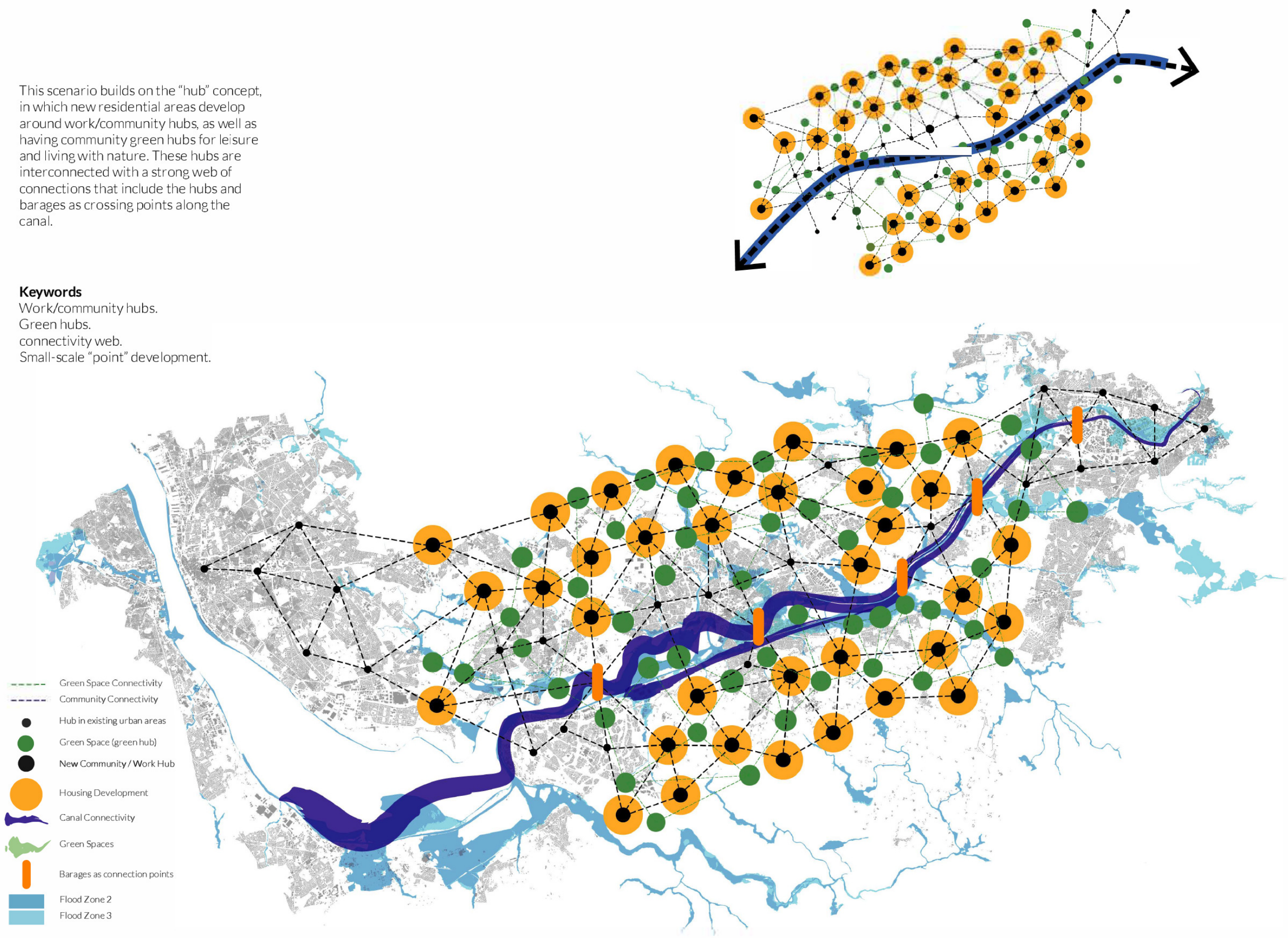

Figure 9. Scenario 5.

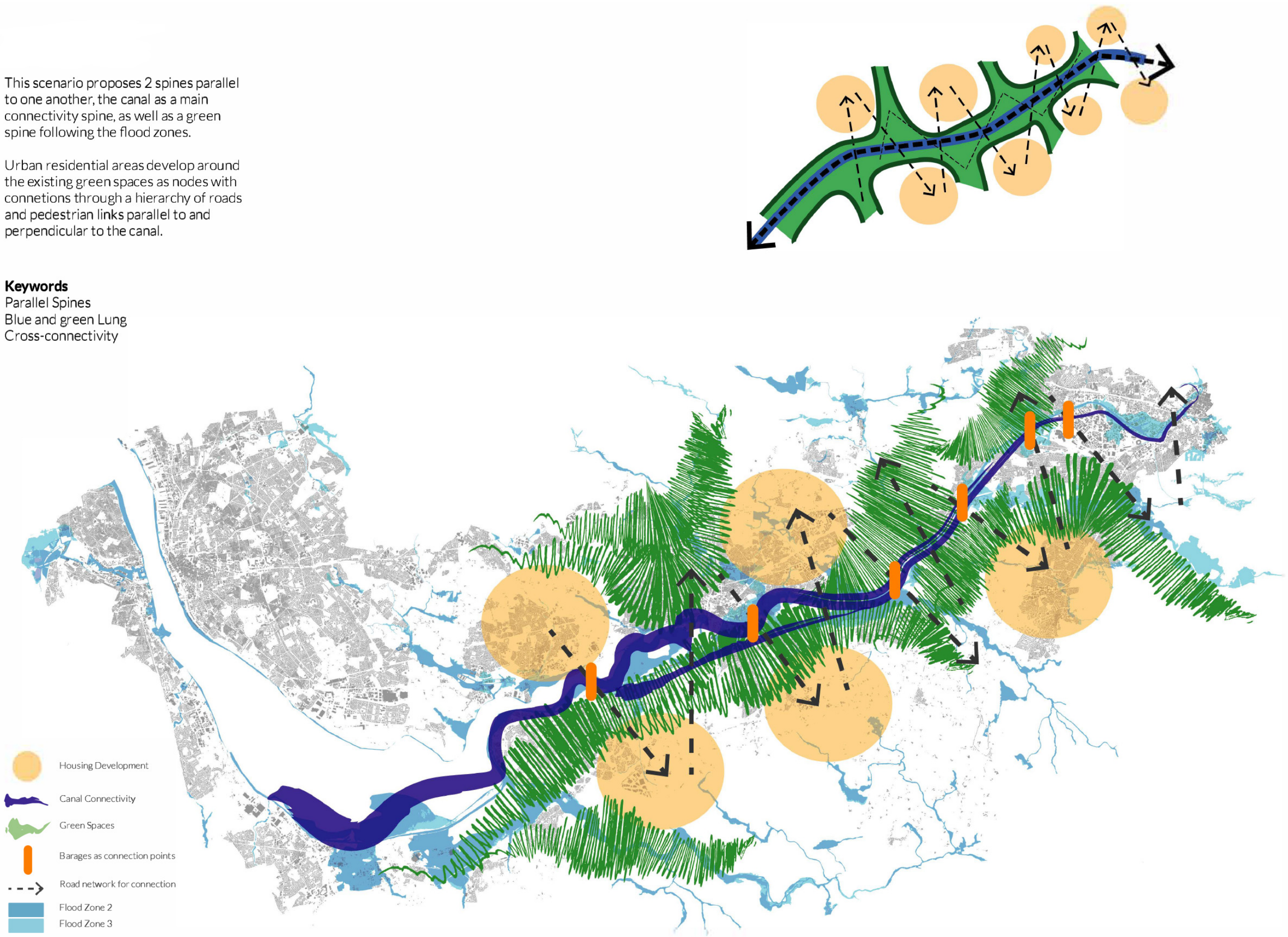

Figure 10. Scenario 6.

Agile policies are the key driver to the MSC urban corridor regeneration. Identifying key moves and catalyst projects allows for the development of multiple smart ecological urban corridor scenarios alongside the MSC.

7. Conclusions

European cities are going through a transformation phase due to several societal and ecological challenges. While some face a shrinking population, others are growing with an increasing demand to meet their environmental challenges. European disused waterways provide opportunities as well as challenges for those growing cities. They present possibilities to install green and blue infrastructure that would positively contribute to sustainable and healthy urban development across their linear configurations. Waterways could also reinvent their past with suitable and more contemporary and sustainable mobility measures. Re-imagining the possible future of disused waterways requires alternative strategic planning processes that would cater for blue-sky thinking and innovation models.

This article provides an alternative approach to strategic urban planning that could be used to develop sustainable and ecologically driven scenarios in a complex large-scale rural/urban setting such as waterways' domains. A catalyst-based approach for urban development around disused waterways is used in this study to develop six different scenarios for the transformation of the Manchester–Liverpool urban corridor alongside MSC. Building on a review of similar waterways' urban development in Europe and an in-depth analysis of the Deux-Rives project in Strasbourg, five common catalysts were identified: connectedness, employability, health and wellbeing, housing, and governance. Through an iterative process, using desk-based and stakeholders' workshops applied to the MSC case study based on synthesising, modifying, and testing to improve the activity, selectivity, and scope of the identified catalysts, a number of ecologically based scenarios were developed.

Through a thematic analysis of factors that are common in several case studies, six scenarios that could accelerate the development and implementation of smart ecological urban corridors were developed.

The MSC case explored the identified catalysts from the review and the Deux-Rives case study and allowed for the definition/exploration of the catalysts to develop an ecological blue and green urban corridor around the canal. The main challenges of the process were as highlighted in the literature: timeframes, length of the process, and resources. The MSC case study explores the methodology further by identifying future enablers through the imagining of the future of the canal.

The catalyst-based approach presents an evolving methodology in urban development as well as an approach to transboundary collaboration in support of communities and urban ecologies. Through this approach, a number of ecologically based scenarios for the MSC were developed by applying an iterative process invention grounded on the development and application of the identified catalysts.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 425–437
https://doi.org/10.17645/up.v8i3.6752

Article

Review of UK Inland Waterways Transportation From the Hydrodynamics Point of View

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Submitted: 30 January 2023 | Accepted: 7 April 2023 | Published: 26 September 2023

Abstract
There are approximately 7,000 miles of inland waterways in the UK, many of them built during the 18th and 19th centuries principally to transport bulk materials. These waterways provide numerous benefits to society and the economy. However, they have untapped potential for freight transport which could be released to provide more efficient solutions compared to other modes of transport. In addition to providing solutions to reduce emissions from land or air transportation, inland waterways also bring environmental and public health benefits to local communities. Therefore, these blue-green spaces should play a central role in government and local authority planning. This article explores some of the issues which prevent full use of inland waterways transportation from being achieved from the hydrodynamics point of view. Specifically, the concepts and ideas underpinning vessel operation are reviewed and discussed in detail in this article. It is shown how hydrodynamic concepts can inform public policy to maximise the efficiency of transportation from inland waterways.

Keywords
freight transport; hydrodynamics; inland navigation; inland waterways; shallow water hydrodynamics; United Kingdom; vessel performance

Issue
This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

Inland waterways navigation in the UK dates back to the 18th and 19th centuries when a significant number of canals were built, predominantly to facilitate the movement of bulk cargos. Following a peak in activity during the 19th century, activity on and around inland waterways declined due to intense competition first from rail and then from road transport. Today, the UK has some 5,000 miles of inland waterways, 2,700 miles of which form an interconnected network. A further 2,000 miles are in a non-navigable state but have the potential for navigation. Responsibility for the UK's waterways is split among many authorities, the largest of which include Canal & River Trust, Environment Agency, Broads Authority, and Scottish Canals.

Urban inland waterways are seeing a revival as a result of the recognition of their value to society, primarily through the lens of blue-green spaces. Such spaces are known to enhance local people's and visitors' mental and physical health with tangible monetary contributions to public health. Although further research is necessary to establish the exact link between exposure to blue spaces and health (McDougall et al., 2020), Tieges et al. (2020) found that following the restoration of a canal in North Glasgow, mortality rates fell by 3% in the community residing within 1 km of the canal. Shorter-term exposure to blue spaces was studied by Vert et al. (2020), who found that walking in the vicinity of a blue space for 20 min enhanced people's mood.

Since over 50% of the world population lives within 3 km of a freshwater body (Kummu et al., 2011), the potential for enhancing public health through urban waterways is significant. Inland waterways, particularly in the UK, were typically constructed or manipulated to allow for navigation. In that light, O'Gorman et al. (2010) monetised the social benefit of inland waterways to society, finding that navigable waterways typically score higher in this respect (Hazenberg & Bajwa-Patel, 2014). A recent report by Canal & River Trust (2022a) estimated the annual social value of the waterways under their care at £4.6 billion. In addition, they reported a £1.1 billion annual saving to the National Health Service budget, and a £1.5 billion in gross value added through tourism and leisure activities. While these figures are significant on their own, it should be kept in mind that Canal & River Trust oversees only a part (approximately 2,000 miles) of the UK's waterways.

Some 8.5 million people in the UK live within 1 km of a waterway—approximately 15% of the population (Parry, 2021). The Inland Waterways Association (2022) estimates that of those, three million reside next to a derelict inland waterway; that is, a waterway that is not being maintained. Similarly, based on data reported by McLennan et al. (2019), the Inland Waterways Association estimates that 75% of districts with the highest deprivation indices in England are located on or near an inland waterway. Even if only a small fraction of the aforementioned benefits were to be realised, the economic, societal, and public health benefits would be substantial.

In addition to public health, inland waterways are thought to provide added resilience to extreme climate events, for example, by mitigating the urban heat island effect. That effect can be characterised by a significant increase in the temperature in cities compared to surrounding areas, compromising human comfort during heat waves. Research has questioned the effectiveness of inland waterways in reducing urban heat island effects (Jacobs et al., 2020). However, UK-specific case studies report a reduction in ambient temperature in the vicinity of canals of approximately 1.5 °C (Hathway & Sharples, 2012; McDonald et al., 2019), most likely due to the vegetation surrounding many canals in the UK.

Inland waterways can also contribute to mitigating the impact of other extreme climate events. For example, the Glasgow Smart Canal system incorporates weather forecasts to control the water level. The implemented system can lower water levels by up to 10 cm in advance of heavy rainfall, creating 55,000 m^3 of capacity for run-off and unlocking 110 ha of land for development (Glasgow City Council, 2018; Scott et al., 2023). Thus, significant potential for flood prevention could be created across the UK. While the Glasgow Smart Canal is designed to improve resilience to heavy rainfall, the River Severn to River Thames Transfer project does the opposite, moving up to 500 megalitres of fresh water per day (Severn Trent, 2021). Namely, water is transferred from wet to dry parts of the country through inland waterways to combat the worse effects of prolonged droughts.

The above evidence shows that inland waterways in the UK can be regarded as working industrial heritage with contributions to the economy, public health, and climate change adaptation, but the benefits that inland waterways deliver to society do not stop here. Transport over water is significantly more energy efficient than other forms of transport. That is the reason inland waterways were built across the UK in the late 1800s. Per tonne of goods carried, transport over inland waterways requires only 17% and 50% of the energy needed for road and rail transport, respectively (Jacobs, 2022). A focus on energy efficiency can create a measurable reduction in greenhouse gas emissions, allowing additional time for other means of industrial decarbonisation to mature, such as increasing the share of renewables in the energy mix and vehicle electrification. Focusing on such energy efficiencies in the short term decreases greenhouse gas emissions and postpones what are known as tipping points due to climate change (Lenton et al., 2019).

The present article aims to support the discussion around the use of inland waterways for transport by providing additional context to the debate. Namely, we explore the reasons why transport over water is more energy efficient with the objective of enriching decision-making particularly as it relates to maintenance and repair of navigable waterways. This is done by reviewing the factors affecting the efficiency of a vessel sailing in a confined waterway and by pointing out research gaps and opportunities for further research.

2. Activity on UK's Inland Waterways

Goods-carrying inland vessels emit about 1% of the UK's greenhouse gas emissions (Walker et al., 2011) while carrying 5% of all goods (Department for Transport, 2021). More recent statistics include inland vessels' emissions in the "domestic shipping" category contributing about 5% in 2020, but that includes coastal transport. The waterways where traffic primarily takes place are depicted in Figure 1, which shows a significant reduction in activity in the period between 1994 and 2020 from a total of 7.54 million tonnes to 2.69 million tonnes; a reduction of approximately 65%. The same figure also demonstrates that these reductions are primarily driven by a collapse in

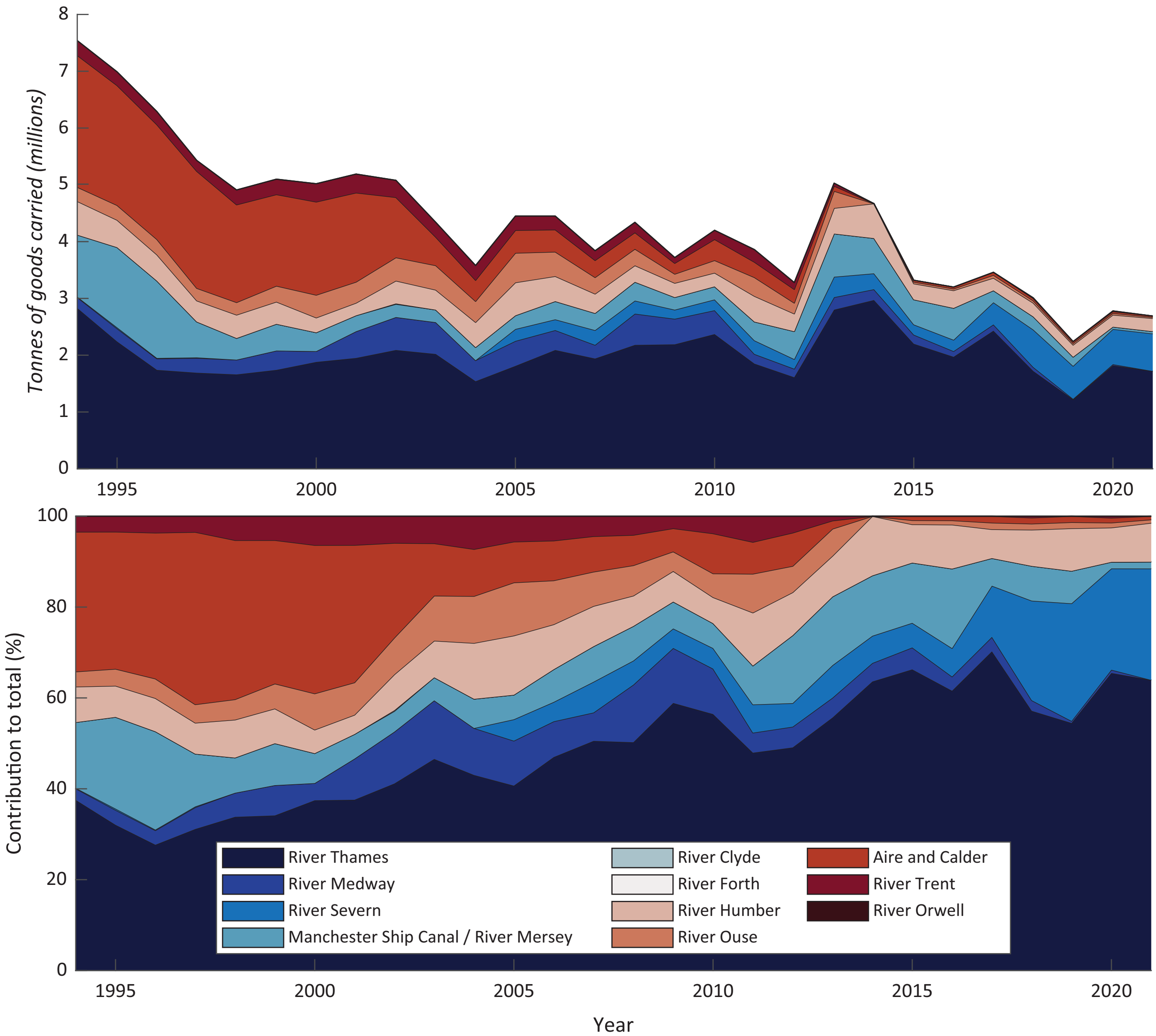

Figure 1. Freight statistics on the UK's inland waterways. Source: Authors' work based on Department for Transport (2021).

activity in the North of England. In relative terms, 14.5% of all goods transported through inland waterways took place on the Manchester Ship Canal in 1995; in 2021, that figure was 1.4% which represents a decrease of approximately two orders of magnitude in real terms (from 1.09 million tonnes to 0.04 million tonnes).

In addition to commercial activity, recreational boating takes place across the UK's navigable waterways. Although exact figures vary by source (Walker et al., 2011), there are an estimated 80,000 commercial and recreational hydrocarbon-powered crafts (Inland Waterways Association, 2020), but statistics for their contribution to the country's greenhouse gas budget are not known at present. Many of these crafts also have a residential function, contributing to their carbon footprint. To support the UK's net zero plans, all sectors must seek solutions aimed at rapid decarbonisation (Department for Business Energy and Industrial Strategy, 2021), while making full use of energy efficiency measures (Department for Transport, 2019). Inland waterways are an untapped resource in that sense due to the scale of potential savings of the UK's greenhouse gas budget. For example, inland waterways transport accounts for 1% of London's emissions according to the Port of London Authority (2020), but nationwide this value is significantly lower.

Inland waterways are melting pots where the interests of a multitude of stakeholders can collide. A good example of the problem can be illustrated by Canal & River Trust's (2022b) investigation on the Aire and Calder where navigation was temporarily suspended to determine whether fish deaths were related to barge traffic. Similar conflicts can arise due to inland waterways users' diversity which includes towpath use, recreational sports and water-based leisure activity, angling, and freight transport. Due to the frequently incompatible goals of waterways users, prioritising the interests of one group inevitably creates conditions where another group perceives an interference or threat to their goals or activities (Church et al., 2007). Such conflicts can be easily resolved when they occur between groups whose ultimate goals align. For example, boat-generated waves can erode canal banks, which left unchecked can progressively damage towpaths and prevent others from using the towpath, but this situation is easily remedied through bank protection and maintenance. By contrast, the aforementioned report by Canal & River Trust (2022b) shows that stakeholders with fundamentally opposing goals and uses cannot resolve easily resolve conflicts. In such cases, knowledge of the hydrodynamic aspects governing the observed phenomena can inform how to best resolve a dispute.

The UK's inland waterways system is unique in its extensive reliance on a complex network of locks, without which transport is not possible. Historically, these locks were manned, which is increasingly rare in the recent past. The reliance on what are in many cases old manually operated locks creates an added layer of complexity which is not explored in the present article.

3. Hydrodynamics

The fundamental reason why a vehicle requires energy to move is a consequence of Newton's third law: Every action has an equal and opposite reaction. To sustain a constant speed, a vehicle, whether terrestrial, aerial, or aquatic, must produce a force in the direction of motion such that a given resistance is overcome. In terrestrial transport, that reaction consists of, for example, friction between a vehicle's tires and the road and the aerodynamic force acting on the external surface of a car. The former does not exist in floating craft, instead, only fluid forces affect the performance of a vehicle operating at the air-water interface because no contact exists between the vehicle and the seabed.

The discipline of hydrodynamics is concerned with estimating the aforementioned forces with the aim of understanding their source and magnitude. Unfortunately, the hydrodynamic forces acting on a steadily translating body at the water surface are highly complex and consist of several subcomponents. These forces and their subcomponents have been subject to intense research for more than two centuries (Gotman, 2007). Yet there are many unresolved questions, a sample of which are explored in the following sections. Although the following discussion focuses on the energy efficiency of floating craft, the same arguments apply to minimising the environmental footprint of a vessel in terms of local disturbance. That is, a more energy-efficient craft will create a lesser disturbance in terms of waves, current, and pollution, meaning that actions beneficial for energy efficiency are analogous to measures to minimise detrimental interactions such as bank erosion.

3.1. Dimensionless Groups

When a boat advances at a steady velocity it produces waves, meaning that some amount of energy is radiated into the environment from the vessel. One way to estimate that energy is to measure the deformation of the water surface. Similarly, the vessel produces turbulence and accelerates a mass of water in its direction of motion, which also requires energy. The challenge for hydrodynamicists is to use the physical mechanisms driving these phenomena and devise strategies to maximise cargo/carrying potential and speed while reducing the fuel consumed.

A set of dimensionless parameters govern the performance of a steadily advancing floating vessel. These include the Reynolds number ($Re = VL\rho/\mu$, where V is the velocity, L is the vessel length, ρ is the density of water, and μ is the dynamic viscosity), the ratio of inertial, and viscous forces. The Reynolds number is useful in quantifying the flow regime; that is, whether the water surrounding a vessel is turbulent or laminar. For example, Reynolds numbers above 10^5 indicate the flow is mostly turbulent. Even at very high Reynolds numbers, in the range 10^9, some of the flow near the bow of the vessel will remain laminar.

The friction a vessel experiences as a result of viscosity can be characterised by the Reynolds number through correlation lines such as the International Towing Tank Conference line or other friction lines (Grigson, 1992). Recent research by Zeng et al. (2018, 2019a, 2019b) showed that the submerged geometry of a vessel is critically important in determining how friction changes with the Reynolds number in shallow water, hinting that no universally valid expressions can be derived. The formulations that Zeng et al. (2019a) arrived at depend on the Reynolds number and water depth, reflecting the fact that proximity to the seabed is important in determining the resistance due to friction. To the best of the authors' knowledge, no similar work exists for cases when lateral confinement due to a canal bank is introduced. Friction dominates the viscous component of the force experienced by the vessel; therefore, its estimation is critically important in deriving power requirements. The unavailability of fast, robust expressions to estimate that component injects a level of epistemic uncertainty in predicting and optimising performance. It also prevents reliable estimates of fuel consumption.

A second dimensionless parameter is the Froude number ($F_n = V/\sqrt{gL}$, where g is the acceleration due to gravity), the ratio of inertial and gravitational forces. In shallow water, the Froude number is replaced with the depth Froude number ($F_h = V/\sqrt{gh}$, where h is the water depth). Unlike in deep water, where the length of a wave determines its speed, in shallow water, a single wave speed exists ($c = \sqrt{gh}$). Due to this fact, the depth Froude number is analogous to the Mach number in aerodynamics where the wave speed is the speed of sound. F_h then represents the vehicle speed as a fraction of the speed of the fundamental wave in a given medium and controls wave-making, i.e., deformations of the water surface. This has far-reaching consequences; for example, the frictional component formulations produced by Zeng et al. (2019a) are valid for low speeds only because they did not take into account depth Froude number effects and, therefore, deformations in the water surface.

Changes in the depth Froude number have a profound effect on the geometry of the boat-generated wave system. Increases in the depth Froude number are linked to a greater transfer of energy from a craft onto the wave system. Unlike frictional effects which grow following an approximately quadratic curve with increasing speed, wave resistance can oscillate due to interference between the wave systems generated at the bow and stern. In general, waves are only shed from locations where the cross-sectional area (or beam) of a vessel changes. Thus, no waves will be emitted from the parallel midbody of a vessel.

At depth Froude numbers below approximately 0.5, the wave pattern in shallow or confined waters will closely resemble a deep water equivalent shown in Figure 2 with the exception that waves will typically be higher. This shows that more energy is radiated as waves when the water depth is shallow. Further increases in the depth Froude number cause the wave system to undergo a dramatic change, best expressed through the Kelvin half-angle (illustrated in Figure 2) as shown in Figure 3. Namely, the divergent wave system broadens to become near-perpendicular to the vessel track while the transverse wave system can no longer keep up with the vessel.

Although the geometrical properties of a craft and its draft play a role in determining the underlying forces, it should be noted that such properties do not play a role in the relations used to construct Figure 3. In other words, the waves emitted from a point disturbance will undergo the same transformation as the waves shed from a barge. Since the angle at which waves propagate from a vessel depends on the speed in shallow waters, adequate speed limits must be observed. A consequence of the fact that water depth is involved in the definition of the depth Froude number is that high F_h values can be produced even at relatively low speeds (in m/s). Thus, sedimentation of a waterway can cause a shift in F_h even if the speed (in m/s) is kept constant by varying the depth Froude number through the water depth. As mentioned previously, the energy radiated in the form of waves grows rapidly at high depth Froude numbers (Jiang, 1999; Terziev et al., 2018), meaning that maintaining adequate depth levels can reduce power requirements and erosion.

3.2. Confined Water Effects

The depth Froude number and Reynolds number cannot account for canal bank effects since the width of a waterway does not play a role in either of these dimensionless groups. Researchers have therefore introduced a third parameter, the blockage ratio, $m = A_S/A_C$, where A_S is the cross-sectional area of the hull (usually the maximum is taken) and A_C is the canal cross-sectional area. A value of $m = 1$ indicates that a vessel occupies the entire canal, while a value of $m = 0$ can be attained in infinitely wide or deep waters.

Similar to flow in a pipe of a varying cross-section, conservation of mass and energy can be applied to predict the change in pressure and velocity of water around the vessel. Unlike pipe flow, the presence of the water surface exposed to atmospheric pressure imposes certain limits to the interplay between pressure and velocity, since a reduction in pressure lowers the water surface. That can only occur up to a point, causing violations

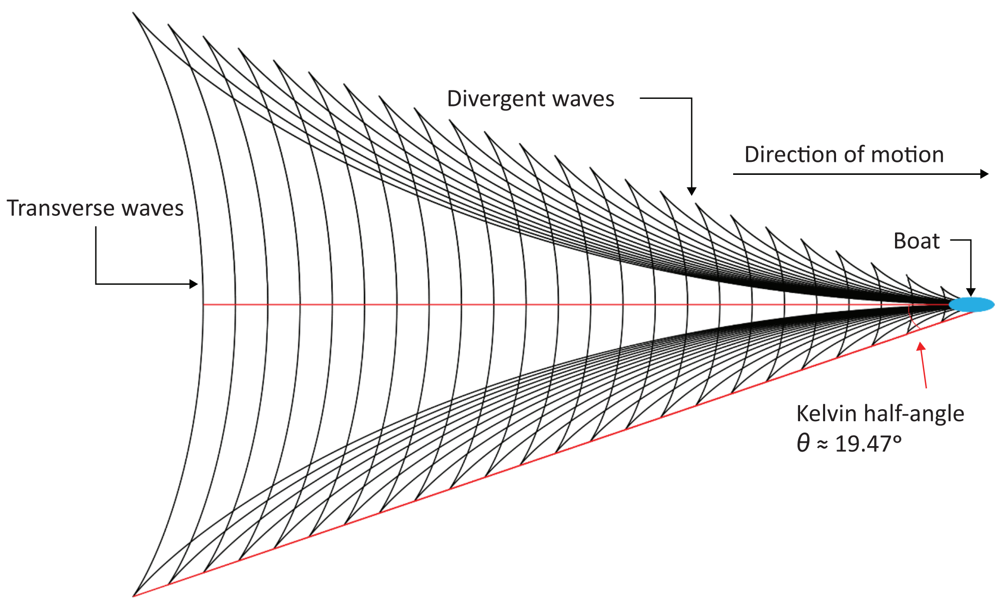

Figure 2. Wave system generated by a steadily advancing craft in deep waters.

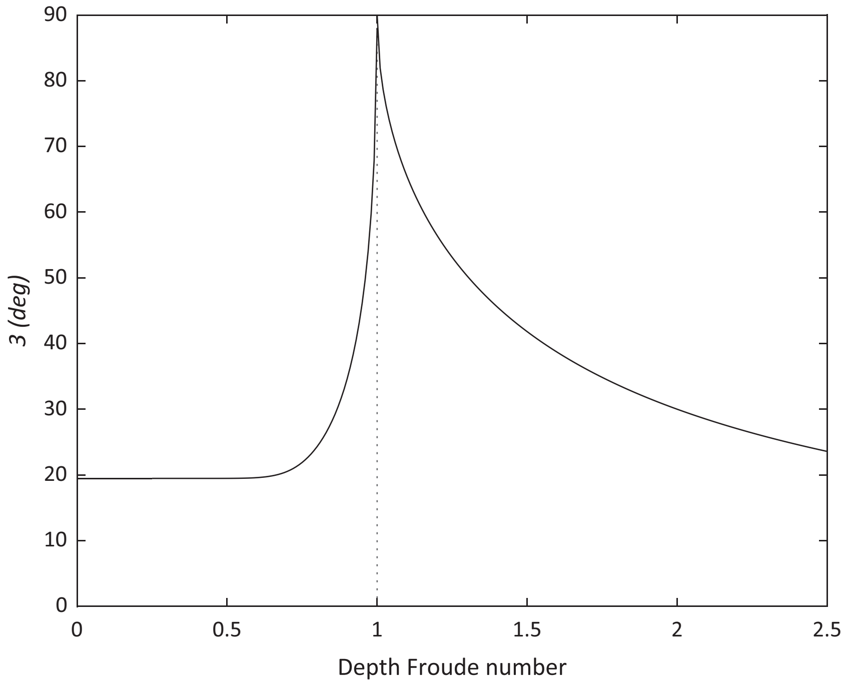

Figure 3. Kelvin half angle as a function of the depth Froude number. Source: Authors' work based on the relationships given in Havelock (1908).

in the steady form of the law of conservation of mass (Lataire et al., 2012). In other words, under certain conditions, illustrated in Figure 4 as the transcritical region, water cannot pass through the space between a boat and the canal banks in a steady manner, producing hydrodynamic instabilities. It is highly unlikely that a typical vessel will have sufficient power to traverse the boundary between the sub- and transcritical regions, because of the exponential rise in resistance associated with the latter region (Terziev et al., 2018). Thus, the attainable speed of a vessel is limited by the available cross-sectional area.

As mentioned previously, the transcritical region is characterised by an inability to achieve a steady flow

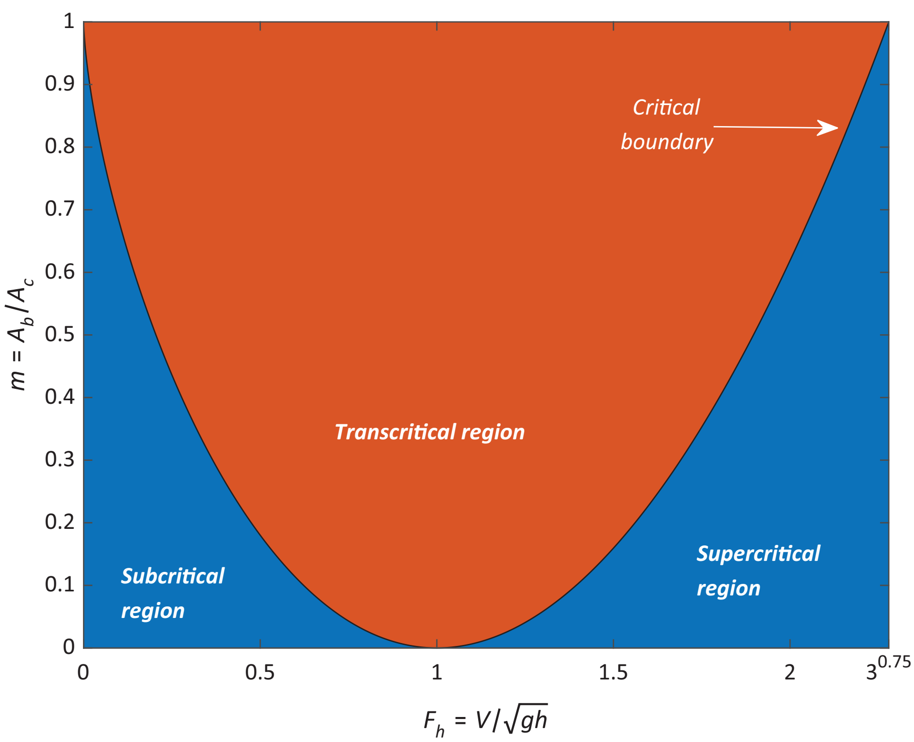

Figure 4. Speed-blockage relation. Source: Authors' work based on equations given in Lataire et al. (2012).

in the vicinity of a craft. That creates a hydrodynamic instability which is expressed as a build-up of energy ahead of the vessel in the form of a wave elevation. Once the wave elevation reaches a critical threshold, it has modified the local water depth sufficiently to bypass the restriction imposed by the wave speed ($c = \sqrt{gh}$) and is able to escape upstream; that is, a wave which can move at speeds faster than the limiting wave speed is formed. This is known as a solitary wave (Katsis & Akylas, 1987; Turner, 2006), first discovered by John Scott Russel in the late 1800s (Darrigol, 2003). Soon after this discovery, engineers realised that exceeding the transcritical region and operating in the supercritical region through an increase in speed can lower power requirements. In essence, a vessel will experience less resistance to motion if it advances at depth Froude numbers to the right of the transcritical region in Figure 4 than it would at lower speeds within or near the transcritical region (Du et al., 2020).

The dominant physics within the transcritical region are highly non-linear. Such conditions are difficult to replicate experimentally, and theoretical methods to analyse such conditions have matured only relatively recently. Little is therefore known about the exact behaviour one may encounter in that region. The high blockage ratio values that craft experience in the UK can also be used as a full-scale laboratory to predict phenomena in international waterways, such as the Suez Canal and Panama Canal. If ship dimensions continue their historical trend of growth, the levels of restriction typical for the UK will find applications internationally in many rivers, canals, and ports.

In 2018 and 2022, extreme droughts across Europe and China caused water levels of rivers used for navigation to drop to dangerously low levels (Vinke et al., 2022). This prevented the carriage of goods, compromising supply chains and creating shortages of materials. If such climate events are to become more frequent (Christodoulou et al., 2020), industries dependent on bulk materials which are principally transported through large rivers will suffer. Since reductions in water depth cause an increase in the blockage ratio and depth Froude number, everyday hydrodynamics of UK canals must be studied to obtain further information on how a vessel performs under extreme conditions. Such knowledge could facilitate safe operations of ships and barges internationally even in low water level conditions.

3.2.1. Effects of Fluid Mud

As sediment accumulates at the canal bed, it is not immediately compacted to a rigid boundary. Water can permeate a layer of the canal bed creating fluid mud. The density of this layer is typically significantly higher than that of the fluid above it. Nevertheless, a vessel can move through such a layer without being in contact with a rigid surface, creating ambiguity in defining the water depth. McAnally et al. (2016) define nautical depth as "a safe and effective channel bottom criterion in areas where fluid mud confounds conventional acoustic (echo sounder) surveying methods." Alternatively, "the level where physical characteristics of the bottom reach a critical limit beyond which contact with a ship's keel causes either damage or unacceptable effects on controllability and manoeuvrability" (Delefortrie et al., 2005, p. 3).

For many ports, it makes sense to use echo sounder measurements and define the water depth as the location where the fluid density reaches a certain value. For example, Welp and Tubman (2017) compiled international nautical depth criteria, showing that 1,200 kg/m^3 is the most frequently used value. Most ports are frequented by sea-going vessels which enter ports for brief periods of time. They spend the majority of their time, and, therefore, greenhouse gas budgets, offshore. Transferring practice from ports onto inland waterways in that respect would not be beneficial due to the fundamentally different modes of operation.

The effects of fluid mud do not necessarily end if a clearance is present between the hull and the mud-water interface. Although a fluid, this type of mud behaves in a non-Newtonian manner (McAnally et al., 2007). The complex behaviour of fluid mud allows for a second wave system to be generated within the mud layer in addition to the one at the air-water interface. Since producing waves requires energy, the overall energy expended by the vessel to maintain the forward speed must increase (Delefortrie et al., 2010; Kaidi et al., 2020).

4. Slope Stability and Erosion

The likelihood of the banks and slopes of inland waterways eroding depends on the balance of forces acting on the sediment.

On the bed, the applied energy in the form of applied shear stress is balanced by stabilising/resistive forces including gravity and cohesion. As the fluid-transmitted forces exceed the stabilising forces, the erosion threshold is breached and sediment is transported as a bed or suspended load. Several stages of erosion of cohesive sediments have been identified in the marine environment, ranging from erosion of loose surficial bed material or aggregates (Type I) to mass failure of the bed (Type II; Amos et al., 1992; Parchure & Mehta, 1985; Winterwerp & Van Kesteren, 2004), which are transferable to freshwater environments.

On banks, both erosion of the bank face due to the hydrodynamic forces and gravity-driven bank failure processes occur, often cyclically. When applied shear stresses exceed the erosion threshold of the sediment the bank face erodes, and as these processes create overhangs, cantilevers, or bank steepening, geotechnical failure occurs as a result of gravity-induced mass movement (Fischenich, 1989), enhancing bank retreat and depositing sediment into the waterway.

Erosion is therefore dependent on both the hydrodynamic forces and the nature and history of the sediment which makes up the bed or bank—i.e., grain size, proportion of sand to clay/mud (Mitchener & Torfs, 1996), and clay mineralogy (Torfs, 1995)—and consolidation processes (i.e., bulk density/bed strength) which are related to sediment supply and cycles of deposition and resuspension (Thompson et al., 2011). These sediment properties are related to the underlying and catchment geology, which vary at both local and national scales.

Where waterways are tidal, beds and banks are subject to bidirectional flows which vary in intensity over the tidal cycle. This can result in cycles of deposition and resuspension across the tidal cycle, influencing consolidation processes (Mehta, 1989) and ultimately bed and bank stability. Variations in water level also influence the area of the bank over which the hydrodynamic forces act. In addition, frequent cycles of wetting and drying can destabilise bonds between sediment particles, enabling erosion under low-energy conditions over medium timescales (one to 10 years), as often seen in intertidal creeks (Chen et al., 2012).

Additionally, vegetation influences bed stability in a number of ways, which may enhance or decrease the likelihood of erosion. At small scales, microbial influences can stabilise sediments through the formation of biofilms which bind sediments and protect them from the flow or destabilise them through modification of their density, reducing stabilising forces depending on their developmental stage (Zhang & Thompson, in press). At larger scales, vegetation can reduce applied shear stress through flow modification (reducing fluid transmitted forces) as well as binding sediment (increasing stabilising forces) through the influence of roots (Chen et al., 2012).

5. Relevance for Decision-Making

The information discussed above has several practical implications. Firstly, it is important to acknowledge limitations in current understanding and, therefore, the ability to provide precise advice. Some gaps in understanding have been known for a considerable length of time (Tuck, 1978), while others are emerging with new research. For example, Raven (2022) was motivated by discrepancies in observations and calculations to provide an extensive list of corrections one may apply to simpler cases (e.g., infinitely wide shallow water) to obtain a confined water result. The aim of these factors is to correct for confined water effects. Raven (2022) also developed a correction aiming to reduce these discrepancies. Although these corrections may be useful for moderate water depths and low blockage ratios, they show too much disagreement in the cases that would be relevant for UK inland waterways. Inland waterways in the UK are for the most part considerably narrower and shallower than waterways in Europe, China, and the US. It should be kept in mind that, historically, UK inland waterways were dug by manual labour only to the point thought sufficient to allow for a barge to pass. In a sense, that makes the challenges around inland waterways faced in the UK unique. The increased use of canals to absorb excess run-off also has consequences for sedimentation with knock-on effects on other users' ability to use the waterways. Vessel-induced disturbances such as waves and currents are responsible for a significant portion, if not the majority, of the energy budget in inland waterways. The accurate estimation of hydrodynamic forces is therefore critically important not only for vessel efficiency but also to ensure banks are protected as discussed previously.

A useful piece of information one may extract is concerned with speed with consequences for erosion. The energy within a vessel-generated wave can be released through, for example, wave breaking, causing erosion which widens a canal. Under a fixed quantity of water or controlled water level within a canal, the blockage ratio is maintained constant while the depth is reduced. This increases the depth Froude number, causing more energy to be expended as waves, creating a positive feedback loop.

Canal & River Trust recommend a speed of no more than 4 mph on their waterways. However, it is the authors' understanding that such speeds are unattainable in many cases due to blockage effects. A speed of 4 mph maps onto a depth Froude number of 0.807 and critical blockage of m = 0.025 if a water depth of 0.5 m is used. Assuming the critical speed and blockage point cannot be exceeded due to the unavailability of power, the vessel can occupy no more than 2.5% of the canal's cross-sectional area in order to sustain a speed of 4 mph. If the speed were halved to 2 mph, the equivalent critical blockage becomes 0.262, i.e., the vessel can occupy up to approximately 26% of the cross-sectional area. These effects are depicted in Figure 5.

At speeds near or above the critical boundary, large volumes of water are mobilised causing friction on the canal bed resulting in erosion, sediment resuspension, and poor water quality. This means that erosion and other adverse environmental effects can occur even at very low depth Froude numbers provided the blockage is sufficiently high. Canal & River Trust have extensive online resources explaining, in practical terms, wash and its contribution to bank erosion. However, as discussed above, wave-related phenomena are not dependent on the speed in dimensional values (e.g., mph); they depend on the depth Froude number. A speed of 4mph may result in a low depth Froude number and minimal wavemaking if the water depth is sufficient. In other cases, 4 mph may cause extreme disturbances in the canal and promote erosion by transferring energy into the wave system and through the return flow. As illustrated by Figure 5, the depth and blockage determine the attainable speeds for a vessel and show the useful domain of operation (to the left of each circled point).

The specific case of the Aire and Calder investigation by Canal & River Trust mentioned previously can be used as an example to illustrate the effects discussed above. Using the method used to construct Figure 5 and taking as

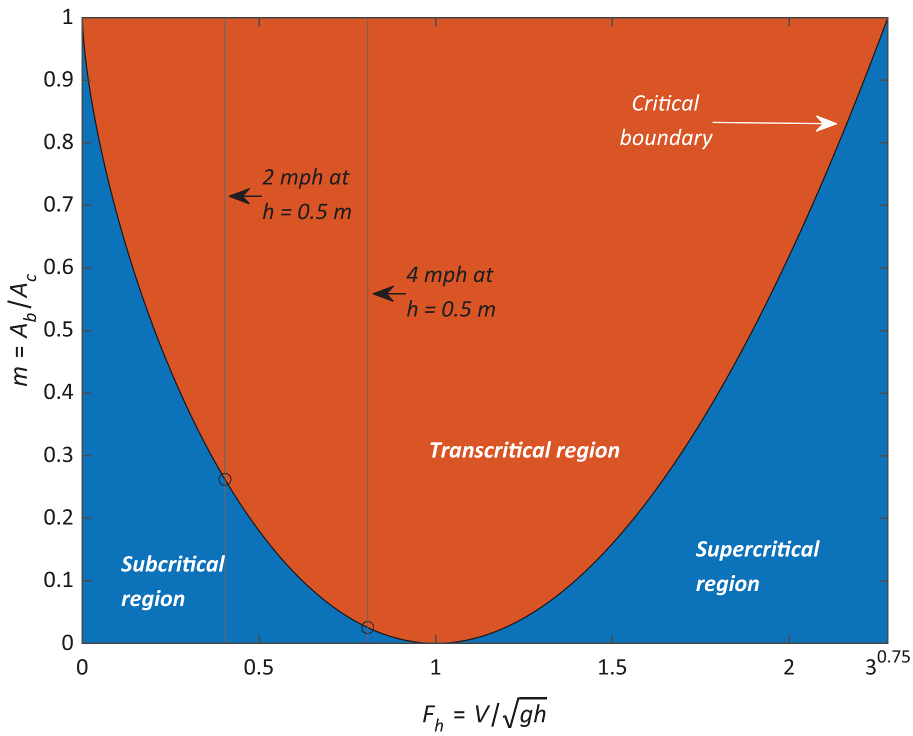

Figure 5. Speed-blockage relation. Notes: Vertical lines show the depth Froude numbers achieved for 4 mph (as recommended by the Canal & River Trust) and 2 mph if the water depth is assumed to be h = 0.5 m; the intersections of those lines with the transcritical boundary are depicted by circles. Source: Authors' work based on equations given in Lataire et al. (2012).

an example a vessel that occupies one-third (m = 0.333) of the available cross-sectional area of a canal moving at a speed of 4mph at a depth that is 1.5 times the vessel's draft ($F_h \approx 0.14$) results in a local disturbance characterised by flow speeds of approximately 50% of vessel speed. In other words, a current of strength 2 mph in the direction opposite to that of the vessel is created, which may pose a danger to recreational users and aquatic life. Such a current is likely to create sufficient turbulent friction on the canal to suspend sediment causing erosion and disturbing aquatic life which creates a multitude of conflicts from a number of perspectives including but not limited to water sports users and anglers. Halving the speed also halves the produced current strength, but doubling the depth (m = 0.166) creates a current that is only 20% of the vessel speed, that is, approximately 0.36 m/s or 0.81 mph. The relationship between the cost and the delivered benefit must be understood to allow informed decision-making. It is unlikely that a navigation authority would be able to double the depth during a dredging campaign, but, as demonstrated here, simple calculations can give an estimate of the associated trade-offs.

As evidenced by Canal & River Trust's (2015) strategic priorities, tourism, the well-being economy, and heritage are the primary focus in waterway management and restoration, while freight is promoted as a secondary item. Many of the benefits to society, the economy, and public health cited in Section 1 are based on leisure activities rather than on commercial activities. It is therefore important to recognise the need for synergy between freight transport and all other stakeholders, that is, conflicting goals of different users must be reconciled through informed decision-making.

Finally, although the effects of blockage have been discussed, the effect of shape has not. It is known that varying the submerged geometry of a canal, for a constant depth Froude number (near the vessel) and blockage, affects power requirements. However, to the best of the authors' knowledge, no set of geometrical optima have been produced. This is an area where hydrodynamics research can inform dredging practice. It is plausible that simple alterations in the shape of a canal, created during maintenance dredging, can influence the overall fuel consumption and disturbance created by a vessel and minimise the energy and burden of dredging.

6. Conclusion

Inland waterways in the UK have significant untapped cargo-carrying potential which may be used to affect a reduction in greenhouse gas emissions from the transportation sector. However, commercial activity in the UK has reduced by approximately 65%, driven primarily by changes in practice in the North of England. Transport over inland waterways requires only 17% of the energy consumed by road transport per tonne-mile. With the series of tipping-point events facing humanity, all energy efficiency measures should be adopted to postpone irreversible climate change. Such energy efficiencies can contribute to greenhouse gas budgets, allowing additional time for other decarbonisation strategies to be implemented at scale.

Increasing recognition of inland waterways, ranging from public health, through climate change adaptation and prevention, calls for better and smarter use of inland waterways. This article examined some factors affecting the operation of inland craft from a hydrodynamic point of view. Emphasis was placed on conditions affecting craft in the UK. Specifically, UK waterways, particularly those constructed during the 18th and 19th centuries are significantly narrower and shallower than many navigable rivers internationally. This creates a set of unique challenges, for example, restricted space particularly in urban settings is likely to cause conflicts between different users of the waterways. Knowledge of the hydrodynamics governing flow behaviour can be used to devise effective measures to minimise disruption through cost-effective decision-making. In this context, it is particularly important to understand the trade-offs between vessel speed and depth or blockage.

The present article reviewed the parameters governing the resistance of a craft advancing steadily in confined water. Examples of several outstanding research questions were discussed. In addition, some limitations of current advice issued by navigation authorities were discussed. It was demonstrated that more targeted advice, taking into account local conditions is necessary if decarbonisation of inland waterway transportation in the UK is to be optimised.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2023, Volume 8, Issue 3, Pages 438–454
https://doi.org/10.17645/up.v8i3.6740

Article

The Spatio-Functional Role of Navigable Urban Canals in the City: Cases From London and Amsterdam

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Submitted: 29 January 2023 | Accepted: 22 May 2023 | Published: 26 September 2023

Abstract

Cities incorporating navigable canals have played a crucial role in global trade and provided a platform for a range of activities for people from various locations. This research aims to comprehend the role of inner-city canals, formed as branches of shipping canals, in the spatial accessibility and functional structure of two contemporary urban systems: London and Amsterdam. Both cities are major post-industrial hubs in Europe and their spatial development and socioeconomic conditions have been greatly influenced by waterways. While the canal network in Amsterdam was planned alongside street layout planning in the early 17th century, serving commercial purposes, canals were integrated into London's pre-existing urban form mainly for transportation in the 19th century. The current situation in these cities is impacted by this disparity in three ways: (a) the potential use of canals in the urban transportation system; (b) the spatial accessibility of street networks; and (c) the correlations between street accessibility and land use patterns in canal neighbourhoods. The research employs analytical methods of space syntax, geographic information systems, and statistical techniques to create and apply integrated urban models, incorporating spatial network measures, retail density, and functional diversity for street segments, to compare various urban conditions. The research reveals the crucial finding that the incorporation of canals into the street system leads to a substantial increase in the mean values of street network accessibility in Amsterdam. Additionally, the study highlights the vital contribution of diagonal streets linked with canal networks towards retail density in this city. In contrast, the accessibility measures and spatial patterns of urban functions in London are predominantly influenced by proximity to canals.

Keywords

data-driven urbanism; navigable canals; space syntax; urban functions; waterways

Issue

This article is part of the issue "Shipping Canals in Transition: Rethinking Spatial, Economic, and Environmental Dimensions From Sea to Hinterland" edited by Carola Hein (Delft University of Technology), Sabine Luning (Leiden University), Han Meyer (Delft University of Technology), Stephen J. Ramos (University of Georgia), and Paul van de Laar (Erasmus University Rotterdam).

1. Introduction

Urbanisation processes, occurring in cities worldwide, highlight the spatial culture and lifestyle patterns of residents. This necessitates data analysis in urban research and academia to support decision-making in design processes. The physical form and structure of cities have various impacts, including environmental consequences like greenhouse gas emissions and thermal comfort, economic effects such as high taxes, public service expenditures, and property values, as well as social and political issues like inequality and segregation. Therefore, urban morphology—the field of urban studies concerned with the physical characteristics, temporal dynamics, and their interactions with non-spatial factors—provides a reliable foundation for quantitative analysis of the urban environment. Cities are the epicentre of political, economic, and social activities, intricate entities woven together by people, activities, and spaces. They also reflect geography, commerce, culture, and society.

Shipping canals and their branches, as navigable urban canals, have played a significant role in shaping street layouts, activity patterns, and the creation of sedentary settlements. Water influences the functionality and aesthetic quality of cities, giving rise to distinct patterns of urban structures. While there is considerable research utilising quantitative methods to assess urban performance from the perspective of street layout (Hillier, 2007; Hillier & Iida, 2005; Omer & Kaplan, 2019), density patterns (Berghauser Pont & Haupt, 2021; van Nes et al., 2012), sustainability and resilience (Feliciotti et al., 2016; Lai et al., 2018), urban sprawl (Gielen et al., 2018; Thomas et al., 2010), and urban growth patterns (Al-Sayed et al., 2009; Dhanani, 2016; Griffiths, 2009, 2012), there is a limited focus on issues specifically related to canals and their role in urban planning and design decisions.

The narrative surrounding waterways often portrays them as victims of urbanisation, their natural cycles disrupted to the point where their existence is threatened (Biscaya & Elkadi, 2021; Palanisamy & Chui, 2015). However, recent studies have challenged this perspective, highlighting the coevolutionary relationship between cities and waterways, characterised by reciprocal interactions throughout history (Knoll et al., 2017). While numerous studies have explored this relationship in the context of rivers (Everard & Moggridge, 2012; Knoll et al., 2017), there is a lack of research on canals and their impact on the surrounding built environment.

This research aims to investigate the reciprocal dependency between canal phenomena and urban morphology by examining how canal structures impact the relationship between the built form and socioeconomic activity patterns in Amsterdam and London, two cities with distinct canal structure–city relationship paradigms. The primary research question is how the spatial function varies between these cases. Our literature review focuses on studies related to waterways and canals, as well as quantitative techniques for investigating the spatial configuration of cities in relation to canal neighbourhoods or canal-side settlements. Given the complexity of canal phenomena, this research views canals as systems of city networks. The third section of the article describes the main methods and tools used to address the problems discussed in the previous section.

The study utilises an analytical framework to assess the performance of urban forms in terms of their potential to shape the movement of inhabitants and distribution of functions. Amsterdam and London have different waterway-street layout relationships: Amsterdam has a compact grid city form designed around its canal structure, while London can be considered a naturally grown city. Various historical and practical factors have influenced the growth and development of these cities. In the predominantly water-dominated mainland, Read (1999) defines the design of Amsterdam as a necessary product of water engineering and top-down planning. Water engineering has, therefore, artificially influenced how Amsterdam appears today in terms of the arrangement of its parts, the edges, and the clarity of the whole (Read, 1999). Due to this circumstance, urban growth has not generally been as organic as London's progressive infilling of areas on the margins of its villages/towns caused by linear movement (Hillier & Vaughan, 2007).

This research aims to demonstrate how the spatial structures of these two post-industrial cities can affect the integration of canals, spatial accessibility, and socioeconomic activities of canal-side neighbourhoods. The study focuses on the neighbourhoods of Grachtengordel in Amsterdam and Regent's Canalside arm from Camden Lock to York Way in London. These two canal districts are notable examples of enduring urban development in Europe during the early modern period, with a unique combination of street and canal layout and functionality of the canal-side. What makes them particularly compelling as case studies in enduring urban development is the fact that they have been preserved for well over 250 years in cities that have experienced highly dense urban development processes as post-industrial cities. Unlike other historic canal districts, such as Venice or Bruges, which function as open-air museums and are extensively studied, Grachtengordel and Regent's Canalside arm have demonstrated remarkable adaptability and resilience over time, even in the face of new challenges. During their construction, both areas were in close proximity to the economic functions of their respective city cores, with the Regent's Canal and Grachtengordel designed to serve the needs of residential and industrial activities. Today, they serve as excellent examples of long-term urban architecture and resilience. Therefore, this article aims to conduct a data-driven advanced analysis of the spatial characteristics, including accessibility, density, and diversity of functions, affected by inner-urban canals and how these patterns are influenced by the relationship between canal-city structures.

While the focus of this study is on London and Amsterdam, the analytical approach used to assess urban performance can have a significant impact on the future development of cities worldwide, particularly when it comes to analysing cities with canals. Geographic information systems (GIS) are increasingly used to merge socioeconomic data and facilitate urban studies. This research applies a network-based accessibility analysis of space syntax, using GIS to create an integrated urban model that incorporates space syntax measures, retail density, and functional diversity on each street segment. Statistical analyses are then performed to compare the results of the analysis in London and Amsterdam and to investigate the correlations between street accessibility, density, and diversity of functions in each city.

The results demonstrate that canals play a crucial role in urban functionality, as evidenced by the analysis of street accessibility, retail density, and functional diversity. In Amsterdam, the geometric interaction between the street and canal networks has a clear influence on the distribution of activities. In contrast, London's functional distribution varies depending on the distance from the Regent's Canal. This study's methodology can effectively enhance urban planning and design processes and can be applied at specific stages of a design process. As Karimi (2012, 2018) explained, these advanced spatial analysis tools, space syntax methods, and configurational approaches can provide improved design solutions at specific stages of project implementation by investigating a selected number of projects.

2. Theoretical Background

2.1. Canals in Urban Studies

Numerous intra-city canals and canal-side areas have been extensively studied in the fields of ecology (Biscaya & Elkadi, 2021), landscape and restoration (Button & Pearce, 1989; Palanisamy & Chui, 2015), health and well-being (Vaeztavakoli et al., 2018), as well as the regeneration and transformation of canal-side areas (Buckman, 2016), to create sustainable urban spaces that seamlessly connect the city environment with its waterways. To mitigate the adverse effects of urbanisation on canal systems, there has been a growing body of literature focusing on the restoration and revitalisation of lost waterways (canals, rivers, etc.). These efforts seek to restore the ecological balance, conserve regional biodiversity, enhance cultural value, and ensure the proper functioning of canal ecosystems as blue corridors (Biscaya & Elkadi, 2021).

Also, the decline of canal-side areas and the loss of the global economic fortune of the canals in post-industrial cities and towns have created new opportunities for regeneration, and numerous studies have examined the effects of waterside regeneration initiatives on urban landscape development (Cabau et al., 2021; Fageir et al., 2021; Ponzini & Akhavan, 2020). Studies of various waterfront initiatives have all reached a similar conclusion that they have transformed the character of cities and increased pedestrian activity, cultural facilities, and functional diversity (Ponzini & Akhavan, 2020). On the other hand, gentrification has impacted some of these regeneration initiatives. For instance, Edwards (2009) evaluates the King's Cross Regent's Canalside regeneration project as a corporate activity aimed at expansion and competitiveness and susceptible to gentrification, which has led to increased rent levels in its borough.

Finally, studies on physical activity, well-being, and health have also explored the role of canals. Research investigating the impact of natural settings on human health has found that being near water promotes a variety of physical activities, positively affects overall annual health, and reduces the risk of developing illnesses such as diabetes, particularly in communities with an ample presence of blue spaces (Vaeztavakoli et al., 2018; Vert et al., 2019).

2.2. Quantitative Approaches in Urban Studies and Space Syntax

Studies on the quantitative analysis of urban form can be categorised into three primary research goals: measuring urban performance, enabling comparisons between different case areas, and analysing urban growth using analytical tools (Fleischmann et al., 2021). Studies measuring urban performance focus on specific aspects of urban form, including network-based accessibility (Hillier, 2007; Hillier & Iida, 2005; Krizek, 2003; Omer & Kaplan, 2019), density (Berghauser Pont & Haupt, 2021; van Nes et al., 2012), economy (Shen & Karimi, 2017; Solis et al., 2022), sustainability (Haggag & Ayad, 2002; Lai et al., 2018), and resilience (Feliciotti et al., 2016; Marcus & Colding, 2014). In network-based accessibility studies, space syntax theory asserts that the configuration of the street network significantly influences movement patterns (Hillier et al., 1987; Hillier & Hanson, 1984). Hillier and Hanson (1984) introduced the concept of axial lines, representing the longest straight lines that denote the maximum extension of a point in space. Another method derived from the road centreline transport network is segment analysis, which involves topological, angular, and metric analyses (Hillier, 2007; Hillier & Iida, 2005). The metric integration measure determines the proximity of one segment to all others based on the metric distance, which is the distance between the mid-points of two adjacent segments along the lines. The metric choice measure counts the frequency of each segment appearing on the shortest path between all pairs of segment analyses within a given metric distance (Hillier, 2009). On the other hand, the angular choice measure considers the straightest route as the one with the least angular variation. Angular integration analysis calculates the proximity of each segment to others based on the total number of angular changes made along each route. The reciprocal of the normalised angular total depth represents the measure of normalised angular integration, allowing for comparisons between different systems (Hillier & Iida, 2005).

In terms of space syntax studies focusing on cities dominated by canals, Read (1999) examines the spatial configuration of Dutch cities, including Amsterdam, Den Haag, Haarlem, Alkmaar, and Zaanstad. The studies explore the nature of spatial-functional relationships in these cities. The main finding is that urban development often involves the transformation of unused or abandoned industrial or agricultural land into liveable settings through water engineering. This process entails creating a spatial pattern from scratch rather than inserting a pattern into an existing urban spatial structure (Read, 1999). Furthermore, Psarra (2018) investigates the island communities of Venice and their pedestrian and combined system of routes using space syntax methods. The main analysis suggests that navigation on a large scale is easier through canals than streets within these island communities. Psarra (2018) evaluates the structure of Venice within the concept of a generic city. In theory, a generic city consists of a foreground network of interconnected centres at various scales, embedded in a background network of residential areas (Hillier, 2001, 2007). Comparing the space syntax analysis of the street network and the combined network of streets and canals in Venice, it becomes evident that the canal system is stronger in terms of the background network than the foreground network (Psarra, 2018).

To conclude, the main theoretical framework of this study aims to provide insights into the relationship between canal structure, the morphological characteristics of cities, and the analytical tools used to measure these attributes. While canal structures have been studied in various contexts, including landscape, ecology, health and well-being, restoration, urban transformation, and regeneration, the intersection of canal structures with urban form, spatial configuration, and land use has not been extensively explored using analytical methods and tools. This research aims to fill this gap by focusing on canal phenomena at the neighbourhood scale. With advancements in computational power and the availability of comprehensive spatial and socioeconomic datasets, it is now feasible to conduct configurational analyses that can address multiple issues, such as built form, street and canal arrangements, and land use types. In this research, we situate ourselves within this context and employ an analytical approach for morphological and socioeconomic analyses. The following section introduces the primary methods and tools used in this research to accomplish these objectives.

3. Methodology and Datasets

The areas of study are Regent's Canalside arm from Camden Lock to York Way in London and Grachtengordel in Amsterdam (see Figure 1). The main reason for selecting these areas is that both have historical significance in Europe in terms of scale, mixed-use development, ecological principles, and architectural aesthetics, with their well-preserved historic buildings. The importance of preserving both areas has been recognised by the heritage departments of both countries. The preservation and transformation projects in these areas address similar fundamental issues in strategies and policies for the future, which emphasise the historical origins and contemporary challenges of urban canals (King's Cross, 2020; Nijman, 2020).

The study consists of two main stages. The first stage focuses on examining the movement potential of Grachtengordel and Regent's Canalside. The second stage involves analysing building and socioeconomic data to assess the impact of the canal and canal-side spatial characteristics on land use distribution and economic activity. This stage considers three key aspects: land use distribution, retail density, and land use diversity.

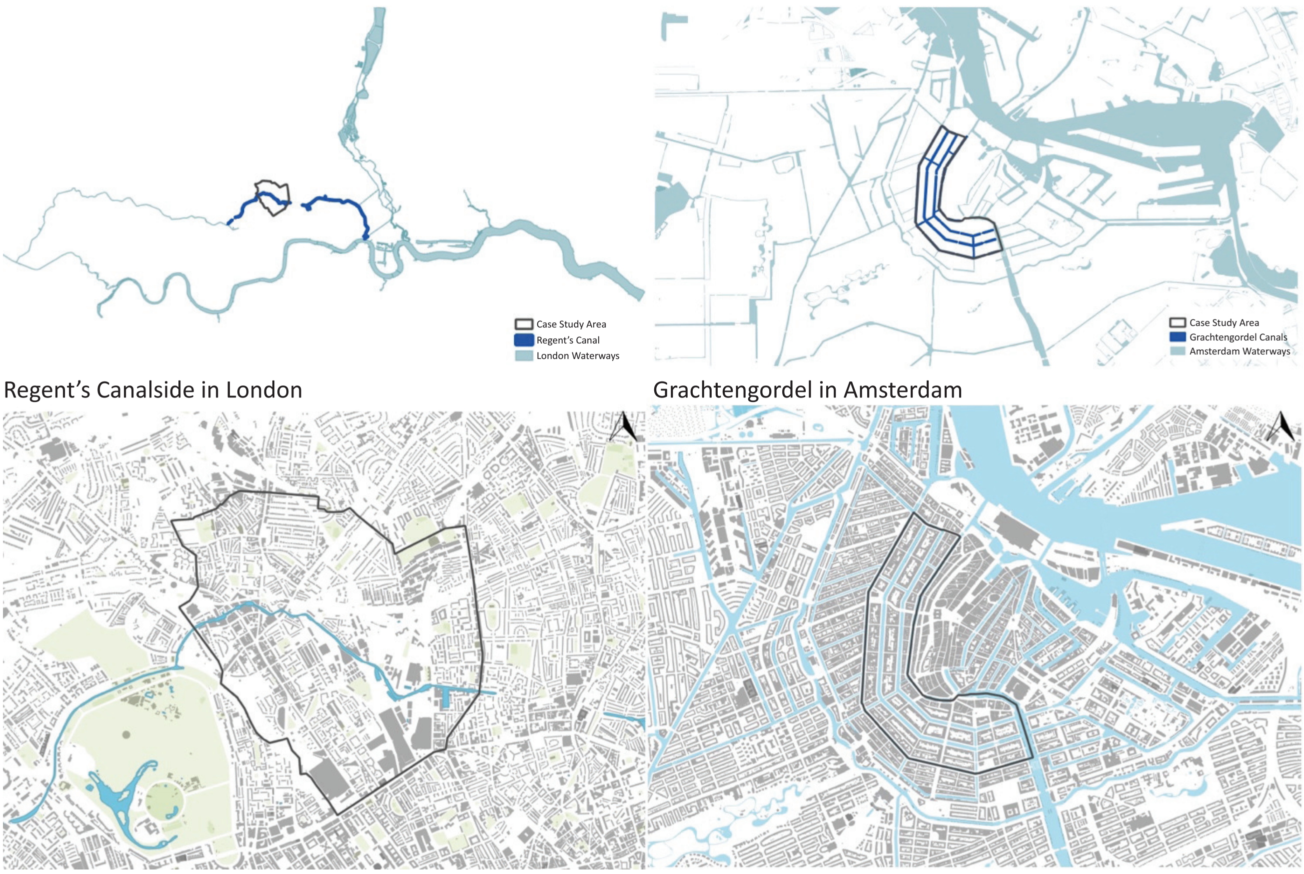

Figure 1. Case study areas.

To analyse the spatial configuration, a space syntax approach is employed, and an integrated urban model is developed by combining various datasets, including building form and land use types, with the street network. Space syntax involves measuring distance using three different metrics: metrical, topological, and geometrical distance (Hillier & Iida, 2005). The research utilises readily available data from the Netherlands and the UK, allowing for the layering of these different datasets. The network's spatial configurations are represented as segment line models, derived from the road centreline Ordnance Survey MasterMap Integrated Transport Network for London and Nationaal Wegenbestand for Amsterdam. Building footprint data is obtained from the OpenStreetMap source, while land use type data are sourced from Colouring London and the Data Amsterdam Website as of July 2020 (see Table 1).

In the second stage, the study examines land use distribution to investigate the economic activities surrounding the canals. The results of the syntactic analysis are then subjected to statistical analysis in conjunction with retail density to determine whether network accessibility correlates with economic activities. Finally, the study explores the influence of canals on land use diversity to determine if canal structures contribute to creating a mixed-use environment in contemporary cities.

For the analysis of spatial configuration, the primary measures of street network accessibility are the segment angular integration (Equation 1) and choice (Equation 2) values in space syntax. The case study areas encompass a city-wide scale and consist of a 5 km round circular spatial model centred on a focal point within each city's canal networks. This model includes a 2.5 km contextual area and a 2.5 km buffer area to avoid edge effects. As mentioned earlier, the street segment models for London and Amsterdam (Berghauser Pont et al., 2017) are derived from the road centreline maps, specifically the Ordnance Survey MasterMap Integrated Transport Network for London and the Nationaal Wegenbestand for Amsterdam. The Space Syntax Toolkit for GIS (Gil et al., 2015) is utilised to calculate the segment angular integration and choice measures (Hillier & Iida, 2005; Hillier et al., 2012; Turner, 2001).

$$\mathrm{INT}_{(i,r)} = \frac{(N_i - 1)}{\sum_{i=1}^{j} \mathrm{Dep}_{(i,j)}}, \left\{\mathrm{dis}_{(i,j)} \leq r\right\} \tag{1}$$

In this equation, $\mathrm{INT}_{(i,r)}$ is the segment angular integration value at the radius r is demonstrated as the reciprocal of the mean angular depth from segment i to all reachable street segments j within a zone defined by a radius r.

$$\mathrm{CHO}_{(i,r)} = \sum_{k=1}^{K} n_{jk}, \left\{\mathrm{dis}_{(i,j)} \leq r;\ \mathrm{dis}_{(i,k)} \leq r\right\} \tag{2}$$

In this equation, $\mathrm{CHO}_{(i,r)}$ represents the segment angular choice value, which is similar to the concept of betweenness in graph analysis. It measures the number of times the targeted segment i has been traversed in the angular shortest paths from segment j to segment k within a reachable area defined by a radius r.

Hillier et al. (2012) propose a normalisation procedure for the angular weighted graph distance, taking into account the balance between the urban system's tendency to optimise travel distance between all origins and destinations and the potential cost of segregation due to system size. This normalisation procedure facilitates comparisons across different scales within a city or between cities.

According to Hillier et al. (2012), normalised angular integration $\mathrm{NAIN}_{(\theta)}$ for a graph G' of size n is defined as flows:

$$\mathrm{NAIN}_{(\theta)} = \frac{(n+2)^{1.2}}{\left(\sum_{i=1}^{j} d_{(\theta)}(x, i)\right)} \tag{3}$$

Where $d\theta$ is the length of a geodesic (shortest path) between vertex x and i.

Table 1. Datasets of the research taken.

Datasets	London	Amsterdam
Street segments	Road centerline map from Ordnance Survey MasterMap ITN Source: https://www.ordnancesurvey.co.uk	Road centerline map from Nationaal Wegenbestand Source: Berghauser Pont et al. (2017)
Waterway segments	Waterway centreline map from OpenStreetMap Source: http://download.geofabrik.de	Waterway centreline map from OpenStreetMap Source: http://download.geofabrik.de
Building form	Building footprint data from OpenStreetMap Source: http://download.geofabrik.de	Building footprint data from OpenStreetMap Source: http://download.geofabrik.de
Land use	Colouring London Source: https://colouringlondon.org	Land use type Point of Interest (POI) data from Data.Amsterdam Website Source: https://data.amsterdam.nl

Normalised angular Choice $NACH_{(B)}$ is defined as follows:

$$NACH_{(B)}(x) = \frac{\log\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sigma(i, x, j) + 1\right)}{\log\left(\sum_{i=1} d_{\theta}(x, i) + 3\right)} \quad (i \neq x \neq j) \quad (4)$$

Where (i, x, j) = 1 if the shortest path from i to j passes through x and 0 otherwise.

POI data refers to precise point locations representing retail stores, schools, stations, businesses, and other relevant establishments. The following formula is employed to calculate the retail density (Equation 3):

$$\text{retail } p_i = \frac{\text{SUM Retail POI}}{\text{LEN}_i} \quad (5)$$

The retail density of a street segment is represented by retail p_i, where i represents a street segment; LEN_i to the length of a street segment; SUM Retail POI is the sum of the total number of retail numbers in each street segment.

Land use diversity is a metric used to assess the extent to which a variety of categorised functions are present within a predefined region (Dhanani et al., 2017; Yoshida & Tanaka, 2005). In urban studies, an entropy-based measure of diversity is often employed, and this study adopts Shannon's Diversity Index to account for the mixture of land uses within a specific unit (Equation 4). The following formula represents how land-use diversity is calculated in the study:

$$H = \sum_{i=1}^{s} p_i \times lnp_i \quad (6)$$

Shannon's Diversity Index is represented by H in this equation, where i is the number of land uses and p_i is the proportion of land uses i relative to the total number of uses provided in each street segment.

After conducting the analyses, statistical tests are performed to investigate correlations between the integration of the street network, retail density, and functional diversity. Additionally, a statistical comparison of values is carried out to examine the proximity to the canal in London and the geometric relationship with the canals (whether they are perpendicular or parallel to the canals) in Amsterdam. This comparison aims to determine whether the canals have an impact on the street network in terms of potential movement, density, and functional distribution.

4. Results

4.1. Background and Urban Context of the Case Study Areas

In the early 17th century, Amsterdam implemented new expansion strategies to address increasing population density, stimulate economic growth, and manage water in the Dutch landscape. One of the key elements of this plan was the construction of the Grachtengordel, also known as the Canal District in English, which was built between 1613 and 1663. In 2010, this area was designated as a UNESCO World Heritage site and comprises Amsterdam's four main canals: the Singel, the Herengracht, the Keizersgracht, and the Prinsengracht. The total length of the main canals in Amsterdam is 72 km, while the canals within the heritage site measure 12.5 km, with an average width of 4 m. To regulate water levels in the city canals, a sophisticated system was developed to control and release water as needed.

The construction of inner-city waterway structures and the accompanying neighbourhoods was driven by the commercial use of the canals. As Amsterdam continued to expand, the circular Singel Canal was the first to be built, followed by a series of parallel canals that connected to the growing area. The Grachtengordel plan stood out for its distinctive features, incorporating the aesthetic and classicist preferences of the era. The result was a symmetrical and regular layout with rectangular blocks and lots that achieved a balance between appearance, functionality, and profitability (Berghauser Pont & Haupt, 2021).

Regent's Canal, on the other hand, was constructed between 1812 and 1816, spanning a length of 13.8 km with a width of 4 m and featuring 13 locks. It originates from Paddington Arm (Grand Union Canal) and terminates at Limehouse, connecting to the River Thames. The canal also includes two branches known as Hertford Union Canal and Limehouse Cut. Unlike the canals in Amsterdam, which have always been integrated into the city's landscape alongside urban expansion, Regent's Canal follows a more peripheral pattern characterised by linear strips of industrial activity (see Figure 1). This research aims to explore how this disparity influences the relationship between canal structure, streets, and land use distribution in these two case study areas.

During the industrialisation period, both countries experienced economic prosperity, and the canals served as both workplaces and living spaces for tradesmen. Wealthy merchants in London and Amsterdam transformed the canal banks from being part of the cities' sewage systems into comfortable areas for production and residential purposes. This transformation continued until the decline of sea trade in the late 19th century. However, renewed interest in nature and the revitalisation of canals has led to the resurgence of canal-side urban areas as regeneration zones during the post-industrialisation period.

Different sections of Regent's Canal, such as Camden Lock to York Way, and the Grachtengordel, a historic district, encompass a mixture of water and green spaces along with buildings, streets, and railways. These areas possess distinct urban elements, structures, and functions, making them special and unique.

Regent's Canal offers a wide range of activities and possibilities, constantly evolving and capable of generating new meanings. In the Regent's Park residential development, the design of the canal-side effectively addressed residents' privacy concerns by implementing a V-shaped cross-section, with the canal positioned between slopes adorned with vegetation (Cabau et al., 2021). In contrast, the King's Cross area, a former industrial zone, underwent a regeneration project that exemplified how industrial heritage can be adapted for contemporary urban living. The circular concourse, serving as an entrance to Battle Bridge Place, emerged as a pivotal link in the pathway leading to Granary Square. Another significant connective element formed by the canal is observed in the cross-section between Victoria Park and Mile End Park Area. In this case, the southern boundary of the park, marked by the canal, was separated from the towpath by a masonry wall, resulting in a lack of connections between the two, unlike the situation in Regent's Park area (Cabau et al., 2021; see Figure 2).

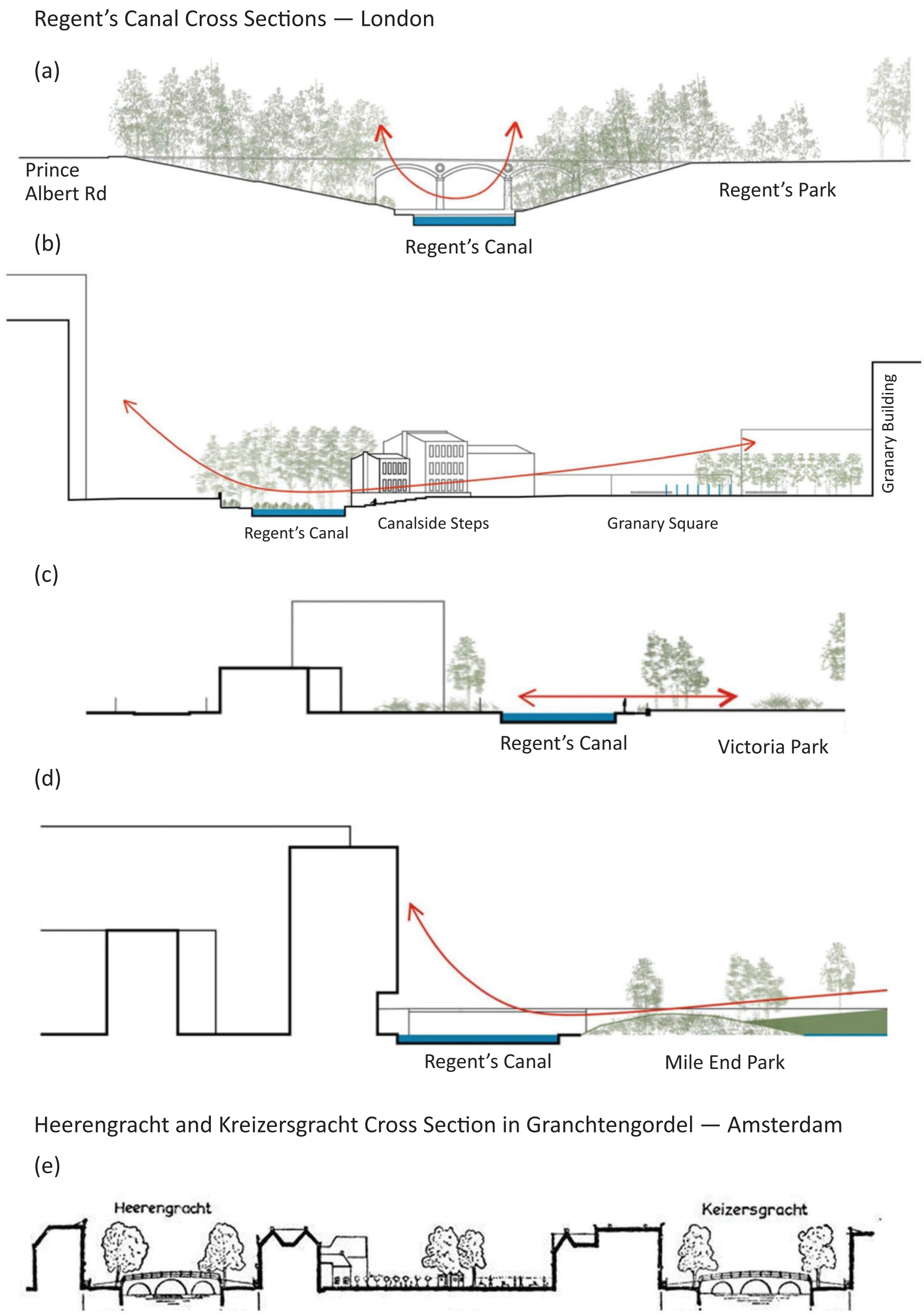

Figure 2. Cross-sections of Regent's Canal. (a) Cross-section of Regent's Canal through Regent's Park, (b) cross-section of Regent's Canal through King's Cross, (c) cross-section of Regent's Canal through Victoria Park, (d) cross-section of Regent's Canal through Mile End Park. Source: Cabau et al. (2021, pp. 292, 296, 300). (e) Cross-section between Heerengracht and Kreizersgracht in Granchtengordel. Source: Peter (n.d.).

Regent's Canal allows for diverse site developments of varying scales and footprints due to its long and linear structure. The canal's character is defined by the topography and spatial features of each bank, with a towpath situated on one side. Conversely, the Amsterdam canal system is seamlessly integrated into the cityscape, characterised by uniform facades, equally sized and arranged houses, and a dense network of canals featuring numerous bridges and towpaths on both sides, without any level differences (see Figure 2).

4.2. The Analysis of Street and Canal Network

This sub-section aims to provide a spatial analysis of Amsterdam and London, employing a series of space syntax analyses to explore their configurational urban structures, street networks, and urban canal networks. Through qualitative evaluation and quantitative comparison of the case studies, the spatial conditions of selected neighbourhoods are examined, shedding light on how canal-side neighbourhoods and navigable canal structures are integrated into the overall urban fabric.

To facilitate a large-scale quantitative comparative analysis spanning a 5 km radius model, angular segment analysis has been conducted across Amsterdam and London. The analysis of Amsterdam's street network reveals that Grachtengordel is among the most integrated areas of the city on both global and local scales. In contrast, the results of the analysis for London demonstrate that while the Camden Lock area exhibits good integration with the city structure, the King's Cross area is significantly segregated at both scales (see Figure 3). Moreover, the analysis findings illustrate that the spatial impact of Regent's Canal varies across different sections of the canal, influenced by the waterbody's location and its interaction with the city's street network.

While London's canal system follows a linear structure, Amsterdam boasts a more intricate and extensive network composed of multiple interconnected canals. A key objective of the Dutch Mobility policy is to improve accessibility for all individuals while promoting safe, environmentally friendly, and carbon-free public transportation. To achieve these goals, the policy strongly emphasises the integration of waterways into smart logistics and mobility planning. By utilising water transportation for both people and goods, carbon emissions can be reduced, and vehicles can be removed from the roads. The Ministry of Infrastructure and Water Management employs models to assess the required capacity for roads, waterways, and rail networks, making investment decisions accordingly (Rijkswaterstaat, 2022). As part of this process, the study examines the spatial configuration of the waterway network to further explore its potential as a mode of transportation.

Analysing the canal structure of Amsterdam in isolation reveals that the Leidsgracht and Prinsengracht canals are the city's most integrated waterways. Figure 4 illustrates how they shape the city's overall movement patterns and serve as highly navigable channels within the foreground grid. The analysis results also highlight that the canal network continues to play a significant role in Amsterdam's transportation infrastructure for the transfer of resources, products, and goods, among others.

The results of the street network analysis for canal bridges aim to determine the likelihood of these bridges being traversed on the shortest paths between all areas within an 800 m radius across the entire street network. In the analysis area covering the entire city, Amsterdam features a total of 731 bridges spanning its canals, with the Grachtengordel area alone accounting for 55 bridges. In comparison, London's Regent's Canal is crossed by 43 bridges. This indicates that, on average, Regent's Canal has approximately 3 bridges per km, while Amsterdam boasts an average of 10 bridges per km. Notably, the canal bridges in both cities exhibit higher mean values for NACH (number of all-space connections through a bridge) and NAIN (number of all-space integrations through a bridge) than the respective street networks of the cities as a whole. The maximum NACH and NAIN values for bridges in Amsterdam far exceed those observed in London (see Table 2). It can be observed that bridges serve as effective connectors between islands, and the canal system in Amsterdam does not create significant divisions between these islands.

The analysis findings of the 400 m buffer area around the canals were compared with the street network in both cities to gain a better understanding of the morphological impact of the canal structure on the street network. Statistical analysis was employed to compare the entire street network of the cities with the 400 m-buffered area from the canals, which approximates a five-minute walking distance and can be considered as the canal-side area. In Amsterdam, no significant difference was found, whereas the mean values of NAIN with 800 m and 2,400 m radii exhibit considerable differences in the statistical analysis results of the comparison between the 400 m-buffered area and the entire street network of London. The mean integration of the canal-side area is lower than that of the city on both local and global scales.

Another statistical analysis was conducted to examine whether Regent's Canal had distinct effects on the north and south sides of the canal in terms of the potential movement within the street network. The t-test analysis comparing the north and south sides of Regent's Canal reveals significant differences in the mean results of the space syntax analysis at both the local scale (800 m) and the global scale (2,400 m). Specifically, the south side exhibits higher normalised integration and choice values.

The next phase of the study aims to identify the specific location where the difference in NAIN values between the north and south sides of Regent's Canal occurs. To achieve this, the analysis is conducted based on the proximity to the canal. The street network is divided into three catchment areas on both sides of the canal: 0–400 m, 400–800 m, and 800–1,200 m. This division allows for the determination of the significant difference in potential movement within the background network between the south and north canal-side networks. The results of the paired T-test clearly indicate that the significant change between the south and north sides occurs within the 0–400m canal-side area.

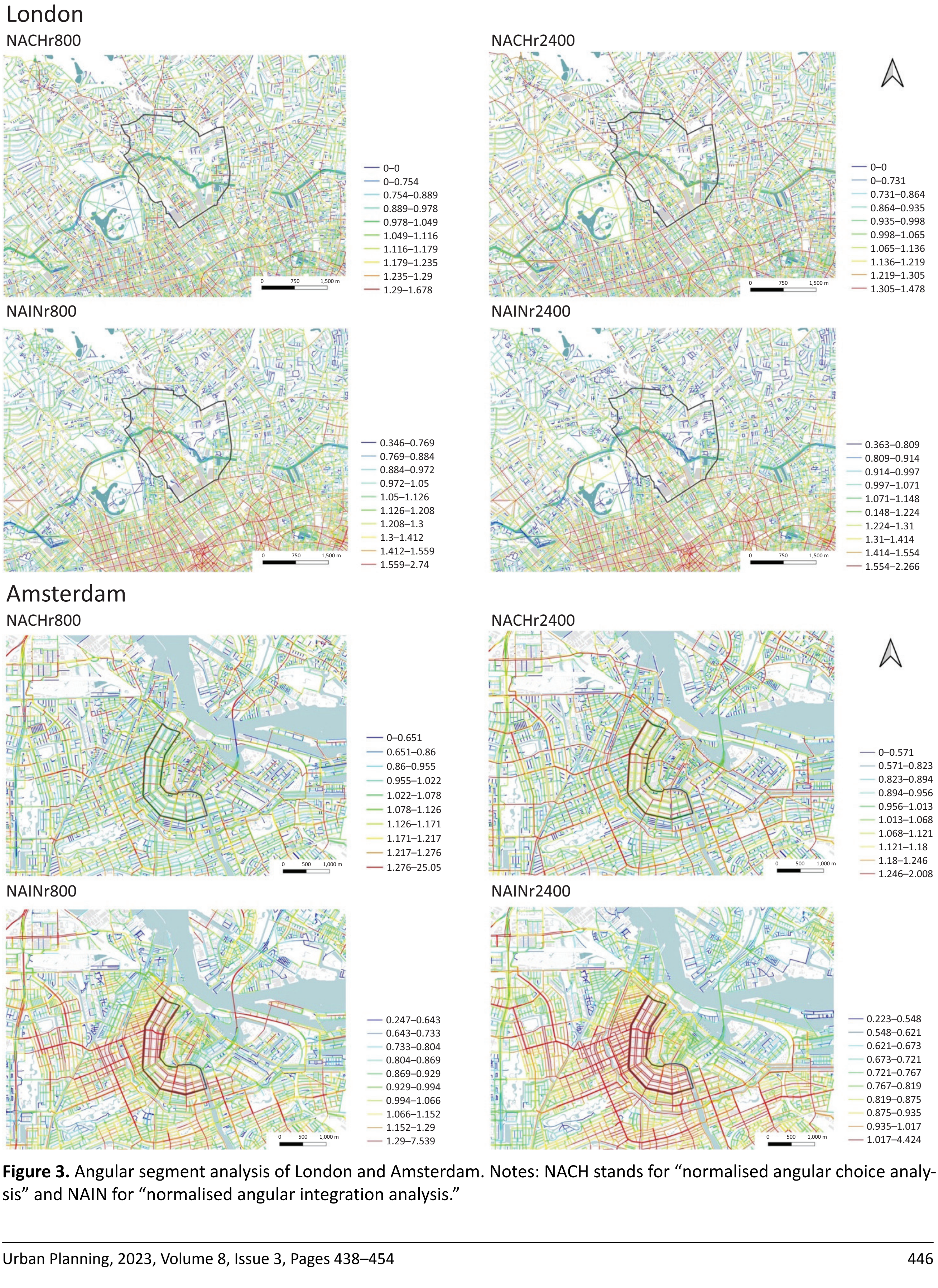

Figure 3. Angular segment analysis of London and Amsterdam. Notes: NACH stands for "normalised angular choice analysis" and NAIN for "normalised angular integration analysis."

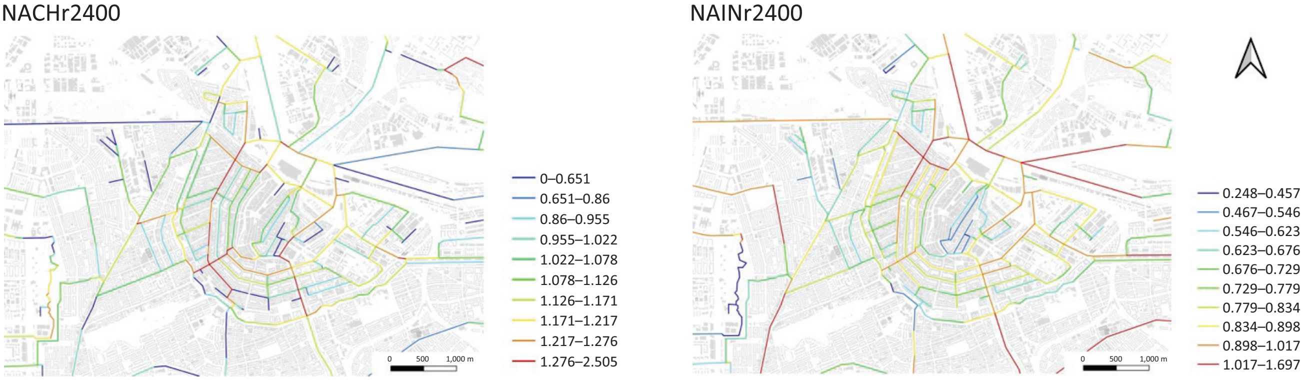

Figure 4. Canal structure of Amsterdam.

Table 2. The comparison of NACH values of bridges, canal-side, and street networks.

	NACHr2400 m				NACHr800 m			
	London		Amsterdam		London		Amsterdam	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Bridges	0.90	1.47	1.05	1.38	1.19	1.37	1.06	2.39
400 m buffered area from canals	0.91	1.44	0.95	1.38	0.92	1.6	0.99	2.33
Street network	0.90	1.47	0.94	2	0.92	1.6	0.99	2.5

4.3. The Analysis of Land Use Distribution

The objective of this sub-section is to investigate the impact of the spatial conditions surrounding navigable canals on local socioeconomic activities. As such, the study examines three socioeconomic variables: land use distribution, retail density, and land use diversity. By analysing the relationship between land uses, street spatial configuration, and canals, valuable evidence is obtained, indicating a correlation between canal structure, network accessibility, and local socioeconomic activities.

Eleven types of land use, including community services, health facilities, industry and business, education, mixed-use, recreation and leisure, religion, retail, transportation, utilities, infrastructure, and residential, are plotted into GIS for analysis. Residential function dominates the land use distribution in both case study areas. In Grachtengordel, retail and business functions prevail among the non-residential land uses, while in Regent's Canalside, mixed-use and retail functions are the most prominent non-residential functions (see Figure 5).

The analysis of land use distribution carried out using various catchments from Regent's Canal reveals that the proportion of retail land use increases as the proximity to the canal increases (see Figure 6).

The space syntax measures have been applied to two variables related to retail distribution: the total number of retailers per street segment and the retail density based on the POI data for retailers on each street segment (see Figure 7). Pearson correlation analysis was conducted to determine the statistical significance of the retail variables in relation to the space syntax analysis results. In the analysis of Grachtengordel, no correlation was found between the geographic distribution of retailers. On the other hand, the analysis of Regent's Canalside indicates that local-scale potential movement has an impact on the number and density of retailers. However, this study does not support the hypothesis that potential movement dominates retail activities in canal-side areas, as suggested by Hillier (1996). One possible reason for this is that the canal network and canal-side regeneration projects have influenced retail distribution. For example, the King's Cross regeneration project has significantly increased the number and density of retailers.

In Amsterdam, streets that run diagonally to canals have a higher retail density compared to parallel streets, as depicted in Figure 7. Lesger and Delaney (2011) conducted a study on the retail layout and urban form in Amsterdam during the mid-18th century and found that the majority of retail activities occurred in and near the old town of Amsterdam. Furthermore, they observed that retail distribution patterns were aligned with streets that had axes leading towards the old town (see Figure 8). The current empirical data and the results of this study's analysis demonstrate a clear correspondence, indicating that the highest concentration of retail establishments is still found along the series of streets with axes oriented towards the old town of Amsterdam. While the accessibility of street configurations does not affect retail locations, the structure of the urban grid does have an impact on retail distribution.

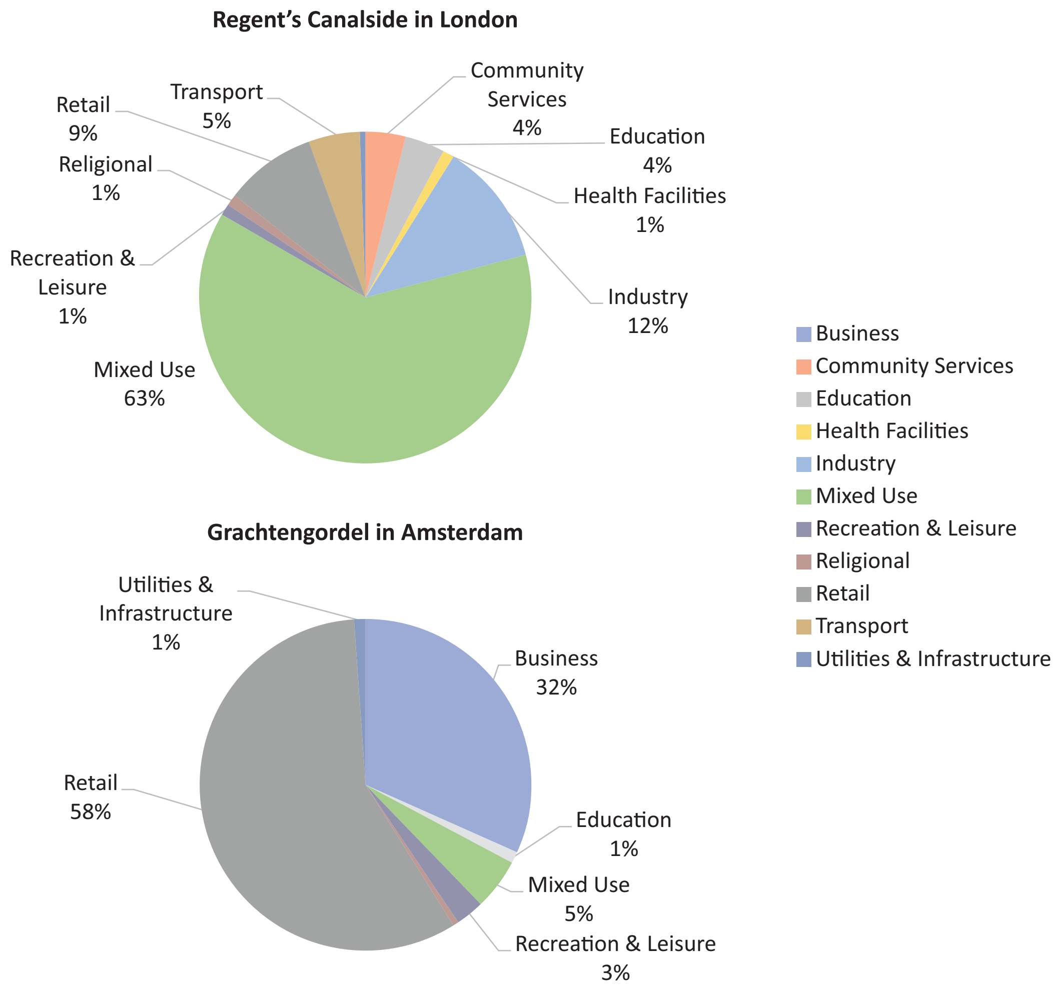

Figure 5. Non-residential land use chart for Regent's Canalside and Grachtengordel.

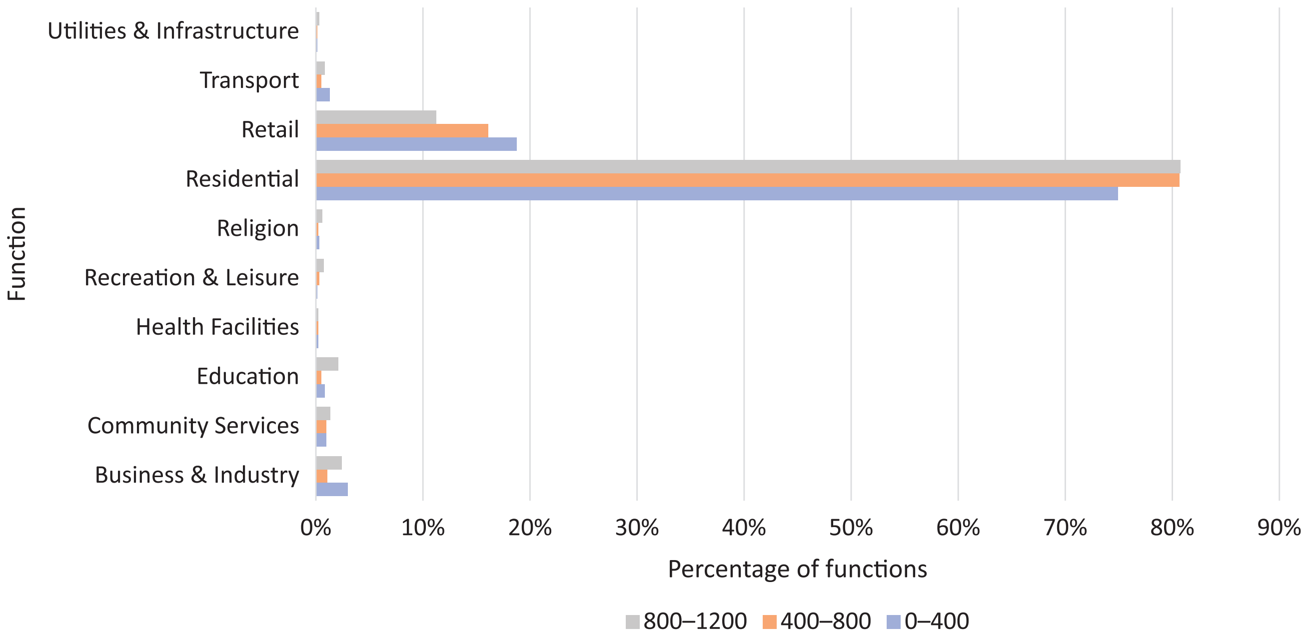

Figure 6. Land use chart for Regent's Canalside in different catchments.

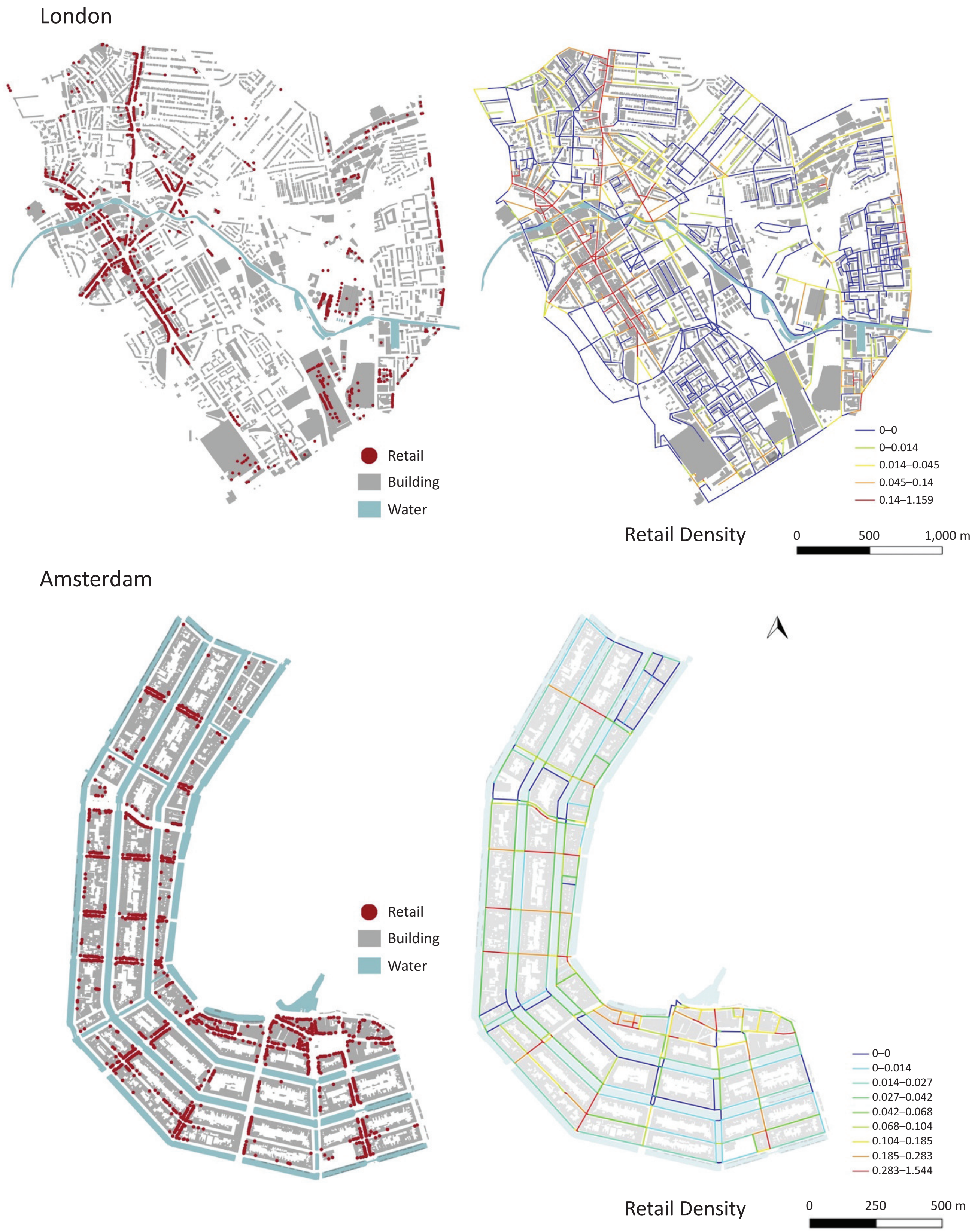

Figure 7. Retails in Regent's Canalside in London and Grachtengordel in Amsterdam: Retail distribution is on the right and retail density is on the left.

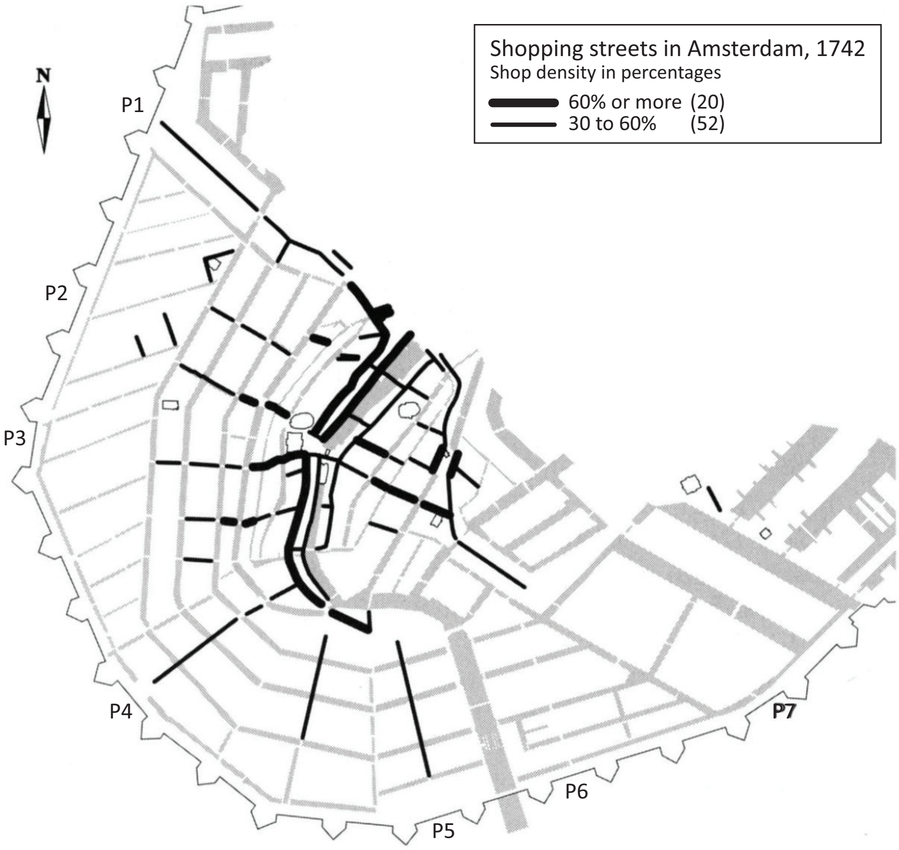

Figure 8. Amsterdam's shopping streets in 1742. Source: Lesger and Delaney (2011, p. 29).

When examining retail density and functional diversity in the Grachtengordel street network, it is evident that diagonal streets have a higher retail density compared to parallel streets. Additionally, the analysis shows that canals do not offer inherent advantages in terms of retail density, but they do have a significant impact on functional efficiency, primarily due to their high diversity. This diversity is evaluated using Shannon's Diversity Index.

5. Discussion

The conducted research aimed to investigate the relationship between canals, functional diversity, and street accessibility in Amsterdam and London. The study involved a comprehensive analysis of the spatial arrangements in both cities to understand the geometric interplay between the canal and street networks. While Regent's Canal exhibits a linear structure, Amsterdam's canals are organised in a regular grid system with cells. The study revealed the significant role played by diagonal streets in the canal grid of Grachtengordel in shaping the distribution of retail establishments. Comparing these findings with Lesger and Delaney's (2011) spatio-historical analysis of retail distribution in mid-18th century Amsterdam, it is evident that the spatial distribution of retail units continues to be oriented towards the old town.

Furthermore, the study explored the spatial patterns of land uses in close proximity to the canals. It was observed that land use types near the canal (within 0–400 m) exhibited a higher concentration of retail units. In the case of London, the percentage of retail units increased as one approached the canal. However, there was no significant correlation found between retail distribution, integration, and choice space syntax measures in both cities. To answer the question of whether retail density follows the high potential mobility pattern, the analysis suggests that, in the canal-side setting, the answer is no. The study demonstrates that the distribution of functional activities exhibits distinct spatial patterns in the canal-side context compared to other parts of the city.

In London and Amsterdam, there are distinct variations in the spatial distribution of functions. The difference in the spatio-functional context related to canals can be attributed to the contrasting urban structures of the two cities. Amsterdam follows a planned regular grid structure, while London's development evolved from the centre, absorbing diverse villages, and suburbs, and exhibiting a multi-functional use of Regent's Canal across different zones and sections. Hillier and Vaughan (2007) describe the formation of cities as a two-step process. On one hand, streets organise space to optimise movement and co-presence, emphasising the importance of public spaces that bring people together. On the other hand, the residential space process focuses on controlling mobility within residential areas and establishing relationships between residents and strangers. This study suggests that London and Amsterdam leverage the relationship between space and movement in diverse ways. The canal structure can be understood through the lens of the public space process, influenced by unique microeconomic factors specific to each city. The canal process shapes the overall structure of each city.

When comparing different sections of Regent's Canal, it becomes evident that certain areas prioritise the privatisation of housing development over other values. Examination of section drawings of the canal revealed that when buildings are tall in relation to the canal, the enclosed character of sections where buildings reach the water's edge diminishes, creating a dark environment. Conversely, when buildings are set back in the drawings, new spaces or paths created on the right bank may be insignificant and hinder the potential for developing new routes along the canal as public spaces. Additionally, some developments lead to the disappearance of spontaneous greenery and the isolation of new buildings, resulting in an overall loss of value.

This study offers valuable insights for future urban design or regeneration processes in the canal-side contexts of both cities. The analysis methods employed in this study can systematically inform the design idea generation and development phases. The analysis results can provide clarity on the project brief, context, specificities, and other relevant spatial, social, and economic factors that are crucial for urban design options. Moreover, the same analytical tools can be utilised to critically evaluate design options, assessing the impact on potential movement, land use distribution, and density patterns before and after the design interventions.

6. Conclusion

The primary objective of this study was to deepen our understanding of the relationship between canal networks and their surrounding areas. By employing analytical approaches and advanced spatial analysis techniques, this study has made a valuable contribution to the field of urban studies. It explores the variations in spatial culture, local socioeconomic activities, and functional utilisation of navigable canals and canal-side neighbourhoods across two distinct geographic locations. The study concludes by emphasising the significance of analytical methodologies based on space syntax in enhancing the integration of canal systems within cities.

One of the main challenges faced in cities is the impact of canals on mobility, which can lead to complex community severance. While canals are designed as transportation networks to enhance mobility, historic canal-side areas can also contribute to increased functional diversity and local development within the urban environment. When examining the organisation of a city, it is often perceived as consisting of multiple layers of infrastructure that support its social and economic operations. These interconnected layers develop together, resulting in diverse interpretations of the city's geographical scope. Dutch cities are renowned for their nearly flawless rationality, achieved through the use of surveying and drawing instruments. Amsterdam seamlessly fits into this pattern, reinforcing the top-down planned urban pattern essential for water management in the water-dominated environment of the Netherlands delta. This pattern influences everything it encounters, shaping models of planning and spatial design to conform to its own scale and geometry. Therefore, the growth of Amsterdam can be easily understood as the coevolution of two distinct phenomena based on the hierarchy of its streets and canals.

On the other hand, the expansion of large cities with an organic character, such as London, involves the assemblages of elemental units such as streets, waterways (rivers and canals), and railways, which have emerged over decades in relation to each other without a distinctive top-down urban planning approach. The introduction of railways in the 19th century decreased the use of waterways and provided waterside industrial areas with railways, as seen in King's Cross, enabling the transportation of heavy goods over long distances. This shaped the urban growth pattern of London, with waterside areas having a unique character as canals, railways, and streets overlapped in different sections.

The research examined the significant spatial and functional influence of the canal structure on accessibility and functional diversity in London and Amsterdam, each with a distinct relationship between the canal system and the street network. The study revealed correlations between street accessibility, retail density, and functional diversity, demonstrating that canals play a role in urban functionality. In Amsterdam, the geometric relationship between street and canal networks appeared to influence the distribution of functions. In London, however, the distribution of functions varied depending on the distance from Regent's Canal.

The research methodology and outcomes have implications for the functioning of canal systems in modern cities across various scales. The strong network accessibility of canal-side neighbourhoods can contribute to the successful optimisation of both local and global urban processes. There are several exciting potential directions for future research. Firstly, the inclusion of new cities in the study, particularly in larger global cities, would be valuable. Secondly, a comparative investigation of multiple canal-side neighbourhoods within a single city would be a novel approach, allowing for an exploration of different geographical conditions and spatial elements that influence canal impacts within a single urban context.

Acknowledgments

We would like to extend our profound gratitude to professor Laura Vaughan, whose insightful contributions significantly enriched this study. Her expertise and guidance were invaluable throughout the process. This work was supported by the Republic of Türkiye, the Ministry of National Education, which provided a postgraduate scholarship to the first author. We affirm that this institution had no influence on the design or execution of the study, thus ensuring no conflict of interest.

Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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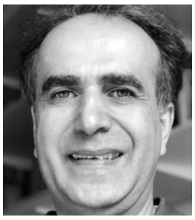

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