

The Digital Twin for Green Shipping



Austin A. Kana

***Associate Professor of Early-Stage Complex Ship Design
Delft University of Technology, Netherlands***



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Agenda



1. Learning objectives
2. What is a Digital Twin and what are the challenges with implementing them for green ships?
3. What is the state-of-the-art in the digital twins in the maritime industry?
4. What are the modeling requirements for a digital twin enabled ship *design* and *retrofit* method?
5. A proposal for a model architecture
6. Questions



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Module Learning Objectives



1. **Define** what is a digital twin as it relates to green shipping
2. **Describe** the state-of-the-art of digital twins for green shipping
3. **Elucidate** the challenges with digital twins for green shipping
4. **Identify** modeling requirements for digital twins for the design and retrofit of green ships



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What is a Digital Twin?

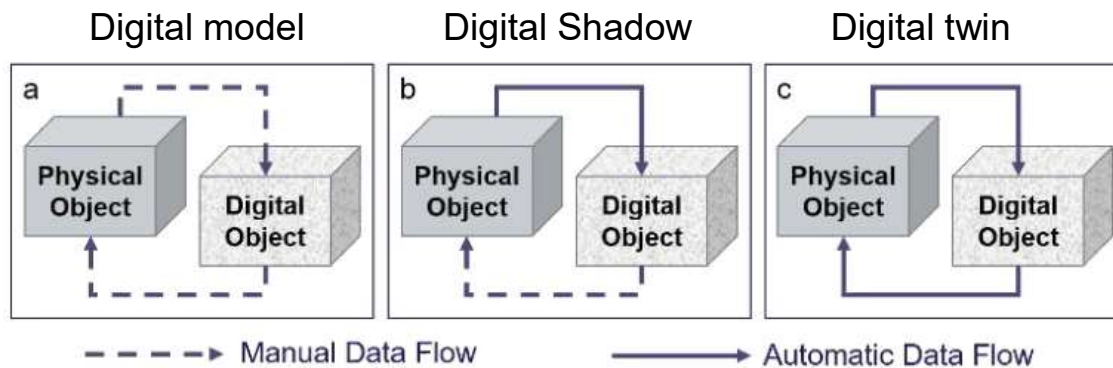


Grieves (2014) definition of a DT:

1. Physical product
2. Virtual product representing the physical product
3. Real-time data connection between the two

Ship Design literature is inconsistent in their use and meaning of “Digital Twins”

Kritzinger et al. (2018) nomenclature



- Grieves, M. (2014). Digital twin: Manufacturing excellence through virtual factory replication. White paper, 1–7.
- Kritzinger, W., Karner, M., Traar, G., Henjes, J. and Sihn, W. (2018). Digital twin in manufacturing: A categorical literature review and classification. *16th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018*, 51(11).
- Mauro, F. and Kana, A. (2023). Digital twin for ship life-cycle: A critical systematic review, *Ocean Engineering*, Vol. 269.



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What is a Digital Twin?

Tasks and Use Cases for Digital Twins

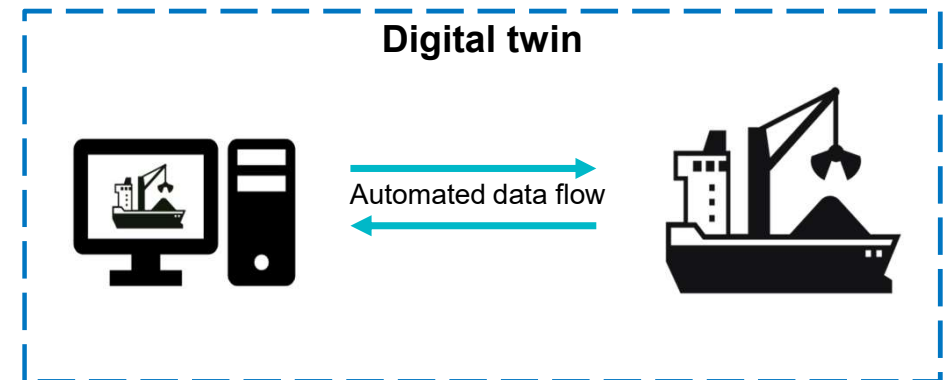
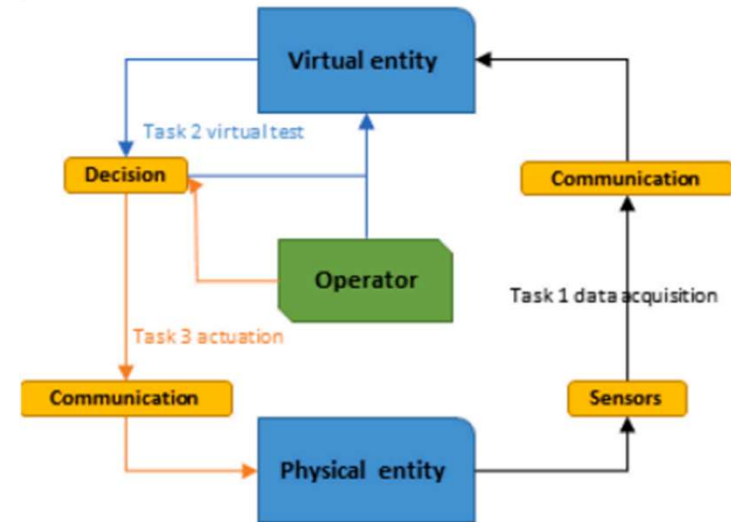


Tasks

1. Data acquisition from physical to virtual entity via sensors
2. Virtual testing to improve the performance of physical entity
3. Enact corrective measures on physical entity by transmitting data to actuators on physical entity

Use Cases

1. Across entire ship lifecycle (design through retire)
2. Structural health monitoring
3. Marine engineering (engine) characteristics
4. Environmental performance



- Mauro, F., Kana, A.A. 2023. Digital twin for ship life-cycle: a critical systematic review. *Ocean Engineering*. 269. DOI: 10.1016/j.oceaneng.2022.113479.
- Hermans, J., Kana, A.A. 2025. From DT-based retrofit to new build: A design framework mapping the challenges and considerations of emission reduction through data-driven ship design. *World Conference on Transport Research SIGA2 Conference*. May 7-9. Antwerp, Belgium.



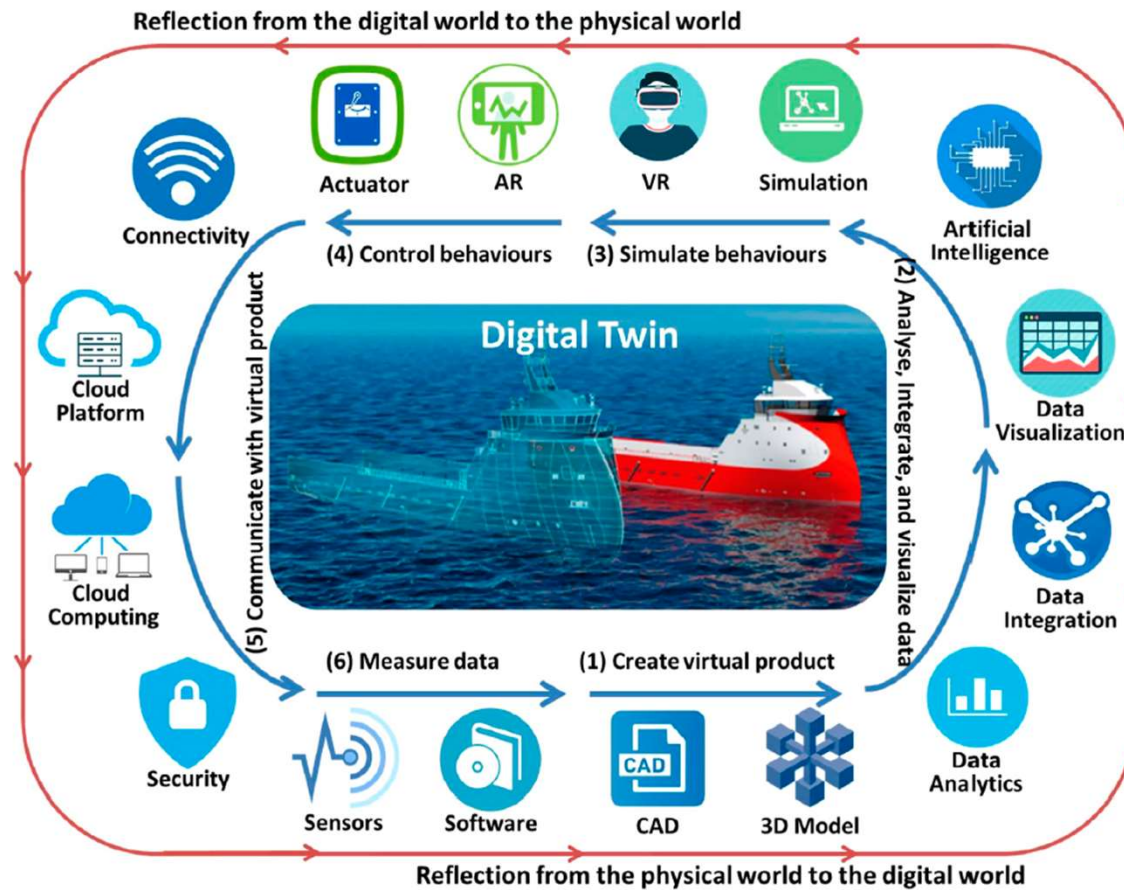
The projects have received funding from the Horizon Europe framework programme under Grant Agreement No 101056799 and No 101095863



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What is a Digital Twin? How it works



Tao, F., Sui, F., Liu, A., Qi, Q., Zhang, M., Song, B., ... Nee, A. Y. C. (2018). Digital twin-driven product design framework. *International Journal of Production Research*, 57(12), 3935–3953. <https://doi.org/10.1080/00207543.2018.1443229>



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What are the challenges with implementing DTs for green ships?



1. **Definition of DT** has been used **inconsistently** mixing “DT” with other digital entities
2. Concept of DT-enabled design following Grieves (2014) in very early stage of development globally
3. Developments in literature have mainly focused on the **operation and maintenance stage and not on design (or retrofit)**.
4. When designing a new vessel, the **physical entity does not exist yet**. Even harder with relatively new “green ships”



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What is the state-of-the-art in the digital twins in the maritime industry?

Design:

- Most research to date has a focus on **parts of a ship not total ship** (i.e. subsystems), conceptional applications, or only general description of application
- **No examples with concrete applications**, only theoretical and conceptual
- Few examples include essential information such as specific methods, I/O data, etc.
- DT-based ship design is in *formation stage*, “very few papers are published as the technological foundations are not mature enough to support effective applications”

Two approaches

1. Design of a physical entity while designing a DT specifically tailored to the physical entity
2. Developing a virtual space where DTs can be developed for different types of ships





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What is the state-of-the-art in the digital twins in the maritime industry?



Production:

- ~5 papers in literature up to 2023, production of the whole ship (digitization of shipyard), integration of 3D virtual environment in production process, production of marine engines, and specific working of data exchange system
- All aligned with the shop-floor DT concept (Tao and Zhang, 2017), which is basis for all digital processes in industrial productions.
- **Shipyards can (mostly) directly use technologies from other industrial sectors.**





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What is the state-of-the-art in the digital twins in the maritime industry?

Operation:

- Most effort in literature: engine, power system, control/motions, and structures (prediction of future loads)
- Most focus on development of digital models, and not true DTs
- Many works erroneously call a data-driven based model or a system engineering model hybridized with machine learning corrections, the DT.
- Almost all models developed in the context of model-based engineering can be directly used or easily adapted to a DT concept.





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What is the state-of-the-art in the digital twins in the maritime industry?



Retire:

- Least researched topic, only 1 paper, concept paper on recycling materials
- As retire phase is end of ship life, it is hard to study digital technologies on ships that have not been designed, built or operated with digital aids
- Likely retire phase will be the last to have a growth of research
- Propose to associate retire with the refitting of an existing unit?
 - Refitting is literally a re-design of the ship, thus topic close to design phase
 - How to integrate operational data into the green retrofitting decisions?





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What is the state-of-the-art in the digital twins in the maritime industry?



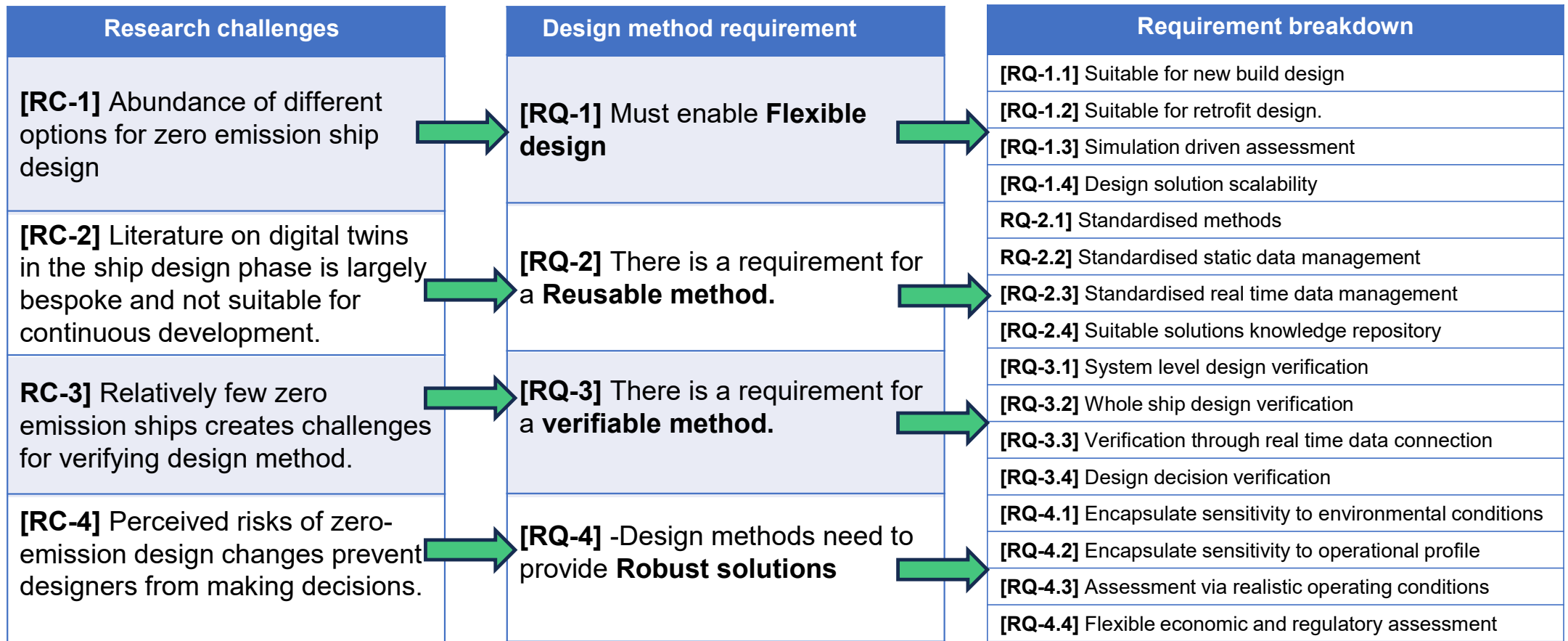
Life cycle (more than 1 phase of ship's lifecycle)

- Only four papers in literature
- All include conceptual description of a DT architecture suitable for the whole ship life cycle (borderline review papers)





What are the modeling requirements for a digital twin enabled ship *design* and *retrofit* method?





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Review of State-of-art methods for DT-enabled ship design



Requirement group	Requirement	Erikstad (2017, 2018, 2019)	Xiao et al. (2022)	Pang et al. (2021)	Dimopoulos et al. (2018)	Nikolopoulos and Boulougouris (2023)	Marzi et al. (2024)	Kana et al. (2024)	Hermans and Kana (2024)
1. Flexible	1.1 Suitable for new build design		✓			✓		✓	
	1.2 Suitable for retrofit design							✗	✓
	1.3 Simulation based evaluation	✓	✓	✓	✓	✓	✓	✓	✓
	1.4 Scalability of design solutions	✗	✗	✗		✗	✗	✗	
2. Reusable	2.1 Standardised system models	✓		✓	✓	✓	✓		
	2.2 Real time data management methods		✓	✗				✗	✗
	2.3 Static data management methods		✓	✓	✓	✓	✓		
	2.4 Knowledge repository	✗	✓		✗	✗	✗	✗	
3. Verifiable	3.1 System level verification	✗			✓	✓	✓	✓	
	3.2 Whole ship verification	✗			✓	✓	✓	✓	
	3.3 Verification through real time data connection		✓	✗				✗	✗
	3.4 Design decision verification	✗	✗	✓		✓	✓	✓	
4. Robust	4.1 Explicit encapsulation of operating environmental conditions and design sensitivity		✗	✗		✓	✓	✗	
	4.2 Explicit encapsulation of predicted operational profile and design sensitivity to it			✗	✓	✓	✓	✗	
	4.3 Assessment via realistic predicted operating conditions	✗		✗	✓	✓	✓	✗	✓
	4.4 Flexible economic and regulatory assessment parameters	✗	✗						✗

Phase 1 DT4GS work

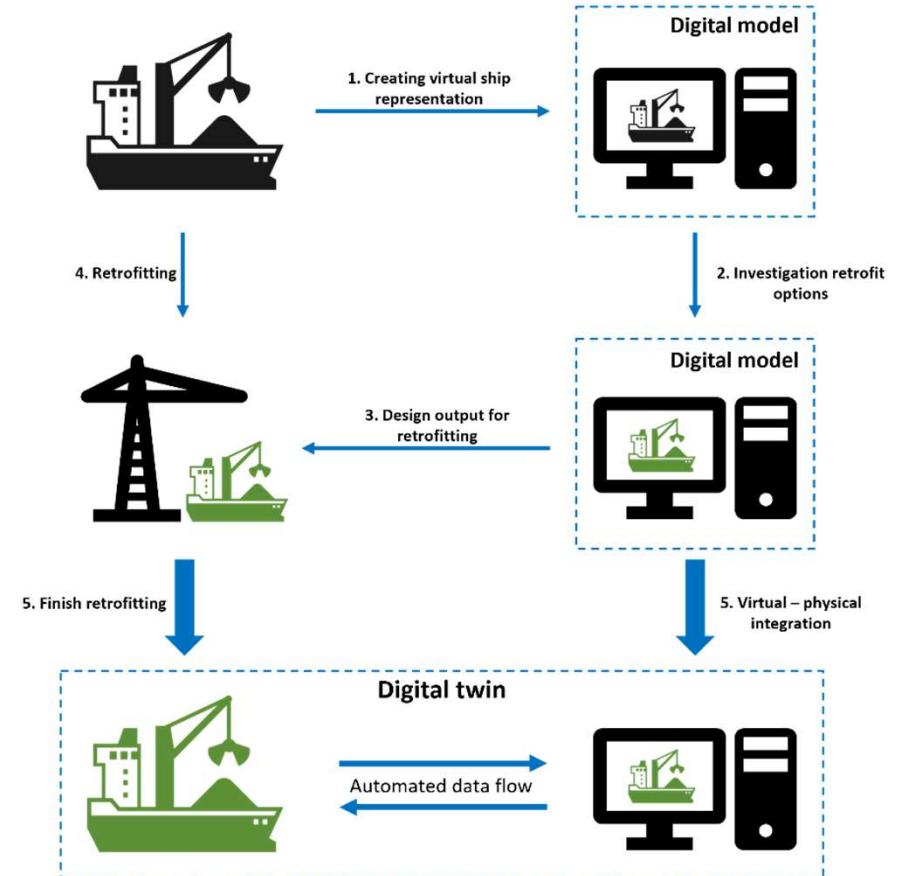
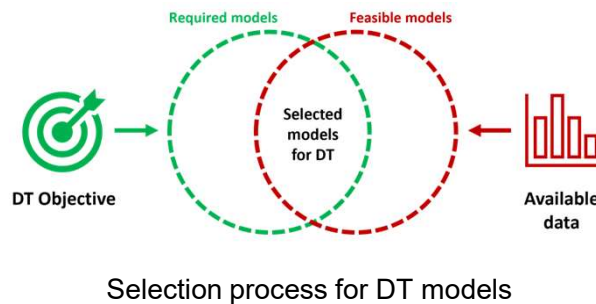
- Karakostas, B., Katsoulakos, T. (ed.) 2024. *State-of-the-Art Digital Twin Applications for Shipping Sector Decarbonization*. IGI Global.
 - Kana, A.A., Li, W., van Noesel, I., Pang, Y., Kondratenko, A., Kujala, P., Hirdaris, S. *Chapter 8 Application of Digital twins in the design of new green transport vessels*. Pg 161-191. DOI: <https://doi.org/10.4018/978-1-6684-9848-4.ch008>
- Hermans, J., Kana, A.A. 2024. Retrofit modeling for green ships. *15th International Marine Design Conference (IMDC 2024)*. June 2-6, Amsterdam, NL. DOI: <https://doi.org/10.59490/imdc.2024.890>



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Theoretical approach for DT-modeling for Design and Retrofit

1. Set up data acquisition
2. Establish a data pre-processing framework
3. Choose modelling approach for virtual models
4. Perform model training
5. Verify and validate virtual models
6. Integrate virtual part with physical part



The development of the digital twin for retrofitting

Hermans, J. (2024). Retrofit modelling for green ships A data-driven design approach for emission reduction using bunker delivery notes. MSc thesis. Delft University of Technology



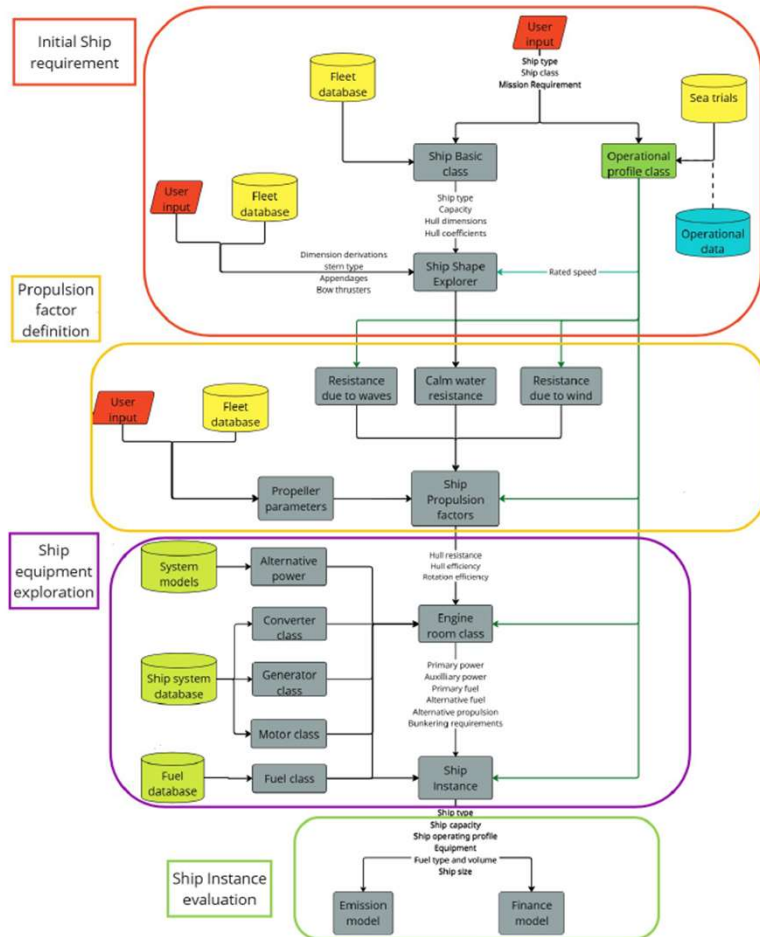
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DT4GS Technical modeling approach for DT-enabled ship *design* and *retrofit* – On-going work at TU Delft



Requirement group	Requirement	Kana et al (2024)	Hermans and Kana (2024)	Proposed DT driven design method
1. Flexible	1.1 Suitable for new build design	✓	✓	✓
	1.2 Suitable for retrofit design	✗	✓	✓
	1.3 Simulation based evaluation	✓	✓	✓
	1.4 Scalability of design solutions	✗	✓	✓
2. Reusable	2.1 Standardised system models	✗	✗	✓
	2.2 Real time data management methods	✗	✗	✓
	2.3 Static data management methods	✗	✓	✓
	2.4 Knowledge repository	✗	✓	✓
3. Verifiable	3.1 System level verification	✓	✓	✓
	3.2 Whole ship verification	✓	✓	✓
	3.3 Verification through real time data connection	✗	✗	✓
	3.4 Design decision verification	✓	✓	✓
4. Robust	4.1 Explicit encapsulation of operating environmental conditions and design sensitivity	✗	✓	✓
	4.2 Explicit encapsulation of predicted operational profile and design sensitivity to it	✗	✓	✓
	4.3 Assessment via realistic predicted operating conditions	✗	✓	✓
	4.4 Flexible economic and regulatory assessment parameters	✗	✗	✓

Final
DT4GS
work

Noble, B., Hermans, J., de Winter, R., Kana, A.A. 2025. A digital twin-enabled zero emission ship design method. *World Conference on Transport Research SIGA2 Conference*. May 7-9. Antwerp, Belgium.



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Conclusions



Conclusion

- **Inconsistent usage of DT definition** across literature
- **Maritime behind other industries** (aerospace, manufacturing, automotive), in literature and adoption of DTs
- Paradox arises when following the definition of a DT regarding new-build green design
 - No standardized design method for DT-based design or retrofit
- Most effort to date towards operation phase
- Little work in literature on promising area of retrofitting using operational data as part of retire phase



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Way ahead



Proposed way ahead for research efforts

1. **Improved consistency with terminology** in research and application of DTs in literature. We argue for the DT definitions proposed by Grieves (2014), and Kritzinger et al. (2018)
2. Development of a generic **standardized DT-enabled framework**, for both new-builds and retrofits, which is flexible, reusable, verifiable, and robust and includes recommendations for specific methods, input data, output data and reliability of the design. Aim to support development of virtual space in which DTs can be developed for different types of ships

**Thank you for your
attention!**

Austin A. Kana
(Delft University of Technology, Netherlands)



a.a.kana@tudelft.nl



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