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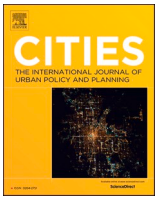

Smart port city: Digital interfaces for enhancing RoPax port and city co-existence

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ABSTRACT

The transition towards smart cities demands a multifaceted approach, which becomes particularly challenging in port cities, where urban life intersects with global logistics. While ports serve as critical logistic nodes, they hold the potential for diverse urban uses beyond mere ship traffic. This study investigates the integration of physical and digital infrastructures in port cities, focusing on the area where urban space expands towards RoPax terminals that combine wheeled cargo and passenger transport. The study is designed as a case study of a Baltic Sea port city undergoing significant infrastructural changes, including the construction of a new passenger terminal and rearrangement of the area surrounding the port. We explore the development of digital infrastructure to facilitate the coexistence of a liveable city and efficient transport connections. Our analysis is based on the dimensions of a smart city and related interfaces. The findings identify key digital interfaces between the city and its port, highlighting five types of such interfaces and the unique challenges and opportunities in balancing the smart city goals of urban and port authorities. This study contributes to the literature on smart cities by demonstrating the critical role of ports in the formation of smart cities, with implications for similar urban contexts.

1. Introduction

The transition towards smart, liveable cities requires a multifaceted approach that encompasses governance, urban planning, and citizen engagement (Cardullo & Kitchin, 2019; Elshater et al., 2022; Jiang, 2021; Edelman et al., 2024; Sharifi & Alizadeh, 2023). Such a transition is even more challenging in the case of port cities, where urban life meets global logistics. While ports can be seen as critical logistic nodes and, often, as bottlenecks for traffic flow, physical areas of ports have much more potential than merely being places where ships enter and depart (van de Laar, 2020). Space limitations, congestion and environmental concerns relevant for container- and bulk cargo-dominated port cities have often been addressed by terminal relocation. While this has been a more viable strategy for the aforementioned cargo segments, it has generally not been as feasible for port cities' combined passenger and wheeled cargo operations. An increasing number of passenger ports have had to adjust and optimise their operations and infrastructure as a response to urbanisation, expanding residential areas and other alternative land use needs by their seafronts. Digitalisation and the general transition towards smart cities (Albino et al., 2015; Hollands, 2008; Szpak et al., 2024), smart ports (Belmoukari et al., 2023; Chen et al., 2024; de Miguel i Capdevila, M., 2023; Du et al., 2023) and infrastructures (Gretzel et al., 2015; Tsvetkova et al., 2021) need to be considered in concert with such physical integration, and possibly as its enabler for achieving goals of sustainability, efficiency, and accessibility.

This study delves into the interplay of physical and digital integration in a port city dominated by RoPax shipping, which combines the transportation of wheeled cargo (roll-on, roll-off cargo, e.g., cars, trucks, trailers) with passenger transport. RoPax ports are often located close to city centres at valuable seafront locations and serve as a tourism gateway. This creates a specific challenge for such port cities in terms of passenger and cargo flow management, while ensuring habitability of the surrounding areas. We explore the development of digital infrastructure in the context of such port cities using a case study of a port city in the Baltic Sea that is undergoing a significant infrastructural

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rearrangement. The study aims to identify digital ways of enabling the coexistence of a liveable port city and functioning transport connections. Our research question is, thus, as follows: "What digital interfaces between the city and the port can support the development of ***smart port cities***?" To answer this question, we identify and analyse digital interfaces between the city and the port by combining several perspectives on a smart port city. We analyse the current digitalisation state and vision at the focal city and the port, followed by a detailed account of data availability and digital affordances in terms of port and city planning and everyday operations.

Our study points to the specifics and challenges of balancing the "smart goals" pursued by the city and port authorities while optimising both cargo and passenger flow. We identify key digital interfaces between the focal city and port and explicate their role in achieving digital integration. We also identify five types of digital interfaces necessary for a smart port city. Thus, we contribute to the literature on smart cities by explicating the role of a port, which is represented by the port authority in this study, as a critical actor in the formation of smart port cities. The findings are especially relevant in the context of the Baltic Sea, as well as beyond, where ports have gained their prominent position in urban spaces.

The remainder of the article is structured as follows. Section 2 reviews recent literature on smart cities, focusing on the dimensions of a smart city, and on port cities, which provide the analytical framework for analysing port city interfaces. Section 3 delineates the methodological choices of this study in terms of research design, data collection, analysis and validation. The findings of the study are presented in Section 4, organised according to six dimensions of a smart city. These results are further discussed with the literature in Section 5, and five key types of digital interfaces between the city and the port are outlined. Section 6 concludes the study, draws managerial and policy implications, and suggests topics for further research.

2. Literature review

2.1. Smart cities

Smart cities have been studied since the 1990s, but despite its wide use, the concept still lacks clarity and use consistency (Ahvenniemi et al., 2017; Albino et al., 2015). The definitions and conceptions vary, and often, the differences relate to how much emphasis is given to technology, people, and sustainability. While sustainability, efficiency, and citizen participation (Townsend, 2013) are often highlighted as positive attributes, the concept of smart cities has faced criticism for its normative and optimistic assumptions of future cities (Vanolo, 2013), centralising on the flow of capital, human resources (Burns et al., 2021; Burns & Andrucki, 2021), and its alignment with neoliberal ideologies (Grossi & Pianezzi, 2017). Concentrating on specific urban contexts and involving local stakeholders might be one way of addressing the local needs that bring more multifaceted understandings around the smart city discussion (Caragliu & Del Bo, 2019; Odendaal, 2020). The digital divide, however, has been the other concern, as smart cities might increase inequalities (Dragan et al., 2024), and therefore, it is crucial to promote inclusivity and accessibility of technological tools for all social groups (Caragliu & Del Bo, 2023; Colding et al., 2024; Kolotouchkina et al., 2022).

A prominent aspect highlighted in the literature on smart cities is "the utilisation of networked infrastructures" to enhance political as well as economic efficiency, while also facilitating "social, cultural and urban development" (Hollands, 2008). Therefore, the use of ICT and new technology is a key component in "smart". It can be described, e.g., as "technological, economic and social developments fuelled by smart technologies that rely on sensors, big data, open data and open Application Programming Interface (API), new ways of connectivity between humans and machines and multi-device, networked exchange of information" (Gretzel et al., 2015). According to Halegoua (2020), a future smart city has been perceived as utilising technology and data to "foster efficiency in city management and governance and to improve quality of life of urban residents". Furthermore, according to Szpak et al. (2024), digitalisation is the foundational basis of a smart city, although the role of other factors is acknowledged as well, such as "political stability, transparency, regulatory policies, equality, and competitiveness". Therefore, the people component is considered crucial in developing a smart city (Cardullo & Kitchin, 2019; Kitchin, 2014). Even though sustainability is a general goal of smart cities, Ahvenniemi et al. (2017) found a gap between the assessment frameworks of smart cities and sustainable cities, and thus, recommended using the term "sustainable smart city" instead of "smart city". However, based on a detailed analysis of smart city discourses, Joss et al. (2019) argue that "smart" does not necessarily mean "sustainable", as environmental concerns and sustainability are not always prominent in how smart cities are outlined. Exceptions to this include the cities of Vancouver, Copenhagen and Vienna, which emphasise "green" initiatives in their smart city agendas.

Albino et al. (2015) conducted an in-depth literature review on smart cities' meaning, dimensions or elements, and performance measures. Based on previous conceptualisations, the authors synthesise dimensions of a smart city, which include 1) networked infrastructure of a city enabling political efficiency and social and cultural development, 2) business-led urban development and creative activities creating urban growth, 3) social inclusion and social capital in urban development, and 4) natural environment as a strategic component for the future.

In a literature review of the dimensions of a smart city, Al Sharif and Pokharel (2022) find that the following six dimensions are commonly conceptualised: 1) smart economy, 2) smart governance, 3) smart living, 4) smart mobility, 5) smart people, and 6) smart environment. These dimensions reflect the application of digital technologies for achieving efficiencies relevant for different aspects of a city and appear in other studies (see e.g. Albino et al., 2015; Giffinger et al., 2007). Altogether, these dimensions support the four pillars of smart cities, namely institutional infrastructure, physical infrastructure, social infrastructure, and economic infrastructure (Albino et al., 2015; Silva et al., 2018). A brief characterisation of the six dimensions of a smart city is presented in Table 1.

The critical role of ports in port cities is underexplored in the literature on smart cities. For this reason, in the following section, we review the literature devoted to port city relationships, and the role of digitalisation in enhancing them.

2.2. Port cities – The interfaces between the port and the city

Port city interrelationships have changed over time, marked by phases of integration, fragmentation, and, more recently, efforts towards re-integration (Hoyle, 2000; Schubert, 2020). The port–city interface, which is the physical and functional space where ports and cities meet, has emerged as a focal point for both conflict and collaboration. Historically, ports and cities were deeply intertwined, but containerisation, globalisation, and urban expansion have led to a spatial and functional separation of these entities (Hesse, 2013; Urbanyi-Popiołek & Klopott, 2016). Today, urban redevelopment and sustainability concerns are driving initiatives to reconnect these spaces, albeit not without challenges (Bruns-Berentelg et al., 2022; Zhao et al., 2017).

Several recurring themes are visible in the literature on port–city relationships. Environmental and social concerns are seen as key tensions central to this discussion, as ports contribute to pollution, congestion, and noise, particularly when located in urban centres (Boulos, 2016; Fenton, 2020; Vroomans et al., 2022). At the same time, governance challenges persist, with urban planners and port authorities needing to balance competing priorities, such as reclaiming waterfronts for urban use versus preserving capacity for maritime logistics (Fenton, 2020; Jansen & Hein, 2023). In response to these tensions, spatial and functional separation of ports and cities happens through relocating port activities to peripheral areas, which reduces urban congestion but

Table 1
Dimensions of a smart city (based on Al Sharif & Pokharel, 2022).

Dimension of a smart city	Definition	Examples	References
Smart Economy	Innovation, competitiveness, use of digital technologies in the overall aspect of the economy, and the socially responsible use of resources	Online platforms for city services Sharing platforms for efficient use of goods and services	Arroub et al. (2016)
Smart Governance	Integrated approach to using digital technologies to enhance the transparency, efficiency, and effectiveness of urban management	Digital solutions for engaging citizens in decision-making, collaborative governance	Silva et al. (2018)
Smart Living	Integration of digital technologies into residential and community settings to enhance education, healthcare, and overall well-being	Smart buildings Support systems for health assistance	Ismagilova et al. (2019)
Smart Mobility	Integration of digital technologies to enhance transportation systems and infrastructure, aiming to alleviate common urban issues like traffic congestion and improve the efficiency, safety, and convenience of commuting in a city	Mobility-as-a-Service platforms Traffic management systems	Ismagilova et al. (2019); Silva et al. (2018)
Smart People	Enhancement of human and social capital through higher education institutions and advanced technologies, aiming to improve knowledge sharing, learning, and civic engagement	Social platforms to spread awareness about smart city applications Education platforms e-government	El-Haddadeh et al. (2019); Ismagilova et al. (2019)
Smart Environment	Integration of digital technologies to manage natural resources sustainably, optimise waste management, and enhance energy systems, contributing to improved air and water quality, increased green spaces, and pollution control	Systems for monitoring air quality Data-driven waste management planning	Appio et al. (2019); Perera et al. (2014)

simultaneously weakens economic ties with cities (Jugović et al., 2021; Urbanyi-Popiołek & Klopott, 2016) and makes governance at the port–city interface challenging (Vroomans et al., 2022).

As a result, collaborative governance is emphasised as a mechanism to align city and port priorities. This involves integrating stakeholders such as municipal authorities, port operators, local communities, and private entities into planning processes. Approaches like participatory forums, public-private partnerships, and regional planning bodies are proposed to address land use conflicts, environmental concerns, and social equity issues (Teschner, 2019; Vroomans et al., 2022). Governance frameworks also play a crucial role in managing the environmental impacts of port operations. Common port city emission reduction targets, green infrastructure, and waste management systems are increasingly embedded in governance strategies (Jugović et al., 2021).

It is worth noting that the themes discussed in relation to port–city relationships and tensions differ depending on the types of port and logistic flow. While some studies concern port cities in general (Hesse, 2013; Jansen & Hein, 2023; Vroomans et al., 2022), others have a more specific focus. In particular, within the context of container ports, often mega-ports like Rotterdam and Hamburg, the discussion of port–city relationships focuses on the relocation of container terminals outside of cities; this is driven by the need for larger spaces and reduced urban congestion (Bartłomiejski, 2016; Urbanyi-Popiołek & Klopott, 2016) and the weakening of direct economic and social ties between the port and the city, creating challenges for maintaining mutually beneficial relationships (Schubert, 2020; Zhao et al., 2017). Environmental concerns, such as emissions and noise pollution from container logistics, are another common topic, bringing research to eco-efficient practices and digitalisation as solutions for sustainable port operations (D'Amico et al., 2021).

As concerns bulk ports and industrial ports, the literature also often highlights their dual role as economic drivers and sources of environmental strain and land use conflicts (Boulos, 2016; Hesse, 2013). Similarly to container ports, the relocation of bulk operations away from urban centres is commonly discussed as a strategy to reduce urban congestion and environmental impact. However, such moves can lead to logistical inefficiencies and governance complexities, particularly when ensuring connectivity to hinterland industries (Jugović et al., 2021). Digitalisation plays a role in improving the efficiency of bulk port operations, such as real-time tracking of cargo flows and optimised hinterland connections, though it is less prominent compared to container ports (D'Amico et al., 2021).

RoPax and passenger ports are less researched and present a distinct set of challenges and opportunities at the port–city interface. These ports remain closely tied to urban centres, driven by their reliance on passenger traffic, urban attractions, and intermodal connectivity (Fenton, 2020; Hermelin & Jonsson, 2021). Literature on these ports often focuses on their integration with city infrastructure, addressing issues such as congestion at terminal access points, energy demands, and waste management from cruise and ferry operations (Fenton, 2020). The key tensions between port and city in the context of cruise operations in particular includes environmental degradation related to pollution and waste management, socio-cultural impacts, including overcrowding and strain on local infrastructure, and economic disparities, where the financial benefits of cruise tourism may not equitably reach local communities (Kulkov et al., 2023). For RoPax ports, which provide passenger transportation service in addition to the tourism experience, these tensions are less pronounced. Moreover, while some RoPax ports serve the so-called cruiseferry vessels, which combine transportation of wheeled cargo with the capability for passenger accommodation and leisure travel, other RoPax ports are predominantly focused on transporting trucks, trailers and cars, providing minimum facilities for the passengers. The challenges of port–city relationships in case of cargo operations are thus partly applicable, especially in the latter type of ports.

To summarise, the challenges related to port–city interfaces in RoPax traffic-dominated port cities, especially cruiseferry ports, include ***spatial tensions*** between the city and the port, the ***environmental impact*** of port operations on the city, the need for ***transport connectivity*** between the two entities, and the role of ***tourism in the economic interdependence*** between the city and the port. The governance of RoPax ports requires particular attention to passenger and citizen needs, emphasising close collaboration between the port and urban authorities to ensure smooth mobility and urban connectivity (Jansen & Hein, 2023). Digitalisation is highlighted as a tool to enhance the passenger experience, optimise terminal operations, and improve intermodal traffic management (Chen et al., 2024), but its potential for addressing environmental concerns, such as emissions and waste, remains underexplored (D'Amico et al., 2021).

In summary, while container ports are characterised by their significant logistical demands and associated environmental pressures and bulk ports primarily focus on industrial integration and hinterland connectivity, RoPax-dominated port cities emphasise passenger mobility, seamless urban access and integration of the port with the city's infrastructure. Digitalisation is recognised as an enabler of more efficient and sustainable port–city interactions, albeit with varying degrees of application and focus. The integration of digital infrastructure between these parties can contribute to improved mobility, cargo flow, monitoring, asset management, and communication, and requires establishing digital interfaces. An interface, in the context of technology

and organisations, serves as both a boundary and a connection point within the architecture of a system or product. It delineates the divisions between different modules or organisational units and defines how they interact and communicate within the larger system (Gawer, 2021). According to Gawer (2021), a digital interface both demarcates and connects various actors within a digitalised context, structuring how they interconnect and facilitate data exchange. In this study, we are interested in the digital interfaces between a city and a port in a port city context, which we broadly define as the existing or potential data exchange between these two entities that facilitates the "smartness" of the port city.

3. Methodology

3.1. Research design and context

Because of the nascent status of the smart port city empirical development and theoretical background, an exploratory single-case study was designed to approach the research question (Mills et al., 2012; Yin, 2009). Exploratory studies allow the contextualisation of new and emerging empirical phenomena (Gustafsson & Tsvetkova, 2017; Swedberg, 2020). The two-year project aims to enhance the digital integration of a focal city and port while considering adjacent urban areas near the port. The focal port city, rich in maritime and cultural history, is located by the Baltic Sea with a population around 200,000–300,000 inhabitants. As mentioned earlier, the focal port is dominated by RoPax traffic, serving predominantly as a cruiseferry port with an annual throughput of around 300,000 vehicle units (of which approximately 70 % are passenger vehicles and 30 % cargo units) and 2.0–2.5 million passengers. Smaller cruise ships also occasionally call at the port, but this is not the port's core business compared to the regular cruiseferry services. The challenges related to the negative social and environmental impacts of cruise tourism on local communities (Kulkov et al., 2023) are not pronounced in the case of cruiseferry operations. The case area in the focal city selected for the study will undergo significant transformations in the coming years where the urban area of the city expands closer to the port. This is part of the city's vision to connect its centre with the sea. The construction of a new terminal building will free up some of the land currently used by the port for urban developments, which will be led by the city as the owner of the land. Rearrangements with the smoother traffic, efficient port operations and expansion of the urban area closer to the port require efficient city–port cooperation, therefore making this area a highly suitable case for our study as the physical and digital interfaces are undergoing transformation.

3.2. Data collection

Data collection for the current study consists of document analysis, semi-structured interviews and a stakeholder workshop. First, the document analysis was performed including research reports, city strategies and visions as well as port strategies and a programme to understand the context of where port–city relationships are situated and prepare for the data collection (see Table 2). The document analysis was re-evaluated in a later phase based on information from additional relevant documents gained through interviews and the workshop, which enabled the creation of a whole picture on how the case is developing towards a smart city.

The document analysis informed the development of the interview framework in the second phase of the study that lasted from September 2022 until May 2024. Data were collected through semi-structured interviews with representatives from different departments of the city and the port, the local Destination Management Organisation (DMO), and during a joint workshop with these stakeholders. In total, 12 interviews were conducted, reaching out to 14 informants (Table 3). These included two interviews with the representatives of the port authority, namely the CEO and the IT manager, 9 interviews with the city involving 11 city representatives from different departments, and an interview with a representative of a local DMO. These interviewees can be characterised in a similar vein as "elite informants" (Aguinis & Solarino, 2019), as they were selected for their expertise and knowledge related to the urban transformation of the area under study where the RoPax port is located, as well as regarding the city's and the port authority's aims for future smart development. Moreover, most of the interviewees were engaged in the research project throughout its duration; that is, they were interviewed, participated in a workshop and were able to review and validate the results through continuous discussion with the researchers.

In the city where the study is conducted, the port authority operates as a wholly owned subsidiary of the city's group of companies. In this context, companies tasked with managing critical infrastructure or special functions for the city have remained under municipal ownership. Consequently, the port authority is not perceived as an isolated entity but rather as an integral member of the city group, contributing

Table 2
Data sources for document analysis.

Type of document	Examples of documents	Number of documents	Number of pages
City strategies, plans and programmes	City Strategy 2030 (16 p.) Mayor's Programme (24 p.) Climate Plan 2029 (69 p.) General Plan 2029 (32 p.) Information Management Strategy 2022–2025 (32 p.) The Vision for the City Centre (104 p.) International Idea Competition for the Port-City Interface – Evaluation Minutes (199 p.) General Plan for Tramway (127 p.) Art Programme for the Port–City Interface (62 p.)	9	665
Port strategies, plans and programmes	Terminal Masterplan (70 p.) General Plan for Transport and Mobility in the Port Area (52 p.) Reference Plan for Port–City Interface (104 p.) Approved Port Detail Plan (4 p.) Annual Report (38 p.)	4	268

Table 3
List of interviewees.

Perspective	Informants' expertise [code names]	Interviewee number	Interview sessions
City [C]	Mobility services [C.A]	1	1
	Digital services [C·B]	1	1
	Traffic management [C·C]	1	1
	Project for focal area development [C·D] and [C.E]	2	1
	GIS data coordination [C·F] and privacy management [C.G]	2	1
	Strategy and development [C·H]	1	1
	Information service [C·I]	1	1
	Urban planning [C.J]	1	1
	Business and economic development [C·K]	1	1
Tourism [T]	Destination management [T.A]	1	1
Port [P]	IT strategy [P.A]	1	1
	Port management [P·B]	1	1
	Total	14	12

collaboratively to the ongoing transformation of the port–city interface.

The port's role is analysed primarily from the perspective of port authority responsibilities, which include infrastructure maintenance, development, and the administration of rental operations. However, this role is about to expand with the integration of new additional infrastructure, services, and operations that have traditionally been managed by private shipping lines within the port. The planning of this transformative process has involved active engagement and consultation with these shipping lines, whose perspectives are indirectly represented through the interviews conducted with the port representatives. Given the port's existing governance model, other operators within the port were not considered relevant for this study.

Prior to the interviews, the interviewees provided written consent by signing an interview data agreement document.[1] Before obtaining this consent, the interviewers also explained orally the content of the agreement, that is, the project's objectives, the purpose of the interviews, and the procedures for handling and utilising the interview transcripts and data. Each interview lasted about 60 min and covered six themes: the development of the area where the RoPax port is located; crucial stakeholders in this development; digitalisation in relation to this specific area; data collection, management and sharing; the meaning of smart city/smart port; and opportunities for tourism and leisure in this area (see Appendix A). The interviews were recorded and transcribed.

Based on the interview analysis, the first draft of the data-application matrix was created and later presented in a stakeholder workshop consisting of representatives from the port authorities and different city departments who were interviewed in a previous phase of the study and were familiar with the project's goals and research outputs. The data-application matrix was presented before the actual workshop in a meeting that lasted two hours. The workshop itself, where the data-application matrix was reviewed and complemented with additional information from the workshop participants, was included in the meeting and lasted 60 min. The data-application matrix provided an overview of the current status of digitalisation, encompassing data collected concerning the port and the city. It included information on existing digital data and implemented digital tools and areas where digital interfaces are lacking or would be valuable.

During the workshop, participants (7 participants representing the focal city and port and 5 researchers) started to work with the matrix based on discussions around the themes that formed the structure of the matrix and filling the gaps on digital information that we could not identify from the data collected with interviews. The workshop was divided into two smaller groups, where five researchers facilitated the group work and took notes on the two parallel group discussions. These notes were compared later and gathered into one file. The workshop participants made their own additions to the data-application matrix during the workshop. The researchers' notes as well as modifications and additions made by workshop participants were used to improve the matrix in its revised version, which were then reviewed by the workshop participants as follows. The matrix was sent to the participants via an online collaborative tool so that participants were able to make more comments and additions after the workshop and review the outcomes of the workshop.

3.3. Data analysis and validation

Interview transcriptions were analysed with the NVivo 14 software program starting from initial coding, followed by focused coding that enabled categorisation codes for building the structure for the analysis (Charmaz, 2006; Creswell & Báez, 2020). The initial coding was performed by five researchers, two of which continued with the focused coding independently, with the main focus on data collection, processing and data sharing, data storage and data application. Although one of the interview themes was specifically related to the data, the information gained from discussing other interview themes also became relevant for creating the data-application matrix, addressing not only the current situation but also the data needs and ideas for application that do not yet exist but could be beneficial in the future. Then the researchers compared the codes and merged and revised them through discussions within the researcher team.

In the second phase of the analysis, the interview analysis and workshop notes were structured using the data-application matrix as described above. They were further analysed by applying the theoretical framework, namely the six dimensions of the smart city: smart economy, smart governance, smart living, smart mobility, smart people, and smart environment (see Section 2.1). These dimensions are used to categorise the observed instances of existing or potential digital solutions that concern the focal city integration with the port. These findings are presented in detail in Sections 4.1–4.6. Taking such an abductive approach (Dubois & Gadde, 2002), we were able to explore which dimensions of a smart city are more relevant in the context of smart port cities dominated by RoPax traffic. Further, we attempted to identify patterns and associated challenges in the formation of digital interfaces between a city and a port.

4. Analysis

4.1. Smart economy

One of the critical connections between city and port operations is tourism, which, in turn, is critical for the economy of the focal port city. Digitalisation can help integrate port activities and urban economic dynamics. Specifically, the use of digital tools to assess, as one interview labelled it, the "vitality" of the port area can provide insights into the types of businesses present and their economic impact. These data are crucial for assessing how tourist spending, influenced by attractions in the area such as museums, contributes to local commerce. More accurate digital records, as compared to currently collected data, and more fine-grained analyses can help city planners make more informed decisions in terms of investments in cultural attractions. It was unclear for some representatives of the city, however, how such data could be collected, but as interviewees indicated, big data are the key to understanding the effects of tourism, including the share brought by the ferry connection, on the local city economy.

"… we have been interested in calculating how much … tourists spend in the area … because there will be this new Museum so. It will tell the people.… Is it the decision that should be made. They [cultural events and attractions] … bring the tourists in, and then how much they spend in the area, that's the one thing that we would like to know. And we have tried to do some research, but it's very hard, very hard."

– Informant C.D.

Another application of digital technologies mentioned concerns the potential of using data to enhance tourism strategies in the focal port city. Currently, the city uses data on hotel stays collected through hotels and data on tourism movements collected by mobile operators, but these data are not integrated, limiting the insight. There is potential to expand this approach by integrating more detailed analytics, possibly through digital twin simulations that could visualise tourist movement patterns and interactions, especially with new museums and due to increased ship arrivals.

Continuing from the above, by collecting and analysing data on tourist movements and spending patterns, particularly those linked to events and new attractions like museums, the city can optimise its marketing efforts to encourage tourists to explore further into the area. A

[1] In addition to the Interview Data Agreement Document from the project, there was a privacy notice for processing personal data for scientific research according to the EU General Data Protection Regulation GDPR (EU 679/2016), Art. 13–14.

corresponding digital interface, such as marketing city destinations on social media, would not only help in strategically marketing the city as a vibrant destination beyond the summer season but also in managing and directing tourist flows more effectively from the port to other parts of the city. The data necessary for such a digital application are partly available in national-level statistics repositories, but there are also commercial actors offering a data platform with tourism-related data, and, for example, bank card systems like Visa collecting relevant consumer data. Tourism office representatives noted that although such data are expensive, there is a potential to collaborate with other cities and share the costs. They also mentioned that they see themselves as responsible for obtaining data, analysing it and offering the insights to the local tourism ecosystem, especially in supporting ecosystem partners who do not necessarily have the resources for acquiring and analysing such data.

"… we collect the data, we analyse it, we will actually give it to the industry through the coworking space.… From the companies' point of view, we need to push them a lot to, to understand where the consumers really are today. They book, they find information in the digital world, but our companies are not there."

– Informant T.A.

The local DMO saw engaging visitors and citizens as crucial in the development of tourism and recognised that digitalisation offers new opportunities to do that. However, mostly because of resource restrictions, this remains to be realised in the future.

"There are so many methods in the service design. So, I mean, it's the key element to success in the future … whether it's inhabitants or whether it's visitors. I think we definitely need to get them to join.… There's such a powerful …, I would say, engagement tools through [which] to have people part of the process."

– Informant T.A.

Finally, the possibility to facilitate shared economy was discussed considering a city-operated digital service for booking spaces or facilities in the city. The service is already in use for common spaces, like sports facilities, which can be booked by citizens online. As the new terminal planned in the port is likely to have spaces that are not in use in between ship departures, this sharing service can enable a higher utilisation rate of these facilities by making them open for rental for the citizens. Security concerns may arise due to the sensitivity of the port area in this respect, but these can be solved by the fact that such space bookings are personal and trackable, as illustrated in the following quotation:

"So, one solution is [that] when we start building … you have electronic locks installed in every building, and they work as a code for a person that holds the key, so you can build the system when you're starting to build the area. You can … put in all the spaces with all the codes and locks … [to a] renting system for spaces whilst you're developing. So when that building opens it might have … leisure rooms for residents, so you can put it in the aerial portal and then you can say that it's available 10:00 in the evening, and then maybe somebody [who] wants to have a dance class can rent out the space and have a dance class. And then because it's your personal key, it records the info on who opens the door.… So this is one way of working around the security aspects of sharing the spaces and the digitalisation."

– Informant C.E.

Table 4 provides an overview of port–city interfaces, associated digital interfaces, and the challenges involved in establishing these interfaces.

4.2. Smart governance

While digital efforts in the domain of smart governance were not specifically discussed by the research participants, the wish to involve citizens in a digitally facilitated and transparent way in the decision-making process around the port area's development was expressed. One potential digital solution for that was mentioned: the city data model. The city data model encompasses a comprehensive assortment of municipal records and processes, including land use plans, street layouts, green areas, building permits, real estate transactions, population data, environmental permits, and public area permit information. Our analysis indicates that this model could be partly open for the citizens and used for discussions around the development of the new area, including the port area.

"… [At the] architect offices they are building these digital models on how the city area looks like. I think we should integrate them more to our 3D model or the digital twin, so that it is visible there. But I think the whole planning is partly already going to a digital mode, so it's happening there…

– Informant C.H.

"… we are planning to use it [the digital twin] in participation to the public too, so we can publish there, in a public, these areas, plans and visions and so on."

– Informant C.F.

In addition, certain digital services discussions, e.g., in Section 4.5, devoted to the smart people dimension can be loosely connected to empowering the citizens in this respect.

Table 5 provides an overview of port–city interfaces, associated digital interfaces, and the challenges involved in establishing these interfaces.

4.3. Smart living

In the case of the focal port city, digital solutions are already used and are being explored to enhance smart living by reducing the negative impact of the port's close proximity to residential areas, for instance, through traffic management. The city utilises data from traffic light sensors and video analysis to manage traffic flows and reduce congestion throughout the city (see Section 4.4 for more details). These data also assist in strategic planning for traffic infrastructure, particularly aiming to divert through-traffic away from the city centre. Additionally, there is

Table 4
Summary of port–city interfaces and related digital interfaces identified within the smart economy dimension.

Port–city interface	Digital interface	Challenges
- Collaboration on tourism insights and development - Understanding tourist movement patterns for improving services - Improving utilisation rate of facilities in the port area	- Data on tourist spending and moves shared between port authority and city - Simulations of tourist movements in a digital twin of the port and city areas - Use of city's platform for booking facilities in the port area	- Limited real-time data - High data collection costs - Need for data from external actors, high cost

Table 5
Summary of digital solutions and related interfaces identified within the smart governance dimension.

Port–city interface	Digital interface	Challenges
- Integrated planning of port and city development - Participatory governance and citizen involvement in the waterfront development	- Use of the city's platform for port planning - Use of the city's digital twin for engaging citizens	- No digital interface from the digital twin to the citizens

potential for using digital twins and city data models to simulate traffic scenarios and urban development also for the developing area around the port, as illustrated by the quotation below:

"We could … combine all that data and create a kind of visibility … [of] how the life looks like there. There are, anyway, the harbour area and a lot of traffic … how it is affecting the people."

– Informant C.H.

While the port authority is also developing a digital twin of the port area, no clear interfaces have been established between them yet.

Table 6 provides an overview of port–city interfaces, associated digital interfaces, and the challenges involved in establishing these interfaces.

4.4. Smart mobility

The proposed smart mobility solutions focus on optimising the passenger experience at ferry terminals through advanced digital planning tools. These tools are designed to facilitate pre-trip planning, providing detailed information on parking availability, accessible entry points for individuals with disabilities, and efficient route planning within the terminal area. Such enhancements are intended to not only streamline navigation and reduce unnecessary vehicle emissions but also to align with broader environmental goals, including efforts towards achieving carbon neutrality in the region. To enable this solution, data on the port area such as roads, parking areas, etc., need to be processed and delivered to customers of the port authority – ferry passengers, as the following quote indicates.

"Today we do not have any communication or co-operation with the ferry operators, but in the future, I hope we have, when the new terminal has been built. We can offer people systems for traffic management through info screens, applications on how to easily and sustainably use transportation services to and from the city centre."

– Informant C.A.

It was discussed that a separate app with this functionality is unlikely to succeed, but the data on the terminal situation and total journey planner can be embedded in existing apps offered by the shipping lines operating in the port. Alternatively, these functionalities can be embedded on the port authority's website.

Another area for further development focuses on enhancing the interconnectivity of transportation modes. As discussed earlier, the integration of data-driven methods helps optimise traffic flow, particularly in the congested port area, by coordinating traffic light systems and transportation schedules. The primary challenge lies in effectively linking the port with other major transportation hubs – train station, bus terminal, and the airport – to facilitate smoother intermodal transfers for passengers and make commuting more attractive and efficient as compared to using private cars. The city has already implemented a Mobility-as-a-Service (MaaS) solution, which allows citizens to plan and pay for their trip within the city using an integrated app. It allows for combining the trips by public transport and local micromobility such as city bicycles, as explained in the following quotation:

Table 6
Summary of digital solutions and related interfaces identified within the smart living dimension.

Port–city interface	Digital interface	Challenges
- Traffic management in the city and port area - Creation of liveable area around the port	- Real-time data from sensors in the city to manage traffic flow to the port via smart traffic lights - Use of the city's platform for visualising traffic in the port area	- High cost - Lack of interfaces between city and port digital twins

"If you have a mobile phone and you have the public transportation application installed on it, it would like automatically pay for the e-scooter ride and the city bike ride and the bus ride and so on."

– Informant C.I.

Although this solution can be used for planning trips via public transportation to and from the port, ultimately reducing the influx of private cars in the area, the challenge is to ensure that the app is also convenient for tourists.

Regarding vehicle traffic management, digital tools are already in use or have been piloted. In a pilot project, IoT-based sensors, radars, and cameras were installed at strategic cross-sections to monitor traffic flows and violations, such as illegal lane changes and mobile phone usage while driving. Also, pedestrian and bicyclist calculators are installed on some roads. Data on traffic flows at certain roads and intersections are intended to assist in planning transportation infrastructure and can also be collected and utilised when developing the area around the port, accounting for the specific traffic patterns, which vary seasonally and throughout the day.

Currently, real-time data collected from traffic light sensors facilitate immediate adjustments to traffic signals, helping to alleviate congestion and improve navigation. The port authority representatives discussed that it would be beneficial to provide priority to the vehicles coming in and out of the port area around the ship departure times, and the city representatives confirmed that it is possible. However, they also noted that improving traffic flow to and from the port through traffic light management is challenging because changes in traffic light sequences to alleviate congestion can lead to unintended queues in other directions. The system requires constant monitoring and adjustment to avoid these issues, and the complexity increases at major intersections where traffic light failures can lead to safety risks for pedestrians and cyclists. Moreover, reliance on real-time data and operational consistency makes it difficult to maintain system integrity without dedicated oversight.

Adding the harbour area as one of the locations for the park-and-ride solution currently being piloted by the city would be one way to make use of the parking area near the port to utilise its full potential. The challenges related to this location, which would not currently enable a smooth or logical route to continue the journey with the other modes of transportation, have hampered expansion of this solution to the harbour area. However, using the parking spaces near the port, which remain empty for most of the day, poses a problem that the city and the port authority are actively seeking to address:

"… in the port area, there is a lot of free space most of the time. And then there's a couple of times a day that it is quite hectic. But it would be interesting that the parking garage could be used for people coming into the city centre, for example."

– Informant C.C.

Here, the traffic analysis supported by digitalisation could help to understand the actual needs of the city as well as the port authority, also considering their future developments – both urban- and port-related.

Finally, in the ongoing redevelopment of the port area, the adoption of advanced digital tools like city data models and digital twins was discussed. These tools are being evaluated for their potential to enhance urban planning and mobility management by enabling precise simulations of traffic flow and infrastructural changes.

Table 7 provides an overview of port–city interfaces, associated digital interfaces, and the challenges involved in establishing these interfaces.

4.5. Smart people

Regarding the smart people dimension of the smart city, discussions have focused on leveraging digital platforms to enhance community

Table 7
Summary of digital solutions and related interfaces identified within the smart mobility dimension.

Port–city interface	Digital interface	Challenges
- Integrating port and city functionally for smooth passenger flow - Integrating port and city functionally for smooth vehicle flow - Linking port and city hubs through different transportation modes - Improving the utilisation rate of parking areas around the port - Integrated port city planning	- Journey planner for travellers/passengers - Traffic management through smart traffic lights - Mobility-as-a-Service - IoT-based road monitoring for infrastructure planning - Park-and-ride solutions - Traffic and infrastructure change simulations in the city digital twin	- Difficulties finding the interface for passengers, especially tourists - Need for interfaces with other stakeholders - Congestion elsewhere in the city due to signal changes - Need for costly real-time data oversight

engagement and resource sharing among residents and businesses. For instance, area portals similar to those in other cities have been considered, where locals can communicate, share information, and organise community events or activities. Like the digital service for space booking discussed in Section 4.1, such platforms also facilitate the borrowing or renting items like tools or equipment, promoting a shared economy.

The focal city already has a set of digital services for citizens, many of which are operated by people, mostly citizens. In light of port–city interfaces, it was discussed that the new approach to digital solution development in cities focuses on creating user-friendly interfaces tailored to specific groups while maintaining a common back end.

"… there is kind of a new way of thinking … how digital solutions are created in cities and … how a kind of user interface is differentiated and taking apart from the back-end solution. So, I think we should have … digital solutions that are tailored for needs of different groups, for example, tourists may maybe should have kind of own digital solutions for permits (?) and it shouldn't be kind of cut off from other data or other solutions, but it should be in a way that makes it more approachable and usable for people who haven't visited Turku."

– Informant C.B.

Applying this thinking in this context would allow the creation of distinct, accessible digital services, such as tourist-specific applications, that provide essential local information and navigation tips for those unfamiliar with the focal city.

Table 8 provides an overview of port–city interfaces, associated digital interfaces, and the challenges involved in establishing these interfaces.

4.6. Smart environment

Digitalisation efforts within the smart environment domain aim to enhance sustainable urban mobility and environmental management. Techniques such as scanning vehicle registration plates to match emission data from a national database have been tested, allowing for a preliminary assessment of traffic emissions and mobility types. A city representative describes the experiment:

"… we were scanning registration plate data and connecting it to the [traffic authority's] information, so that we collected basically the emissions from the traffic database. We didn't keep the register plate information – we just searched the emission rates of different vehicles based on the registration data from the database. Based on that we calculated how many emissions the traffic was causing …"

– Informant C.I.

Although promising, scaling these initiatives city-wide poses financial challenges. Both the city and the port authority employ similar statistical methods for emission calculations, yet there is no integrated system allowing for shared data usage.

The port authority representative explains their technique of calculating emissions as follows:

"Currently our emission calculation is based on statistical data and not measured data. The new [smart port system] should enable more accurate calculations, but actual measuring may not be possible. The emissions from land transportation should also be possible as the emission of certain vehicle types, makes and models of the vehicles are known."

– Informant P.A.

Future developments seek to establish more sophisticated digital tools and interfaces, enhancing sustainability efforts under the EU's sustainable mobility plans and advancing carbon neutrality goals within urban and port areas.

Then, to comply with new regulations requiring vessels to connect to onshore power, the port authority will need to implement digital solutions for energy management that integrate with the city's infrastructure, ensuring efficient energy use.

Finally, the planning of green areas in the city, particularly in the port area as desired by many citizens, was also brought up during interviews. The goal to rewild the area close to the port was explained by Informant C.E.:

"…it means that you are trying to bring as much green into the area and think about in which ways you can incorporate greenery in every step of the way."

The city data model mentioned in the previous sections also includes green areas according to Informant C.G. and, thus, could aid in that respect, too.

Table 9 provides an overview of port–city interfaces, associated digital interfaces, and the challenges involved in establishing these interfaces.

Table 8
Summary of digital solutions and related interfaces identified within the smart people dimension.

Port–city interface	Digital interface	Challenges
- Inclusion of port authority in citizen engagement activities - Enhanced sharing economy platforms including facilities in the port area - Improving utilisation rates of facilities in the port area	- Digital portals for resource sharing - Use of the city's platform for booking facilities in the port area - Tailored digital interfaces to citizens	- Security concerns with space bookings - Data privacy risks

5. Discussion

5.1. The role of digitalisation in enhancing the port–city relationship

In this paper, we have identified several interfaces between the focal city and the focal port, represented by the port authority, which are

Table 9
Summary of digital solutions and related interfaces identified within the smart environment dimension.

Port–city interface	Digital interface	Challenges
- Aligned environmental goals and measures for achieving them - Integration of energy management	- Vehicle registration plate scanning for emission calculations - Energy management with onshore power - Visualization of current and planned green areas in the city	- Financial limitations for data collection - New technology challenges

pertinent to the six dimensions of a smart city (Al Sharif & Pokharel, 2022; Albino et al., 2015; see also Section 2.1) and were able to identify how digitalisation can aid in addressing the tensions in port–city relationships that have been discussed in previous research (see Section 2.2 and Table 10). The port being a critical transportation hub, it is unsurprising that most critical need to integrate the physical and digital infrastructure can be observed in the dimension of smart mobility. In this context, intermodal inefficiencies and underutilised spaces, e.g. for parking, present challenges. Digitalisation through data-sharing platforms like Mobility-as-a-Service solutions can link ferry schedules with public transport and micromobility options, improving the passenger experience and reducing congestion in the nearby area. Additionally, historical data on parking utilisation can inform better allocation and planning, addressing the spatial tensions between the port and the city (Fenton, 2020; Jansen & Hein, 2023).

The port being a critical transportation hub, it is unsurprising that most critical need to integrate the physical and digital infrastructure can be observed in the dimension of smart mobility. In this context, intermodal inefficiencies and underutilised spaces, e.g. for parking, present challenges. Digitalisation through data-sharing platforms like Mobility-as-a-Service solutions can link ferry schedules with public transport and micromobility options, improving the passenger experience and reducing congestion in the nearby area. Additionally, historical data on parking utilisation can inform better allocation and planning, addressing the spatial tensions between the port and the city (Fenton, 2020; Jansen & Hein, 2023).

Smart economy, given the significant role of the port in bringing tourism to the focal city, is yet another pronounced smart city dimension that supports the economic infrastructure of a city (Silva et al., 2018) and benefits from digital interfaces between the port and the city. As gateways for tourism and economic activity, ports often lack sufficient collaboration with cities to maximise economic synergy in this respect (Fenton, 2020; Hermelin & Jonsson, 2021). In the focal case, this is further impaired by underutilised facilities in the port area, which could contribute to the local economy. Digitalisation offers opportunities to address these issues through data integration and sharing, enabling the analysis of tourist spending and movement patterns to inform urban planning and marketing strategies. Additionally, using existing digital infrastructure, such as city platforms, for booking underused spaces and facilities located in the port area can foster shared economic activities and enhance resource efficiency. Data sharing with the port authority, city, shipping lines, and external actors like telecoms and banks are essential for insights into mobility patterns and passenger experiences, which means that interfaces beyond the port–city dyad need to be established.

Although less pronounced, we were able to identify critical interfaces in the remaining four smart city dimensions as well. Of particular interest are the interfaces within the smart people and smart governance dimensions, which imply the empowerment of citizens in affecting the development of the port area and increasing the utilisation efficiency of its facilities. Governance challenges, stemming from conflicting priorities between urban development and port operations, are a common problem in port cities. Limited citizen and stakeholder involvement in port area planning often exacerbates these tensions (Jansen & Hein, 2023; Teschner, 2019). Our analysis shows that digital interfaces, for example, established through virtual models and digital twins, can facilitate participatory governance, improving transparency and enabling meaningful engagement with citizens.

This also underlines the critical role of the people component in developing smart cities (Cardullo & Kitchin, 2019; Kitchin, 2014).

Governance challenges, stemming from conflicting priorities between urban development and port operations, are another recurring theme. Coordination using real-time data also supports integrated planning, aligning port authority and city priorities to foster collaborative decision-making (Vroomans et al., 2022).

Finally, environmental and social concerns remain central to port–city dynamics, particularly the negative impacts of congestion, pollution, and proximity of ports to residential areas on urban liveability (Fenton, 2020; Jugović et al., 2021). Digital solutions such as IoT-enabled traffic management systems and emission monitoring platforms offer practical tools to mitigate these challenges. Real-time traffic data can optimise flows around port areas, while shared environmental monitoring systems align urban and port sustainability goals. Planning tools, including digital twins, further support the integration of green spaces and sustainable design into port-adjacent areas, enhancing quality of life for residents.

Table 10
The role of digital interfaces in enhancing port-city interfaces.

Smart city dimension	Port–city interface	Possible port–city tensions	Example of a digital interface to improve port–city integration
Smart Economy	Tourism economy	Ports serve as gateways for tourists, impacting the local economy, but insufficient collaboration limits economic synergy	Data on tourist spending and movements shared between the port and the city; obtaining data from external actors
	Utilisation of facilities in the port area for shared economic purposes	Underutilised port spaces fail to contribute to local economic activities	Use of the city's platform for booking port facilities
Smart Governance	Participatory planning and stakeholder engagement	Limited citizen and stakeholder involvement in port area development can lead to social tensions	Use of the city digital twin for engaging citizens in planning
	Integrated planning of port and urban areas	Conflicting priorities between urban and port developments result in governance challenges	Digital tools to integrate real-time data for joint port and city planning
Smart Living	Traffic management near port areas	Congestion from port-related traffic negatively affects urban liveability	Real-time traffic management using data from sensors and smart traffic lights
	Liveability of areas near port	Proximity of ports to residential areas often reduces quality of life	Use of the city's platform for visualising urban planning and green space development
Smart Mobility	Intermodal connectivity	Lack of intermodal integration causes inefficiencies and passenger inconvenience	Mobility-as-a-Service platforms to link ferry schedules with public transport
	Parking spaces in and near port	Underused parking spaces during off-peak times contributes to space use tension	Data on parking use shared between the port authority and the city for optimised allocation
Smart People	Engaging citizens in port city planning	Poor citizen engagement in decision-making processes fosters dissatisfaction and opposition	Use of digital platforms for involving citizens in port city planning discussions
	Shared economy	Lack of community integration in port area reduces local engagement	Digital portals for resource and facility sharing among port users and city residents
Smart Environment	Port and city environmental goals	Ports contribute to air and noise pollution, which contradict urban sustainability goals	Emission-monitoring systems shared between the port authority and the city for coordinated planning
	Energy management for port and city use	Lack of synergy in energy management hinders sustainability efforts	Energy management systems integrating onshore power with city energy infrastructure

5.2. Types of digital interfaces between the city and the port

Certain challenges for establishing digital interfaces between the focal city and the port authority are common. For example, the distinction between historical and real-time data was highlighted as essential for enabling efficient resource use, especially in reacting to abnormal situations. Additionally, missing interfaces between existing digital solutions, such as digital twins and emission assessments, could hinder coordinated planning and efficiency improvements for both the city and the port.

Based on the discussion above, we were able to identify several types of potential digital interfaces, acknowledging that the need and approach for integrating the port and the city may differ depending on the city and port authority goals, as well as the current state of digitalisation at both parties. Fig. 1 categorises the port–city interfaces, which were identified as necessary in the focal case, into five main types.

First, data integration and sharing are necessary for unlocking the benefits of a smart port city, as one party is able to improve their performance by using the data from the other party. To provide an example, the data on parking availability, traffic and passenger flow can be relevant for smart mobility solutions implemented by the city in order to provide more accurate Mobility-as-a-Service solutions. Second, in certain cases, it is possible to use already existing digital infrastructure for integrating the port and the city, as in the case of using and extending the city data model for opening the discussions with citizens on the development of the port area. Third, we have identified several relevant interfaces that concern coordination between the city and the port authority using real-time data. Such interfaces are most difficult to establish, given the investments needed by both parties in terms of the data collection, processing, and storage. Efficient solutions for utilising these data, for example, in optimising traffic and passenger flow to and from the port, are also needed and require the involvement of third parties. Fourth, in a similar manner, the data collected by the city or the port authority can be used for informed planning, such as infrastructure planning, on a regular basis. In this case, however, it is often sufficient to obtain historical data, for example, on the traffic flow or the use of facilities and infrastructure, which requires lower investments in digital infrastructure. Fifth, to integrate the port and the city and achieve benefits of such integration, it is sometimes necessary to establish interfaces with external actors in the form of data sharing or synchronisation, which supports earlier studies on the importance of data sharing in ports (Iancu et al., 2023). This can be illustrated by the need to obtain data on tourist and visitor spending or movements in the port area from external data providers to harness the smart economy.

6. Conclusions

Digitalisation holds the potential to help cities become smart and sustainable, for example by enhancing efforts to reduce noise, congestion, and emissions, and to create spare space for residential areas. In the context of port cities, some smart city dimensions (Al Sharif & Pokharel, 2022) are more pronounced due to their inherent integration with port operations. We have identified key digital interfaces between the focal city and its port, represented by the port authority. We have further explained their role in achieving the digital integration of the city and the port as well as identified the challenges of using them for balancing the “smart goals” pursued by the city and by the port while optimising both cargo and passenger flow. High costs, especially related to data collection, together with certain technical challenges still seem to be among the biggest obstacles towards a greater integration of the city and its port.

This paper contributes to the research on smart cities and port cities by bridging the gap between the two fields, highlighting the critical yet underexplored role of ports in smart city development. By integrating

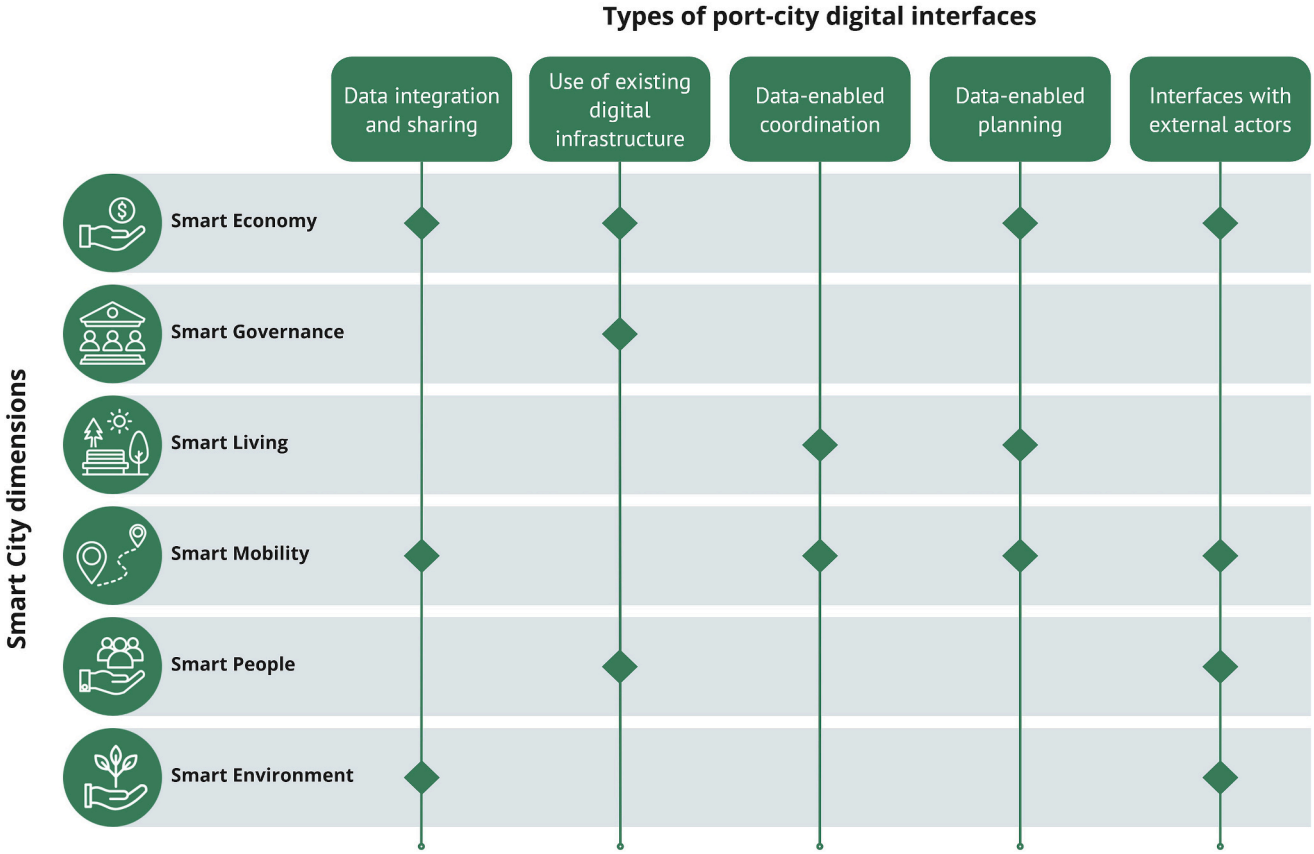

Fig. 1. The need for different types of interfaces within smart port city dimensions.

the concept of smart city dimensions with port–city relationships in the context of port cities dominated by RoPax traffic, it offers a framework for understanding how digital interfaces can address the unique tensions at this interface. The study advances the discourse by identifying specific types of digital interfaces needed for port–city integration, providing a perspective that connects digitalisation strategies to the distinct operational and governance dynamics of port cities.

As a policy recommendation, we pinpoint that balancing "smart goals" between the city and port requires optimising both cargo and passenger flow while mitigating potential issues like traffic congestion or contradictory interests of these two actors, like area use. Policymakers must navigate the dual demands of economic growth through port operations and the city's sustainability goals by promoting green technologies, renewable energy integration, and emission-reduction strategies that align with urban sustainability plans.

Challenges in data sharing emerge due to security concerns and limited real-time access, which can hinder digital co-development efforts. Thus, another recommendation is to encourage partnerships with private-sector actors, such as data providers and shipping lines, in order expand the digital capabilities of port cities, enhancing their ability to adapt to smart city principles and addressing gaps in mobility, governance, and environmental performance. Addressing these gaps by promoting shared platforms and standardised protocols can enhance cooperation.

As one of the barriers for further integration between the city and the port authority seems to be the high data collection costs, one practical implication of our research is that city managers should carefully investigate what kind of generative affordances such integration could provide and the true desire for such affordances among its citizens and commercial stakeholders. In this regard, the living lab concept might be a useful management tool promoting harnessing the promise of open innovation (Schuurman et al., 2016). Future research could focus on what kind of new data-enabled services could come out of cocreation between city planners and residents and visitors.

Another recommendation vis-à-vis high data collection costs is the exploitation of already existing data sets. It seems that lots of data are collected all the time but for rather limited purposes. That data could be gathered on a platform (potentially enriched with external data sets), and differentiated access could be granted for various user groups.

Although our study comprises only one port city, the findings and their implications are likely to be relevant for other similar port cities dominated by RoPax traffic. Our study was done in a specific geographical area, where digitalisation is rather advanced. Hence, the findings are transferrable to areas with similar levels of digitalisation, such as to other RoPax ports in the Baltic Sea, the North Sea, and the English Channel. In addition, the types of port–city interfaces identified in the current study can be generalised (Flyvbjerg, 2006) to the other contexts where RoPax ports are located in central urban areas. The typology of port–city interfaces could, therefore, be tested in further studies and modified accordingly. Finally, although the importance of establishing digital interfaces with actors beyond the port–city dyad was identified, it is beneficial for future studies to consider the role of other stakeholders, such as shipping and logistics companies, in the development of smart port cities.

CRediT authorship contribution statement

Anastasia Tsvetkova: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Irina Wahlström:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Kristel Edelman:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Riikka Franzén:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Yiran Chen Zhou:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Magnus Hellström:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT4 to improve the readability and language of some sections in the paper. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article. The language editing by a professional language editor was further done for the final version of the paper.

Declaration of competing interest

None.

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Appendix A. Smart Port City interview themes

A.1. Theme 1: The development of the port city interface and harbour area

- *In your opinion, what makes the development plans of the port city interface innovative nationally or internationally?*

A.2. Theme 2: Stakeholders' involvement and co-creation

- *Who are the most important (internal and external) stakeholders in the port city interface development? How are they involved in co-creating smart and sustainable city?*
- *How are they involved in co-creating smart and sustainable port/city (*e.g.*, providing solutions for passenger and cargo transportation/mobility/logistics/passenger and cargo security* etc.*)?*

A.3. Theme 3: Digitalization in the development of the port city interface and the harbour area

- *How is digitalisation taken into consideration in the development plans of the port city interface and the harbour area? How could the potential of digitalization be utilised more?*

- *How could digitalisation support the transformation of the port city interface, its liveability, attractiveness, and its functioning as a recreational area?*
- *What type of digital solutions could/will be involved in the development of the port city interface or at later phases when the area has been transformed as multifunctional urban area?*

A.4. Theme 4 a: Data collection, management & sharing

- *What kind of data does the city collect that contributes to the development of the port city interface?*
- *What other data would be needed? What kind of data is provided/could be provided by stakeholders?*
- *What data is made accessible to other actors outside of city government? Who are these other actors?*
- *What kind of data does the city receive from the port and v.v. that contribute into the development of the port city interface?*
- *How is the data exchanged, shared and made available?*
- *How is this data managed, analysed, shared between different departments of the city?*
- *What are the main challenges related to data?*

A.5. Theme 5 a. Smart City

- *What does it mean for the city to become a Smart City (from the port city interface and overall city perspective)*?
- *What makes a city "smart" in a context of the city?*
- *How could citizens contribute into the process of the city becoming a smart city?*
- *Have smart mobility solutions already supported the aim that the city will become more car-free? How much information is available?*
- *Seasonal differences in smart mobility?*

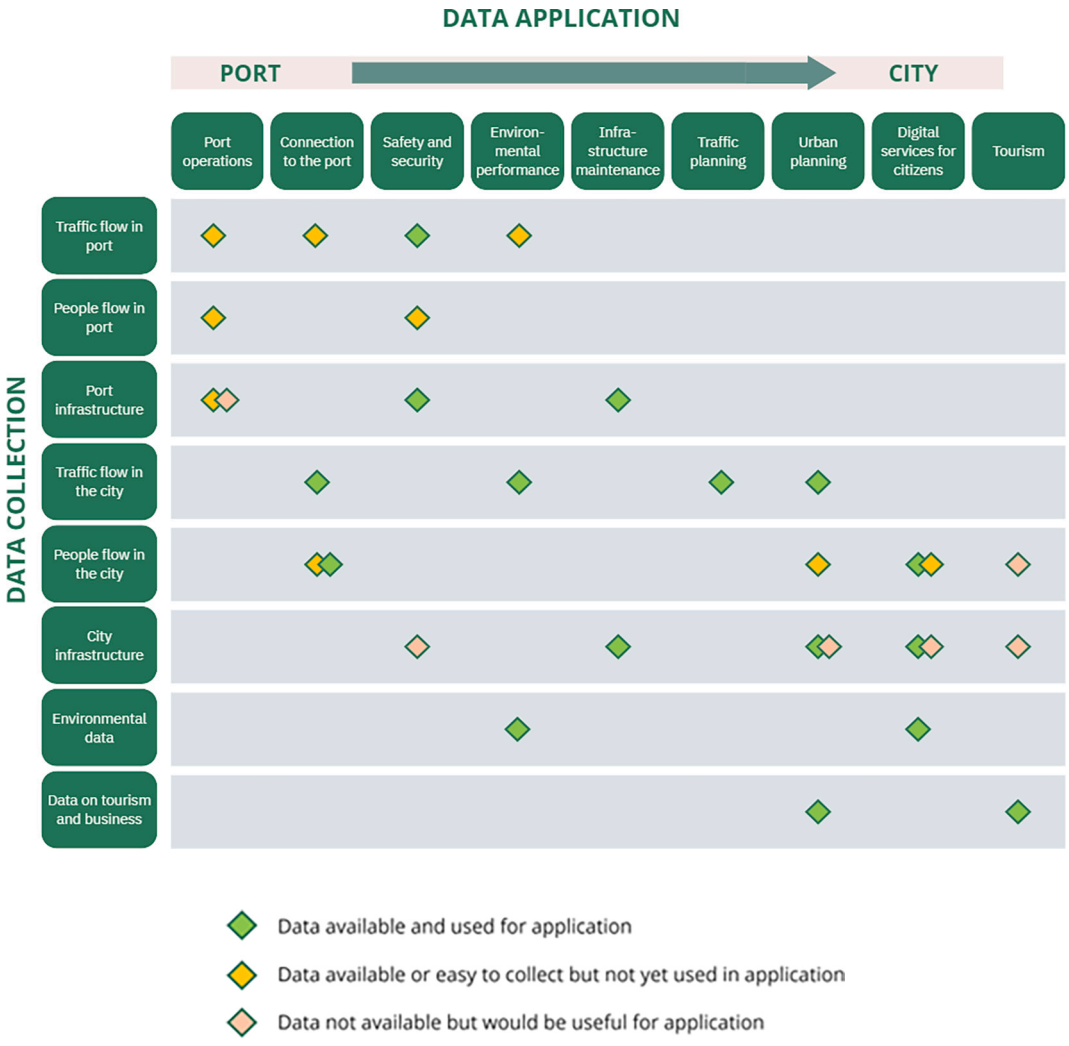
A.6. Theme 5 b. Smart Port (port specific interview questions for port representatives)

- *How would you define a "Smart Port"?*
- *What are the ports stepstones towards becoming a "Smart Port"?*
- *How will the port as a "Smart Port" contribute/integrate with the city's ambition of to becoming a "Climate-Neutral and Smart City"?*
- *How could passengers/citizens contribute into the process of the port and city becoming a Smart Port/Smart City?*
- *How can the port contribute or incentivize the development of more sustainable and smart transport/mobility/logistics?*
- *Who are the key actors in developing smart transport/mobility/logistics?*
- *The current state and plans for finding suitable resting places for truck drivers?*
- *Development plans for charging stations for electric trucks?*
- *How can the port enhance the use of public transportation and mobility options?*
- *Have existing smart mobility solutions already supported the aim of reducing the use of own car?*

A.7. Theme 6: Tourism and leisure

- *How does the transformation of the port city interface support the (sustainable) tourism in the city?*
- *How does the city expect the waterfront development in the port city interface to contribute to sustainable tourism?*
- *What could be considered most significant digital information that concern tourists and ferry passengers?*
- *How could existing digital information be more incorporated into tourist activities (*e.g.*, transport provider app and similar apps, information on smart mobility, information on planned events, art performances in the port city interface in a future* etc.*)?*
- *How could passenger/tourists be more involved in supporting the city in the process of becoming smart (and sustainable) city? (*e.g.*, engaged in data sharing).*

Appendix B. Data-application matrix



Data availability

The authors do not have permission to share data.

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