



Digital Twin Resilience in Portuguese Atlantic Corridor Ports: A Stakeholder Study

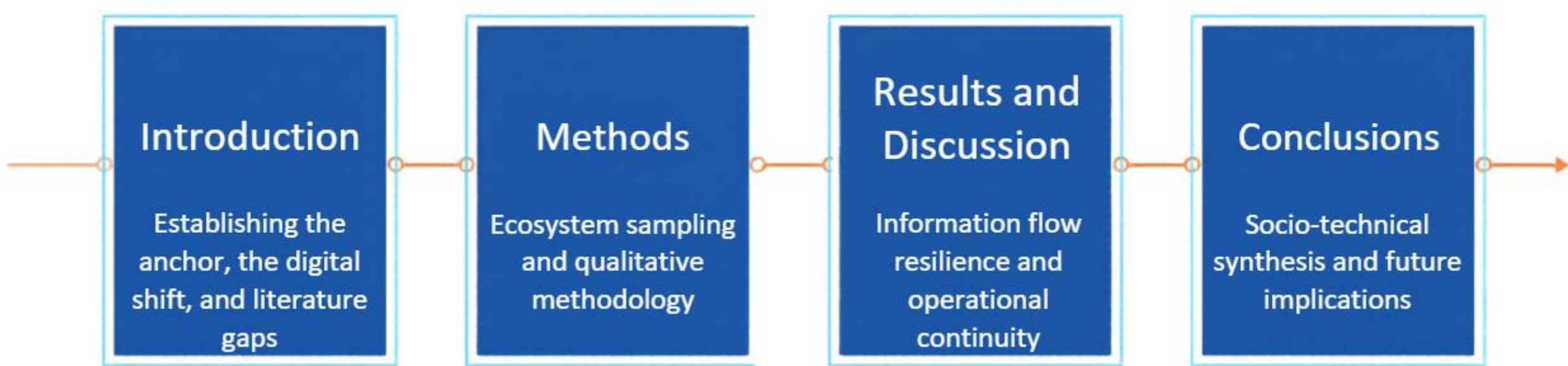
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Agenda



Introduction

Seaports are the Critical Nodes of Global Stability

Volume

~90% of global goods are transported by sea.

Economic Impact

Essential catalysts for regional and national development.

Vulnerability









Due to high interconnectedness, localized disruptions (natural disasters, health crises, technical failures) cause global cascading effects.

Port Resilience: The capacity to anticipate, prepare for, respond to, and recover from disruptions while maintaining essential functions.



Introduction

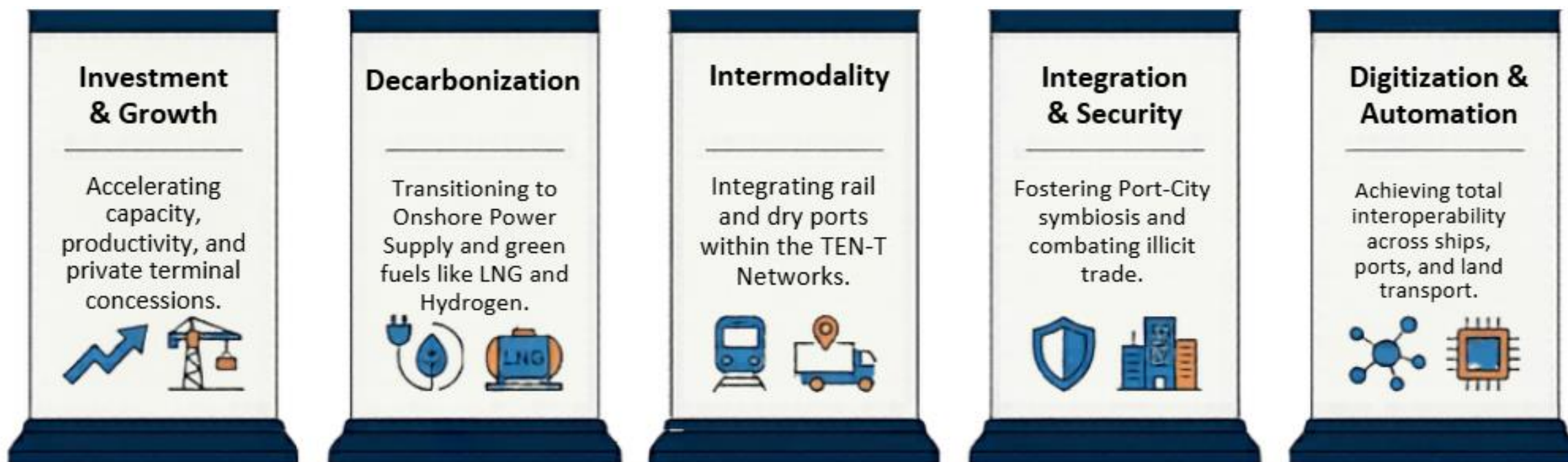
The Paradigm Shift: From Reactive to Proactive Governance

	Traditional Fragmented Port	Digital Twin Ecosystem
Coordination Model	Fragmented & Siloed Data 	 Data-Centric Orchestration
Disruption Response	Reactive Governance & Post-Event Recovery 	 Predictive Intelligence & Anticipation
Contingency Planning	Manual / Paper-Based Fallbacks 	 Unified Cyber-Physical Backup
Ecosystem Role	Infrastructure Provider 	 Collaborative Network Orestrator

**Industry 4.0/5.0 demands a systemic review of governance.
The goal is adapting to dynamic changes without catastrophic loss of function.**

Introduction

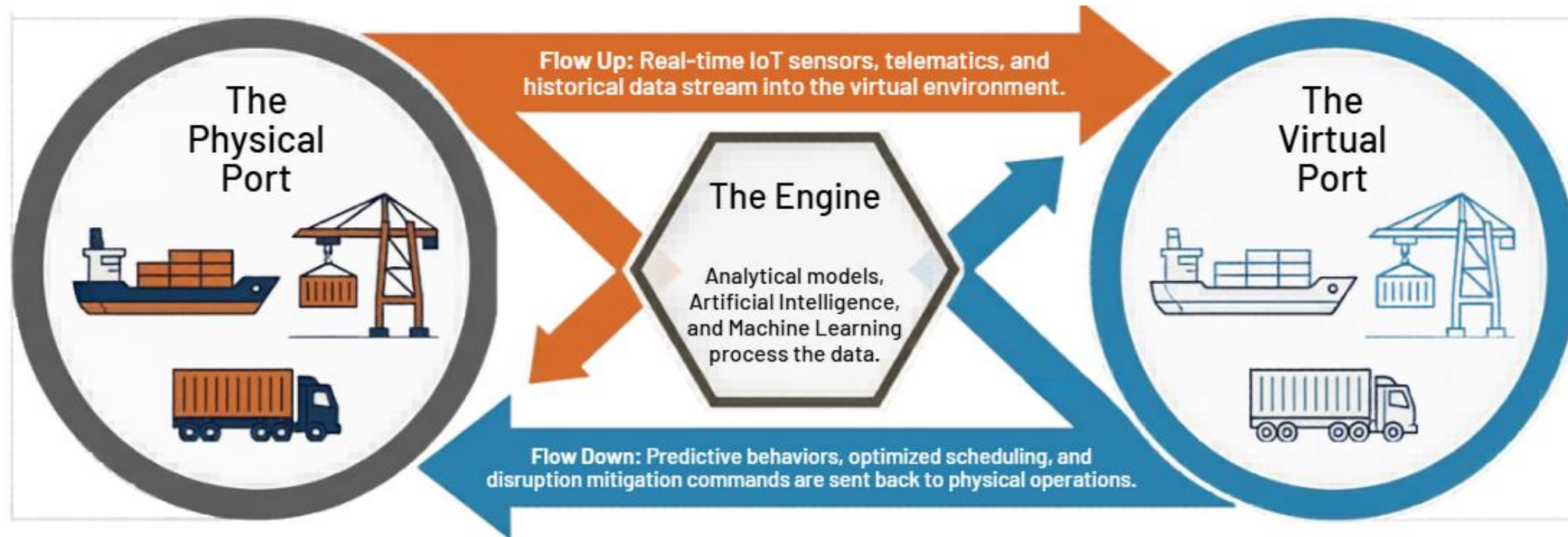
Portugal Ports 5+ Strategy (2025-2035)



JUL 5+ (Single Logistics Window) | €70 Million Investment in Advanced Digital Technologies & Automation

Introduction

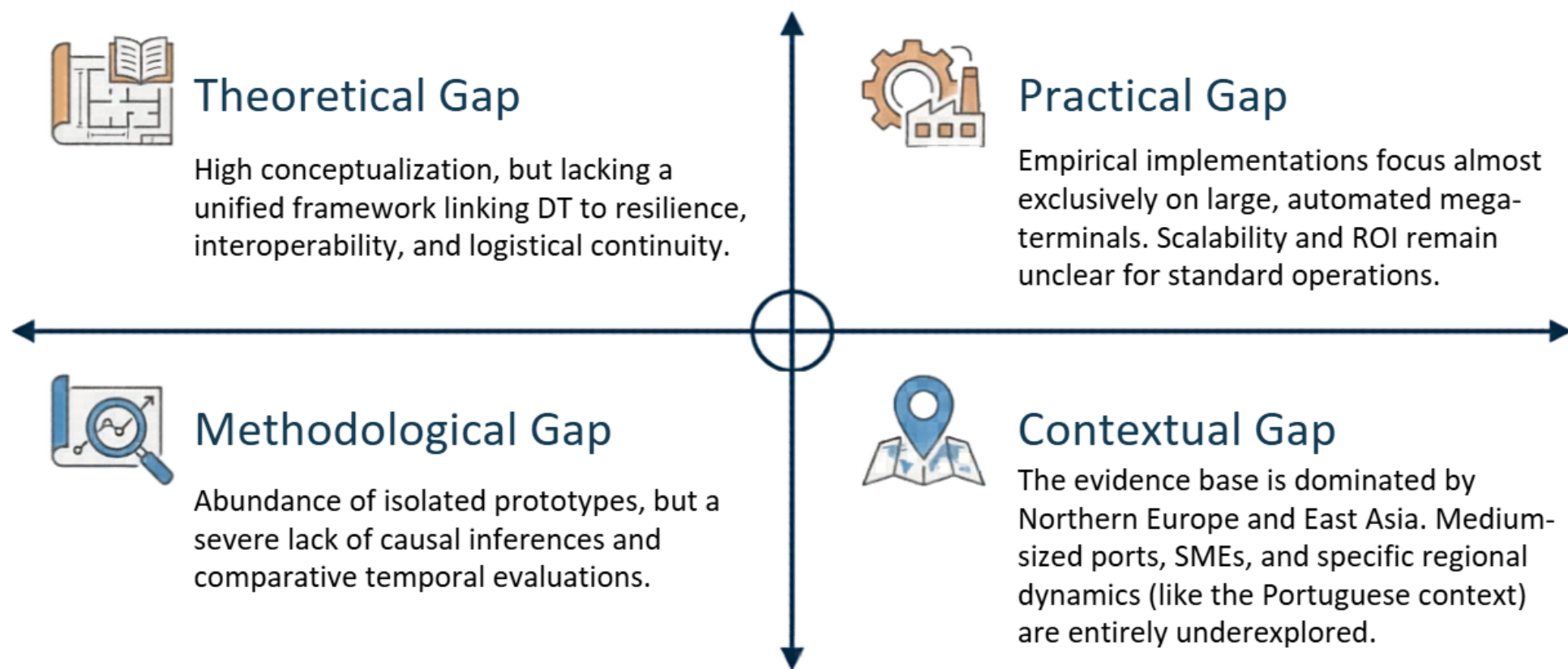
Defining the Seaport Digital Twin



Transcending mere 3D modeling, the DT is a dynamic decision-support ecosystem maintained in continuous synchronization through bidirectional data flows.

Introduction

Identifying Gaps



Introduction

Research Context: The Trans-European Atlantic Corridor



- **The Focus:**

A core Portuguese Atlantic seaport serving as a vital node in the TEN-T network.

- **The Profile:**

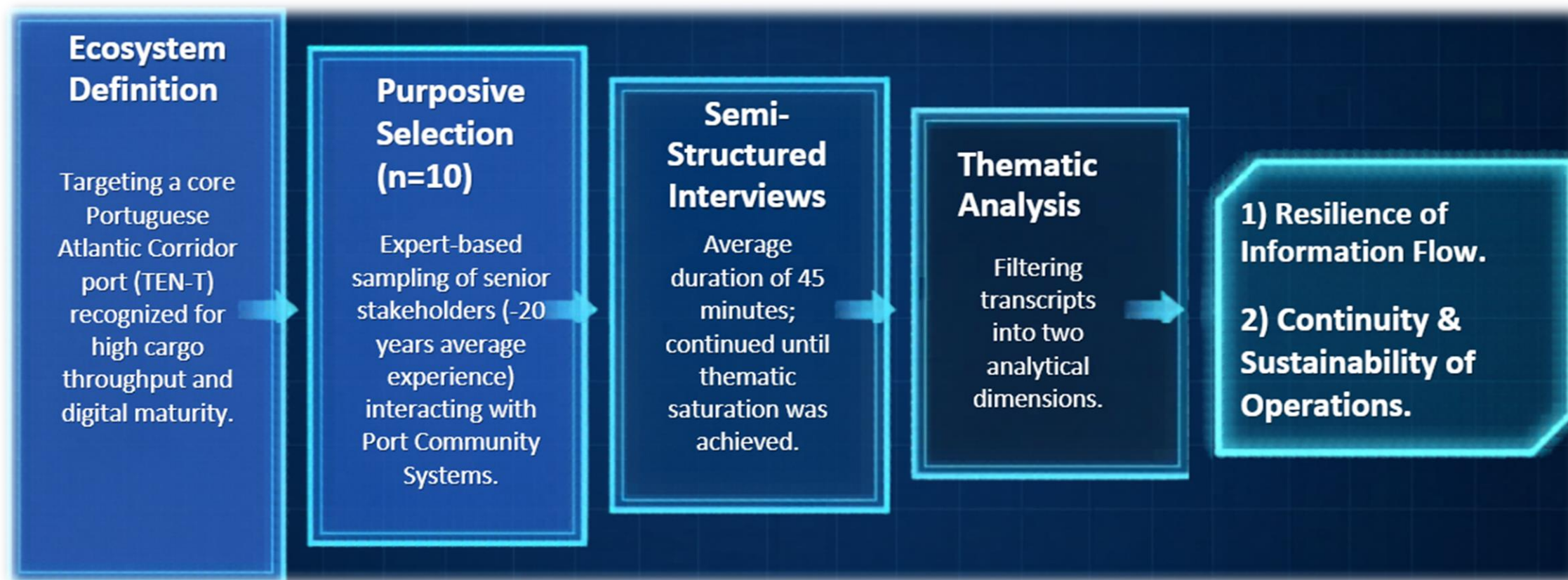
High cargo throughput, strong international connectivity, and high levels of technological interoperability.

- **The Inquiry:**

To what extent do stakeholders perceive DT solutions as capable of enhancing information flow resilience and operational continuity in medium-sized seaports?

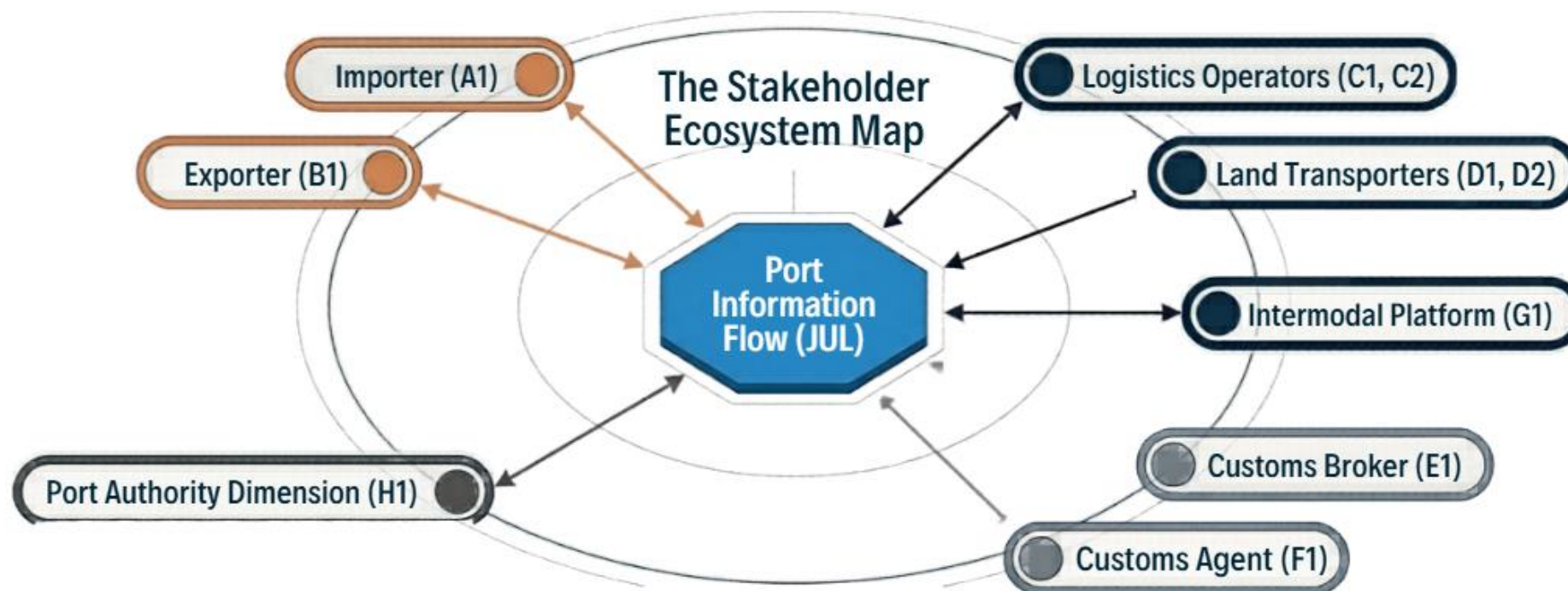
Methods

An exploratory Qualitative Approach



Methods

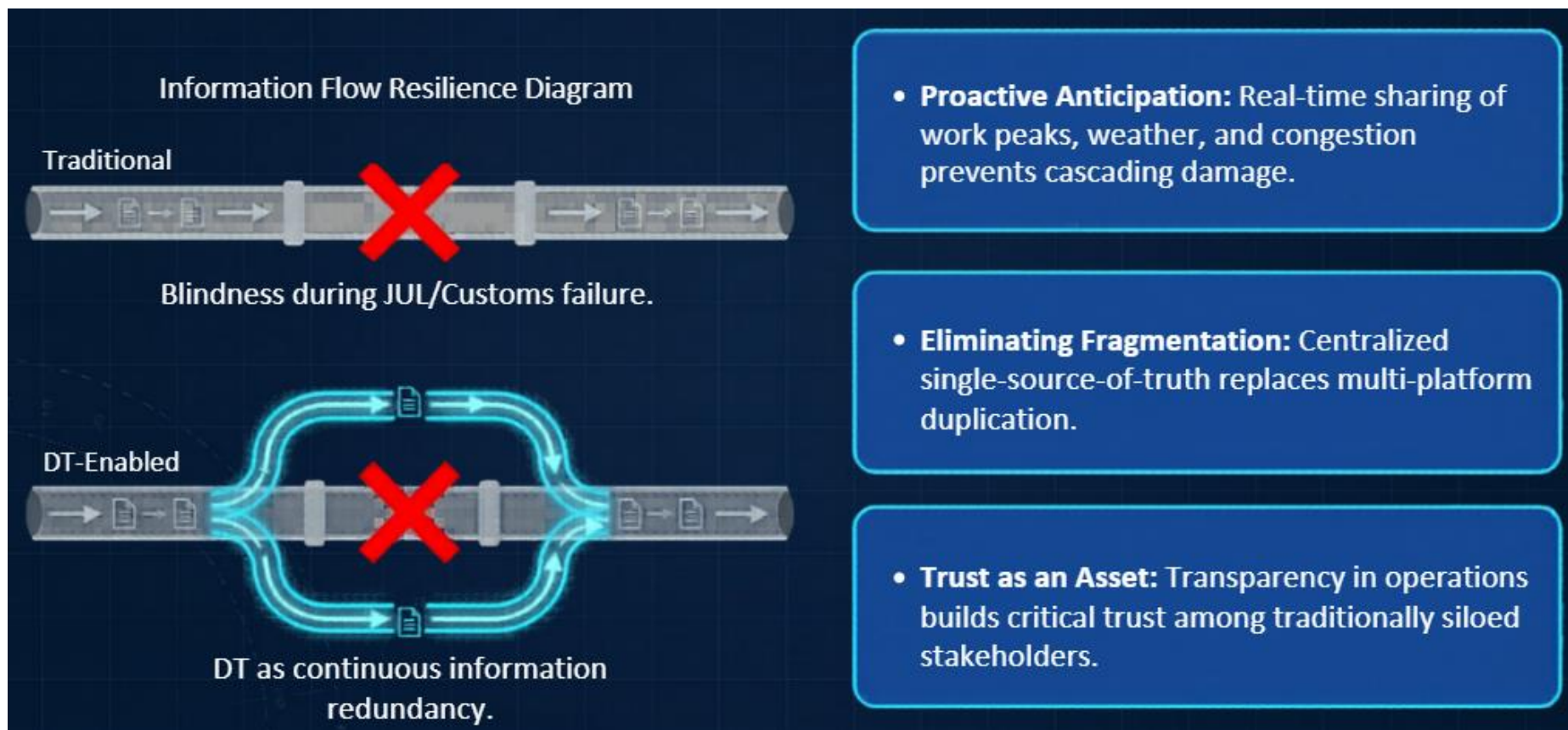
Capturing the Ecosystem Perspective



The port ecosystem is a complex network of stakeholders with divergent operational, regulatory, and strategic objectives. Successful DT implementation requires aligning these frequently antagonistic perspectives.

Results & Discussion

AD I - Resilience of Information Flow



Main Themes

Anticipating Disruptions and Proactive Planning

Operational Continuity and Information Redundancy

Centralization and Elimination of Fragmentation

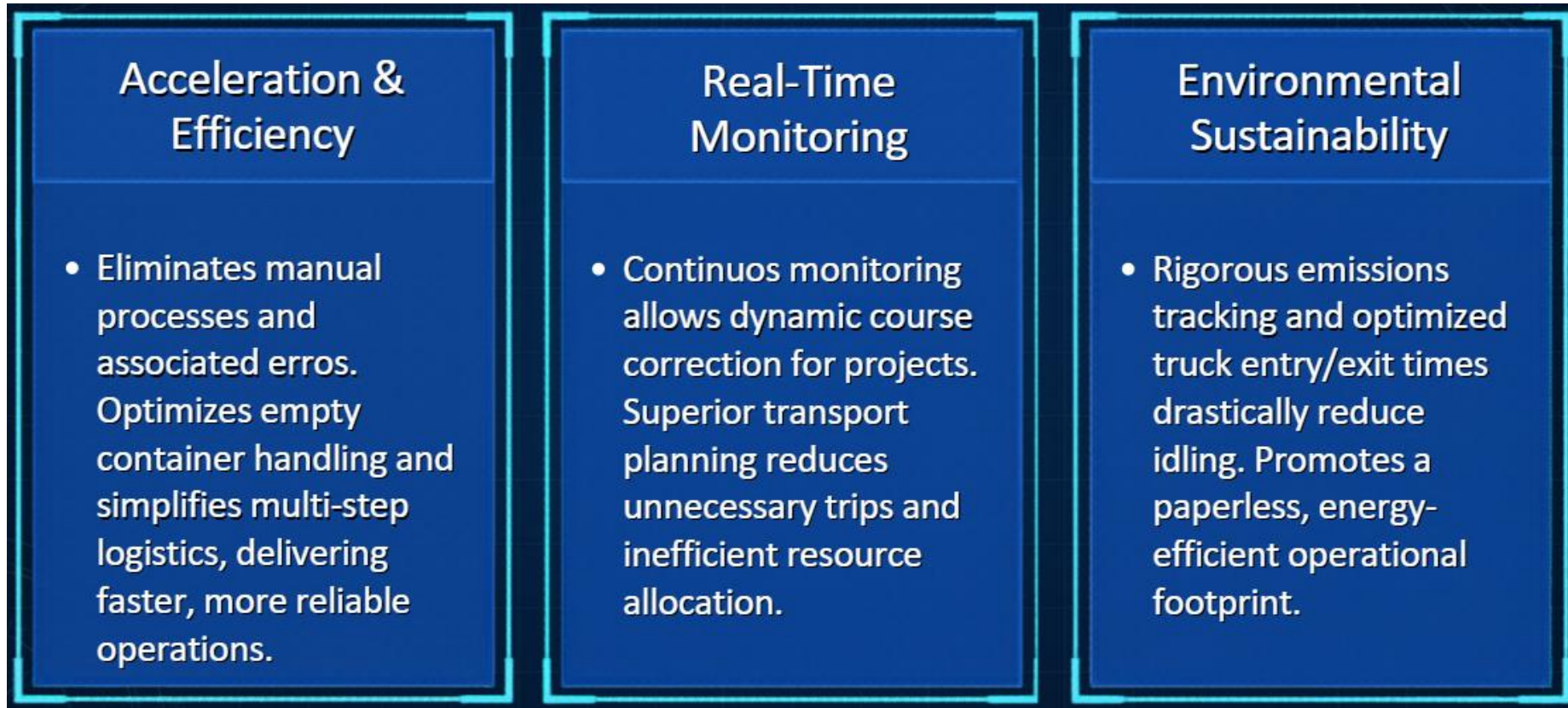
Strengthening Trust and Transparency

Organizational Commitment and Governance

Responsiveness to Unforeseen Events

Results & Discussion

AD II - Continuity and Sustainability of Port and Logistics Operations



Main Themes

Acceleration, Efficiency, and Continuous Improvement

Real-Time Monitoring and Anticipation of Disruptions

Operational Continuity and Risk Reduction

Environmental Sustainability and Carbon Footprint Reduction

Innovation, Competitiveness, and New Business Models

Resource Optimization and Loss Minimization

Conclusion

Digital Twin as a Socio-Technical Enabler



Technology alone is insufficient. The research proves that **seaport resilience cannot be engineered exclusively at the infrastructure level**; it requires deep interorganizational alignment and cultural commitment to shared digital ecosystems.

Conclusion

Strategic Implications and Future Horizons



References

- Ahmed, S. K., Mohammed, R. A., Nashwan, A. J., Ibrahim, R. H., Abdalla, A. Q., M. Ameen, B. M., & Khedhir, R. M. (2025). Using thematic analysis in qualitative research. *Journal of Medicine, Surgery, and Public Health*, 6, 100198. <https://doi.org/10.1016/j.glmedi.2025.100198>
- APS—Administração dos Portos de Sines e Algarve, S. A. (2022, April). *Innovation Agenda for Digital and Green Transition*. <https://nexuslab.pt>
- Bao, X., Jia, F., Zhong, J., Zhang, L., Liu, C., Chen, L., & Zheng, Y. (2024). Digital twin system for automated container terminal and a case study. *IEEE International Conference on Automation Science and Engineering*, 142–147. <https://doi.org/10.1109/CASE59546.2024.10711351>
- Braun, Virginia., & Clarke, Victoria. (2022). *Thematic analysis : a practical guide*. SAGE.
- Cai, J., Li, G., & Zhang, L. (2022). Study on the Construction of Digital Twin- Oriented Operation Ecosystem Model of Large-Scale Comprehensive Port. *Advances in Transdisciplinary Engineering*, 31, 1280–1285. <https://doi.org/10.3233/ATDE220998>
- Ding, Y., Zhang, Z., Chen, K., Ding, H., Voss, S., Heilig, L., Chen, Y., & Chen, X. (2023). Real-Time Monitoring and Optimal Resource Allocation for Automated Container Terminals: A Digital Twin Application at the Yangshan Port. *Journal of Advanced Transportation*, 2023, 1–12. <https://doi.org/10.1155/2023/6909801>
- Eom, J. O., Yoon, J. H., Yeon, J. H., & Kim, S. W. (2023). Port Digital Twin Development for Decarbonization: A Case Study Using the Pusan Newport International Terminal. *Journal of Marine Science and Engineering*, 11(9). <https://doi.org/10.3390/jmse11091777>
- Epiphaniou, G., Hammoudeh, M., Yuan, H., Maple, C., & Ani, U. (2023). Digital twins in cyber effects modelling of IoT/CPS points of low resilience. *Simulation Modelling Practice and Theory*, 125. <https://doi.org/10.1016/j.simpat.2023.102744>
- Fonseca, A., de Oliveira, F. F., & Gaspar, H. M. (2023). OPEN FRAMEWORK FOR DIGITAL TWIN SHIP DATA: CASE STUDIES ON HANDLING OF MULTIPLE TAXONOMIES AND NAVIGATION SIMULATION. *Transactions of the Royal Institution of Naval Architects Part A: International Journal of Maritime Engineering*, 165(1), A23–A42. <https://doi.org/10.5750/ijme.v165iA1.813>
- Giering, J. E., & Dyck, A. (2021). Maritime Digital Twin architecture A concept for holistic Digital Twin application for shipbuilding and shipping. *At-Automatisierungstechnik*, 69(12), 1081–1095. <https://doi.org/10.1515/auto-2021-0082>
- González-Cancelas, N., Martínez Martínez, P., Vaca-Cabrero, J., & Camarero-Orive, A. (2025). Optimization of Port Asset Management Using Digital Twin and BIM/GIS in the Context of Industry 4.0: A Case Study of Spanish Ports. *Processes*, 13(3). <https://doi.org/10.3390/pr13030705>
- Guizzardi, R., Piest, J. P. S., Akyazi, A., Ariji, S., Tao, T., Bastani, M., Scheijgrond, A.-R., Kromanis, R., Vahdatikhaki, F., Hüllmann, J. A., & Mes, M. (2025). *Requirements Analysis for a Digital prTwin to Increase the Resilience of Multimodal Corridors: A Case Study in the Twente Region* (pp. 219–230). https://doi.org/10.1007/978-3-031-94931-9_18
- Hakimi, F., Khaled, T., Al-Kharaz, M., Gouabou, A. C. F., & Amzil, K. (2025). *Towards a Digital Twin Modeling Method for Container Terminal Port*. <https://doi.org/10.1016/j.procs.2024.09.361>

References

- Homayouni, S. M., Pinho de Sousa, J., & Moreira Marques, C. (2025). Unlocking the potential of digital twins to achieve sustainability in seaports: the state of practice and future outlook. *WMU Journal of Maritime Affairs*, 24(1), 59–98. <https://doi.org/10.1007/s13437-024-00349-2>
- Infraestruturas de Portugal. (2021). *Corredor Atlântico*. Infraestruturas de Portugal. <https://servicos.infraestruturasdeportugal.pt/pt-pt/parceiros/corredor-atlantico/corredor-atlantico-ips>
- Jović, M., Tijan, E., Brčić, D., & Pucihar, A. (2022). Digitalization in Maritime Transport and Seaports: Bibliometric, Content and Thematic Analysis. In *Journal of Marine Science and Engineering* (Vol. 10, Number 4). MDPI. <https://doi.org/10.3390/jmse10040486>
- Klar, R., Fredriksson, A., & Angelakis, V. (2023). Digital Twins for Ports: Derived From Smart City and Supply Chain Twinning Experience. *IEEE Access*, 11, 71777–71799. <https://doi.org/10.1109/ACCESS.2023.3295495>
- Neugebauer, J., Heilig, L., & Voß, S. (2023). *Digital Twins in Seaports: Current and Future Applications* (pp. 202–218). https://doi.org/10.1007/978-3-031-43612-3_12
- Neugebauer, J., Heilig, L., & Voß, S. (2024). Digital Twins in the Context of Seaports and Terminal Facilities. *Flexible Services and Manufacturing Journal*, 36(3), 821–917. <https://doi.org/10.1007/s10696-023-09515-9>
- Paredis, R., Vangheluwe, H., & Albertins, P. A. R. (2024). *COOCK project Smart Port 2025 D3.2: “Variability in Twinning Architectures.”* <http://arxiv.org/abs/2409.01859>
- Presidência do Conselho de Ministros. (2019). *Diário da República, 1.ª série Presidência do Conselho de Ministros: Cria a Janela Única Logística, transpondo a Diretiva n.º 2010/65/UE*.
- Presidência do Conselho de Ministros. (2025). *Resolução do Conselho de Ministros n.º 119/2025: Aprova a Estratégia para os Portos Comerciais do Continente 2025-2035 — PORTOS 5+.* *Diário da República: 1.ª série, n.º 154*. <https://files.diariodarepublica.pt/1s/2025/08/15400/0001400035.pdf>
- Su, Z. (2026). Digital Transformation in Port Logistics. *Encyclopedia*, 6(1), 28. <https://doi.org/10.3390/encyclopedia6010028>
- Tsoulfas, G. T. (2025). Port resilience: a systematic literature review. *Maritime Economics and Logistics*. <https://doi.org/10.1057/s41278-025-00326-3>
- Valenzuela-Silva, L., Muñoz, M., Lagos, C., Sepúlveda-Rojas, J. P., & Carrasco, R. (2025). Assessment of Differences Between the Ports of Rotterdam, Valparaíso and San Antonio Towards Smart Ports, Emphasising Digital Technologies. *Journal of Marine Science and Engineering*, 13(12). <https://doi.org/10.3390/jmse13122220>
- Yao, H., Wang, D., Su, M., & Qi, Y. (2021). Application of Digital Twins in Port System. *Journal of Physics: Conference Series*, 1846(1). <https://doi.org/10.1088/1742-6596/1846/1/012008>
- Zavvos, E., Zavitsas, K., Latinopoulos, C., Leemen, V., & Halatsis, A. (2024). *Digital Twins for Synchronized Port-Centric Optimization Enabling Shipping Emissions Reduction* (pp. 137–160). <https://doi.org/10.4018/978-1-6684-9848-4.ch007>
- Zhou, C., Xu, J., Miller-Hooks, E., Zhou, W., Chen, C. H., Lee, L. H., Chew, E. P., & Li, H. (2021). Analytics with digital-twinning: A decision support system for maintaining a resilient port. *Decision Support Systems*, 143. <https://doi.org/10.1016/j.dss.2021.113496>

Port Authority
Consortium Leader



Importers and Exporters



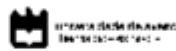
Port Operator



Land Infrastructure



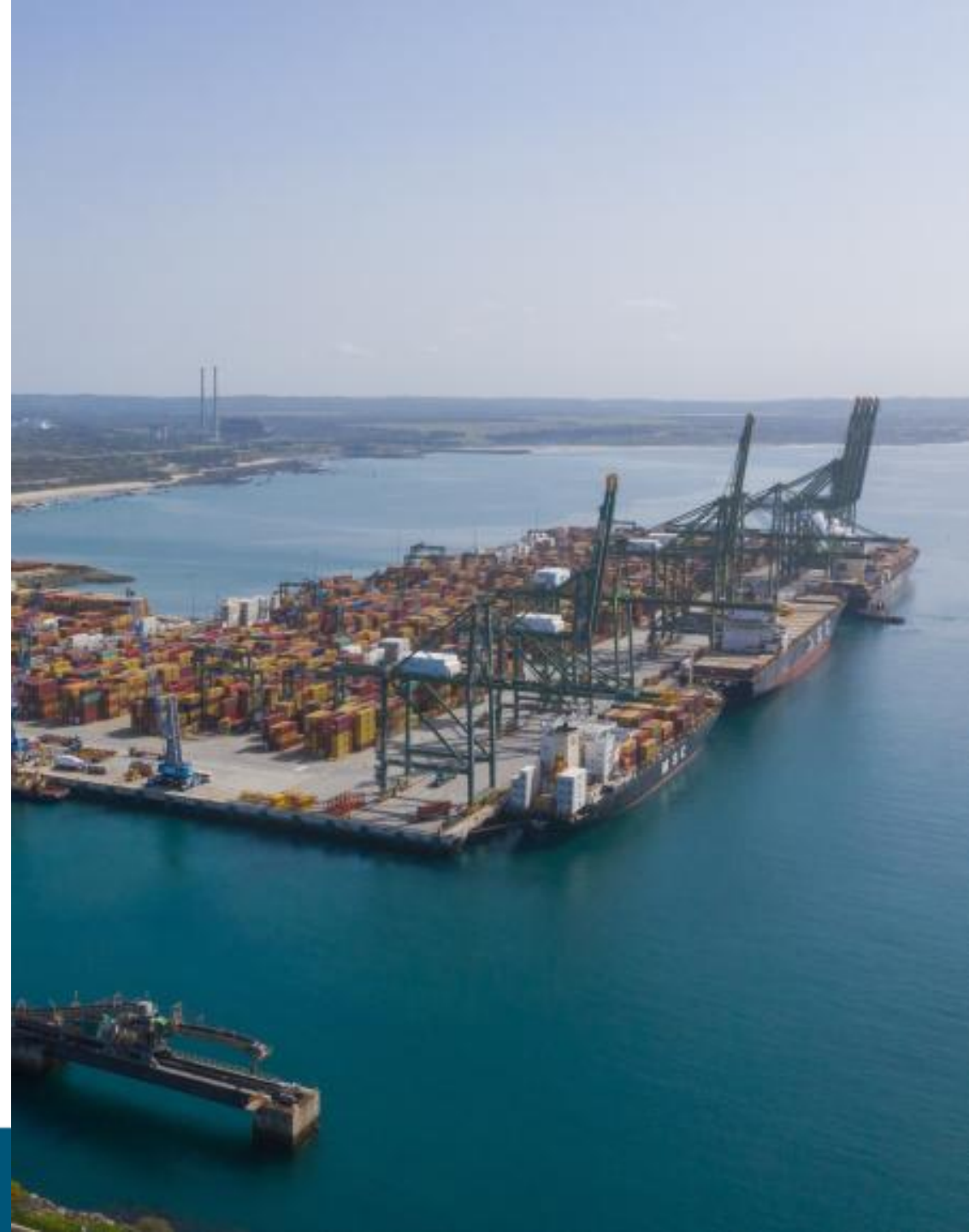
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