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Walkability and Flood Resilience: Public Space Design in Climate-Sensitive Urban Environments

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Abstract

In the contemporary urban landscape, walkability is shaped by the spatial characteristics of the built environment and its ability to adapt to environmental risks, particularly those posed by climate change. This study explores the intersection of walkability and flood adaptation strategies in waterfront public spaces across nine cities in the Baltic Sea Region, analysing their morphological characteristics with a focus on connectivity, accessibility, and climate adaptability. Using a mixed-method approach that integrates spatial mapping, quantitative metrics, qualitative analysis, and comparative case studies, this research evaluates the effectiveness of urban structure transformations and the introduction of blue-green infrastructure, floating structures, and nature-based solutions in enhancing walkability while mitigating flood risks. The findings reveal significant improvements in connectivity, as indicated by extended pedestrian route networks (increases of 6%–28%), enhanced link–node ratios (increases of 24%–39%), and a substantial rise in the number of urban nodes with direct water access (150%–1900%). These results demonstrate that climate-adaptive urban design not only strengthens flood resilience but also fosters vibrant, walkable, and socially inclusive public spaces. This study provides valuable insights for urban planners, architects, and policymakers, proposing strategies to integrate flood resilience into walkable urban environments. By emphasising the synergy between walkability and climate adaptation, this research advances the discourse on sustainable urban planning. The findings highlight the potential of adaptable waterfronts, incorporating blue-green infrastructure and flexible design principles, to enhance urban resilience while maintaining public space quality and accessibility.

Keywords

blue-green infrastructure; flood risk; public space design; sustainability; urban resilience; walkability

1. Introduction

In recent years, walkability has become increasingly relevant in urban studies, reflecting its essential role in promoting sustainable, healthy, and vibrant cities (Gehl, 2010; Maghelal & Capp, 2011; Pafka & Dovey, 2016). Defined as the extent to which the built environment encourages walking as a mode of transport, leisure, or physical activity, walkability has been linked to many benefits, including enhanced public health, reduced environmental impact, and increased social interaction (Westenhöfer et al., 2023). However, as the consequences of climate change grow, walkability becomes increasingly linked to the concept of urban resilience, understood as the ability of urban spaces to adapt and respond to climate-related natural disasters (Davoudi et al., 2013, pp. 307–322; Goldhill & Fitzgibbon, 2021).

Flooding is one of the most pressing environmental risks facing urban environments today, especially in coastal areas. Rising sea levels and the increasing frequency of extreme weather events due to climate change have heightened flood risks in many cities, which demands the integration of climate adaptation strategies to create more walkable and resilient environments (Burda & Nyka, 2017; Dal Cin et al., 2021, p. 218; Intergovernmental Panel on Climate Change, 2014). This issue is particularly relevant for coastal cities in the Baltic Sea Region, where low-lying urban areas located by water are increasingly vulnerable not only to coastal, riverine, but also urban flash flooding. Simultaneously, there is a strong impulse to develop new systems of public spaces along waterfronts and even extend them towards water to provide liveable urban environments and enhance the urban experience. Consequently, there is a growing demand for adaptable, resilient urban design approaches that can safeguard waterfront public spaces while maintaining pedestrian accessibility and usability (Dal Cin et al., 2021, p. 218; Wamsler & Brink, 2014). Emerging approaches are rooted in the principles of adaptive architecture, green infrastructure, nature-based solutions, and flexible design (Meerow et al., 2016, pp. 38–49; Silva, 2020).

Given the growing threats of climate-induced consequences for urban environments, this study explores the intersection of walkability, urban resilience, and flood risk management, taking waterfront public space design in flood-prone urban areas as the key aspect of the study (Leichenko & O'Brien, 2019). It focuses on morphological features of public spaces, particularly those related to their connectivity, resiliency, and adaptability to flooding events. The research focuses on nine coastal cities in the Baltic Sea Region, where newly created waterfront public spaces are analysed for their capacity to enhance walkability and maintain usability while adapting to flood hazards. Through this analysis, the study aims to identify design strategies for public spaces that foster vibrant, walkable waterfront urban environments that are flood-resilient.

The findings of this study are expected to provide useful tools for urban planners, architects, and policymakers in proposing more resilient urban scenarios. By emphasising the dual goals of enhancing walkability and increasing flood resilience, this research advances an evolving knowledge base on the links between flood risk and urban design. It highlights how resilient public spaces, incorporating blue-green infrastructure and adaptive structures of different proximity to water, including floating architecture, can respond to climate-related risks while maintaining pedestrian accessibility. These insights encourage the development of comprehensive design strategies that integrate resilience without compromising public space usability and quality. Ultimately, this study offers practical insights into how cities can adapt to climate change while continuing to support sustainable, pedestrian-friendly, and walkable waterfront environments.

This article is structured as follows: The next section outlines the theoretical framework and methodology employed in the study, followed by an analysis of the selected cities and their public spaces. The results section presents the findings, highlighting key design strategies. Finally, the discussion and conclusions reflect on the implications of these findings for urban theory, planning practice, and policy recommendations, and suggest avenues for further research.

1.1. Theoretical Framework

This theoretical framework synthesises core research topics to establish a comprehensive foundation for examining walkability, resilience, and flood risk management in climate-sensitive waterfront urban areas.

1.1.1. Walkability

Walkability has emerged in recent years as one of the key indicators of high-quality urban environments (Delavar et al., 2025; Kim & Gong, 2023). This topic, however, has been researched for decades, dating back to the seminal works of Jacobs (1961) on urban vitality and Ewing and Handy (2009) on urban design qualities related to walkability. Research indicates that walkable urban environments encourage physical activity, which is associated with lower rates of obesity, cardiovascular disease, and other health conditions (Ewing & Handy, 2009; Forsyth, 2015). Walkable cities support active lifestyles, mental well-being, and social cohesion, facilitating social interactions that contribute to the liveability and vibrancy of urban spaces (Ewing & Handy, 2009). They also promote community engagement and a sense of belonging, enhancing place identity (Handy et al., 2002, pp. 64–73). This aligns with broader sustainability goals, as walkability supports environmentally friendly transportation choices and helps reduce the carbon footprint of urban areas.

The morphological properties of urban structure play a pivotal role in supporting walkability (Hillier, 2007; Maghelal & Capp, 2011; Pafka & Dovey, 2016). Among these, permeability is a key determinant of pedestrian movement, referring to the extent to which an urban area is accessible via interconnected public spaces (S. Marshall, 2005). Permeability is often evaluated based on block size, street network density, and the availability of multiple route choices for pedestrians (Jacobs, 1961; Stangl, 2015). Research suggests that permeable, fine-grained urban grids support vibrant urban life (Carmona, 2021; Pafka & Dovey, 2016). For this reason, one of the most widely used metrics in walkability research are block size-based connectivity measures, which evaluate the relationship between block configuration and pedestrian accessibility (Boeing, 2021; Stangl, 2015).

Studies have shown that smaller block sizes and higher intersection densities contribute to greater walkability by providing shorter and more direct routes for pedestrians (Huang & Khalil, 2023; W. E. Marshall & Garrick, 2010; Stangl, 2015). In addition to traditional connectivity measures, recent studies emphasise the significance of "interface catchments" in walkability assessments and the "area-weighted average perimeter," which provides a refined approach to evaluating permeability (Pafka & Dovey, 2016). Some authors have indicated that walkability measures relying exclusively on intersection density and block size may overlook other important factors such as street orientation, permeability, and land use distribution. For instance, Boeing (2021) critiques overreliance on network-based metrics, while Knight and Marshall (2015) highlight the role of street alignment and connectivity hierarchy. Similarly, Pafka and Dovey (2016) emphasise the importance of considering spatial morphology and interface density in walkability analysis.

To support measuring walkability, the Global Walkability Index was created, becoming an internationally recognised tool for assessing urban walkability and identifying gaps in pedestrian infrastructure. Developed through collaborations with the World Bank and other organisations, the index evaluates critical aspects of walkability, including pedestrian safety, infrastructure quality, accessibility, land use, and access to essential services (World Bank, 2018). These elements serve as benchmarks for enhancing walkability, which has been linked to numerous urban benefits, such as reduced traffic congestion, improved air quality, and better public health outcomes (Frank et al., 2009, pp. 924–933; Lee & Talen, 2014; Litman, 2018, pp. 3–11). Connectivity is one of the key indicators used in the Global Walkability Index, relying on various data, including the link–node ratio, which is a strong morphological feature of public spaces (Knight & Marshall, 2015; World Bank, 2018).

Waterfront spaces are unique, often defined by rigid, linear post-industrial embankments. Analytical studies have examined the transition from these single-use lines to more complex configurations of blue public spaces (Proença et al., 2023). These spaces not only follow the lines of embankments—now often transformed into boulevards—but also extend towards water bodies in intricate forms, elevated or floating, creating a setting for dynamic urban activity (Burda & Nyka, 2023). However, these findings have not yet been supported by calculations of link–node ratio shifts and identification of new nodes located near or on the waterbodies. This study seeks to address this gap.

1.1.2. Climate Adaptation and Resilience

In flood-prone areas, creating walkable environments involves the added challenge of responding to extreme weather events. The City Resilience Index, developed by Arup in collaboration with the Rockefeller Foundation, provides a broad and holistic framework for assessing a city's capacity to respond to and recover from various shocks and stresses, including natural disasters, social challenges, and economic disruptions. This framework emphasises the role of blue-green infrastructure as a key indicator of urban resilience, particularly in addressing climate change threats (Arup, 2016; Arup & The Rockefeller Foundation, 2015).

Blue-green infrastructure—a strategy that incorporates natural elements like permeable surfaces, bioswales, wetlands, retention ponds, and rain gardens—offers a valuable approach to urban adaptation. Implementing blue-green infrastructure in flood-prone areas provides numerous benefits, allowing cities to manage surface water effectively and reduce runoff (Azadgar et al., 2025; Fletcher et al., 2015, pp. 525–542; Thomson & Newman, 2021). By facilitating the retention and gradual infiltration of stormwater, this infrastructure alleviates pressure on drainage systems and mitigates the risks of surface flooding (Liu et al., 2019). Moreover, blue-green infrastructure supports walkability by maintaining the accessibility of urban spaces even during adverse weather. It not only enhances flood resilience but also boosts urban biodiversity, improves air quality, and enhances the aesthetic appeal of public spaces (Benedict & McMahon, 2006; Coutts & Hahn, 2015). Integrating blue-green infrastructure with walkability initiatives allows cities to create multifunctional spaces that are visually appealing, environmentally sustainable, and resilient to climate challenges (Kuitert & van Buuren, 2022).

Cities' efforts to enhance walkability and urban resilience are closely linked to flood risk management strategies (Porębska et al., 2019; van den Brink et al., 2014). As climate change intensifies, urban areas are increasingly exposed to risks associated with rising sea levels, more frequent storms, and unpredictable weather patterns (Dangendorf et al., 2019, pp. 705–710; Leichenko, 2011, pp. 164–168). Consequently, climate adaptation in urban planning has become a priority for cities aiming to preserve functionality and liveability amid these challenges (Hallegatte et al., 2013, pp. 802–806; Neumann et al., 2015). Notable case studies in cities like Rotterdam, New York, and Copenhagen highlight the successful integration of climate adaptation measures in waterfront areas, with features such as elevated walkways, flood-resilient parks, and multi-use public spaces that function in both dry and flood conditions (Djenontin & Meadow, 2018; Moe & Müller, 2024). These examples provide practical models for integrating flood risk management, resilience, and walkability, offering adaptive frameworks for other cities to consider.

In flood-prone urban areas, climate-adaptive infrastructure ensures that public spaces remain accessible and functional under both regular and extreme conditions. Research on coastal cities in the Baltic Sea Region demonstrates that adaptable urban design is crucial for managing flood risks while enhancing urban resilience and public space quality (Nyka & Burda, 2020). By transforming hard land–water boundaries into more flexible zones, waterfront spaces maintain functionality and accessibility for communities during extreme weather events (Aerts et al., 2014, pp. 473–475; Tonmoy et al., 2020).

This study explores the intersection of walkability and flood resilience by proposing a novel analytical framework that can be applied across cities to evaluate public space development strategies. By incorporating objective variables such as the use of specific nature-based solutions, calculating the added length of pedestrian routes, analysing the link–node ratio shift, and assessing the increase in the number of nodes with a direct relationship to riverine or coastal water basins, the study contributes to a better understanding of waterfront public space morphology. The proposed approach provides insights into the walkability of waterfront areas in relation to climate adaptability, identifying key design principles tailored to Baltic coastal cities. The framework thus supports the creation of sustainable, walkable urban environments that are resilient to climate-related challenges.

2. Methodology

This study employs a mixed-method approach to evaluate walkability, resilience, and flood-risk management in public spaces across nine coastal cities in the Baltic Sea Region: Stockholm, Jönköping, Gothenburg, Copenhagen, Vejle, Gdańsk, Pärnu, Helsinki, and Turku. The analysis assesses the ability of waterfront public spaces to support walkability while mitigating flood and environmental risks. The integration of analytical components allows for a structured assessment of urban characteristics, facilitating comparisons across diverse urban scales, designs, and resilience strategies.

The methodology consists of four main phases, illustrated in Figure 1 and described in more detail in the next sections.

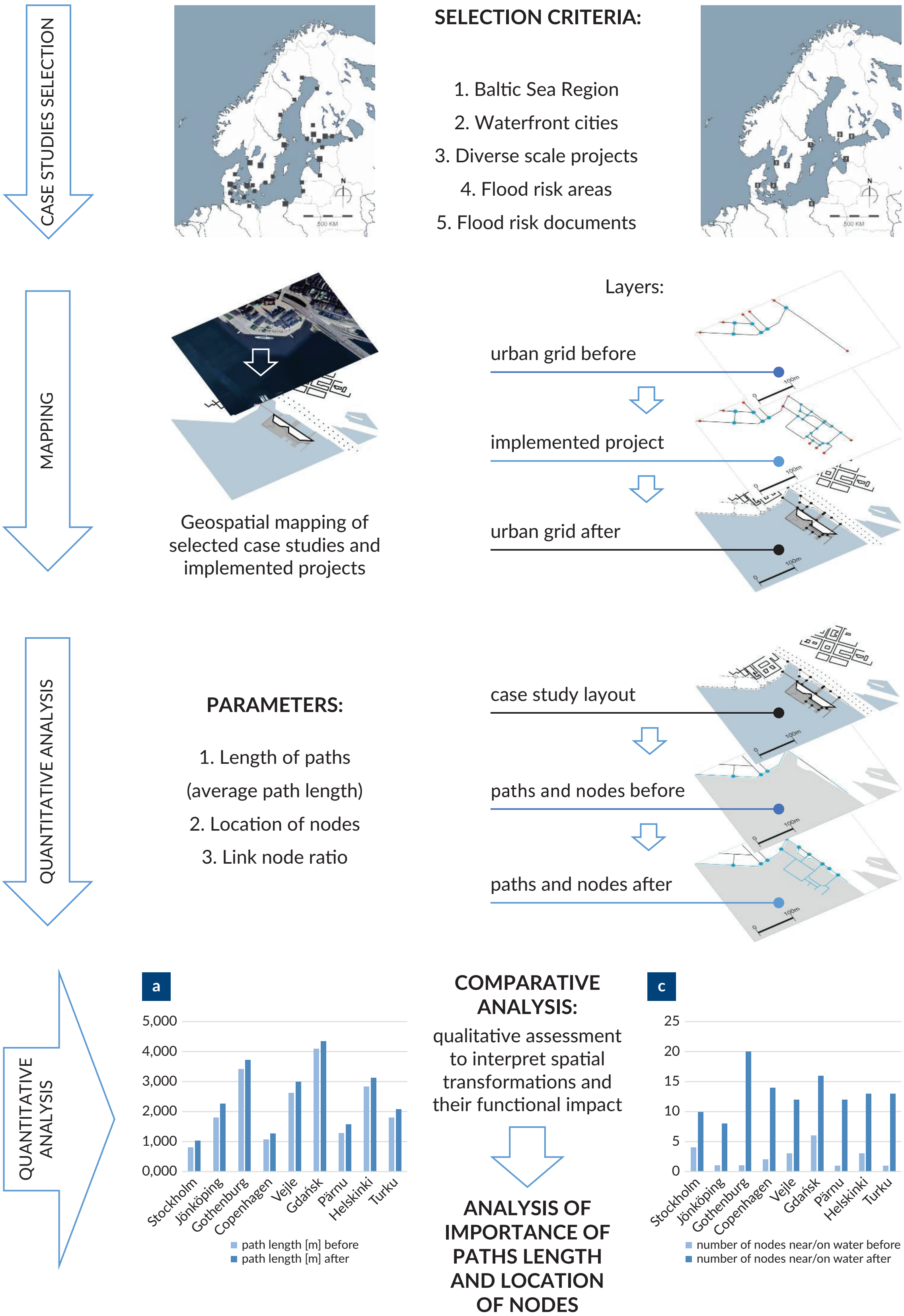

Figure 1. Methodology flowchart.

2.1. Case Study Selection

A systematic selection process was applied based on predefined criteria to ensure consistency and relevance. The study focused on waterfront cities in the Baltic Sea Region, selected from 33 pre-identified cases. The final selection was based on the following criteria:

- Location within the Baltic Sea Region, ensuring a shared climatic, cultural, and economic context (Michałowska & Głowienka, 2022).
- Urban projects featuring documented flood-risk management strategies (Irvine et al., 2023).
- Availability of spatial and policy documentation related to interventions (Ruskule et al., 2021).
- Representation of varied urban scales, from small-scale modifications to large-scale planning initiatives (Bielecka et al., 2020; Mabrouk et al., 2024).

All selected projects were situated in areas classified as flood-prone, ensuring that resilience measures were integrated into their planning (Burda & Nyka, 2023). This selection process enabled an evidence-based assessment of the spatial adaptation strategies, implementation effectiveness, and planning considerations (Doornkamp et al., 2024; Prashar et al., 2024, pp. 8235–8265).

2.2. Mapping

Following the selection of case studies, a geospatial mapping process was conducted to analyse the transformation of the public spaces. Online geoportals (such as national GIS platforms and municipal planning databases) were used to map existing waterfront public spaces and water bodies. In cases of conceptual projects (pre-implementation), geoportal-based maps were supplemented with design proposals illustrating the planned transformations.

The mapping process included:

- Spatial representations of projects before and after implementation.
- Multi-layer analysis of the urban grid and pedestrian pathways (Molaei et al., 2021, pp. 49–61).
- Assessment of connections between flood protection elements and urban accessibility (Batica & Gourbesville, 2014; Porębska et al., 2019).

This step provided both a visual and analytical basis for evaluating the urban transformation and flood resilience measures (Michałowska & Głowienka, 2022; Rezvani et al., 2024).

2.3. Quantitative Analysis

This phase focused on measuring the effects of urban interventions through spatial parameters. Three primary indicators were analysed:

- Path Length: Measures changes in connectivity by calculating the average path length.
- Location of Nodes: Assesses the number of nodes located near or on waterbodies.
- Link–Node Ratio: Assesses changes in the relationship between pedestrian paths and nodes (Gunn et al., 2017; Knight & Marshall, 2015).

Each parameter was analysed before and after the project implementation to quantify the urban transformation effects. Additional assessments included:

- Nodes located near or on the water, essential for evaluating waterfront accessibility (Molaei et al., 2021, pp. 49–61).
- Connectivity between project sites and the existing urban fabric (Ewing et al., 2020; Suits et al., 2023).

A comparative analysis was conducted using AutoCAD 2024 tools to calculate pedestrian route lengths and link–node ratios. These indicators were standardised per 100 metres to facilitate cross-city comparisons. To support the analysis of flood resilience, geospatial methods were employed to examine the spatial relationships between the connectivity and resilience features, ensuring a comprehensive urban assessment (Baltranaitė et al., 2020; Irvine et al., 2023).

2.4. Qualitative Analysis

The final phase involved a comparative qualitative assessment to interpret spatial transformations and functional impacts. This analysis focused on:

- The role of path length and node location in shaping urban accessibility.
- Morphological changes in public spaces (Porębska et al., 2019).
- Integration of floating structures, blue-green infrastructure, and stormwater management elements (Doornkamp et al., 2024; Prashar et al., 2024).

By systematically integrating quantitative and qualitative methods (Baxter & Jack, 2008), this study provides a comprehensive assessment of public space resilience and walkability in Baltic coastal cities. The methodological framework ensures rigorous data collection, comparative analysis, and actionable insights for urban planning and flood adaptation strategies (Furlan & Sinclair, 2021; Molaei et al., 2021, pp. 49–61).

3. Case Studies

This study examines the practical application of walkability and resilience in nine waterfront areas within the Baltic Sea Region (Figure 2): Stockholm, Jönköping, Gothenburg (Sweden), Copenhagen, Vejle (Denmark), Gdańsk (Poland), Pärnu (Estonia), Helsinki, and Turku (Finland). These case studies encompass diverse geographical and urban contexts, including coastal, estuarine, and riverine environments, representing both major cities like Stockholm and smaller urban centres such as Vejle and Pärnu. The selection criteria included varied urban adaptation approaches to flood risks and climate variability, reflecting different governance structures, socio-economic conditions, and urban forms.

Despite facing common hydrological challenges in the Baltic Sea Region, these cities have implemented distinct adaptive strategies. Their interventions combine conventional flood risk management with innovative blue-green infrastructure solutions, integrating contemporary flood mitigation methodologies into municipal planning. This comparative analysis highlights how adaptable design strategies enhance walkability, resilience, and community engagement in flood-prone areas. Collectively, the case studies

Figure 2. Study area. Analysed cases' locations in the Baltic Sea Region: 1. Stockholm (Sweden); 2. Jönköping (Sweden); 3. Gothenburg (Sweden); 4. Copenhagen (Denmark); 5. Vejle (Denmark); 6. Gdańsk (Poland); 7. Pärnu (Estonia); 8. Helsinki (Finland); 9. Turku (Finland).

provide a comprehensive foundation for analysing adaptive urban design, offering transferable lessons for other cities facing similar climate challenges.

The redevelopment of Stockholm's *Hamnbad* area exemplifies a comprehensive intervention aimed at revitalising a previously underutilised waterfront while enhancing climate resilience (Oopeaa, n.d.). Stockholm, Sweden's largest city, faces unique flood risks due to its archipelagic geography. The 2.5-hectare project incorporated floating pools capable of functioning during high-water events, green roofs on adjacent buildings, and permeable pavements along pedestrian pathways. These measures, outlined in municipal planning documents (Stockholms Stad, 2020, 2021, 2023), were implemented to improve stormwater management and mitigate flood risks. Beyond their hydrological benefits, these interventions contributed to the revitalisation of the public realm, strengthening urban connectivity and expanding pedestrian networks. Stockholm exemplifies the integration of public waterfront accessibility with adaptive flood mitigation, effectively addressing rising sea levels and stormwater challenges.

The *Vattenstaden* project in Jönköping is a strategic urban adaptation initiative addressing fluctuating water levels in Lake Vättern while ensuring urban connectivity (Vilhelm Lauritzen Architects, n.d.). Covering 3.0 hectares, it integrates floating walkways, modular platforms, and bioswales that function both as retention systems and pedestrian access points. Unlike coastal cities facing storm surges, Jönköping's adaptation focuses on fluctuating lake water levels, demonstrating how mid-sized inland cities can implement flood-resilient public space design. Municipal strategies (Länsstyrelsen i Jönköpings län, 2016; Municipality of Jönköping, 2013) emphasise the importance of uninterrupted pedestrian mobility, even during significant hydrological variations. The project underscores how flexible infrastructure can mitigate flood impacts while fostering a more connected urban environment.

The *Frihamnen* district of Gothenburg, with a transformed former industrial area of approximately 4.0 hectares, is an example of adaptive urban regeneration (NG Architects, 2016). Situated at the mouth of the Göta River, Gothenburg contends with both riverine and coastal flooding. The redevelopment integrates elevated walkways and floating platforms to ensure that pedestrian access routes remain functional during flood events. Gothenburg combines flood barriers with urban regeneration, ensuring resilience while maintaining economic viability—a key contrast to cities like Vejle, where nature-based solutions predominate. The city has invested in major infrastructural adaptations, such as the Göta River flood barrier, while also enhancing waterfront accessibility (Göteborgs Stad, 2015, 2021). This redevelopment exemplifies how industrialised cities can blend recreational and economic spaces in flood-prone areas.

The *Urban Rigger* project in Copenhagen is an innovative response to high population density and flood resilience (Iype, 2020). The initiative, which covers an area of 2.0 hectares, comprises modular floating housing units that adapt dynamically to fluctuating water levels, as well as an extensive network of new pedestrian pathways. Copenhagen's approach demonstrates how modular floating housing can simultaneously address urban densification and flood resilience, optimising limited waterfront space. The citywide integration of blue-green infrastructure, including cloudburst roads and stormwater parks (Københavns Kommune, 2011, 2017, 2024), serves as a model for other urban environments.

The *Floating Gardens* initiative in Vejle transforms 1.8 hectares of waterfront into a multifunctional public space, integrating flood management with ecological enhancement (Entropic, 2020). Given Vejle's vulnerability to fjord flooding, its approach prioritises nature-based solutions over large-scale infrastructural interventions, contrasting with cities like Gothenburg. This intervention combines landscaped green spaces, floating platforms, and pedestrian connectivity, improving both urban ecology and flood resilience. Municipal strategies (Vejle Kommune, 2014, 2016, 2020) emphasise community engagement, demonstrating how scalable, cost-effective strategies enhance walkability and flood adaptation.

The redevelopment of *Granary Island* in Gdańsk integrates flood resilience with heritage conservation, transforming 2.2 hectares of historic waterfront into an accessible, climate-adaptive space (Granaria, n.d.). As a city vulnerable to sea and river flooding, Gdańsk's approach illustrates the harmonisation of modern resilience features with historical landscapes, an essential consideration for cities with cultural landmarks. The project features elevated walkways and strategically positioned flood barriers, ensuring pedestrian safety while maintaining historical integrity (Gdańsk City Council, 2020). This model demonstrates how urban resilience can be integrated without compromising architectural heritage.

The *Baltic Sea Art Park* in Pärnu, a 1.5-hectare site, exemplifies cost-effective, small-scale flood adaptation strategies, integrating floating art installations, permeable paving, and pedestrian pathways (WXCA, n.d.). As a tourism-dependent city with limited resources, Pärnu prioritises small-scale interventions over large-scale infrastructure, contrasting with cities like Stockholm. This approach demonstrates how cities with budget constraints can implement flood resilience while maintaining waterfront accessibility (Government of Estonia, 2022; Keskkonnaministeerium, 2022).

Helsinki and Turku integrate flood resilience with multifunctional public spaces, but with distinct approaches. Helsinki mitigates storm surges through permeable surfaces, green roofs, and floating residential units in the *Verkkosaari* floating neighborhood (3.5 hectares; Asuntomarkkina ja maankäyttö, 2020; Helsingin kaupunki, 2017, 2024; Helsingin seudun ympäristöpalvelut – kuntayhtymä, 2012). Turku, along the Aura River, prioritises river flood management, using elevated walkways and permeable surfaces in the *Linnanniemi* district (30 hectares; Turun kaupunki, 2021, 2022, 2024). These interventions underscore how flood adaptation strategies vary based on geographic and hydrological risks, offering transferable insights for other cities.

By analysing both conceptual and completed projects, this study enables a systematic comparison between the intended outcomes and real-world impacts, providing transferable lessons for cities facing similar climate risks. The integration of flood resilience with walkability strategies demonstrates a holistic, context-specific planning approach, emphasising multifunctional public spaces and blue-green infrastructure. This comparative analysis underscores how cities can tailor their flood adaptation measures based on local geography, economic conditions, and governance structures. The findings offer a replicable model for sustainable urban development, aligning with global calls for climate-resilient cities.

4. Results

This study presents a comprehensive comparative analysis of transformative urban design interventions undertaken across nine strategically selected coastal cities within the Baltic Sea Region. Each of these cities faces distinct yet comparable challenges related to the escalating impacts of flooding, climate variability, and urban population pressures on public space functionality and resilience. In response, these cities have engaged in proactive adaptation by implementing many innovative strategies designed to enhance urban walkability, integrate blue-green infrastructure, strengthen flood resilience, and foster active community engagement within public spaces.

Table 1 summarises the investigated urban morphology transformations across the nine cities, focusing on walkability and flood resilience. For clarity and brevity, each case study is assigned a code (CS1 = Stockholm, CS2 = Jönköping, etc.), which is used consistently in the tables throughout the article. Key metrics include path length, link–node ratio, and number of nodes with a direct relationship to water, comparing pre- and post-intervention conditions. All the case studies show an increased path length (ranging from +200 m to +480 m) and improved link–node ratios, indicating enhanced connectivity. The number of nodes near or on water rises significantly, particularly in Gothenburg (1 to 20) and Gdańsk (6 to 16), reinforcing water-integrated urbanism. Floating interventions vary, including pools, platforms, docks, modular housing, and green spaces, demonstrating diverse adaptive strategies. These changes enhance walkability, accessibility, and climate resilience, offering a scalable model for sustainable waterfront development.

Table 1. Urban morphology changes: Enhancing walkability and flood resilience.

Code/city/project	Change in morphology	Path length before (m)	Path length after (m)	Path length added (m)	Link–node ratio before	Link–node ratio after	No. of nodes near/on water before	No. of nodes near/on water after	Floating structures enhancing walkability
CS1/Stockholm/Hamnbad	Expanded with floating pools	794	1,014	+220	2.8	3.5	4	10	Floating pools
CS2/Jönköping/Vattenstaden	Extended lakefront with floating paths	1,789	2,269	+480	3.1	4.2	1	8	Floating platforms
CS3/Gothenburg/Frihamnen	Redesigned with river docks	3,405	3,720	+315	2.9	3.9	1	20	Floating pools and docks
CS4/Copenhagen/Urban Rigger	Modular floating housing added	1,059	1,259	+200	2.6	3.6	2	14	Floating housing
CS5/Vejle/Floating Gardens	Blends green paths with fjord access	2,613	3,013	+400	3.0	3.8	3	12	Floating green spaces
CS6/Gdańsk/Granary Island	Historical area reconnected to river	4,093	4,343	+250	2.7	3.5	6	16	Elevated pathways only
CS7/Pärnu/Baltic Sea Art Park	New water square with floating pavilions	1,294	1,574	+280	2.9	3.6	1	12	Floating art structures
CS8/Helsinki/Verkkosaari	System of interconnected piers for a floating residential neighbourhood	2,831	3,131	+300	3.2	4.1	3	13	Floating housing units
CS9/Turku/Linnanniemi	Integrated floating gardens	1,804	2,084	+280	2.8	3.9	1	13	Floating gardens

The graphs in Figure 3 indicate that, in the analysed case studies, compared to the pre-implementation state, moderate increases in path lengths were observed (depending on the project, the path length increase ranged from 6% to 28%), and there was a moderate rise in the link–node ratio, which increased by 24% to 39% depending on the project. However, a comparison of the number of nodes located near or on the water reveals a marked increase, ranging from 150% to 1900%, depending on the project. The placement of a greater number of intersections along waterfront paths or on water-based structures significantly enhances movement opportunities towards and along the water (Figure 4). Taken together, these three increased values highlight the shift towards more extensive, connected, and integrated urban spaces, providing an assessment of the extent to which the projects improve pedestrian connectivity.

The comparative analysis of waterfront resilience strategies can be further elaborated using the gathered data (Table 1). The data reveal measurable improvements in walkability and flood adaptation through the integration of floating structures and redesigned pedestrian networks. The increase in path lengths after the interventions indicates a substantial enhancement in pedestrian accessibility. Jönköping's Vattenstaden project recorded the highest absolute increase in pedestrian pathways (+480 m), followed by Vejle's Floating Gardens (+400 m) and Gothenburg's Frihamnen (+315 m). These cities have effectively leveraged floating platforms and docks to create continuous pedestrian networks, ensuring uninterrupted accessibility even in flood-prone areas. Similarly, Stockholm's Hamnbad demonstrates a significant improvement in its link–node

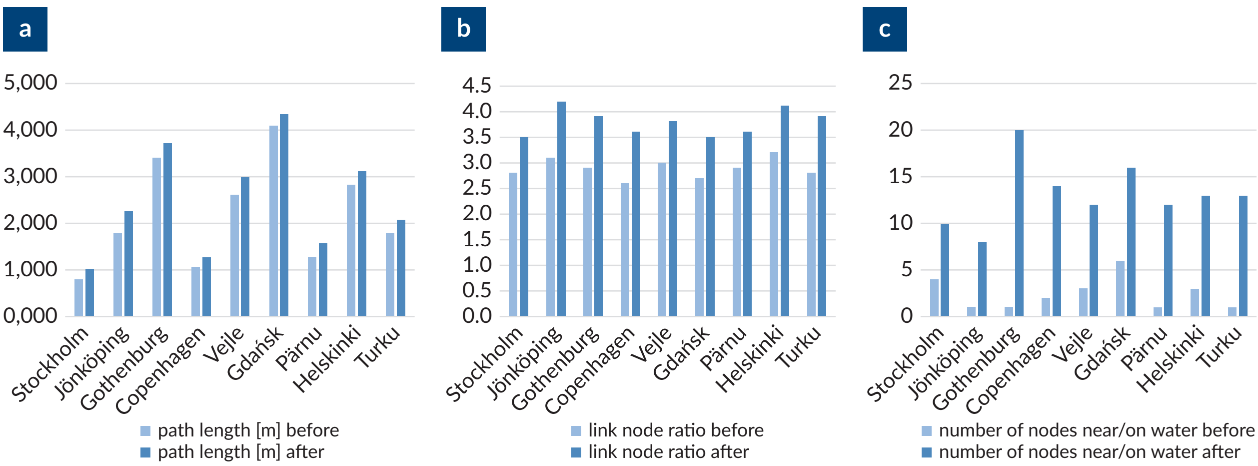

Figure 3. Comparison of the nine case studies (CS1–CS9) according to: (a) path length; (b) link–node ratio; and (c) number of nodes located near or on water.

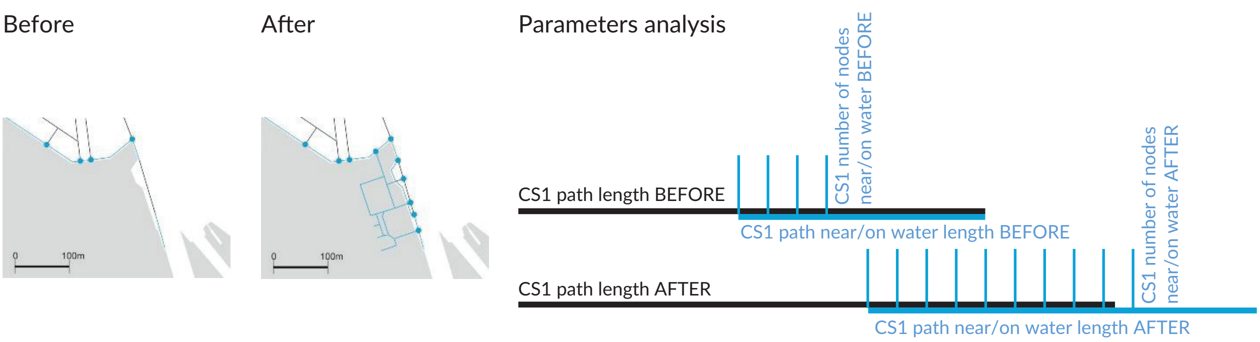

Figure 4. Visualisation of parameter analysis according to the gathered data.

ratio, increasing from 2.8 to 3.5, which suggests a more interconnected and accessible waterfront. Likewise, Helsinki's Verkkosaari and Jönköping exhibit some of the highest increases in link–node ratios (3.2 to 4.1 and 3.1 to 4.2, respectively), reinforcing the role of floating infrastructure in enhancing urban walkability.

A key differentiating factor among these cities' approaches is the type of floating infrastructure used. While Stockholm, Gothenburg, and Pärnu incorporate floating pools and art structures, emphasising recreational and cultural integration, Copenhagen and Helsinki focus on floating housing solutions, integrating residential resilience with urban adaptability. Meanwhile, Vejle and Turku prioritise floating green spaces, demonstrating a nature-based approach to flood adaptation. In contrast to these floating solutions, Gdańsk follows a different path by using elevated pathways rather than floating structures. This allows the city to integrate flood resilience while preserving its historic urban character, making it a valuable reference case for other heritage waterfront cities.

The data also reveal distinct strategic differences between historic waterfronts and newly developed areas. Gdańsk's Granary Island represents a heritage-sensitive approach where flood resilience measures are seamlessly incorporated into the existing urban morphology without altering its historical aesthetics. On the other hand, cities like Copenhagen (Urban Rigger) and Helsinki (Verkkosaari) showcase large-scale floating urban expansions, aligning their resilience strategies with broader municipal climate adaptation plans rather than site-specific interventions. This contrast highlights how different urban contexts require tailored resilience solutions that balance historic preservation with modern infrastructure.

Another important distinction emerging from the data is the contrast between small-scale, cost-effective resilience strategies and large-scale infrastructural approaches. Smaller cities like Pärnu and Vejle employ high-impact, low-cost solutions, such as floating gardens and art-driven placemaking, which enhance urban resilience while maintaining local vibrancy. Conversely, larger cities like Stockholm, Gothenburg, and Helsinki incorporate flood resilience into comprehensive urban development plans, integrating multiple functions such as housing, public spaces, and green stormwater management. This demonstrates how scale and context play a significant role in determining the feasibility and effectiveness of climate-adaptive waterfront solutions.

Figure 5 offers visual representations of the adaptive design strategies employed across the studied cities, including morphological changes, and enhancements in walkability and connectivity. These visuals provide a clearer comparison of each city's approach to flood resilience and walkability, helping to contextualise the study's findings and emphasise the diversity in adaptive urban design across regions.

Overall, the increase in link–node ratios and pedestrian path lengths across these projects confirms that floating infrastructure and adaptive waterfront design significantly improve walkability in flood-prone urban environments. Cities like Jönköping, Stockholm, and Helsinki, with some of the highest link–node ratio improvements, set a strong precedent for integrating climate resilience into pedestrian networks. Meanwhile, cities like Gdańsk and Pärnu highlight that even historic or small-scale urban areas can adopt context-sensitive solutions without compromising cultural integrity. This dataset underscores the growing importance of climate-adaptive urban design and floating infrastructure, including modular housing, in supporting pedestrian connectivity.

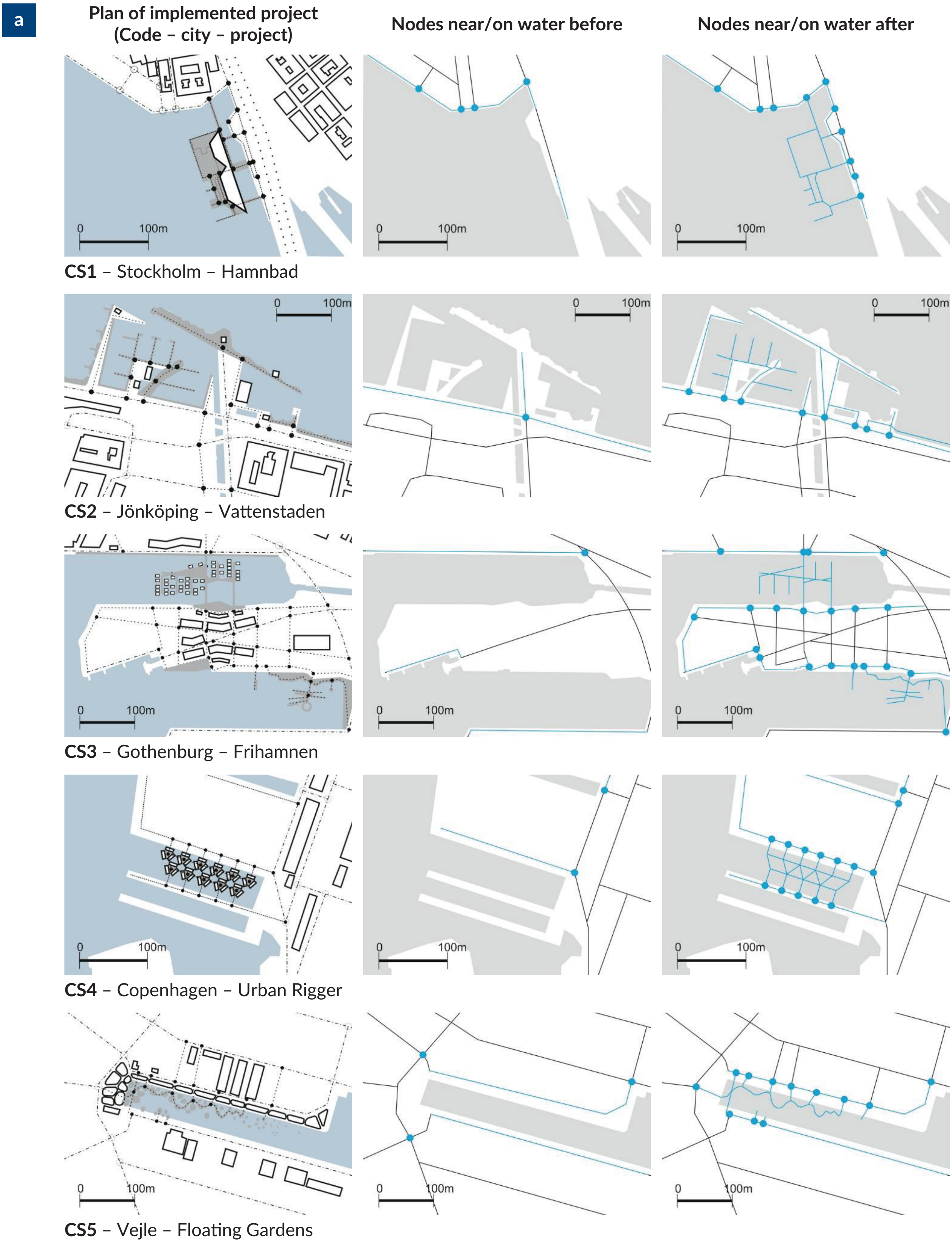

Figure 5. Layouts of the morphology of the case studies—(a) Stockholm, Jönköping, Gothenburg, Copenhagen, and Vejle; (b) Gdańsk, Pärnu, Helsinki, and Turku—and schemes for parameters analysis.

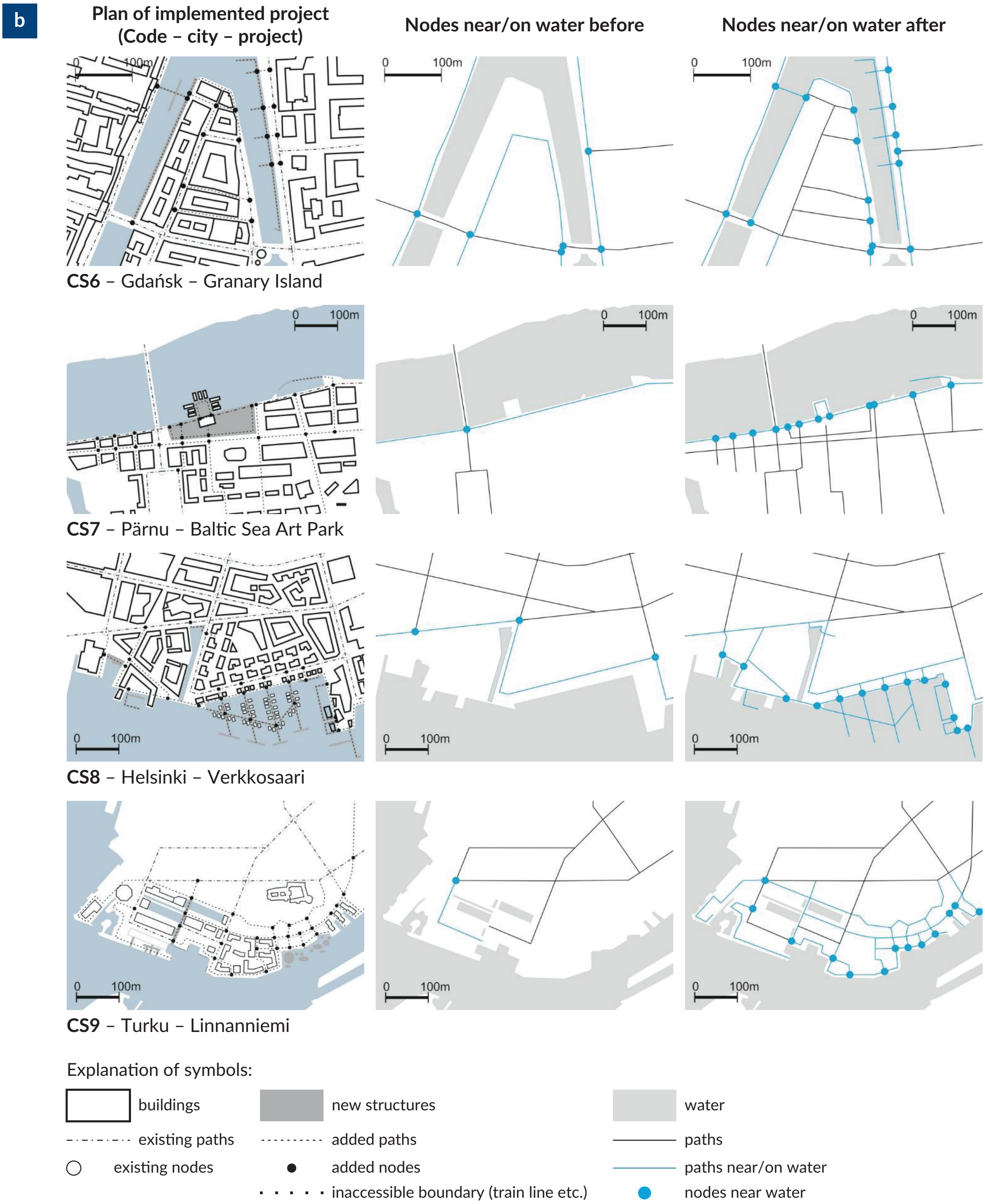

Figure 5. (Cont.) Layouts of the morphology of the case studies—(a) Stockholm, Jönköping, Gothenburg, Copenhagen, and Vejle; (b) Gdańsk, Pärnu, Helsinki, and Turku—and schemes for parameters analysis.

Table 2 summarises the adaptation strategies across the nine case studies, integrating floating structures, blue-green infrastructure, permeable surfaces, and flood risk management. All cases incorporate floating elements (e.g., pools, walkways, housing) adaptable to water-level changes. Blue-green infrastructure (bioswales, retention ponds, green roofs) supports water absorption, while permeable surfaces enhance drainage. Flood management includes elevated pathways, flood barriers, and adaptive zones to maintain functionality during extreme weather. These strategies combine floating infrastructure and nature-based solutions, creating flood-resistant, adaptable, and accessible urban spaces.

Table 2. Adaptation strategies. Source: own elaboration based on planning documents and descriptions of implemented projects referenced in Section 3.

Code	Incorporated solutions	Blue-green infrastructure	Permeable surfaces	Flood risk management	Presence of floating structures	Overall adaptation strategy
CS1	Floating pools adaptable to changing water levels	Green roofs, permeable paths	Increased permeable paving	Floodable zones	Yes	Integration of floating infrastructure for recreation allowing the area to remain usable during floods
CS2	Floating walkways and houses, elevated pathways	Proposed bioswales, greenspaces	Permeable materials planned	New flood barriers and floodable zones	Yes	Floating structures for flood resilience in housing and walkways
CS3	Elevated walkways and retention basins, floating houses and pathways	Retention ponds, green roofs	Shift to permeable surfaces	Elevated walkways	Yes	Elevated infrastructure and retention systems for public access and flood management
CS4	Floating student dormitories designed to rise with changing water levels	Planned bioswales, green islands	Permeable pathways	Naturally adapted to water	Yes	Modular floating housing units addressing housing shortages and flood risks
CS5	Water retention systems within public spaces, floating platforms and winding paths	Native vegetation, bioswales	Permeable walkways	Flood-absorbent pathways	Yes	Blue-green infrastructure integrated with aesthetic garden design to manage water
CS6	Elevated walkways and flood-resilient public areas	Retention ponds	Combination of permeable paving	Flood barriers	Yes	Mixed-use waterfront redevelopment with flood-resistant infrastructure
CS7	Floating platforms as part of art park and water square with art installations	Natural plantings	Permeable materials used	Adaptive to high tides	Yes	Floating platforms extended towards the water to ensure functionality during high water periods

Table 2. (Cont.) Adaptation strategies. Source: own elaboration based on planning documents and descriptions of implemented projects referenced in Section 3.

Code	Incorporated solutions	Blue-green infrastructure	Permeable surfaces	Flood risk management	Presence of floating structures	Overall adaptation strategy
CS8	Floating housing and public pathways	Green installations	Permeable paths around units	Flood-resilient floating units	Yes	Floating residential and public spaces resilient to water-level changes
CS9	Elevated walkways and water plazas	Green roofs, water-absorbent paths	Shift to permeable surfaces	Elevated paths, floating gardens	Yes	Elevated pathways with flood risk management and social spaces integrated

Table 3 presents the integration of blue-green infrastructure and environmental sustainability across the nine case studies. Key elements include bioswales, retention ponds, permeable surfaces, green roofs, and water-sensitive urban design. Most of the cases incorporate permeable surfaces to enhance stormwater management, with exceptions (CS1/Stockholm, CS4/Copenhagen) that focus on floating structures but have potential for future green infrastructure integration. Several cases (CS3/Gothenburg, CS5/Vejle,

Table 3. Blue-green infrastructure and environmental sustainability. Source: own elaboration based on planning documents and descriptions of implemented projects referenced in Section 3.

Code	Blue-green infrastructure features	Permeable surfaces	Environmental sustainability
CS1	Limited integration of blue-green infrastructure	Yes	Focus on recreational floating structures with potential for future blue-green infrastructure integration
CS2	Retention ponds and natural water management systems	Yes	Blue-green infrastructure to manage stormwater and improve environmental quality
CS3	Bioswales, permeable pavements, green roofs	Yes	Comprehensive integration of blue-green infrastructure to mitigate stormwater and flood risks
CS4	Limited blue-green infrastructure but potential for rooftop gardens	Yes	Focus on floating housing; green roof additions would enhance sustainability
CS5	Bioswales, permeable pavements, water retention gardens	Yes	Strong integration of water management features with public garden design
CS6	Green roofs, permeable surfaces, water-sensitive urban design	Yes	Sustainable redevelopment with focus on environmental quality and flood management
CS7	Floating platforms with green spaces integrated	Yes	Use of floating structures and water gardens to enhance resilience
CS8	Water gardens, permeable surfaces, green roofs	Yes	Strong focus on environmental sustainability and blue-green infrastructure
CS9	Green spaces, permeable pavements	Yes	Designed for resilience with emphasis on environmental quality and stormwater management

CS8/Helsinki) demonstrate comprehensive blue-green strategies, improving flood resilience and ecological quality. The findings highlight the synergy between floating infrastructure and nature-based solutions, reinforcing urban resilience, environmental quality, and sustainable water management.

Table 4 evaluates the walkability, public accessibility to water, and social interaction across the nine case studies. All the projects emphasise high walkability, incorporating floating paths, elevated walkways, and integrated public spaces to enhance pedestrian connectivity. Most of the cases provide high public accessibility to water, supporting recreational, cultural, and social engagement. Notably, CS1/Stockholm and CS3/Gothenburg include public swimming areas, while CS7/Pärnu integrates art-focused spaces for cultural interaction. CS4/Copenhagen, featuring student housing, has moderate accessibility, with the potential for further community integration. The findings highlight the role of floating and waterfront infrastructure in fostering walkable, socially vibrant, and interactive urban environments, promoting community engagement and connectivity in water-adjacent spaces.

Table 4. Walkability, connectivity, and social use.

Code	Walkability	Public accessibility to water	Social interaction
CS1	High walkability with floating pools accessible to the public	High	Public engagement through recreational swimming pools along the waterfront
CS2	High walkability with well-designed pathways along the water	High	Residential and public spaces designed for interaction and leisure along the waterfront
CS3	High walkability with elevated walkways and public paths	High	Focus on public engagement through leisure spaces such as public pools and social plazas
CS4	Floating structures create new pedestrian routes along the waterfront	Moderate	Focus on student housing, but could expand social engagement with more public spaces
CS5	High walkability with garden pathways and integrated public spaces	High	Strong focus on community interaction within garden spaces; designed for social engagement
CS6	High walkability with pathways along the revitalised waterfront	High	Mixed-use spaces encourage public interaction along the water, creating a vibrant social environment
CS7	Floating platforms provide walkable public paths and access to art installations	High	Art-focused public spaces designed for cultural and social engagement
CS8	High walkability with public pathways connecting floating homes to the urban core	High	Residential spaces are connected with public pathways, encouraging social interaction in a water-adjacent area
CS9	High walkability with elevated public paths and social spaces	High	Public spaces designed to enhance interaction along the waterfront

4.1. Key Insights From the Analysis

The analysis of the nine case studies revealed several recurring patterns and design principles that support walkability, blue-green infrastructure integration, and urban resilience. These key insights are summarised below:

1. Increasing walkway lengths and node density (link–node ratio parameter) significantly enhances the urban connectivity and fosters social cohesion by ensuring accessible, well-integrated public spaces.
2. An increase in the number of nodes directly connected to riverine or coastal water basins enhances the walkability by providing opportunities to view or spend time on the water, which serves as an important attractor.
3. Nearly all the projects integrate blue-green infrastructure to manage stormwater, as evidenced by the use of bioswales, retention ponds, and permeable surfaces.
4. The study's focus on floating structures—demonstrated by projects such as Urban Rigger in Copenhagen and Hamnbad in Stockholm—highlights an effective strategy for adaptive design that delivers both flood resilience and social value.
5. Cities like Gdańsk and Pärnu successfully incorporate cultural and historical elements into their resilience strategies, merging heritage conservation with flood adaptation.

5. Discussion

This research underscores the critical potential of integrating walkability principles and urban resilience frameworks into the design and adaptation of waterfront public spaces in flood-prone urban areas. The comparative analysis across nine Northern European cities, ranging from major metropolitan hubs like Stockholm and Copenhagen to medium-sized and smaller cities such as Pärnu and Vejle, reveals a spectrum of effective approaches to environmental adaptation. The findings emphasise the necessity of incorporating adaptive infrastructure and walkability as interconnected components that not only bolster urban resilience but also significantly enhance the quality of life (Childers et al., 2015; Le et al., 2019; Wamsler et al., 2014).

The results demonstrate that blue-green infrastructure plays a fundamental role in promoting both flood resilience and walkability. The integration of permeable surfaces, urban greenery, and bioswales not only mitigates flooding risks but also contributes to the creation of aesthetically pleasing and socially engaging public spaces (Kabisch et al., 2016; Mell, 2016). For instance, both the Frihamnen project in Gothenburg and Vejle's Floating Gardens illustrate how adaptive urban design can serve a dual function—as both flood protection measures and as catalysts for community interaction (Hansen & Pauleit, 2014; Thorne et al., 2018, pp. 960–972). These findings align with previous research emphasising the environmental, social, and economic benefits of blue-green infrastructure in contemporary urban planning (Houghton & Castillo-Salgado, 2017; Sussams et al., 2015, pp. 184–193).

A notable transformative insight from this research is the reconceptualisation of waterfronts from traditionally peripheral, underutilised areas to dynamic, multifunctional urban hubs. Projects such as Stockholm's Hamnbad exemplify how floating infrastructure can revitalise urban waterfronts, enhancing accessibility, vibrancy, and climate resilience (Meyer et al., 2016). In this context, the lowering and reconfiguration of waterfront zones facilitates greater public interaction with natural water-based environments, blending recreational spaces with resilient urban planning. This shift aligns with a broader transformation in urban design, where waterfronts are increasingly seen not as rigid barriers but as dynamic connectors linking cities to their aquatic surroundings, strengthening both urban usability and ecological integration (Gyurkovich et al., 2021; Valencia et al., 2019, pp. 4–23). Crucially, water reservoirs should not be treated as impassable barriers within the urban structure. Instead, they should be seamlessly integrated into the walkability framework through floating architectural elements, extending pedestrian networks beyond conventional land-based infrastructure.

This study also highlights the pivotal role of adaptive design strategies in enhancing urban connectivity. Innovative projects such as Copenhagen's Urban Rigger, which incorporates floating student housing, demonstrate the potential to integrate previously isolated waterfronts into seamless pedestrian networks. Such design interventions foster social cohesion and reinforce urban walkability (Davids & Thaler, 2021). By increasing the number of pathway intersections and nodes, these strategies bolster community resilience, ensuring that waterfront urban areas remain accessible even in the face of flooding events (Armitage et al., 2007; Chidambara, 2019, pp. 183–195). The implemented projects have not only resulted in the creation of nodes connecting transformed urban areas with existing urban spaces, but have also led to the emergence of additional nodes related to water, which in turn influence overall mobility. In the context of walkability analysis, the locations of the individual nodes are crucial.

The incorporation of flood resilience within public space design transforms these areas into multifunctional environments that serve environmental, social, and cultural purposes (Frumkin et al., 2017; Rega & Bonifazi, 2020). For example, Pärnu's Baltic Sea Art Park, with its floating art installations, exemplifies how resilience measures can also function as valuable cultural and social assets (Avendano-Uribe et al., 2022, pp. 278–294). These multifunctional spaces align with the contemporary paradigm of resilient urbanism, prioritising inclusivity, adaptability, and long-term environmental sustainability.

The comparative analysis of both realised developments and conceptual proposals offers crucial lessons for adaptive urban planning. Implemented projects, such as Gdańsk's Granary Island and Stockholm's Hamnbad, provide empirical evidence of the feasibility, social impact, and long-term benefits of these design strategies. In contrast, conceptual initiatives, such as Vattenstaden in Jönköping (CS2), explore emerging and experimental solutions, including 3D-printed floating structures, that may define future resilience paradigms (Brandt et al., 2021, pp. 258–271; Ghasemzadeh et al., 2021). This dual perspective highlights the importance of integrating both proven and cutting-edge approaches in response to evolving climate challenges (Meerow & Newell, 2016).

Indicating limitations of the study, it should be noted that evaluating the link–node ratio shift does not fully capture the permeability of urban environments or the pedestrian accessibility of flood-prone zones. Integrating additional parameters, such as the pedestrian catchment area, which may become a topic of further studies, can provide a supplementary framework for evaluating walkable access to urban waterfronts (Pafka & Dovey, 2016). Additionally, future studies may leverage the development of GIS tools and computational models that give rise to new opportunities for advanced analysis of urban areas, including the structural features that contribute to walkability (Sevtsuk & Mekonnen, 2012).

Importantly, this study did not delve into how flood risk affects walkability, which could become a field of further research. Future research should focus on developing scalable and adaptable urban resilience models that address local environmental and socio-economic contexts. A key opportunity lies in integrating emerging smart technologies for real-time climate monitoring, responsive flood mitigation, and data-driven urban management (Delavar et al., 2025; Swanson, 2021, pp. 287–297). Additionally, analysing the long-term viability of floating structures in conditions of limited energy access and off-grid functionality will be crucial for future urban resilience efforts (Gorzka et al., 2024, pp. 42–60; Ilugbusi et al., 2024, pp. 18–23). Future studies should also focus on identifying key pedestrian catchment areas and mapping critical points that enhance the continuity of pedestrian networks. Instead of emphasising specific project contact points, which are often undeveloped or undergoing transformation, a broader systemic approach to resilient, walkable urban environments is required. Positioning waterfront areas as living laboratories for sustainable innovation can foster experimental urbanism and dynamic community engagement (Sharp & Raven, 2021).

Moreover, a comprehensive approach should actively involve local communities in real-time communication networks and participatory flood risk monitoring systems, empowering residents and enhancing localised resilience strategies (Witte et al., 2021, pp. 283–294; Wolff et al., 2021, pp. 351–364). Ensuring that flood resilience strategies do not merely address risk mitigation but actively enhance walkability and public engagement is key to fostering a more adaptable, socially inclusive urban future.

6. Conclusions

This study underscores the importance of integrating walkability, adaptive infrastructure, and urban resilience to create dynamic and sustainable public spaces in flood-prone areas. The research reveals that successful urban resilience strategies must balance ecological, social, and technological considerations. By enhancing pedestrian connectivity and integrating water-adaptive solutions, cities can foster environments that are both resilient and accessible. The analysed projects illustrate the effectiveness of floating structures that offer promising avenues for future urban adaptation. The use of blue-green infrastructure, improved connectivity, and multifunctional urban spaces promotes environmental sustainability while enhancing community well-being. Key findings emphasise the broader applicability of these approaches, suggesting that many cities in Europe can adopt similar strategies to address climate-related challenges. This research demonstrates that flood resilience and walkability should not be treated as separate challenges, but rather as interdependent components of an adaptive urban framework. Water reservoirs and waterfronts, rather than being viewed as barriers, can serve as extensions of pedestrian networks through floating pathways, adaptable public spaces, and water-integrated mobility solutions.

In all the analysed cases, specific nature-based solutions were identified. Moreover, the calculations revealed an increase in pedestrian route lengths ranging from 6% to 28%, a rise in the link–node ratio by 24% to 39%, and a significant growth in the number of nodes with direct connections to riverine or coastal water basins, ranging from 150% to 1900%. This study enhances the understanding of waterfront public space transformations aimed at improving walkability and urban resilience. The proposed approach offers valuable insights into the walkability of waterfront areas in the context of climate adaptability, identifying key design principles tailored to Baltic coastal cities. The framework thus supports the development of sustainable, walkable urban environments that are resilient to climate-related challenges.

In conclusion, this research provides a robust framework for understanding how urban resilience can be harmonised with walkability and social inclusivity. By prioritising community engagement, environmental stewardship, and innovative design, cities can transform climate challenges into opportunities for sustainable and adaptive urban development, fostering vibrant public spaces that are both resilient and inviting for future generations.

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Conflict of Interests

The authors declare no conflict of interests.

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