Design vs Disegno. Real vs Virtual. The Digital Twin as a Holistic Approach to Sustainability

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Abstract

In the Digital Era, among emerging technologies, the Digital Twin (DT) is also experiencing rapid and steady development. The DT is a virtual representation of an object or system, connected to it throughout its life cycle. It is a highly complex computerized model, an exact replica of its physical counterpart. The application possibilities of the Digital Twin in the design of products and their subsequent development are greatly increasing due in part to the possibility it offers to interpret various roles of the entire life cycle of the artifact to which it refers.
Research in this field is proceeding with the goal of getting to the point of optimizing the internal design process (from concept generation to material selection, from design verification to manufacturing, from delivery to use, and reaching end-of-life management). Based on these considerations, the article aims to highlight how DT can drive innovation in sustainable and circular economy, supporting companies, entities, and institutions to reduce costs, optimize resource use, and decrease carbon footprint. However, despite their potential, DTs have not been critically examined in sustainability paradigms and their benefit toward promoting the Sustainable Development Goals.

Keywords: digital twin, design for future, sustainable development, planet life design.

Introduction

Derived from the Latin *designare*, the term 'design' takes on the dual meaning of 'design' and 'drawing,' expressing the concept of the intention and design activity of an inventive nature [Maldonado 2013], although in common parlance it also continues to denote concrete and tangible expression: a drawing, decoration, motif, ornament, style or visual composition. Understood as design practice and subjective ability to produce aesthetic, sense and sometimes economic value in industrial products, whether they are material or communicative artifacts, physical or virtual: in the difficult task of shaping the language of modernity, design today expresses itself in very broad valences, from the real to the virtual, from products to services [Trabucco 2015]. The WDO (World Design Organization) defines design as "a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences. […] Design provides a more optimistic way of looking at the future by reframing problems as opportunities. It links innovation, technology, research, business, and customers to provide new value and competitive advantage across economic, social, and environmental spheres" [1]. And again "Design is a problem-solving activity, a creative activity, a systemic activity, and a coordinating activity" [Borja De Mozota 2003, p. 23].
In parallel, for Industrial Law the term 'design' is synonymous with graphic realization aimed at outlining the appearance of a two-dimensional product; 'model,' by

contrast, expresses the same concept in relation to a three-dimensional product [Floridia 2020].
In analyzing the relationship between design and drawing, it therefore appears interesting to investigate the relationship between 'reality' and its 'image,' between the design process and the bivalence of its final outcome that runs on two levels, the physical artifact and its digital model, focusing on the specificity of the disciplinary field of drawing, in the generation, construction and analysis of drawings, images and models, as outcomes of scalar representations of existing or designed realities.
From the ethical and cultural point of view, Baudrillard's interpretation of codes, models and signs, emphasizes the forms of organization of a new social order dominated by simulation and a paradoxical 'hyperreality' where human experience is an emulation of reality [Baudrillard 1981]. Baudrillard reinterpreted contemporary social reality by defining it as the result of a process of simulation and substitution that ends at the stage where the simulacrum stops being a copy of reality by detaching itself from it '*in toto*' [Caro et al. 2020]. Without having to consider the most glaring examples represented by social networks and the resulting culture of image fetishism, even more emblematic is the recent phenomenon of the emergence of metaverse and Non-Fungible Tokens (NFTs).
A universe, that of the virtual, which puts back at the center of the discussion the theme of the utility and ethics of Design: if we cannot and do not want to exempt ourselves from living with the hyperreal, we ask ourselves what role Design, which by definition presides over the configuration of the morphological, aesthetic, symbolic, cultural, relational, functional, technological and productive characters of artifacts, material and immaterial, can assume. Objectives of design action are to improve the quality of life of people in different contexts, present and future, and to contribute to the innovation of socio-technical systems towards models of sustainability, circularity, inclusion, and social equity. In this sense, the disciplinary scope of design shifts its horizon to include emerging fields in the strategic-organizational, digital, and social innovation fields, and is open to continuous updating in relation to the challenges of contemporary societies and new scientific-technological frontiers. In this sense, the application potentials of the visual-synesthetic and information-computational domains typical of design are explored, as well as possible innovations in applications supporting the realization process at various scales.

The Digital Twin

The term Digital Twin (DT) is increasingly used in technical discussions and common jargon, especially in connection with, but not limited to, the digitization of industrial processes. In research fields too, the term is increasingly adopted in connection with the study of complex systems by means of digital technologies. For example, in life science we speak of Digital Twin of the human body, in the field of climate change we speak of Digital Twin of planet Earth.
The Digital Twin differs from 3D reconstruction, which provides a static representation of the physical model, in that it is dynamic due to the ability to exchange data in real time with its physical homologous using Internet of Things (IoT) systems.
It was Michael Vickers who first presented a prototype of DT in 1970; it involved NASA's simultaneous use of fifteen computers to create the simulations that guided the Apollo 13 crew in the space recovery operation.
The first industry-wide software application, however, was due to Michael Grieves, who in 2002 presented the digital twin as a conceptual model for product lifecycle management (PLM) [2].
As Grieves [Grieves, Vickers 2016] states, the DT is a conceptual model that demonstrates that all information embedded in a tangible product can exist digitally.
The DT is a computer model, fed with data collected from a real system, that can concisely but faithfully represent (often through visualizations with 3D models, graphs, curves, and dashboards) the overall state of the real twin. It is an executable software model that runs on a host system. It emulates the hardware, including CPU instruction sets, memory maps, registers, and interrupts, to a sufficient level that it can be adapted to software development. On the software side, it is binary compatible with the emulated hardware, allowing users to run unmodified binary images of the entire software stack, which includes everything from low-level devices and firmware to operating systems, middleware, and, finally, the application to be developed. Simplifying, we could say that the DT is a seamless integration between the cyber space and the physical space; it is the equivalent of a real twin control center, developed inside software and running even without the controlled system.
According to Grieves' schematization [Grieves 2020] 2020], the Digital Twin is composed of three distinct ele-

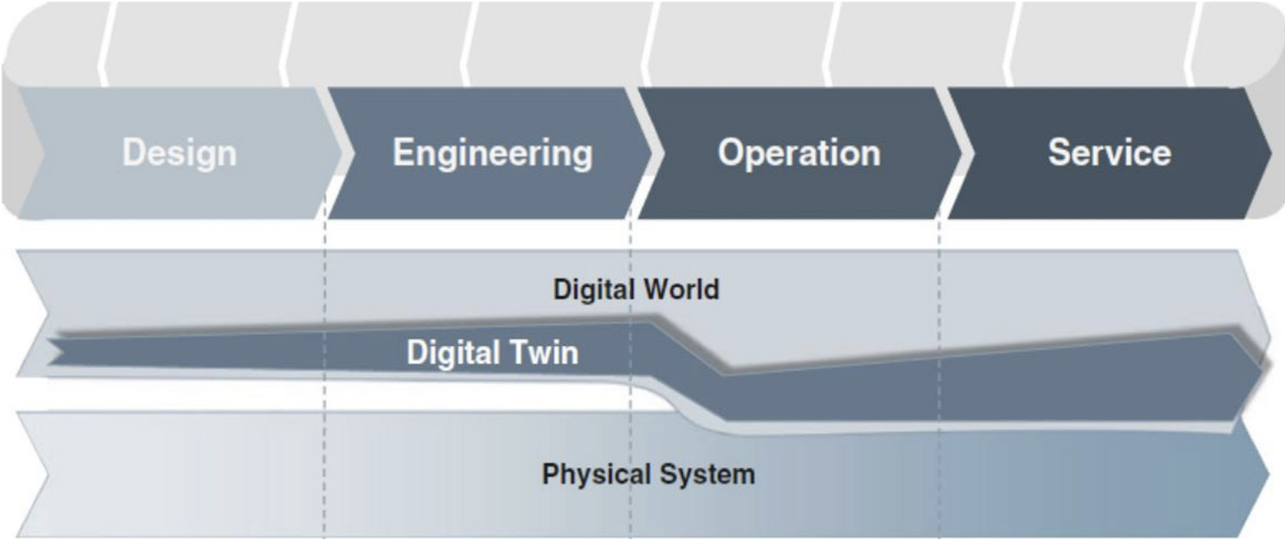

Fig. 1. Diagram of application of DT to different steps of the design process.

ments: there is the physical product that has always existed, which we can call the 'physical twin,' then there is the virtual counterpart, precisely the 'virtual twin,' and finally the third element is given by the 'two-way connection between the physical and virtual versions,' thus the data from the physical world, collected and transmitted to its digital twin.

Back in 2019, Gartner, a leader in technology research, included DT in its Top Ten Strategic Technology Trends [3], but recently, the concept of DT is taking on new meanings, expanding to a holistic digital model of a real system. It is an incredibly powerful tool because it allows not only to be in control of functions in their current state, but also to be predictive. This is made possible in large part by the computing power and data analysis available today in supercomputers or in the cloud.

The application possibilities of the virtual twin are further amplified in industry by the increasing automation of processes, where everything is managed by remote sensing systems and reconfiguration and maintenance operations must take place without human intervention, becoming one of the most promising enabling technologies for the realization of smart manufacturing and Industry 4.0 [Tao et al. 2018].

Digital Twins can provide the manufacturing sector with solutions that optimize asset performance across multiple dimensions of sustainability, safety, and profitability through adaptive models, shared data, and advanced visualization (fig. 1). Virtual twin technologies can also increase the speed of time-to-market while reducing the risk associated with complex projects [Lo 2021]. As our physical and digital worlds converge, digital twins can play a key role in helping society overcome some of its most pressing sustainability challenges with a view to ensuring a better quality of life for all [Tao et al. 2020].

Holistic approach to sustainability through the Digital Twin

Sustainability is a multifaceted, environmental, economic and social goal. The ultimate tool for achieving it is knowledge, in its various forms, above all, that of ecosystem complexity. Ecosystems have within them the great potential to preserve life, with a dynamism characterized by cyclicality and mutual subsidiarity. Unfortunately, this ecosystem subsidiarity is strongly modified in direct and

indirect ways by the anthropogenic footprint [Tartaglia et al. 2021].
Therefore, the term sustainability is increasingly associated with the term responsibility, i.e., the need to interpret in fieri social needs, security, environmental protection, and production ethics, and provide a just response to them.
The European Green Deal [4] is the action plan for making the EU economy sustainable, turning climate and environmental challenges into opportunities, and making the transition inclusive. The European Green Deal is tasked with avoiding CO_2 emissions by 2050 by promoting an economic growth model decoupled from resource use, with a specific focus on inclusiveness, which means that no person and no place should be left behind. The main points concern the efficient use of resources by moving to a clean and circular economy, include restoring biodiversity, decisively reducing emissions and pollution of soil, water and air. A range of funding instruments have also been made available to support the creation of a European climate law, which is necessary to transform theoretical and political commitment into a legal obligation and thus into effective action. Achieving this goal will require action by all sectors of the European economy, including investment in innovative and environmentally friendly cross-cutting technologies, support for industry innovation, the spread of cleaner, cheaper and healthier forms of public and private transport, and the decarbonization of the energy sector.
In this sense, the role of design appears imperative, precisely because it is oriented toward shaping complex scenarios and defining the ways in which humans interact with humans, and humans with their habitat [Terenzi 2021].
In parallel, today we move in changing patterns that need to respond rapidly to social cultural and political stimuli. Models that therefore take on the character of high flexibility and adaptability.
The fluidity of the context has exponentially broadened the operational and epistemological boundaries of design, which is no longer design of the aesthetic component of mass production but becomes design for the development of new behaviors, where objects and services are designed not only to respond to expressed needs, but also and above all to identify and anticipate latent needs in the context of sustainable development.
Anticipation is increasingly at the center of urgent contemporary debates, from climate change to the economic crisis. This aspect underscores the anticipatory

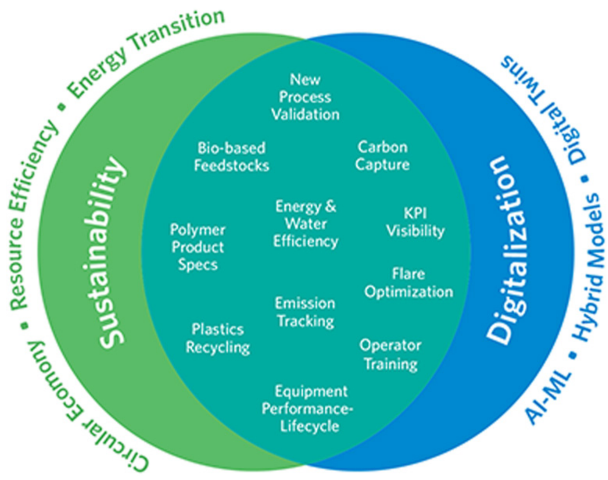

Fig. 2. The diagram shows the role of Digital Twins as an integral part of the sustainable approach. <https://www.automation.com/en-us/articles/march-2022/make-digital-twins-sustainability-program> (accessed 21 December 2022).

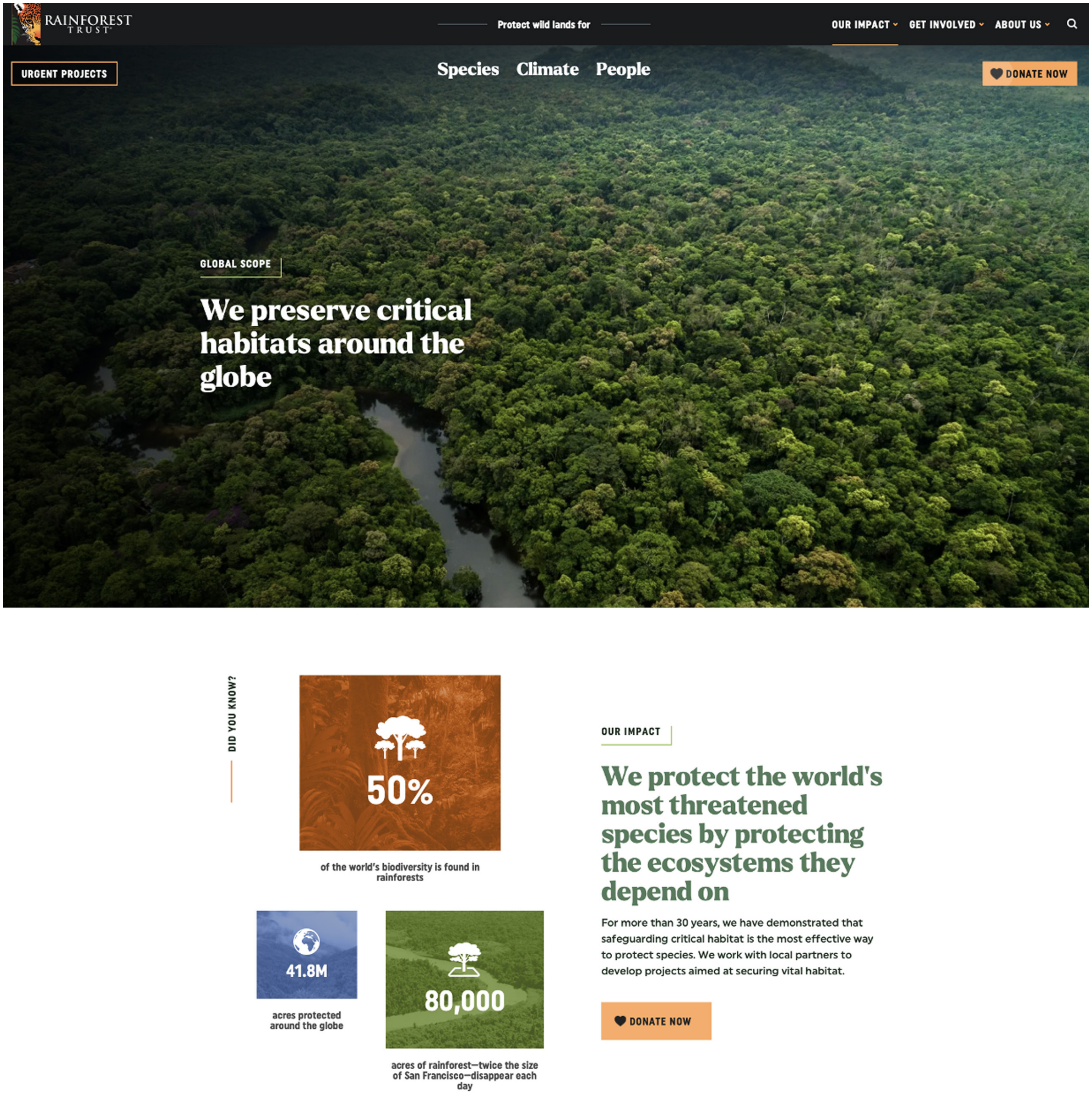

Fig. 3. Homepage of the Rainforest Trust platform.

component to which the project, now more than ever, is called upon to respond. According to Bernard Cazes, thinking ahead has always been an essential component of human nature, and anticipatory practices are coming to the forefront in political, organizational and personal life, but also in design practices [Arnaldi, Poli 2012]. If for Viktor Margolin [2017] designing in the present requires a vision of what the future could and should be, according to Bertrand de Jouvenel [2018] we have possible futures, or futuribles, while for Berger the French conception of perspective as a vision of the future refers to three aspects: - knowledge about the past and the present; - imagination; - will [Arnaldi, Poli 2012].
In this context, design action becomes the practical nexus between the past and the 'possible future,' and the material and immaterial artifacts it produces make explicit the possibility of existence at the very moment they are realized and at the same time their potentiality for what they could be. Between the concept of sustainability and the possibilities of prediction, digital transformation takes on a new role (fig. 2).
Digitization has proven to be one of the main enablers for building more sustainable economies and societies, due to its current and future potential in facilitating new patterns of consumption, production, and work, and thus, also supporting the realization of the 17 UN Sustainable Development Goals [Tzachor et al. 2022]. The growing abundance of available data can guide choices toward smarter, more informed decisions, while the growth of automation and AI can make our actions more efficient and effective.
A digital environment that copies and evolves before the physical environment, such as that of the DT, is a unique advantage from a sustainability point of view because it allows us to predict the evolutions of elaborate complex systems.
DTs can drive sustainability, basically on two different levels. On the one hand, they can be used to acquire, organize, and visualize data to provide a realistic model of the physical world. This aspect is a valuable aid aimed at understanding and quantifying what is happening, and to combine different data useful for observing the impact of decisions with respect to the processed system.
The value of the Digital Twin is that information replaces the waste of physical resources. Bits are cheaper than atoms, while bits become cheaper at an exponential rate and atoms more expensive at the rate of inflation. We

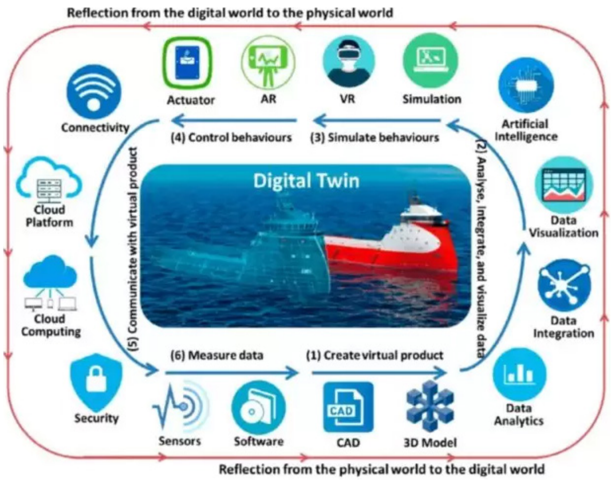

Fig. 4 ILIAD project Digital Twin of the Ocean (DTO). Cf. : <https://zeroemission.eu/ue-stanziati-17-mln-di-euro-al-progetto-iliad-per-lelaborazione-gemello-digitale-degli-oceani/> (accessed 19 December 2022).

can use the information of the Digital Twins to create, produce, operate and support products and systems more effectively and efficiently.
On the other hand, the digital model can take on the role of a predictive guide to the future, comparing possible scenarios and predicting the outcome of different alternatives before decisions are made. These potentials represent wide-ranging benefits in a variety of areas [Tao et al. 2019]. The dynamic nature of modeling lends itself to optimizing resources, processes, and systems in areas such as resource management, traffic management or logistics optimization, balancing energy networks or facilitating resilience in the face of climate change impacts. The Digital Twin model has been used by NASA for spacecraft [Glaessgen, Stargel 2012] and by the U.S. Air Force for jet fighters [Tuegel 2012].
The oil industry is exploring the use of Digital Twin for ocean production platforms [Renzi et al., 2017] while General Electric has used the term extensively, especially for power generation equipment [Castellanos 2017]. DTs have been used in the development of 85 percent of the world's electric vehicles, more than 75 percent of global wind power, enabled the world's first solar aircraft, and contributed to the development of numerous biomaterials.
The description of some practical examples helps to better understand the possibilities for sustainable development of DT.
The Rainforest Trust is a conservation organization that creates Digital Twin of rainforests in the tropics. The goal is to interpret data to allow experts to identify landscapes that need immediate protection, to prioritize species that are most threatened, and to have the immediate positive effect of biodiversity tutale for the planet's tree species. Based on the predictions, the Rainforest Trust acquires land with specific efficiency characteristics to save the most impactful acres for wildlife protection (fig. 3).
The European Digital Twin Ocean (DTO) born to support the framework of the EU Mission Restore Our Ocean and Waters by 2030 and to enable the ambition of the European Green Deal. To strengthen EU leadership in protecting the Ocean, European Commission President Ursula von der Leyen launched this important project. In this sense, the ILIAD Consortium has been awarded a €17 million grant from the European Union to develop and launch a DTO that will provide highly accurate predictions of changing data in the global seas through Artificial Intelligence (AI) algorithms. The ILIAD

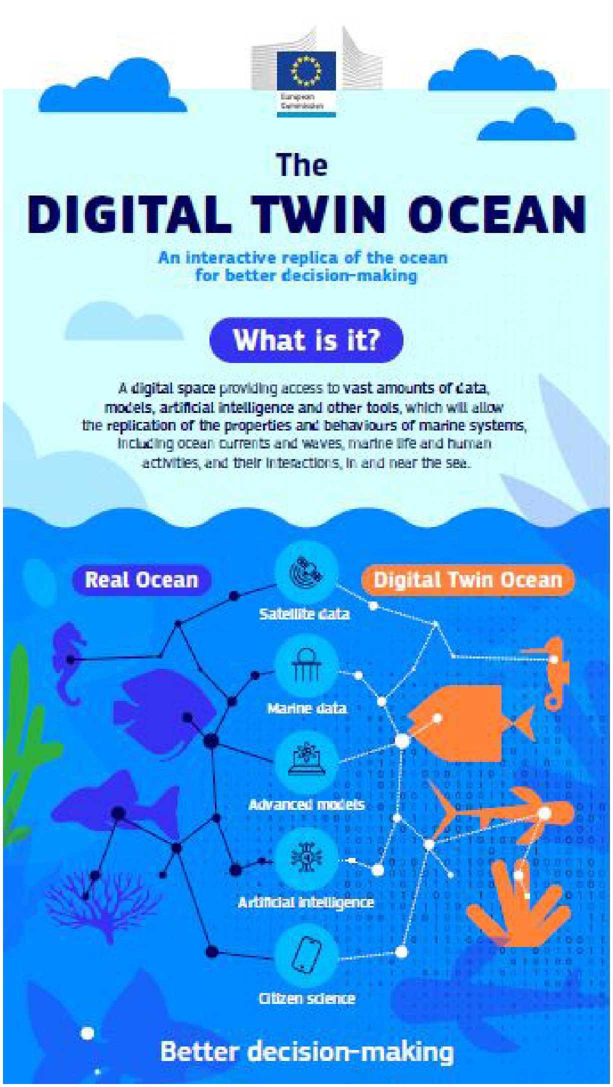

Fig. 05. Digital Twin of the Ocean, EU Missions in Horizon Europe. Cf.: <https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters/european-digital-twin-ocean-european-dto_en> (accessed 19 December 2022).

ILIAD FIELDS OF APPLICATION OF DTs

Wind energy	Blue economy, harness ocean electricity, integrate data, models, physical ocean observatories at sea and digital technologies (HPC, AI, data analytics), a clean, productive, predicted, safe ocean.	Pollution	Pollution monitoring, mitigation, and remediation, integrate data, models, physical ocean observatories at sea and digital technologies (HPC, AI, data analytics), high resolution, near real time, stop waste entering the ocean, a clean, healthy and resilient, productive, predicted, safe ocean.
Renewable energy from the ocean: currents, waves, floating solar	Blue economy, harness ocean electricity, integrate data, models, physical ocean observatories at sea and digital technologies (HPC, AI, data analytics), a clean, productive, predicted, safe ocean.	Met ocean data: hind-, now- and forecasts	Integrate data, models, physical ocean observatories at sea and digital technologies, mapping the ocean (share and manage ocean data), understand & forecast ocean behaviour & climate change, sea level rise and extreme values in coastal environments, a predicted, safe, accessible, inspiring & engaging ocean
Fisheries and aquaculture	Farm to fork, integrate data, models, physical ocean observatories at sea and digital technologies (HPC, AI, data analytics), High resolution, near real time a clean, healthy and resilient, productive, predicted, safe ocean.	Biodiversity assessments and monitoring	Protect biodiversity, Integrate data, models, physical ocean observatories at sea and digital technologies (HPC, AI, data analytics), a clean, healthy and resilient, predicted, safe, accessible ocean
Marine traffic and harbour safety	Marine socio-economic systems, blue economy, integrate data, models, physical ocean observatories at sea and digital technologies (HPC, AI, data analytics), a productive, predicted, safe, accessible ocean.	Insurance for marine and maritime activities	Marine socio-economic systems, blue economy, integrate data, models, physical ocean observatories at sea and digital technologies (HPC, AI, data analytics), a productive, predicted, safe, accessible ocean.

Fig. 06. ILIAD fields of application of DTs. Cf. : <https://www.ocean-twin.eu/news/article/what-is-a-digital-twin-of-the-ocean-and-what-can-it-be-used-for> (accessed 19 December 2022).

project will develop a DT containing virtual representations of the sea that will complement and extend EU Earth observation through predictive models and digital infrastructure to provide highly accurate data and predictions from climate change to marine renewables (figs. 4-6). At the One Ocean Summit in February of 2022 Ursula von der Leyen explained that a digital twin of the ocean is an opportunity for Europe to focus attention strongly on in our collective ocean resources to preserve.
To date, one of the most advanced City Digital Twins is that of the city of Zurich. In support of smart cities, the City Digital Twin is expected to be able to reflect and purposefully influence urban functions and processes to improve their implementation, operation, and management. As an important part of the city's smart strategy, Zurich's digital twin was developed to support decision-making through a digital spatial image. It enables visualization of street spaces, underground services and selected public buildings at higher levels of detail. In addition, several benefits and applications have been tested that have proven useful in the context of urban planning decision-making, such as comparing and evaluating different urban development scenarios, facilitating public participation in planning, integrating urban climate issues into development plans with simulation of the effects of environmental change, supporting the achievement of climate-neutral goals defined in the Climate-neutral and smart cities EU mission.
The city of Zurich's digital twin shows high potential for improving the city's visualization and planning and the inclusion of stakeholders with a view to improving the quality of life of its citizens (fig. 7).
Finally, we see how the difficult management of the volume of data used to make all this possible can itself be made more sustainable. Indeed, as is well known, data centers, physical spaces dedicated to the storage of computer systems that house servers, contribute significantly to CO_2 emissions. For example, every online search has an environmental cost to the planet, so much so that in processing 3.5 billion searches per day, Google accounts for about 40 percent of the Internet's carbon footprint. The mechanical movements within Computer Processing Units (CPUs) and the continuous rotation of hard drives require large amounts of electricity and thus cooling capacity. A Digital Twin of this process could identify potential alterations to reduce data duplication in storage (Dark Data) and also improve performance in centers to minimize unnecessary power consumption. In this sense, DT can reveal small but high-impact changes to data center management, which can achieve benefits of up to 70 percent energy reduction, correlated with cost savings.

Conclusions

There is no denying that science and technology are accelerating at an unprecedented speed, but it is necessary to understand today the implications of how these technological advances will directly affect all aspects of society, and how to turn them to the betterment of life on the planet.
While just a few years ago, an Internet search for the term Digital Twin would have produced a handful of results, today the same search produces more than a million results, while a DT image search produces half a million images, including applications in a wide variety of fields.
The benefits of virtual twins are numerous, and the most important is the support and acceleration these technologies can provide for the transition to a more circular economy. As organizations and our society mature digitally, the digital twin can move from describing elements of present reality, what is happening, to describing the prediction of the future and why, to proposing interventions and, potentially, giving great impetus to the ecological transition. Important support in this regard is also provided by the methods of representation used and further refined aimed at defining virtual twins, and thus their design, understood in the broadest sense as a cognitive means of formal structure, as a tool for the analysis, transmission, fruition and dissemination of existing values, tangible and intangible. And this can be applied to the entire life cycle of the asset, process, system, or organization, creating value through continuous innovation.
In the virtual twin, the real and the virtual exist as a function of each other, the intangibility of the DT goes through a reconstruction of reality, in a two-way exchange, with the goal of arriving at an evolution of the existing in a near scenario, which is defined to be manipulated with a view to forecasting the future.
An inherent peculiarity of the system, which has not yet been fully unraveled, is undoubtedly that of reading the

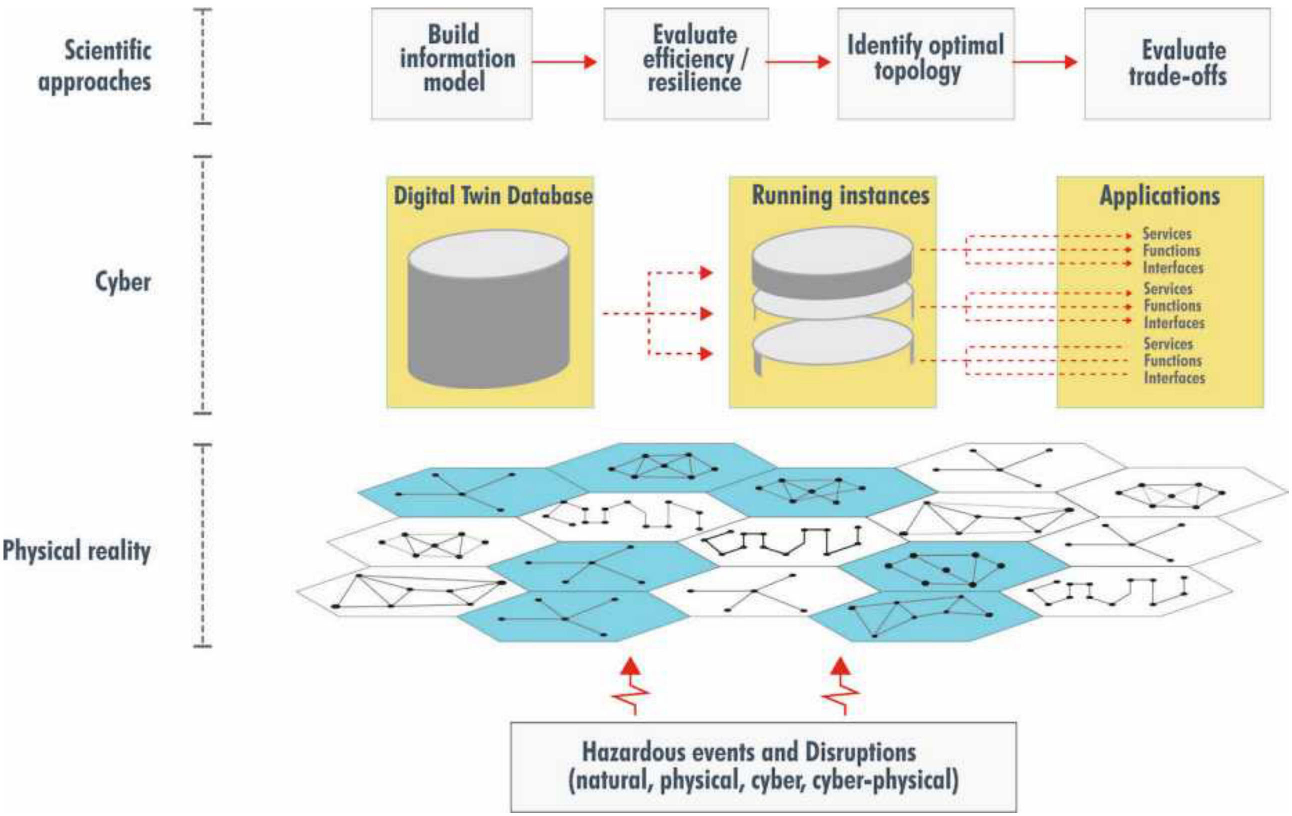

Fig. 7. Outline of the digital model of the city of Zurich. Information models together with multiphysics models highlight interdependencies within a collaborative decision support environment enabled by the Digital Twin. Cf.: <https://frs.ethz.ch/research/cyber-physical-systems/digital-twin-enabled-system-resilience.html> (accessed 19 December 2022).

potential of the virtual twin from the perspective of the possibilities it offers for decreasing CO_2 emissions, in all its potential declinations. According to analysts, the DT market will amount to as much as 35.8 billion euros in 2025, almost ten times its value six years earlier, and can lead to 7.5 Gt of CO_2 emission reduction by 2030.
To maximize its benefits, digital twins will not have to focus on individual resources, but rise to understand and operate on entire processes and contexts. Achieving the fragile balance of sustainability goals, considering people, planet, and profit equally, is a considerable challenge, but one that must be addressed, and digital technologies will be at the heart of this transition.
To do this, it is important that the ecosystem be flexible enough to adapt as it grows, considering a changing world and an expanding geographic and social reach.
On the one hand, there are undoubted advantages; on the other, there are limitations to the scope, and one of these is related to, for example, privacy. The other issue is that of individual and collective responsibility, of preventing the triumph of the container from supplanting the content, that the ubiquitous presence of symbols, fallacious and virtual narratives, assuming more and more prominence and importance at the expense of the realities they describe, ends up becoming the only interpretive tool available.
In this sense, it seems, finally, interesting to open the perspectives and draw a parallel with another virtual system that affects the transformation of the contemporary era, such as the concept of the metaverse.
Digital Twins, being digital copies in real time of a physical object, can be defined as constituent elements of the metaverse, and they see precisely in the metaverse their natural evolution, as the general connection between the digital world and the physical world that allows and exploits the possibility of switching from one reality to another and expands the possible experiences. The metaverse synthesizes the path of replacing reality, of individual and concrete value, with a new ontological conception of truth: the truth of illusion, of 'reality without reality.' In other words, while the DTs and the metaverse share the same basic logic of operation, it is equally true that while the former consist of a series of virtual instances of a physical asset, characterized by a continuous flow of real-time data that enables the use of IoT, AI and Machine Learning, to perform predictive analytics and complex simulations in real time, for the metaverse there is still no clarity of purpose on how to channel the potential of fully immersive experiences into a simulated reality, not necessarily twin to the real world.
Regarding their sustainability, in environmental terms, although there are already early studies that also indicate the likely positive effects in terms of CO_2 reduction of a progressive and massive use of the metaverse, this is yet to be verified. Replacing physical goods with virtual ones may ideally allow, for example, to reduce the environmental impact of production chains; furthermore, favoring digital events, preferring them to in-person ones, would decrease the need to travel by polluting means, and migrating social activities into virtual reality would allow for a drastic reduction in waste produced, eliminating waste. It should be noted, however, that this trend may still risk leaving a footprint on our ecosystem because it opens the way to new needs and new habits and consumption patterns, closely linked to Internet use, which would still increase demand for new related services and commodities.

Notes

[1] Cf.: <https://wdo.org/about/definition/> (accessed 19 December 2022).

[2] Cf.: <https://studylib.net/doc/15295818/plm-presentation> (accessed 19 December 2022).

[3] Cf.: <https://www.gartner.com/en/documents/3904569> (accessed 19 December 2022).

[4] Green Deal. Available online: <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_it> (accessed 30 September 2022).

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