Deltares

Digital Twins

Promising tools for water & subsurface management

The Deltares perspective

Digital Twins for environmental systems are where the European Union's Green Deal meets the EU's digital ambition. They are a cornerstone of the EU's strategy to support policymakers when facing challenges related to climate change mitigation and adaptation. Currently, many R&D European projects contribute to the development of research fields necessary for digital twinning of environmental systems.

This article focusses on Digital Twins for water and subsurface management, and aims to set out what Digital Twins are, what they are used for, what developments are needed, and the status of these developments. The article presents the perspective of Deltares – one of the many actors in the field of Digital Twins. To illustrate this, current and past projects are used that show the variety of parallel developments on six aspects of Digital Twins, that are defined as interactivity, integration, real physics, real data, social and photorealism. Opportunities and challenges are discussed, resulting in a vision for further development. This article is also an open call for cooperation for readers that share the same vision and ambition and can contribute complementary expertise and experience.

Introduction

Deltares is a mission-driven knowledge institute for water and the subsurface. We are guided by the major societal issues and actively seek innovative solutions to keep rivers, estuaries, coasts, and seas safe, sustainable, and habitable – both now and in the future.

Advancements in computer technology, data sciences, and environmental sciences have transformed these ambitious goals into tangible possibilities. This transformation includes the emerging development of tool collections that facilitate process description and interaction with digital replicas, known as 'Digital Twins.'

This article addresses key questions: *Why do we need Digital Twins? What are Digital Twins in the field of water and subsurface management? How does Deltares embrace them? What contributions can Deltares offer in the evolving landscape of Digital Twins? And how do we move forward as a renowned leader in this field?*
The goal of this article is to offer a clear overview of Deltares' perspective on Digital Twins. We hope it promotes collaboration between scientists, public and commercial organisations, and private users to co-define the Digital Twins and explore their potential applications in the water sector.

Why do we need Digital Twins?

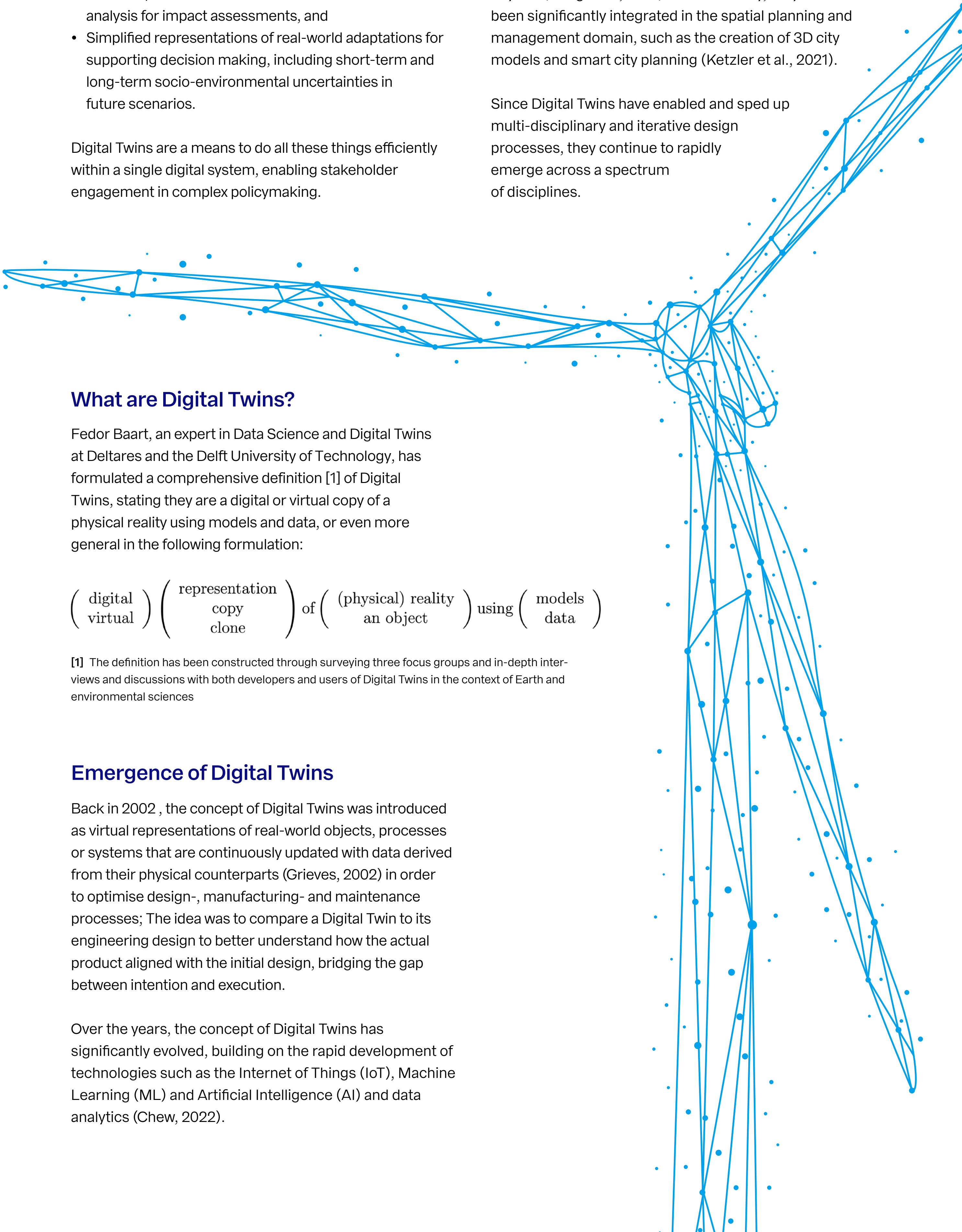
To manage physical objects, the following is required:

- Data collection and -processing for monitoring
- Virtual representations and statistical- or scenario-based analysis for impact assessments, and
- Simplified representations of real-world adaptations for supporting decision making, including short-term and long-term socio-environmental uncertainties in future scenarios.

Digital Twins are a means to do all these things efficiently within a single digital system, enabling stakeholder engagement in complex policymaking.

Digital Twins are widely applied across several industries, playing a key role in manufacturing, supply chain management, automotive, engineering, healthcare, and beyond (Jiang et al., 2021). More recently, they have been significantly integrated in the spatial planning and management domain, such as the creation of 3D city models and smart city planning (Ketzler et al., 2021).

Since Digital Twins have enabled and sped up multi-disciplinary and iterative design processes, they continue to rapidly emerge across a spectrum of disciplines.



What are Digital Twins?

Fedor Baart, an expert in Data Science and Digital Twins at Deltares and the Delft University of Technology, has formulated a comprehensive definition [1] of Digital Twins, stating they are a digital or virtual copy of a physical reality using models and data, or even more general in the following formulation:

$$\begin{pmatrix} \text{digital} \\ \text{virtual} \end{pmatrix} \begin{pmatrix} \text{representation} \\ \text{copy} \\ \text{clone} \end{pmatrix} \text{of} \begin{pmatrix} \text{(physical) reality} \\ \text{an object} \end{pmatrix} \text{using} \begin{pmatrix} \text{models} \\ \text{data} \end{pmatrix}$$

[1] The definition has been constructed through surveying three focus groups and in-depth interviews and discussions with both developers and users of Digital Twins in the context of Earth and environmental sciences

Emergence of Digital Twins

Back in 2002 , the concept of Digital Twins was introduced as virtual representations of real-world objects, processes or systems that are continuously updated with data derived from their physical counterparts (Grieves, 2002) in order to optimise design-, manufacturing- and maintenance processes; The idea was to compare a Digital Twin to its engineering design to better understand how the actual product aligned with the initial design, bridging the gap between intention and execution.

Over the years, the concept of Digital Twins has significantly evolved, building on the rapid development of technologies such as the Internet of Things (IoT), Machine Learning (ML) and Artificial Intelligence (AI) and data analytics (Chew, 2022).

We identify three different types of Digital Twin applications: industry, city, and environment (see table 1). After industry, cities were one of the first adopters of the concept. Cites have started to add Internet of Things (IoT) sensors, filled the streets with cameras, and replaced old maps with 3D Building Information Models (BIM). This allowed the transition to interactive 3D visual live representation of the city's state.

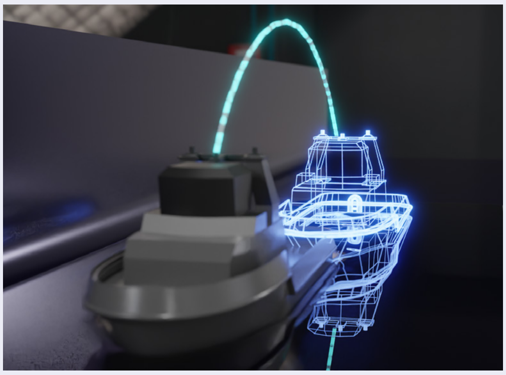
Environmental Digital Twins developed slightly differently, as they represent large systems-of-systems, for example river basins, oceans and seas, and global climate modelling initiatives. Environmental Digital Twins are either used for real-time data and multiple day forecasts for operational purposes, or for multiple decade scenario simulations for dissemination and policymaking purposes. Environmental Digital Twins are rarely used for intermediate timespans.

Type	Industry	Cities & (air)ports	Environment
Goal	Life cycle management	"Smart" cities & (air)ports	Decision support, risk management & dissemination
Interventions	Adaptive design	Spatial planning and policymaking	System operation (e.g. sluices & locks) & policymaking
Cost reduction	R&D, construction & maintenance costs	Design, construction & maintenance costs	Disaster risk reduction, climate adaptation & biodiversity protection
System representation	Single object with many components	Many objects	Many systems
Timespan	Seconds - 5 years	Days - 10 years	Days or decades

Table 1 Overview of 3 types of Digital Twins

Digital Twins for water and subsurface management

For water- and subsurface management, Digital Twins generate management and policy options, and impact assessments at the level of objects and at the level of large environmental systems. Digital Twins of larger environmental systems and Digital Twins of objects in the environment can co-operate, as the larger Digital Twin can provide information on which interventions on object level are needed. An example is the closure of locks (objects) for river basin management (large environmental system).



Digital Twin used to test green routing and green steaming strategies in inland shipping (Source: DigiPact project)

Digital Twins of objects

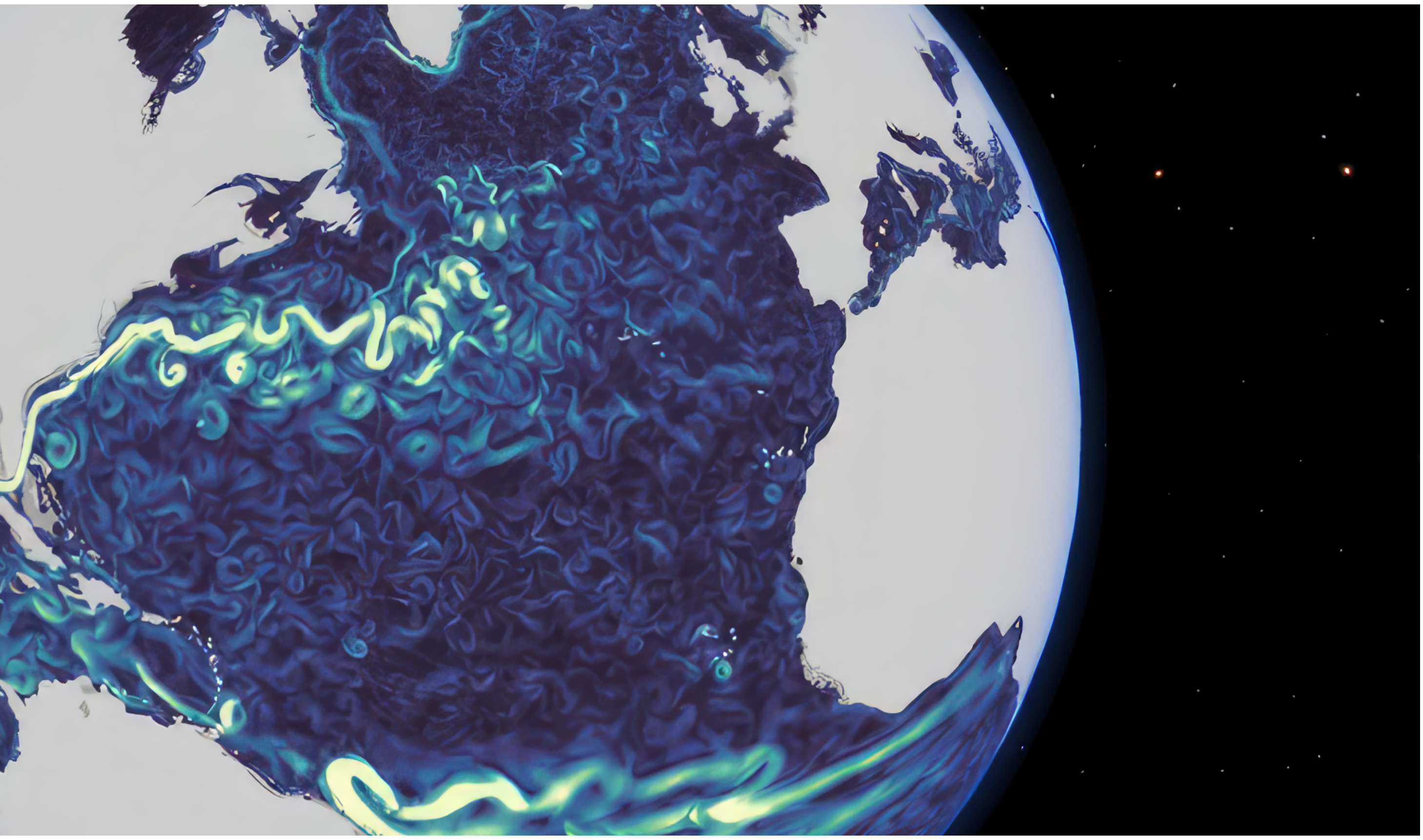
Digital Twins of objects in water- and subsurface management can be subdivided into floating and navigating vessels, and hydraulic structures. There is a wide variety of hydraulic structures for which Digital Twins are developed, including dykes (e.g. Afsluitdijk, Soltegro), storm surge barriers (e.g. Maaslantkering, Aveco de Bondt), quay walls, bridges, and waste-water treatment plants.

Digital Twins of environmental systems

In recent years, there has been a growing number of initiatives aiming at designing Digital Twins for entire environmental systems (Blair, 2021). While Digital Twins at the object-level primarily focus on optimising the efficiency, quality, and performance of a single object within well-defined systems and lifespans, Digital Twins at the environment-level, pose unique challenges as they represent large, dynamic, and complex systems.

Digital Twins at the environment-level involve modelling natural and anthropogenic processes, integrating heterogeneous data sources, managing inherent uncertainties in various processes, and fostering interdisciplinary collaboration among domain experts, scientists, and stakeholders. Therefore, Digital Twins in the natural environment require more integrated and adaptive approaches in development and implementation compared to the relatively more structured and controlled environments of manufacturing systems.

Maaslantkering (Source: Adobe Stock)



Digital Twin of the Ocean (Source: EDITO)

Digital Twins for water and subsurface management in the European context

Since 2020, the European Commission (EC) has been actively investing in Shaping Europe's Digital Future [2] and the European Green Deal [3]. These initiatives aim to empower digital technologies and progress towards a climate-neutral Europe by 2050, respectively. In the specific context of water and subsurface management, the EC seeks to enhance decision-making and policy formulation, emphasizing the integration of digital transformation and sustainable practices to address both crisis-ridden and long-term challenges.

The development of Digital Twins in the water sector has recently gained significant momentum, driven by advancements in technology, computational capabilities, and the increasing availability of data. The EC's Directorate-General for Research and Development defines a Digital Twin as "A digital representation of real-world entities or processes, using real-time and historical data to represent the past and present and numerical models to simulate future scenarios" (European Commission, 2023). Two European Digital Twin initiatives, the Destination Earth and the Digital Twin Ocean, play essential roles in this digital landscape.

Destination Earth (DestinE) develops a highly accurate digital model of the entire Earth. The dynamic digital representation incorporates continuously updated climate-, weather-, land use-, and environmental data. It simulates near-real-time and predicts the interaction between natural phenomena and human activities, providing accurate information for decision-making in environmental management, disaster response, and climate change mitigation (Nativi & Craglia 2021).

The Digital Twin Ocean (DTO) develops a digital representation of the global marine environment, making ocean knowledge available to users ranging from, citizens and entrepreneurs to engineers, scientists, and policymakers. The DTO will facilitate effective strategies for (re)storing marine and coastal ecosystems, a sustainable blue economy, and climate adaptation (Tzachor et al., 2023).

[2] "Shaping Europe's Digital Future" is a strategic initiative by the European Union to promote and advance digital technologies and innovation across Europe in the global digital landscape (European Commission, 2020). It aims to drive digital transformation, enhance technological leadership, develop a common European data space, and improve digital skills. Position Europe as a global leader in the digital landscape, fostering economic growth and ensuring the benefits of digitalization for citizens, businesses, and public services.

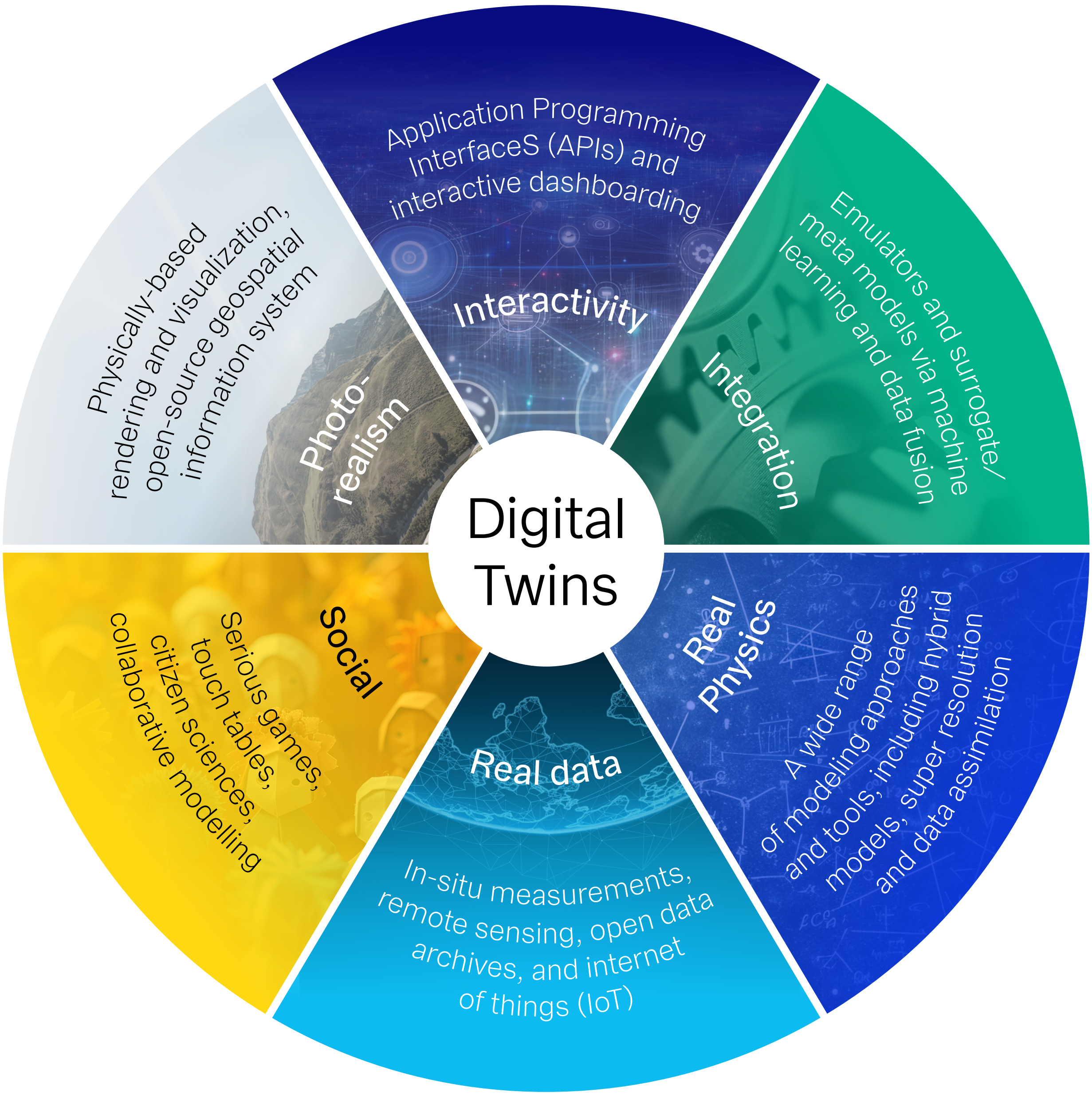
[3] The "European Green Deal" is primarily focused on achieving climate neutrality and environmental sustainability by 2050. It addresses challenges such as climate change, biodiversity loss, circular economy, and sustainable agriculture, aiming to make the EU the world's first climate-neutral continent (Fetting, 2020). The strategy seeks to reshape various sectors, including energy, transportation, agriculture, and industry, to align with environmental sustainability goals.

Digital Twins: Deltares' perspective

Deltares is actively engaged in global Digital Twin initiatives, and in various local and regional Digital Twin projects tailored for water and subsurface management. Baart (manuscript to be published in 2024) has identified six critical aspects to work towards in Digital Twinning projects.

So far some, rather than all, of these aspects are present per project. The six critical aspects consist of:

The figure below illustrates the six aspects of Digital Twins and Deltares expertise that interconnects these aspects. Deltares positions Digital Twins as an evolutionary step beyond traditional modelling approaches, emphasizing a more advanced and comprehensive approach that employs digital technologies to develop dynamic modelling frameworks (backend) with interactive applications (frontend) for a deeper understanding and effective management of water and subsurface systems.



The six aspects of Digital Twins (as defined by Fedor Baart)

The design and focused aspects of each Digital Twin project are tailored to fit its core objective and resource constraints. The subsequent sections of this paper delve into the challenges, focusses, and opportunities that Deltares recognises concerning these six aspects of Digital Twins. Deltares cooperates with various stakeholders and partners on Digital Twin projects that cover both the development of the Digital Twins themselves and the development of infrastructures that support the Digital twins.

Project name	Interactivity	Integration	Real physics	Real data	Social	Photo-realism
Algae radar				✓		
C-Scale		✓				
DestinE: Compound flooding		✓	✓			
DestinE: FloodAdapt framework	✓	✓	✓		✓	
EDITO: Model Lab		✓	✓	✓		
Fairway corridor	✓		✓	✓	✓	
Global Water Watch				✓		
Intertwin		✓		✓		
OR-ELSE		✓	✓	✓	✓	
SALTISoltions' virtual deltas	✓	✓	✓	✓	✓	
Sandbox-FM	✓		✓		✓	✓

Table 2 Reference projects for water- and subsurface management of Deltares and the Digital Twin aspects that are under development in the project. For more information on projects see last page.

Challenges for Digital Twins

Each aspect of Digital Twins has its development challenges and opportunities for progress as presented below. Additionally, we address the challenge in the maintenance of operational Digital Twins.

Interactivity

Increased interactivity introduces technically challenging requirement for modelling frameworks to respond in near real-time to changes made by users, such as in scenarios simulations. Also, the dependence on the internet of things and artificial intelligence increases, pushing for break-through technological improvements.

> Through machine learning and artificial intelligence, Digital Twins can derive patterns between sensed data and operational feedback that human intelligence would possibly overlook. When automating standardised action upon scenarios, skipping active human interaction, Digital Twins can function as intelligent actuators in operational management.

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Integration

Integration of multiple models and tools relies on interoperability and consistent scaling of data formats. The integration of multiple models and tools forms modelling frameworks. Achieving seamless operation of modelling frameworks poses challenges on technological, cultural, and organisational dimensions. Substantial efforts are also needed for integration of modelling frameworks into computational and data infrastructures. An example is the European Digital Twin Ocean, a platform that integrates models and tools, computational infrastructure, and databases.

> We make our resources, tools, and data cloud-ready and scalable to ensure effective integration in future Digital Twins.

Real physics

While physics-based models are computationally expensive and cannot achieve perfect duplication of the real world (Jemberie, 2004), they can be improved or replaced by statistics-based (data-driven) models. The current advancement in AI is progressively replacing (parts of) physics-based models to enhance modelling accuracy and speed.

Due to the utilisation of black-box approaches, computational errors get more challenging to retrace, introducing the risk of models becoming less general and more optimised for a specific application, scenario, or area. It is a challenge to maintain valuable knowledge and broad applicability while ensuring computational efficiency. Therefore, it is important to incorporate physical system understanding in data-driven techniques.

> There is a trend in replacing physical-numerical representation by Artificial Intelligence and Machine Learning techniques to speed up simulation time. Incorporating physical understanding in data-driven techniques ensures general applicability and accuracy of Digital Twins.

Real Data
Observations of the real world are crucial for the effectiveness of models and modelling frameworks (Davidson, et al., 2019). The quality of data input (accuracy, resolution, consistency, etc.) is crucial for modelling and data should be findable, accessible, interoperable and reusable (FAIR) (da Silva Santos, et al., 2016). The Global Water Watch (Deltares, WRI, WWF, 2023) is a good example of the added value of an accurate, up-to-date database, combined with effective visualisation. Limited availability, natural variability, sensor limitations, formats, storage, and quality assurance are some of the many challenges regarding data.

High-quality and FAIR data is essential for Europe's Digital Future.

Social
Diverse perspectives are inherent to environmental policy. Achieving effective and inclusive communication requires overcoming potential barriers such as differences in expertise, culture, and degree of understanding of system complexities. To foster collaboration and identify optimal solutions for the diversity of stakeholders, Digital Twins of environmental systems can benefit from fields such as citizen science (Bonney, et al., 2016), participatory modelling (Basco-Carrera, 2017), serious games (Encarnação, 2009), and interactive tools like touch tables (Van de Ven, et al., 2016).

Digital Twins are collaborative environments that encourage active engagement, feedback, and co-creation between decision makers and stakeholders.

Photorealism
The social challenge of differences in degree of understanding of system complexities can be addressed by three-dimensional photorealistic data visualisation, potentially leading to more intuitive understanding of a much wider audience. The challenge for Deltares in this aspect is the gap between current existing expertise and the state-of-the art. There have been successful collaborations with experts in data visualisation, such as GEODAN.

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Deltares is open to strategic partnerships with organisations specialized in three-dimensional data visualisation.

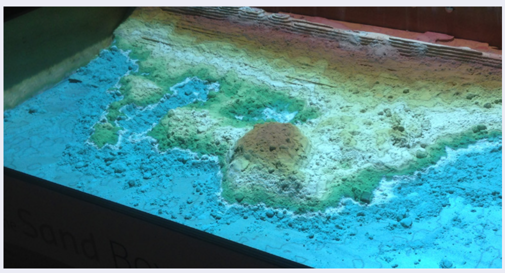
Maintenance
Although technical maintenance is not categorized as one of the six key aspects of a Digital Twin, it poses significant challenges, particularly for public Digital Twins that are developed with R&D funding and are not based on a business case. For many Digital Twins being developed for water- and subsurface management, there is the risk of never reaching to the level of a reliable operation decision support system. End-users and decision makers must be involved in early stages of development of Digital Twins to secure the added value and increase the chances for funded maintenance and hosting.

Together with numerous international partners, Deltares is establishing sustainable platforms to host Digital Twins in the long term and secure continued development.

Co-creating Digital Twins

Deltares is involved in numerous projects that develop the Digital Twins of water and subsurface systems. In many of these projects the questions are “How can we create a lasting innovation?” and “how should we create lasting added societal value?” We believe that co-creation is the answer to both questions.

Additionally, the integration of all 6 components at the highest level requires such a variety of expertise that multiple actors are needed to achieve innovative Digital Twins that add value to society. In the multiple-actor co-creation of Digital Twins, Deltares’ role would be either the initiator, developer, or user. Deltares is seeking for closer collaborations with other institutions to co-create Digital Twins that will solve the most pressing societal problems. This article is therefore also an open call for cooperation for readers that share the same vision and ambition.



Sandbox FM (Photo: Arjen Luijendijk)

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https://www.researchgate.net/publication/320166129_The_Algae_Radar_Towards_prediction_of_cyanobacteria_in_bathing_waters

DestinE compound flooding
End-to-end use case, demonstrating DestinE's capabilities.
https://destination-earth.eu/use-cases/disaster-risk-mitigation-climate-adaptation/

DestinE Adaptation Modelling Framework - Flood Risk Management
https://destination-earth.eu/use-cases/adaptation-modelling-framework/

Fairway Corridor (SmartPort)
A virtual environment of the Rhine-Meuse waterway and logistics.
https://smartport.nl/project/digital-twin-fairway-corridor/

FloodAdapt
An adaptation planning tool for compound flooding.
https://www.deltares.nl/software-en-data/producten/floodadapt

GlobalWaterWatch
A data platform of globally accessible near-real-time information on water.
https://www.globalwaterwatch.earth/

OR-ELSE
An operational recommendations for ecosystem-based large-scale sand extraction.
https://or-else.nl/

SALTISolutions' Virtual Deltas
A toolbox for operational management of saltwater intrusion.
https://www.nwo.nl/onderzoeksprogrammas/perspectief/perspectief-toekenningen/saltisolutions

Sandbox-FM
An innovative technique for immersive interactivity of models and policymaking.
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InterTwin
An interdisciplinary Digital Twin Engine as an open-source platform that offers the capability to integrate with application-specific Digital Twins.
https://www.intertwin.eu/

EDITO Model Lab
Integrating tools for modelling the marine environment on a cloud platform that provides access to dataspaces and computational resources.
https://edito-modellab.eu/

C-SCALE
Provides building blocks for implementing Digital Twins on federated compute and data infrastructures in Europe.
https://c-scale.eu/

enabling delta life

Deltares is an independent institute for applied research in the field of water, subsurface and infrastructure. Throughout the world, we work on smart solutions, innovations and applications for people, environment and society. Deltares is based in Delft and Utrecht.

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