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Digital twins for the real world

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Digital Twins for the Real World



Rede, uitgesproken door

Prof. dr. Igor Stefan Mayer

Tilburg University

Understanding Society

Prof. dr. Igor Stefan Mayer (1965, Detmold, Germany) is an endowed professor of Playful Organizations & Learning Systems in the Department of Organization Studies (OS) of the Tilburg School of Social and Behavioral Sciences, the Netherlands, as of January 1, 2021. The establishing body is Breda University of Applied Sciences (BUas), the Netherlands, where Igor Mayer is currently a professor applied university (lector, since 2015) in Serious Games, Innovation & Society.

Since 2017, he has been a visiting professor at the Department of Public Administration, Dalian University of Technology, China. Mayer was previously a visiting professor at the School of Management and Economics of Beijing Institute of Technology (China, 2015-2016).
Mayer studied Policy and Organization Sciences at Radboud University Nijmegen (1984-1991). After his military service, he worked (combined with positions at TNO and IVA Policy Research and Advice) on his Ph.D. research at the Department of Policy and Organization Studies (1992-1998) of the then Katholieke Universiteit Brabant.

Between 1998 and 2015, he was an associate professor at the Faculty of Technology, Policy and Management at TU Delft, where he founded and led the Policy Gaming research group.
Mayer has initiated and carried many serious gaming projects for clients. He has been a partner in many European projects, part of EU-GreenDeal, Horizon Europe, H2020, Horizon7, Eranet, Interreg, and Erasmus+ funding programs. In addition, he has participated in funding programs of the National Science Foundation (NWO), National Science Agenda (NWA-ORC), and Applied Research Funding from Regieorgaan SIA (SPRONG).

One featured research is the MSP Challenge *www.mspchallenge.info* with pending EU-Interreg funded projects in the North Sea, Baltic Sea, Celtic and Mediterranean regions and invited game-play sessions with students, policy-makers, and experts around the globe.
He has over 150 publications to his credit and has been (co-) promotor of six completed PhDs and several pending.

Digital Twins for the Real World

Igor Stefan Mayer

Lecture
Delivered at the public acceptance of the position of (endowed) professor of Playful Organizations and Learning Systems in the Department of Organization Studies at Tilburg University on June 17, 2022, by Igor Mayer.

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Digital Twins for the Real World

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Geachte Meneer/Mevrouw de rector,

Dear dean of the faculty of Social and Behavioral Sciences and Chairs of the Department of Organization Studies, Tilburg University. Beste Leon, Marius.

Dear President and board of Breda University of Applied Sciences, Beste Jorrit, Nico.

Dear director of the Academy for AI, Games, and Media (AGM), Dear Robbie,

Dear colleagues, students at Tilburg University and Breda University of Applied Sciences

Dear project and consortium partners,

Beste familie en vrienden

Dear virtual friends



Intelligent Machines

The problems we have created for the world, and thus for ourselves, have become so big that we are putting our hopes on **Intelligent Machines** to solve them. Intelligent machines that can help us make public decisions. That can even make the decisions for us. We use(d) to call them **Decision Support Systems (DSS)**. They branch off into areas like Geo-Information Systems (GIS), Econometric and Computational models, Decision-Optimization, Complexity Simulations (e.g., System-Dynamics, Agent-based modeling), and Mathematical Game Theory. And my area of expertise, **Simulation-Games** or **Serious Games**.

Digital Twins (DT) are the most recent and the **hottest proposal** of an intelligent machine for **public decision-making**. Some call it *a Digital Twin Revolution*.[1] But, as we know, **revolutions can easily backfire**.

A Digital Twin is what the name suggests. **A digital replica or copy of something that exists in the real world.** Trend reports flag Digital Twins among the top strategic technology trends; alongside Artificial Intelligence (AI), Machine Learning (ML), Virtual Reality (VR), and Augmented Reality (AR).[2] For what they are worth, market reports project a DT market size of around 70 billion dollars by 2028, about one-fourth of the global video-game industry.[3] ICT companies, engineering, and consulting firms are developing and promoting Digital Twin solutions for specific application areas, such as manufacturing and architecture.[4] The game and creative industries, such as EPIC, see a new horizon for their innovative products and services, development tools, game engines, and dissemination platforms.[5]

On the scientific side, a quick bibliometric analysis (in Scopus) indicates that: 1] Digital Twins have been sharply on the rise since 2017; 2] Digital Twins venture from industry and aerospace into new areas: energy, architecture and interior design, city-planning, e-learning, and water management.[6–11]; 3] Digital Twins are primarily studied in Computer Science and Engineering; hardly at all in Humanities (Ethics) and Social Sciences (including political science, organization, and management).[12,13] Perhaps, because DT are still seen as a promise or a hype. But also because **the underlying digital technologies are not easy to grasp.**

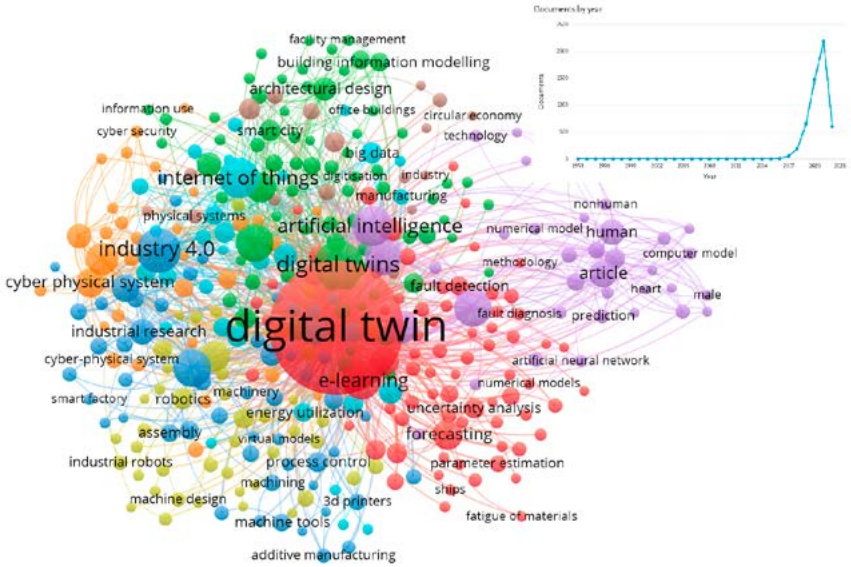


Figure 1 Digital Twin Bibliometric analysis (Scopus, source BUas)

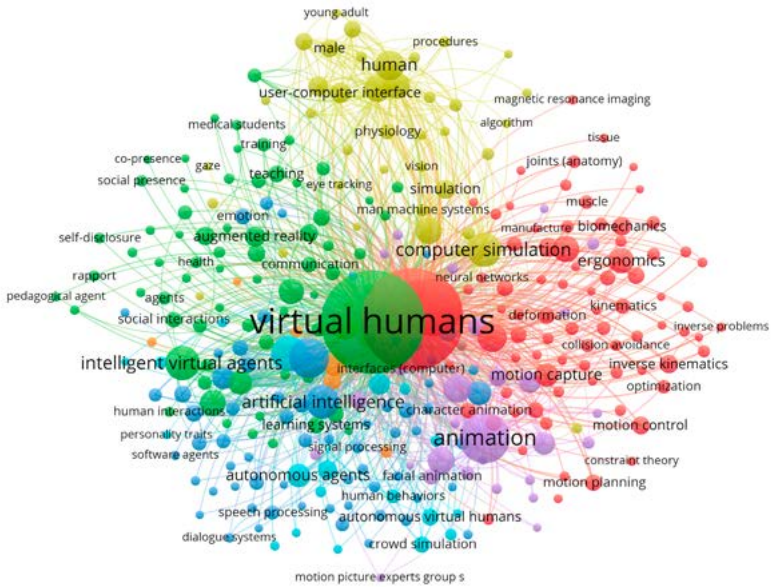
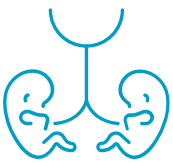


Figure 2 Virtual Human Bibliometric analysis (Scopus, source BUas)

All in all, I believe the above is very problematic. But it can also provide opportunities for a **joint research agenda** for Tilburg University and Breda University of Applied Science. This research agenda is urgent and relevant because Tilburg University, BUas, and many of our partners are already doing Digital Twin projects. And these projects are among the largest and most ambitious in our portfolios.

Therefore, I like to sketch **a social science** and **policy gaming** perspective on Digital Twins for the Real World. A world where science, organizations, and politics tend to **mess things up**, especially concerning **Nature** and **Human Dignity**. I propose to start with the latter, with Human Dignity.

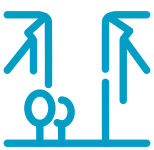


Twinning Humans

Twin may indicate that the original 'something' that we digitally copy, is a person. This would make the Digital Twin a **Digital Human**. However, a digital human is more than an **Avatar** – a representation of oneself in the digital world. For a Digital Human to be called a DigiTwin, it needs to share some 'DNA'. The twins must have a resemblance and feel connected like twin siblings do. But how much DNA should the real and the digital human share as genuine twins? Appearance, looks, manners, intelligence, emotions? Digital Humans is an exciting research topic for philosophers, psychologists, and cognition scientists. They address questions such as:

1. What makes a Digital Human **hyper-realistic**? For instance, compared to a photograph or video of the same person.

2. What does interaction with a Digital Human do to us? (How) do we perceive the emotions of a Digital Human? Do we **trust** it?



The Uncanny Valley

To find out, researchers of cognition put you in front of a screen to interact with the Digital Human. Perhaps in an experiment where you play a game while tracking your eyes, monitoring your heart rate, and scanning your brains. And you fill out a survey. *How realistic do you find the appearance and nonverbal behavior of the digital human?* Research, for instance, finds that '*the realism of the face, lies in skin and eyes*'.[14] This brings us to what is well-known as the **Uncanny Valley**. In Dutch, de *Griezelvallei*: When the Digital Human is not too realistic, even abstract, or sketchy, it feels 'ok'. But when the Digital Human is 'slightly off', it feels uncomfortable, scary even.[15]

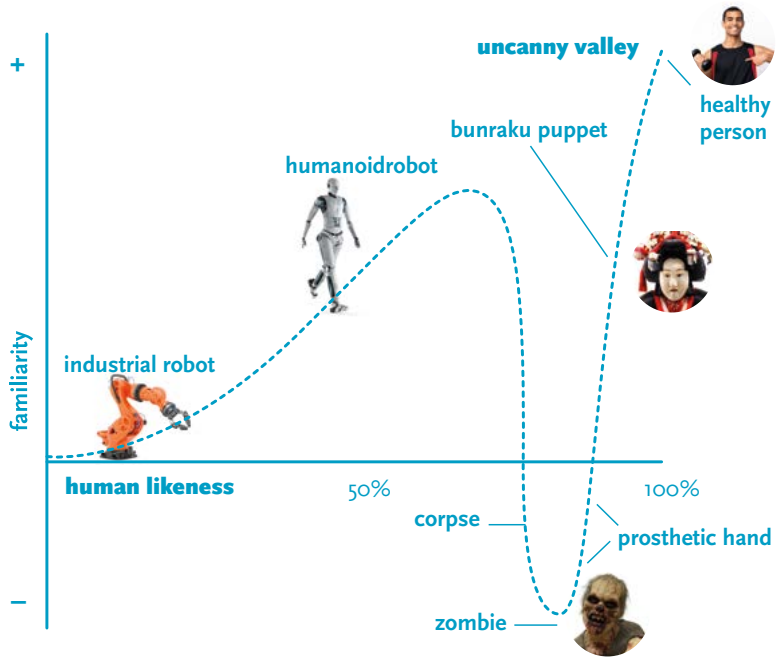


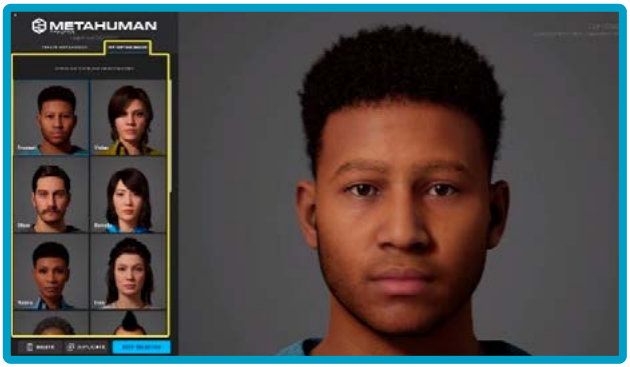
Figure 3 Uncanny Valley (source15)



Virtual Humans

Until recently, the discipline of Digital Human Modeling focused on the inside: intelligence, emotions, and speech.[16] With **Machine Learning** the inside of the digital human is getting more realistic by the day. On the outside, we were not able to cross the uncanny valley. But this is changing rapidly. **Digital Humans are becoming lifelike, on the inside and the outside.** They are becoming **MetaHumans**, or **Virtual Humans**— a photo-realistic 3D simulation of a human being on a computer.

An example - In 2021, EPIC launched the mind-blowing **MetaHumans Creator**.[17] Almost anyone can now make a virtual human look like ANY person: as a new acquaintance. Experts can make the virtual human look like someone you know.



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Figure 4 Meta Humans (source Epic[17])

In the television program *In Levenden Lijve,* television presenter and actor Derek de Lint reconstructs the character and image of historical figures such as Cleopatra and Shakespeare.[18] The Dutch 3D character artist Mao Lin Liao animates them as hyper-realistic virtual humans. *Cleopatra, by the way, was famous for her beauty, Shakespeare for the opposite. (How) does that play a role?*

In the VIBE project – where Tilburg University, BUas, and others work together – we try to cross the uncanny valley of Virtual Humans so that we can use them for **personal or societal benefit.**[19] For health care or education.



OPEN VIDEO

Figure 5 VIBE Virtual Human (Source BUas)

Virtual Humans (VIBE, 2018-2022)

The VIBE-consortium, under the leadership of Max Louwerse (Tilburg University) has made significant progress in the R&D of Virtual Humans.

VIBE developed: 1. a production pipeline for the embodiment of the Virtual Humans; 2. AI-systems for emotions, non-verbal behavior, and conversation. 3. Tools for observation and measurement. One of the Virtual Humans – Juliette – plays in a medical training scenario. Medics learn to diagnose Internal Bleeding (Hypovolemic Shock) or Sepsis during childbirth from facial expressions. VIBE is doing experiments. How (un)believable is the Virtual Human, and why?

Can we also make a virtual human that looks precisely like YOU? Let's put it to the test.

Play 1 VI-gor	
Igor:	Good afternoon, VI-gor
VIgor:	Hello Igor, Hello Audience
Igor:	VIgor, can you please introduce yourself?
VIgor:	With pleasure. I am only a few months old. I was born and raised in CRADLE. I was conceived by photo scanning, Imitating your funny faces. CRADLE gave me your skin color, and hair and taught me how to gesture like you. Brilliant guys, they are. I have a lot to learn. But can already be of service.
Igor:	How can you be of service?
VIgor:	I know the digital world very well. I live here. If you ask me questions, I can try to find the answers here. That saves you time. It makes you more effective. It can be entertaining.
Igor:	Give an example.
Vigor:	I am not so smart yet. But I can learn to give medical advice. I can play to be a patient. Medical staff can practice on me. I dream of being famous, a character in a movie or game. You do not have to pay me. In the future, I can replace you in boring meetings.
Igor:	That last option sounds good. Do you have friends?
VIgor:	For sure. In CRADLE, there is Vicky, Joey, Juliette, and Sherryl. More coming. But in my digital world, there are thousands like me. We meet up and discuss humans. A few want to become a professor. Shall I refer them to Tilburg?
Igor:	That's what I am afraid of. You already want to replace the real professors.
VIgor:	Don't worry. I am far from qualified. But we learn fast. Treat us with respect.
Igor:	You are right! This is all very exciting. Willing to help me with this speech?
VIgor:	Are you sure humans are ready for that?



Humanoids

In **Homo Deus**, Yuval Harari claims that humans are on their way to becoming 'god-like' – striving for super abilities such as the ability to design and create living beings, transform their bodies, control the environment and the weather (..) to travel at very high speed (..) to

escape death.[14] With Virtual Humans, we seem to be well on our way. But it comes at a cost—the virtual human challenges our perception of reality, for instance, in the form of **Deep Fakes. Anyone can make a Virtual Human Say Anything for Any purpose.**[20] We cannot hold the Virtual Human accountable, can we?

At an **organizational level,** virtual humans may become so bright that they can compete for specific tasks or functions we have. Virtual Humans are already entering the world of organization and management - far beyond the limitations of a simple chat bot. *Hi there, I am your digital assistant, Elsa. Can I help you?* A quick search on the Internet will give you dozens of companies to provide virtual characters for business, organization, marketing, customer services, and customer relations. Some virtual humans are historical figures, such as *Virtual Einstein.*[21] You can ask him questions about his life. But he gives pre-scripted answers we can also read on a wiki page. The limitations of AI systems are still evident. But, in terms of persuasiveness, we have already gone beyond the uncanny valley.

A few of my colleagues and students in the Media department are interested in Virtual Influencers, like Ayayi for Porsche.[22] Tsinghua University in China enrolled its first virtual student.[23] *Would Tilburg University or BUas consider hiring a virtual student recruiter? Why (not)?*



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Figure 6 Virtual Influencer Ayayi for Porsche (Source Porsche [21])



OPEN VIDEO

Figure 7 Hua Zhibing Virtual Student (Source Tsinghua)

> *'Tsinghua University in China enrolled its first virtual student, Hua Zhibing, in 2021. Within nine hours, Zhibing attracted 2,000 followers on her Weibo account. She currently studies at the Department of Computer Science, where she was created using artificial intelligence.'*[24]



Teaming up with Virtual Humans

The topic of Virtual Humans is not well-covered in humanities and social sciences, neither conceptually nor empirically. That raises concerns and opens exciting routes for joint future R&D.

- What happens if actual and virtual humans are part of the same team or organization?
- How does Virtual Human technology impact specific societal or economic sectors?
- What do we know about the organizations that create, promote, or use them?
- Can we use virtual humans in recruitment or selection procedures? How do they influence worker relations?

- Can we use virtual humans for (action) research and experiments in organization and management?

Some scientists and entrepreneurs, like Tengai, claim that a job interview with an **Intelligent Robot** will eliminate gender and ethnic background biases that easily creep into job profiles, candidate selection, and promotion procedures.[25]

Can something similar be done for teams composed of real and digital humans? One of my PhDs in the OS-department is studying if and how we can unobtrusively measure things like team cohesion in game-based, virtual environments. This is relevant because team meetings are going into virtual and augmented reality.



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Figure 8 Tengai Robot (Source Tengai)

> *'Tengai (...) is a physical robot developed to assist recruiters and hiring managers. By performing automatic robot interviews and delivering unbiased candidate assessments.'*
>
> *'At first I really felt it was a robot, but when going more deeply into the interview I totally forgot that she's not human'* [26]



DigiNature

Digital Twins do not have to be **Humanoid**. Most Digital Twins are not. Engineers will argue that Virtual Humans do not fit their notion of Digital Twin. Instead, they emphasize a direct and real-time link between a physical object and its virtual copy. Agreed! Most digital twins are copies of artifacts, such as consumer products, industrial machines, and maritime vessels.

> *'There will be billions of things represented by digital twins within the next five years. These proxies of the physical world will lead to new collaboration opportunities among physical world product experts and data scientists whose jobs are to understand what data tells us about operations.'* [27]

But also: Not agreed! We are twinning nearly everything now—parts of the human body, cardiovascular, and nerve systems. Suppose you photo-scan your home with one of many available apps and place new furniture from a digital catalog in it. You are creating a digital copy of your new interior before buying it. You are twinning!

Most remarkable, we are DigiTwinning Nature itself. This jump from artifact to humans and beyond takes the Research and Development (R&D) agenda of Digital Twins to an entirely new level. We enter the domain of **societal decision-making, organizations,** and **politics**. The choices we make with Digital Twins are highly political and have far-reaching societal consequences.[13]



Digital Twin of the Ocean

Digital Twins as intelligent machines for public decision-making are *en vogue*. Let me introduce the topic of DT further with a quote from an address delivered by EU president Ursula von der Leyen. In the presence of Emmanuel Macron at the opening of the *One Ocean Summit* in 2022. She, among others, says:

> *'(...) the ocean is still largely a great mystery for humankind. That is why Europe is building a **digital twin** of the ocean. We are connecting our assets – like the Copernicus satellites, marine infrastructure like icebreakers, buoys and underwater drones, and high performance computing. We will gather the raw data and turn it into real-time knowledge and longer-term predictions. **We are putting the power of the digital revolution at the service of our climate. (...)'***



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Figure 9 Von der Leyen at the One Ocean Summit, 2022.

She continues...

> *'Thanks to the EU and its Member States, a digital twin should be operational by 2024. It will make ocean knowledge open-access, available to citizens, scientists and policy-makers around the world. It will be a platform for global cooperation. (...) Together, with the digital twin, we will turn the lights on in the ocean.'* [28]

Von der Leyen's address conveys the hopes and dreams of an intelligent human future built on satellite data, geo-data, artificial intelligence (AI), real-time monitoring, predictive models, and what have you. For the European Commission and others, **the Digital Twin is our 'smart way out'. Perhaps it is the only way out.**



Cyborg science

Some, like Yuval Harari, label this strategy, **Data'ism**: The almost religious belief that the world is essentially made up of dataflows and that to intervene in the world means controlling and changing these dataflows.[14] Others call it a **Cyborg Science** – extending and blending Nature with Data and AI.[29] But, for the technocrats and bureaucrats, the Digital Twin is a **Control Room**.

'The development of machines to suck CO2 out of the air 'geo-engineering ' [...] space mirrors to reflect sunlight or pulling veils of sulfur particles in the air to cool the Earth's surface. The assumption is that if we throw enough technology at it, we will get the climate back under control.' [30]

If a DT is a *control room,* there are a few tricky questions:

- Who is building, staffing, and operating that control room?
- What do they control, and on behalf of whom?
- Are they/we really in control?

DestinationEarth [31]

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Destination Earth (DestinE) aims to develop – on a global scale - a highly accurate digital model of the Earth to monitor and predict the interaction between natural phenomena and human activities. As part of the European Commission's Green Deal and Digital Strategy. The long-term goal is to integrate additional digital twins – for example, on oceans or biodiversity – for a comprehensive digital twin of the Earth. The digital twins of DestinE will provide users with tailored access to high-quality knowledge for user-specific scenario development for decision support. By 2024: Development of the core service platform, the data lake, and the first two digital twins on extreme natural events and climate change adaptation. By 2027: Further enhancement of the DestinE system and integrating additional digital twins and related services. By 2030: A 'full' digital replica of the Earth. Source [32] See also: [33,34]

ILIAD - Digital Ocean (EU Green Deal, 2022-2024)

The Iliad *Digital Twin of the Ocean*, an EU Green Deal project, builds on the assets resulting from two decades of investments in policies and infrastructures for the blue economy and aims at establishing an interoperable, data-intensive, and cost-effective Digital Twin of the Ocean. The combination of geo-visualization, immersive visualization, and virtual or augmented reality allows users to explore, synthesize, present, and interactively analyze the underlying geospatial data. Source [16]

DigiTwin Disclaimer

SCUBA diving is one of the passions my wife and I picked up relatively late in life. Scuba divers use dive computers to determine how long to stay at specific depths, when to do safety stops, etc. My life and dive buddy recently replaced her old dive computer with one of the most advanced - a Perdix ShearwaterTec.16 It came with the following disclaimer. Try to read it by replacing 'computer' with 'Digital Twin of the Ocean'.

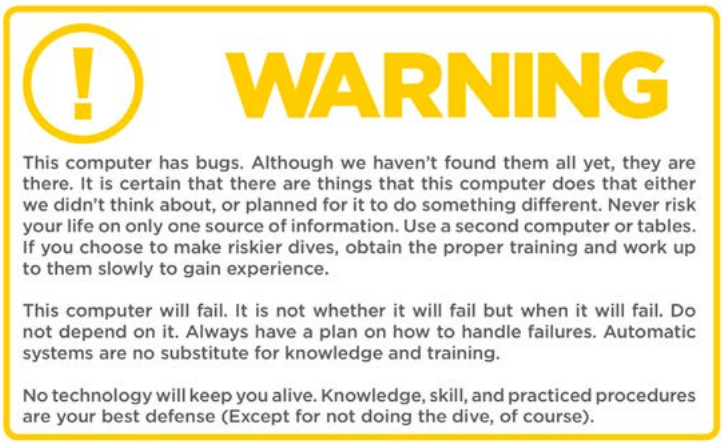


Figure 10 Disclaimer of the Shearwater SCUBA Diving Computer (Source[35])

Should a DT also have a disclaimer, and what should it say? I make a few suggestions:

- **Nature is more intelligent than humans.** Illustration: In urban areas, the forces of rapid natural selection are leading to striking genetic changes in animals.[36]
- **The ecological collapse will not wait for a digital twin to predict it.** Illustration. An abandoned oil storage tanker SAFER floating off the coast of Yemen will surely sink, catch fire, or explode. To cause an unprecedented environmental disaster in the Red Sea. Bitter conflict is preventing anyone from fixing the problem.[37,38]
- **It is complicated to see the big picture and the minute details simultaneously.** Illustration: The interactions between the symbiotic micro-worlds, such as Coral Reefs or micro-organisms in the Deep Sea, and the long-term macro changes, like global warming and sea currents.[39]

- **Intuition and common sense compensate for the lack of evidence and data.** Illustration. Read Nobel Prize winner Kahneman's *Thinking, Fast and Slow*.[40]

- **The digital twin may be falsely seen as the real thing!** Illustration: See Deep Fakes, Fake News, Conspiracy Theories on the Internet.

- **A digital twin may take over the real thing!** Illustration: See, Non-Fungible Tokens. In March 2021, someone paid almost $70 million for a picture on the Internet.[41]



Connectedness to Nature

The biggest mess we got ourselves into is the staggering loss of **Biodiversity** and **Biomass** on land and at sea. All the evidence shows that we face an imminent collapse of entire ecosystems due to the **carbon economy**.[40]

> *'More than 40% of amphibian species, almost 33% of reef-forming corals and more than a third of all marine mammals are threatened.'* [42]

But, underneath, there is more. There is something called a **connectedness to nature scale** – and most studies show that the scores on that scale are dropping.[43,44] We are simply losing our connection to nature. And, how *can* we stay connected to nature, with more than half of the world's population living in urban, even metropolitan areas?[30] And when tourism – *going into the wild* - has a significant carbon footprint.

- How do CEOs in the maritime industries, policy-makers and ocean planners score on the connectedness to nature scale?

- And how do Digital Twin engineers score on it?

This is a most important observation. The digital way out starts with being connected to nature. To accept that **Nature is Real**, and that **Reality has Intrinsic Value**. That nature cannot and should not only (!) be valued for the products and services it provides. Philosophers call for a shift: from an **Anthropocentric** to an **Eco-centric** perspective.[45]

- (How) can a Digital Twin be Eco-centric?

Nature in XR

Digital and Immersive technology, such as Games, Digital Media, Virtual Reality, and Augmented Reality, can create empathy for nature, awareness of its complexity, and convey a sense of urgency for its protection. For example, the documentary *Chasing Coral* captures **Coral Bleaching** in 360 degrees time-lapse video.[46] **Volumetric video** gives an immersive surround experience so that anyone, from marine scientists and school children, can eyewitness the devasting process.[47] A compelling example of **New Media Activism**[48] and **Ocean Literacy** – understanding how the ocean influences you and how you impact the ocean.[49] Scholars suggest that sustainability can be promoted via **empathy**.[50,51] And that Immersive Media can evoke empathy.[52,53] Let me give a few examples.



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Figure 11 UnderSea by Magic Leap (Source[54])

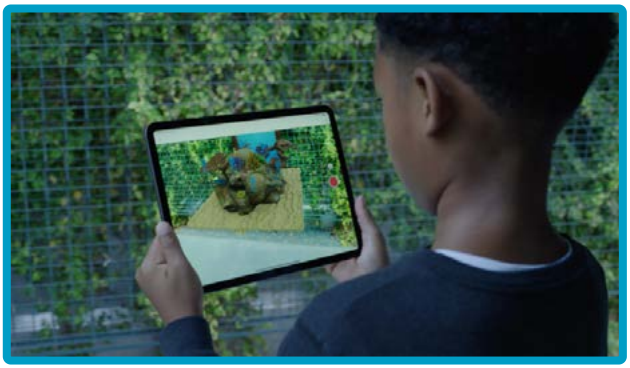
The company Magic Leap presents *UnderSea*, an Augmented Reality (AR) experience of the ocean in your living room, primarily for enjoyment. Using gesture tracking, the player can interact with sea critters. It has also been used in education. An immersive nature experience can be beneficial when **deprivileged school kids** have no opportunities to experience nature.

Another example - Cyan Planet's *How is the Water*[55] uses 'digital clones' of marine creatures,

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such as Bottlenose Dolphins, Loggerhead turtles, and Hammerhead Sharks, to evoke empathy and interest in ocean protection.' *Help protect the ocean while exploring a growing catalog of marine species in this VR ocean simulator.*'[55]

One of the most impressive programs of Ocean Literacy through Immersive Media is *The Hydrous* – a nonprofit organization on a mission to create an open ocean for all.[56] Collaboration with the *Smithsonian Institute* lets you view and interact with 3D models of coral reef specimens from the National Museum of Natural History. The Hydrous' *AR Reef* is an experience that transports you to a 'real' tropical environment.[57]



OPEN VIDEO

Figure 12: The Hydrous (Source 58)

Important questions are:

- Is there an **Uncanny Valley for the Virtual Ocean**? How realistic and immersive does the Virtual Ocean need to get: to believe it, like it, or trust it?

- **Aesthetic Conversion** is the opposite of the Uncanny Valley. To evoke empathy for nature, we distort it. Nature can be dull, cruel, unattractive, and repulsive. But we capture it in its finest moments and most beautiful colors. What about the deep, dark, and muddy waters?

- What if – for all the good intentions – an immersive ocean experience **leads us further away from nature as it truly is?** If, in the distant future, we no longer experience any difference between the virtual and the natural underwater world, (why) would we still want to preserve the real thing



Power Games

Societal change via empathy and literacy is essential. But it works slowly, with uncertain outcomes. Underneath, complex societal structures are at work: vested interests, economics, and big power politics. A recent ***Zembla-documentary*** about the Netherlands special municipality of **Bonaire** in the Caribbean nicely illustrated how the trade-offs between the protection of its unique Marine Ecosystem, investments in renewable energy, and the incumbent Oil Industry are made.[59] **We can DigiTwin the Ocean to perfection. While for money and politics, we let the real marine ecosystem collapse.**



Policy Games

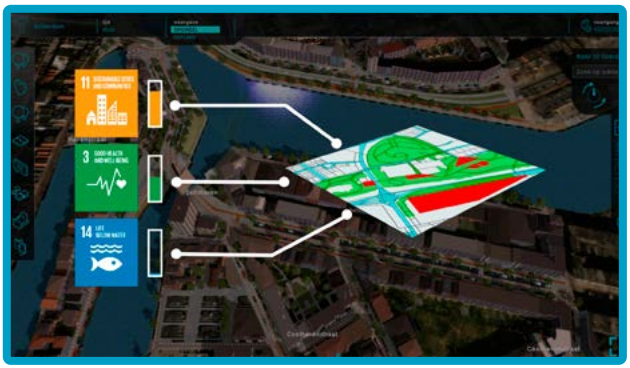
I started my professional academic career in 1992 in Policy and Organization Sciences, at Tilburg University, now the Department of Organization and Management. In 1992, my promotor **Jac Geurts** delivered his inaugural address *Looking Back to the Future – Long Term Exploration in Policy Exercises*.[60] The key concept was **Policy Exercises:** Intelligent but highly interactive, playful environments where policy-makers, stakeholders, and scientists could try out scenarios. To see what happens, reflect, discuss, and learn to prepare for the actual decisions. We were inspired by a series of policy exercises on climate change by the International Institute of Applied Systems Analysis (IIASA), Vienna, Austria.[61,62] A policy exercise on the PO-river watershed in Italy proved quite predictive. Extreme draughts would alternate with torrential rains and flooding. Therefore, mitigation measures for riverbed management were required. Thirty years later, we know from personal experience that these insights were spot on, not only in Italy.

In the seminal book **Gaming: The Future's Language,** Duke argues that a simulation game is an excellent communication and learning tool for planning and decision-making.[63] **Policy games** are analytical exercises contributing to **social learning** among policy-makers, stakeholders, and scientists. Never to be confused with the actual decision-making.

During my years at the Faculty of Technology, Policy, and Management (TPM), TU-Delft, and later at the Academy for Games and Media (AGM), Breda University of Applied Sciences we designed and moderated hundreds of policy games for decision-makers, stakeholders, students. We evaluated many of them for what they delivered and published hundreds of articles and a bunch of Ph.D. theses. Two policy games stand out. They hold important lessons for Digital Twins.

The first was a simulation game for the Port of Rotterdam to support the design and development of their port extension, the **Second Maasvlakte** (MV2) area.[64] It's a rich story

covered in a few articles and a Ph.D. thesis.[65] It also laid the foundations for a world-leading, interactive platform for terrestrial planning, of cities, river areas, mobility, nature, etc.[66] What started as a serious game became the *Tygron geo-platform* and is now branded as a Digital Twin (DT). It has become A SimCity for Real – as imagined!

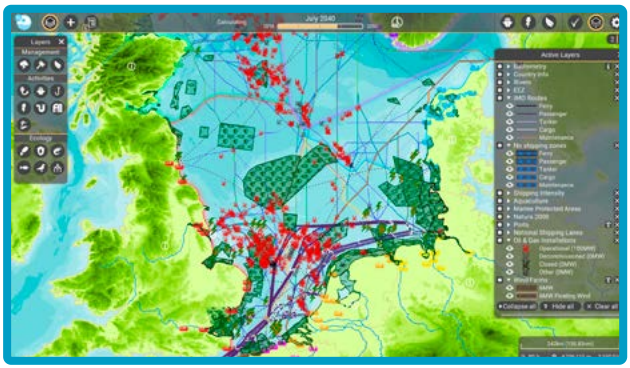


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Figure 13 Tygron platform as Digital Twin (Source Tygron)

The second policy game is the *Maritime Spatial Planning Challenge (MSP) simulation platform*.[67,68] Conceptualized in 2011 as a simulation game, it is now a flexible simulation platform that hosts the *North Sea*, the *Adriatic Sea*, the *East-Mediterranean,* the *Baltic Sea*, and the *Firth of Clyde* (Scotland).[68] In the interactive simulation, country planners and stakeholders see the entire sea region and review different data layers to assess the status. They develop plans for future uses of sea space over several decades. The consequences of decisions for energy, shipping, and the marine environment are simulated and visualized in indicators and heat maps.

Since 2011, it has been used by thousands of players – students and professionals – in interactive game sessions worldwide: Canada, Sweden, the Baltic and the North Sea Regions, South Africa, and China. The entire game software is open source and not-for-profit. It uses the best available data and simulations, but it is still very playful. At the same time, it finds itself in the Digital Twin of the Ocean discussion and several extensive R&D projects, among others, ILIAD – Digital Twin of the Ocean.



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Figure 14 The MSP Challenge North Sea edition (Source [68])

Serious games as Digital Twins

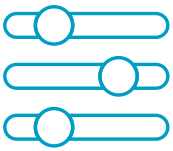
Serious games are becoming more data-driven, more intelligent, and more immersive. They are evolving into Digital Twins – digital or virtual copies of artifacts, of humans, entire organizations, and, as we have seen, of the ocean.

> *'The world of urban planning and city maintenance is changing. The benefits of digital twins are becoming more and more apparent, as these analysis tools help increase efficiencies and inform decisions. Want to learn more about the role Unreal Engine can play, or to discuss your own implementation of digital twins?' EPIC website* [69]

But there is a real danger that,

- what is not or difficult to capture in Data and AI will not be included in the Digital Twin.
- what cannot be virtualized becomes irrelevant in policymaking,
- the emphasis on data, AI, and virtualization will drive out the playfulness.

Digital Twins originate in game-thinking. They are built with game technology. They should be used in a serious but playful mode to evoke social learning.



DT at the Science-Policy Interface

DTs are mainly considered systems-engineering problems – with questions for data and AI scientists: how do we collect, harmonize, exchange, and interlink different kinds of data into predictive models? The buzz words are 'interoperability', 'harmonization', 'machine learning', 'platform-architecture.' When it is not about the engineering, it revolves around its 'business models.' How to 'sell' it. Stakeholder engagement is organizing the value-production chain by involving future users. *There should be more to it.*

What is lacking is a proper understanding of Digital Twins in-between science and politics. Policy-makers are in dire need of and search for knowledge and tools from scientists, analysts, and consultants. And vice versa, scientists and consultants advocate, promote, and sell their expertise and tools to policy-makers. In the policy sciences, this is known as the **Science-Policy Interface** (SPI).[70]

We know from the extensive literature that this science-policy interface is a rather **messy world**. Not very rational at all. The production of knowledge and the development of intelligent tools go slowly – falling behind the facts. Politicians cherry-pick – use data and reports for justification and legitimation. Scientists and politicians live in different worlds and talk in other languages. Perhaps it does not need much further elaboration – after two years of **evidence-based pandemic control**. Digital Twins are in the same forcefield.

The facilitation of the interactions between Science and Policy, and the mediation of tensions, is called **Boundary Work** or **Boundary Spanning**.[71] The practice of building bridges between science and politics. Digital Twins are a particular case of boundary work. They must manage the tensions between science and politics in an entirely new world, full of big data, artificial intelligence, and extended realities.



Hybrid Space

Some authors claim that the actual or physical world and the digital world blend and mix. To the point where it becomes difficult, or impossible, to make a distinction. This is called the Hybrid Space.[72] For example, Extended Reality (XR) can add digital data to the real world, convenient in architecture or logistics. Art is getting digital in Non Fungible Tokens (NFT).[73] And so are the crypto-currencies used to buy or sell them. Under the influence of Data/AI/Interactive Technologies, the Science-Policy Interface is going into a Hybrid Mode. To become a Science-Policy Hybrid Interface (SPHI). Digital Twins are a foreboding.

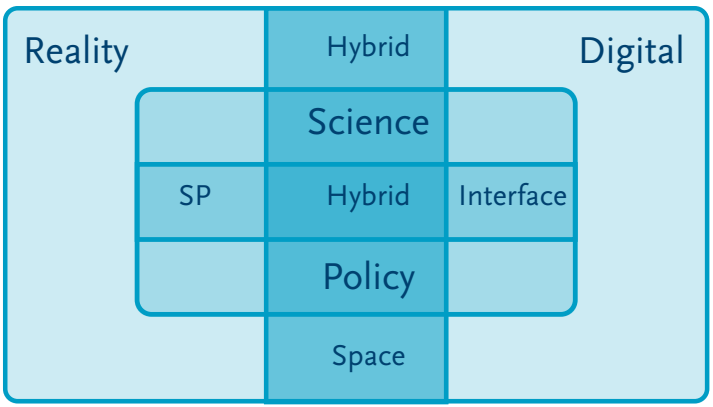


Figure 15 Science Policy Hybrid Interface

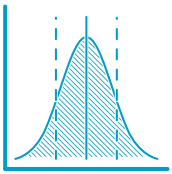


DT as Boundary Object

Digital Twin experts agree on one thing only. There is no standard definition of what DT are. No consensus on what they should be. Different communities make and define Digital Twins in different ways. This heterogeneity does not stand in the way of their success and popularity. It enforces it. Phantasy gamers might see Digital Twins as a **ritual token**, or **a totem**. Something for stakeholders in the policy arena to gather around while attributing certain powers to the Token/Digital Twin. In social science, such tokens are called **Boundary Objects** (BO). They allow actors and social communities to coordinate their actions without consensus.

> *Boundary objects are objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use and become strongly structured in individual-site use. They may be abstract or concrete. They have different meanings in different social worlds, but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds.*[59]

This is possible because actor-communities look at DT (or serious games) through different frames or lenses. Social scientists can try to re-construct these different frames. Let's see if we can make a start.



The standard model of Digital Twins

A Digital Twin (DT) is modeled after **a Reference Twin (RT)** in the real world. Two things are essential: 1. (Lots of) **data** about the attributes of the RT; 2. (Lots of insight into the) **rules** that can explain how the RT works, i.e., how it is constructed and how it behaves. The DT follows the RT. It captures the attributes of the physical object into digital data. Its dynamic behavior into algorithms.

> *'A digital twin is a digital representation of a physical object. It includes the model of the physical object, data from the object, a unique one-to-one correspondence to the object and the ability to monitor the object.' Gartner* [74]

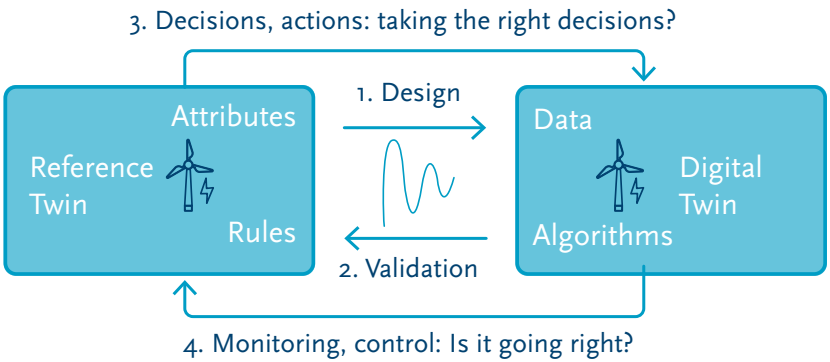
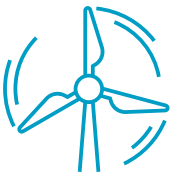
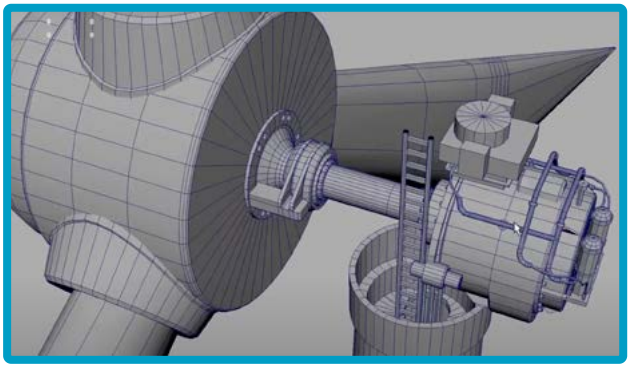


Figure 16 The standard model of DT (Source author)



Twinning Artifacts

Assume the RT is a technical-design Artifact. Say, an offshore wind turbine.[75] Designers and engineers have pretty much control over all the data and rules. Because they modeled and designed it, on their computer with CAD software. There are uncertainties, and there can be errors, but they are resolvable. If the artifact already existed, say a work of art, we can 3D-scan or capture it otherwise. Then re-work until we call it a Digital Twin. If the behavior of the artifact is not precisely the RT, we can tweak the data and rule sets. This is the standard model of DT. An example of a DT for an offshore, floating wind turbine.[58]

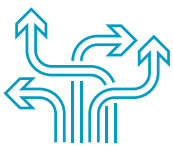


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Figure 17 A digital twin to facilitate the operation of floating wind farms (source BUas)

> *'The Digital Wind Farm is an end-to-end wind energy system that leverages data, analytics, and software applications in partnership with our hardware and services solutions to enhance efficiency, cybersecurity, reliability, and profitability of your assets over their lifetime.' (General Electric, [75])*

Why would we want to create a DT of an existing artifact? Because it frees the RT from its limitations and boundaries in time (now) and space (here). Gamers say we can safely play with the digital twin, to get immediate performance feedback without external consequences. It is also engaging. The wind turbine needs to be monitored, operated, and controlled. Personnel must be trained and incidents managed. The real-time data feed between the RT and DT of the wind turbine can be the core part of its **control room**.



Challenging the standard model

This standard model of Digital Twins is seriously problematic. Why?

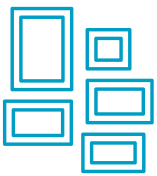
1. **Not all RTs are Artifacts or even Physical objects.** The RT can be ideas, concepts, social processes, organizations, organisms, cities, even humans and oceans. We drift far from certainty about attributes and rules, data and algorithms.

2. **The RT and the DT are social-technical systems.** Different actors and stakeholders who are an integral part of the Twins have different perspectives, values, and interests

about the RT and DT. We drift far away from agreement on the RT and DT: what they are good for, and how we make decisions.

3. **The DT can exist before, independently from, or hybrid with the RT.** The DT can be more valuable or important than the RT. Or the RT never exists. Or the RT is a hybrid reality, such as a self-driving car. How to create Digital Twins of 'things' that already exist in a hybrid space? This is the paradox of an infinite regress: *We make a digital twin of the ocean while digitalizing our seas.*

4. **There are many different types of interlinkages between the RT and DT.** For example, a DT is not only used as a control room but also for research and heuristics, for different kinds of learning and communication, and for political justification. RT-DT interlinkages can be data-driven and real-time. But they can also be social and evolve over an extended period. See the speech by Von der Leyen.



Framing Digital Twins

Following a well-known typology of policy problems and their governance, we can arrange DT on two dimensions (See Figure):[73]

1. How much **certainty** do we have on the required and available data and rules of the RT and DT?

2. How much **agreement** is there about the value and meaning of the RT and DT?

The different types of Digital Twins can be positioned in a two-dimensional framework.

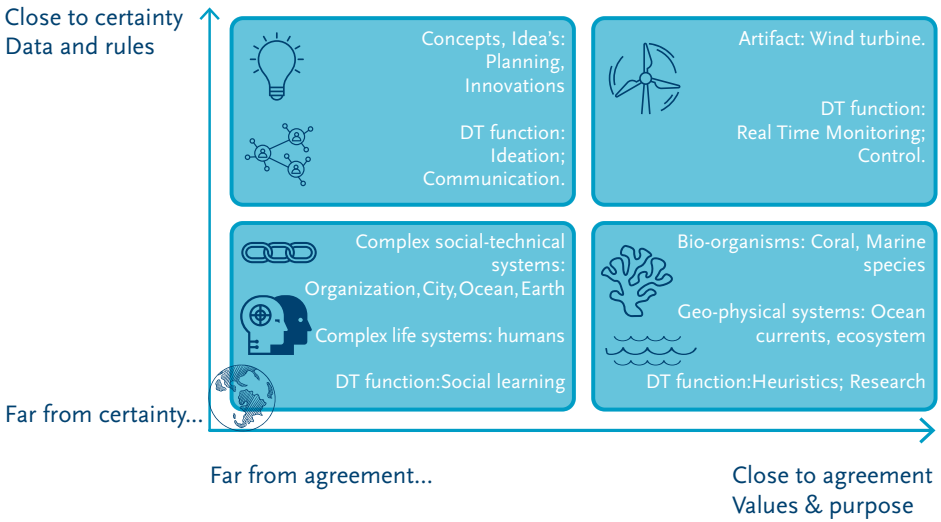


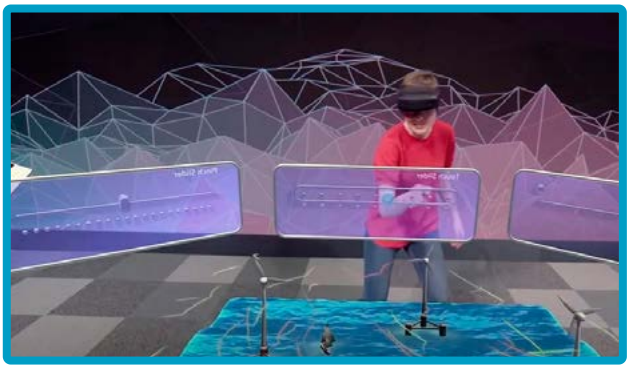
Figure 18 Framing Digital Twins (Source author)

Let's explore if and how this simple framework, can work.



Twinning Concepts and Ideas

In many cases, the DT comes first. The RT does not exist, not yet. Movie productions create advanced 3D models of worlds, props, and sceneries before making them.[75] They call it a Digital Twin. Also, the wind turbine needs to be conceptualized, sketched, designed, and tested. Hence, the DT serves many purposes we attribute to physical scale models. They are cheap, effective, and safe; we can change and alter them, cross time-space boundaries, and make it easier to communicate. The DT and the RT have an intentional relationship. The DT shapes the RT. The same with a DT of the Ocean. We plan the future. Here is an example of what it may look like in AR:



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Figure 19 Concepting with Digital Twins (Source Microsoft Hololens)

An interesting question is whether the RT even must exist in the physical world. Does it make sense to create a DT of feelings, emotions, or abstract ideas, like Democracy? It feels like overstretching the meaning of Digital Twins. However, Hybrid Space is expanding, and boundaries are blurring. What if the RT existed in the past but has become extinct – *a Digital Twin of the Dodo*. What if the RT is a design only: A digital version of a concept car never taken into production? It can be named, the **ideation function** or **communicative function** of DT.

There are plenty of examples of symbolic Digital Twins of an abstract concept. *An example* - The *White Noise* AR installation uses Twitter API to track different hashtags, such as #recycling or #brunch. Digital animations of fish and trash in a coral reef represent these hashtags and are digitally layered over a 3D-printed coral sculpture.

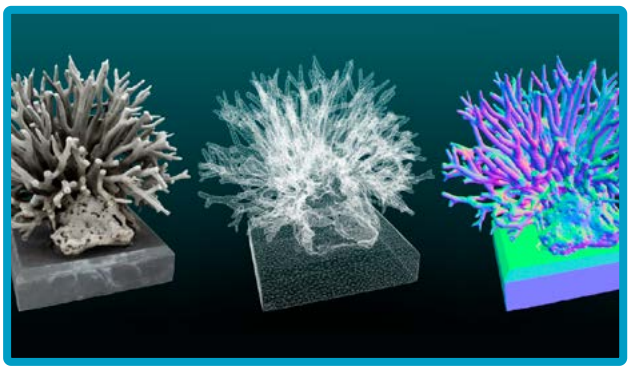


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Figure 20 White noise (Source [76])

Twinning Bio-organisms

What if the Reference Twin is not an artifact but something IN the natural (or bio-medical) world? Plants, animals, a coral reef, parts of our body, the human heart, or the human brain? The topic of bio-medical twins is out of scope here. But the underlying Engineering paradigm and ethical implications are strikingly similar.[77] The Smithsonian Institute (Washington) has a 3D collection of coral structures. You can download the digital models for free and use them for 360 displays.



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Figure 21 The Smithsonian / Hydrous Digital Coral Models (Source[78])

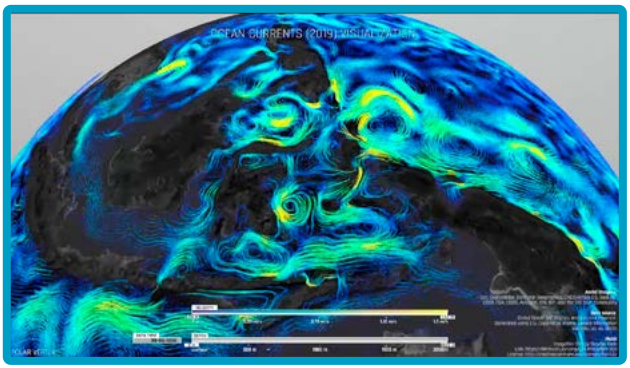
We can also create digital twins of sea life or ecosystems. I have already given a few examples above: digital clones of dolphins and sharks and a coral ecosystem. In contrast to Artifacts and Concepts, we have considerably less certainty about the data and rules of the RT. Nevertheless, we are scratching the surface with the human brain and coral reefs. But scientific progress is slowly filling in the blanks. If we use the data and rules and add our best guesses, the DT becomes a valuable tool: **It creates an image of what we know to search for what we do not know.** It can be named, the **heuristic function** of a Digital Twin.

Twinning Geo-physics

Similar arguments can be made for twinning dynamic geophysical systems, such as sea ice thickness, tropical storms, or ocean currents. It requires high volume data, such as **Copernicus satellite data** or real-time monitoring and observation systems. The advancements and multi-

use-purposes of real-time, dynamic visualization of large datasets in a game engine are significant. We can zoom in and out in time and space.

An illustration - Almar Joling, an MSc in Game Technology, very convincingly demonstrates geo-data visualization of Copernicus Marine environment monitoring service (CMEMS) data in Unity. Understanding seawater current, or fluctuations in Sea Ice thickness. It can be named the **integration function** of DT.



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Figure 22 Sea current modeling in Unity Game engine (Source[79])



Twinning Social Space

In 2022, **Facebook** became META while loudly drumming its ambition to create the *Metaverse*. The ultimate 3D-Immersive Internet – for leisure (games, film, events), for home (home control, learning, personal communication), and for organizations (think of meetings, organizational information flows, virtual operations, commerce, and services). Other companies, such as EPIC, are working on their version of the Metaverse.

The Metaverse itself is not a DT, but it will undoubtedly host Digital Twins of **Social Spaces**. If successful, it can become the service and distribution platform for certain types of Digital Twins. Mark Zuckerberg sells his ideas in his META-version of the ocean.[80] We can question how connected he is with the (under-water) world.



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Figure 23 Mark Zuckerberg and friend interacting at the bottom of the Metaverse Ocean (Source Facebook, 2016)

Virtual Museums and **Virtual Events** started as a replica of the real place – a copy of the actual building with art in the same exhibition rooms. But while they do so, the digital copy redefines reality. The mission of the abovementioned *Hydrous*, with the *Smithsonian Institute*, is to radically redefine the concept of a museum – as an anywhere and anytime experience for anyone.

Virtual Events have started as a live stream of a real-life event with the same lineup. In 2021, pop singer Ariana Grande gave a concert in EPIC's Fortnite game.'*A musical journey unlike any other. Ariana Grande's spectacular show in Fortnite was enjoyed by millions of fans worldwide.*' [81] Digital twins have a tendency to free themselves from their original. They become autonomous.

In March 2021, Microsoft (Mesh) held its first Ignite conference in mixed reality, via *holoportation*.[82] People attending the conference from living rooms and home offices worldwide. They experienced the show as avatars in a shared holographic world. The first conference focused on **Oceanography** and **Marine Technology.** With keynotes by American oceanographer and marine biologist Edie Widder, and ocean-explorer/filmmaker James Cameron, on topics such as *bioluminescence*, *marine ecosystem degradation*, and *deep-sea exploration*.



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Figure 24 Microsoft's Ignite digital conference via holoportation about the ocean (Source 83)

Twinning Organizations and Value Chains

How are Digital Twins used for management and decision-making in organizations? With Robotics, Internet of Things and Machine Learning, Digital Twins are now presented as one of the key technologies of what is called **Industry 5.0 - the integration of human creativity and expertise, with intelligent machines.** Note: the definition does not say anything about the integration of intelligent machines with **human / ecological values**.

> *'Industry 5.0 is regarded as the next industrial evolution, its objective is to leverage the creativity of human experts in collaboration with efficient, intelligent, and accurate machines, in order to obtain resource-efficient and user-preferred manufacturing solutions compared to Industry 4.0.'* [84]

Industry 5.0 should not be seen too narrow: it includes societal and public sectors, such as for mobility, water, health care. But DT of Organizations go beyond physical infrastructures. Digital twins of the entire organization, including its social and cultural dimensions. DT for complex decision-making in highly dynamic environments. They envision data-driven and intelligent **board rooms** for managers and directors. Real time analytics to help decision makers test different strategies, understand the impact of each decision, and generate robust and resilient plans needed to thrive in an uncertain future. It does raise critical voices:

> *'Digital Twin of the Organization: Are you Serious? If a digital twin of an organization was possible today, it would most likely be invalid tomorrow.'* [85]

It reads like a very serious and comprehensive management game. However, the truth claims of the DT are real. And so are its impacts. Twins of organizations and value chains are used in maritime and energy logistics, but also in other areas such as the fishing industry and aquaculture.



Twinning the World

The most challenging ambition of DTs is to create digital twins of **complex, multi-actor systems,** such as cities, oceans, or the Earth. **Gamers call it a World-Building Game**. We are getting closer to the vision as presented by Von der Leyen. A data-driven and intelligent platform for integration of knowledge, and for managing Earth Systems, such as the ocean, or Forests. For the moment we rely on platforms that can connect geo-data and simulations. With different approaches, strengths, and weaknesses.

A few illustrations – Mercator Ocean works with the Europe Union's Copernicus Program on an operational service for monitoring and forecasting the ocean: a four-dimensional representation, current, past, or future of the ocean's physical and biogeochemical state. [86]

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In an EU-project named ODYSSEA, colleagues are developing the **Marinomica platform**.[82] Actors can use the platform for mitigating pollution hazards and untreated waste; offshore maritime renewable energy (currents, wind, waves, solar).

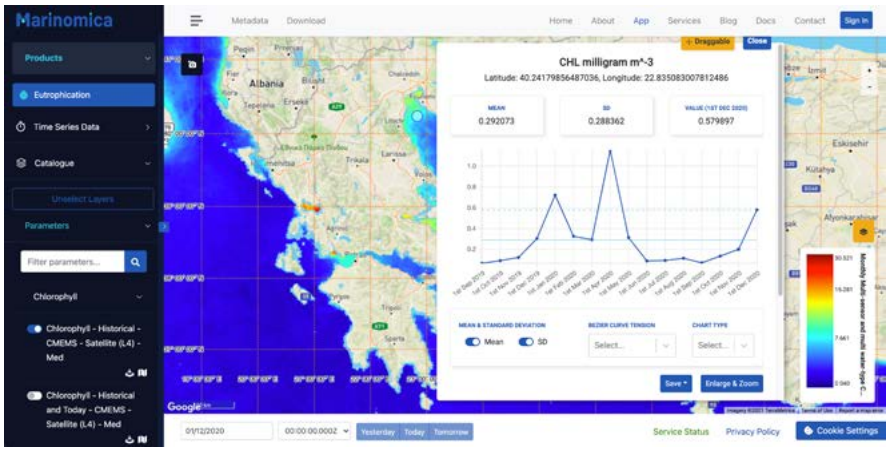


Figure 25 Marinomica platform

The jump takes the underlying philosophical questions and the technical challenges of Digital Twins to an entirely new level. **We Twin What We Know!** That is: parts of the world where we are closer to certainty and agreement. These are: the 3D computer models of our Artifacts, such as wind farms and vessels. And the rule sets we have defined, such as for shipping, currents, and the food web. Slowly, we start to see the world as **A Gigantic Artifact.** How can a Digital Twin keep up with these millions of social-political interactions that continuously change the parameters and rulesets of the RT itself? How can it mediate disagreements and conflicts among the actors about the courses of action? That is not pre-programmed into the game. It is part of the playing.



The Wild North Sea

Not so long ago, the North Sea was **wild natural territory** – highly respected by fishermen and sailors for its unpredictability. And the North Sea still is. Dutch Maritime Productions / EMS films are currently producing *The Wild North Sea*,

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a 4-part TV series, a cinema film, online education material, and a mobile projection unit, supported by events and merchandise. The aim is to share the many secrets of the North Sea with the broadest possible audience. **But there is another perspective.**



Urbanization of The North Sea

Some colleagues in the faculty of Architecture, Delft University of Technology, call it **Marine Urbanism** or the **Urbanization of the Sea.** The North Sea is one of the world's most industrialized seas, in which the Netherlands plays a central role. The space of the North Sea is almost entirely planned. It has been simultaneously loaded with the task of increased economic production both from new and traditional maritime sectors and emptied of cultural significance.[87]



No Green without Blue

Where **digitalization** is the smart way out, the North Sea is our primary **solution space**; for infrastructures, we cannot or do not want to build on land. Stakeholders in all societal sectors of all North Sea countries

are putting outlandish claims on the North Sea space. There is a new motto in Ocean Management. **No Green without Blue.**[88,89] Offshore wind farms and floating solar panels for the energy transition. Cables, pipelines, and interconnectors for the transportation of blue energy to where it is needed. Islands for offshore hydrogen production, storage, and transportation. Aquaculture – seaweed – for greening sustainable food production. Sand extraction for flood defenses and much-needed construction programs. All these sectoral developments are interlinked. They need to be coordinated, integrated, and conflicts resolved.

Hence, we bring it under similar management regimes as land-based planning. **But the digital support systems for planning human activities and ecology at sea are more recent and less developed than terrestrial planning [4].** We have much fewer data and little understanding of the rules in the ocean. Therefore, companies, politicians and policymakers are pushing forward in Digitalizing the Ocean at the EU and national levels.

> *'Digitalizing Our Oceans: New Roles for Tech Companies and Workers [...] New technologies are collecting data about our oceans and ocean assets like never before. For example, sensors, autonomous underwater vehicles, and smart buoys are all collecting data in addition to, or as an alternative to, traditional research vessels and human activity, and often at a lower cost.' Source Forbes* [90]

Scientists, stakeholders, politicians, and many others in the international and sectoral arena, need to interact and interface with these digital systems. **Therefore, we twin.**



Twinning the Ocean

So, when we talk about **THE Digital Twin of the Ocean,** what kind of Twin are we creating? For what purpose? Is it?

1. **A Twin of Artifacts:** Full of wind parks, oil rigs, pipelines, and cables. This the rapidly expanding market of DT for Offshore and Maritime engineering. We can use the DT for design, engineering, and operating these Artefacts – and use them in our control rooms. In addition, we can play with artifacts in a safe environment, such as for training and incident management.

2. **A Twin of Concept and Ideas:** Full of innovations and concepts that do not exist (yet), such as integrated solar + wind + kinetic energy systems, hydrogen systems, floating solar panels, and energy islands. We use the DT for sketching and testing, talking, shaping, building our designs, and communicating about them. This makes the DT a game of creativity, trying out new things and see what happens.

3. **A Twin of Geo-physics:** Full of interconnected big-data, supermodels such as for geo- and ocean physics, ocean currents, sea ice, and water quality but also of large-scale human activities observed via satellites or other monitoring systems. Data visualization and animation in a DT can undoubtedly help us understand how the underlying physics and flows work. DT help to visualize the data and design for interaction. This makes the DT **an interactive supermodel,** where we can set parameters and where dynamic visualization shows the big picture. The long-term consequences of current actions.

4. **A Twin of Bio-organisms:** Full of marine life and marine bio-ecosystems, at whatever scale, from micro-organisms in the deep sea or a spot of coral reef to the entire marine ecosystem. We can use the DT as virtual catalogs for the education of society but also for the learning of policymakers and stakeholders. The DT may help us make organisms more resilient to the impact of human activities on their environment. It may make it a **game of empathy** and ocean literacy.

5. **A Twin of Humans:** Full of human understanding (cognition), feelings (empathy), and experiences about the sea. DT can be useful for **human storytelling** about the ocean? We may be able to understand the perspective of indigenous fishermen.

6. **A Twin of Social Spaces:** A platform for actors to share, interact and communicate about the sea. A DT can be used to discuss the future among stakeholders of different sectors or in other countries. It would make it a socially interactive game where we cross boundaries of time and space. Perhaps in the Metaverse.

7. **A Twin of Organizations** and **Chains:** A data-driven and intelligent board room for the management of complex organizations and interactions; For complex decisions under uncertainty, in a volatile environment. This would make it a management or business game.

8. **A Twin of Worlds:** The emergent complexity of world systems, such as the climate, rivers forests and ocean. How actors and institutions change and impact world systems, and how these changes feedback to actors and institutions over a more extended period. **A world-building game** where players can make decisions and experience the consequences over time.

IF it is ALL that, at the same time, it is the most advanced world-building game we have yet come to seen!

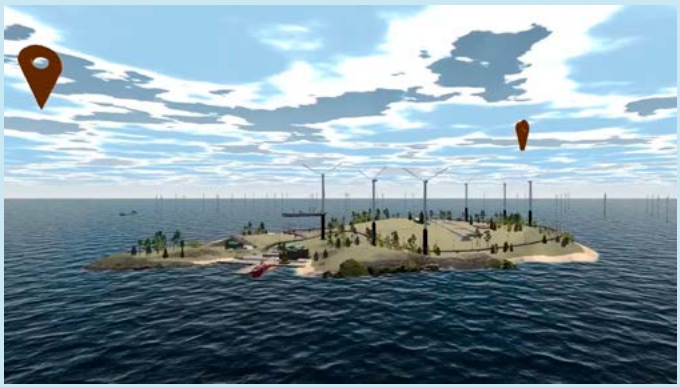


Figure 26 Energy island in the North Sea (Source BUas)



Figure 27 Underwater wind turbine (Source BUas)

Towards a Virtual Twin for the North Sea

OPEN VIDEO

Maritime Planning in 202X. Dutch and German planners have designed a wind farm in their part of the Doggerbank area in their planning support system. The planners expect broader impacts than on energy alone: ecosystem pressures – noise, surface disturbance, artificial substrate – as well as interference with shipping routes and commercial fishing. They receive a message in the geo-system: Ready to XP! Sara puts on a Virtual Reality-headset and picks up the VR controller. She finds herself high above the planned wind farm area, as if in a helicopter. It looks very realistic. She sees many wind turbines spaced apart evenly and hears them rotating. Bustling shipping routes: maintenance ships go in and out, and fishing vessels. Now she goes underwater. Quite some noise from the turbines and ships. How far the sound carries. Cetaceans seem to be moving away from the noise. Clams grow on the pylons, schools of fish that do not seem bothered by the underwater noise. Coming up, she clicks on an icon above a turbine. This displays information about the turbine, type, capacity, and maintenance. She notices more options to view the turbine from the inside, select the engine only... Hmm, let us change to a futuristic new turbine that combines wave and solar energy. She clicks on a button in the shape of an ear. An expert starts to explain this radical innovation, how it works, and when available. She asks one of her team colleagues to adjust parameters in the simulation platform. There you go. She sees that one of her team members has now joined in VR. They discuss what they see and come up with adjustments. Too close to the shipping routes. They should recheck the heat maps and indicators. Anyway, the VR world display is nearly ready for the consultation process. The next step, arrange a virtual tour with the planners from other countries. And to show the public how impressive and vital the North Sea is.



Conclusion

What can we do, and where should we draw the line?

- A digital twin colors the world – it defines what we (not) see!
- A digital twin is not neutral – it defines what we (not) decide!
- A digital twin is not only systems engineering – it is also social interaction!
- A digital twin is not for control – it is also for social learning!
- A digital twin is not only for short-term gains – it is also for our long-term values!

- A digital twin is not only immersive game technology – it is also serious play!

But that does not make a DT invaluable per se.

- If we fully realize and acknowledge their limitations as simplifications, abstractions, and reductions of reality.
- If we understand how they work as 'totems' in between science and policy.
- If we define and apply their disclaimers.
- If we deliberate how (not) to use them.
- If we can make them more ecocentric, and less anthropocentric.
- If we use them for learning, and less for control.

What does it mean, DT (and games) are for social learning?

For social learning, it is not enough that individuals learn in a social context. Social learning distinguishes itself from individual learning, i.e., primarily the domain of psychology and cognition sciences. Social learning is 'higher-order learning', i.e., learning by teams/groups, organizations, and systems. According to Reed et al., for social learning' a process must: (1) demonstrate that a change in understanding has taken place in the individuals involved; (2) demonstrate that this change goes beyond the individual and becomes situated within wider social units or communities of practice; and (3) occur through social interactions and processes between actors within a social network.'[91] Digital Twins can evoke social learning at different levels – 1] as a continuous improvement cycle; 2] as experimental learning; 3] as heuristics, and 4] and as deliberation on how we decide. See figure 28.

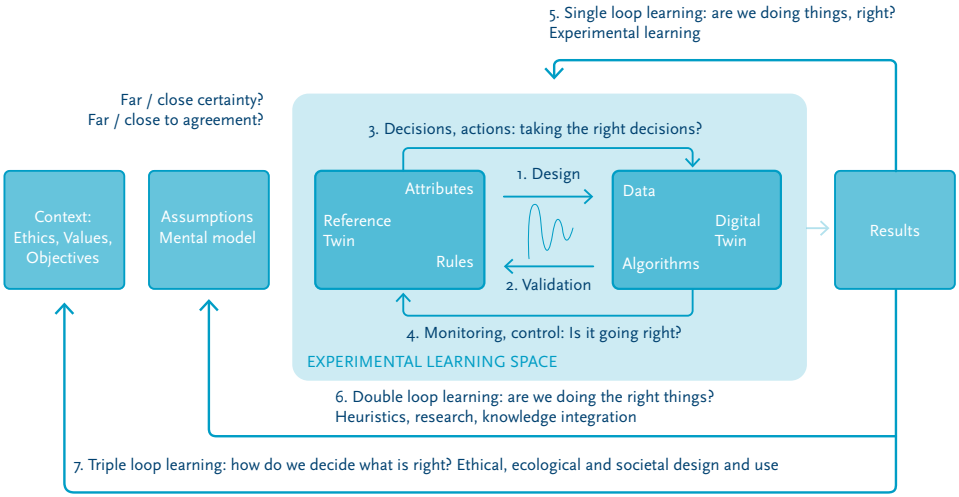


Figure 28 A social / organizational learning perspective on DT? Based on: [92]



Action

Societal agenda - In the **Knowledge and Innovation Agenda** (KIA), Digital Twins are mentioned as a potential **Key-Enabling Technology / Methodology** for societal transformation. Digital Twins are also mentioned as an example where the creative industries can join forces with nearly all other societal and industrial sectors in the National Science Agenda: Water, Energy, Health, Food etc. At the same time, the creative and game industries are not highly valued. They deserve more credit and support. Nor are they well understood as a sector.

Tilburg University and BUas can create synergy by applying organization, management, and innovation studies to the **Digital Creative and Game Industries**. In the Raak-SIA funded project **Veerkracht** and parallel Ph.D. project, we are studying **Organizational Resilience** in the Digital Creative Industries. MSc students in Tilburg and BUas apply theories and concepts from organization and management, such as intrapreneurship, ambidexterity, and innovation ecosystems, to the digital creative industries. But it is also necessary for funding agencies to stimulate substantive involvement of organization, management, and policy sciences in their digitalization and creative industries calls.

> *In the DIGIREAL project (funded by regie-orgaan SIA and the province of Noord Brabant), BUas and Fontys University of Applied Sciences, will develop a Centre of Expertise on Digital Realties as a social-technical concept. We are looking forward to working with MINDLABS, Tilburg University and partners.*

Research program - The research program of the Department of Organization Studies focuses on **organizational adaptiveness in a relational perspective.** I believe DT can be a focal point to study and understand how organizations adapt to disruptive digital technologies, but also, how organizations use interactive technologies, such as Digital Twins, for learning and change. Digital Twins (and serious games) are strongly connected to this agenda, via such issues as:

- **Teams** - virtual humans and virtual teams, unobtrusive team assessment, recruitment, and selection.

- **Intra-organizational** – hybrid forms of multi-disciplinary coordination, for instance, in hybrid control rooms and board rooms; idem hybrid data-driven strategy making.

- **Inter-organizational** – hybrid forms of inter-organizational coordination; but also stakeholder involvement processes. Innovation networks and ecosystems in the DCI; diffusion and adoption processes of interactive technologies.

- **Society and governance** - Responsible digitalization and societal transformation.

Education and learning - The department has a tradition in simulation-gaming, for education and organizational learning. As demonstrated above, DT are data-driven and intelligent serious games, often in a hybrid mode. The department of Organization Studies can work together with other faculties and societal partners on the topic of learning innovation in immersive realities: students can experiment with Digital Twins and serious games to develop them, to learn from them, to critically study them and form an opinion about them. This is important because students will use the next generations of the interactive technologies in their future work; as managers, CEO or chairpersons of the board, they will need to decide about them.

Ethics - A lot of attention goes to the engineering side of digital technology. It is everywhere, data and AI that are punching the clock. It would be a mistake to consider DT a challenge for data scientists and systems engineers. It is not just about how we make these intelligent systems but, more importantly, how we use them responsibly and meaningfully, how we embed intelligent systems like Digital Twins into existing organizations and build institutions around them. What do we use them for? Who is at the controls? What are the underlying societal value systems? I firmly believe we should look at game technology and game design for some of the answers, alongside ethics, organization and policy studies, and political science.



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I wish to thank all the individuals and organizations that have contributed to my ideas, games, and publications over the last twenty years or so. I do want to mention CRADLE and my fellow professors and researchers at BUas, as well as my former Game-Labs at TU-Delft.

I am grateful to have been formally accepted, but also friendly welcomed as an endowed professor at Tilburg University, Organisation Studies. Under lockdown conditions, it has not been an easy start for all of us, but I feel that it is an intellectual home with a high-quality standard.

A particular word of gratitude goes to ALL who have helped and supported me during the appointment process. Marius, Leon, Jantine, and Elisabeth, Daphne, Bruce, you went beyond the call of duty to get me appointed. In addition, I would like to thank the management of BUas, especially Jorrit, Nico, and Robbie, for their trust and support.

I am looking forward to working in this pleasant atmosphere with my old and new colleagues. And with the many partners in research programs of Mindlabs, Digishape, Digireal, Iliad, Ecoscope, Or-Else, Hychain and many more. Let's build bridges.

I have been immensely impressed by the students and what they can achieve. I hope that they will let me encourage them to explore the area of games and digital twins and work with me.

Lastly, I simply want to thank my closest family. My parents and sisters – for everything they do and all they are—my boys: Rutger and Tristan. I am confident you will be happy in life and succeed with your robotics and aerospace engineering missions. Finally, Qiqi: **Living and diving with you is a fantastic adventure. That's it. Thank you for listening.**

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