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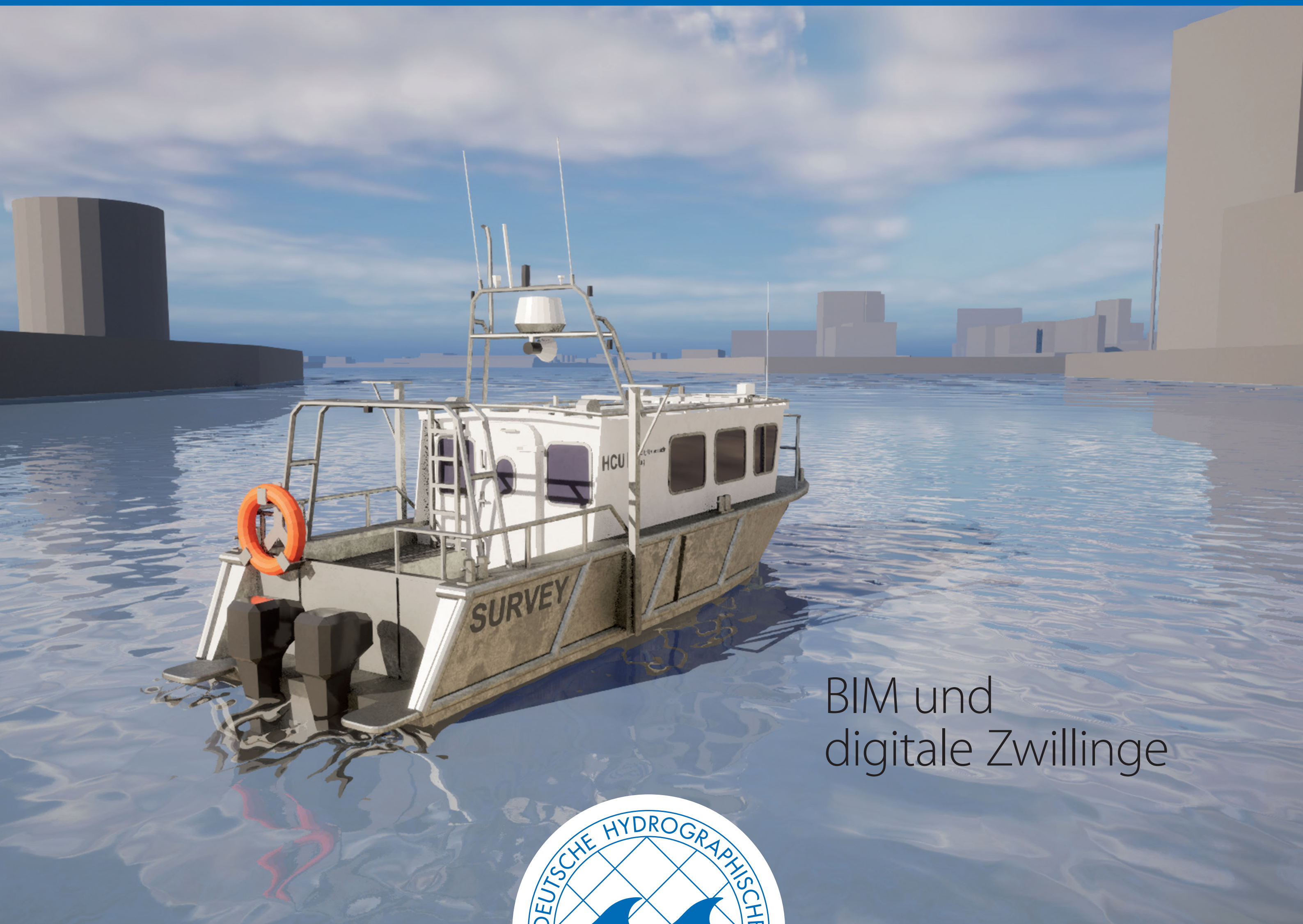

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Current state of digital twins in the maritime sector

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Digital twins show considerable potential to revolutionise any domain they are deployed in. There is increasing interest of various actors in projects that focus on implementing a digital twin. However, there appears to be a discord about the definition of a digital twin. This article starts with an introduction and continues with a definition of the digital twin that fits the most popular criteria. The next section explores the current implementations of digital twins in various domains, with a focus on the maritime domain. These projects are then evaluated according to our definition. The last section concentrates on future implementations and the challenges that need to be addressed to ensure the promised revolution.

digital twin | digital master | digital shadow | Industry 4.0 | digital ocean
digitaler Zwilling | digitaler Master | digitaler Schatten | Industrie 4.0 | Digitaler Ozean

Digitale Zwillinge haben ein enormes Potenzial, jeden Bereich, in dem sie eingesetzt werden, zu revolutionieren. Das Interesse verschiedener Akteure an Projekten, die sich mit der Einführung eines digitalen Zwillings befassen, nimmt zu. Es scheint jedoch Uneinigkeit über die Definition des digitalen Zwillings zu herrschen. Dieser Artikel beginnt mit einer Einführung und fährt mit einer Definition des digitalen Zwillings fort, die den gängigsten Kriterien entspricht. Der nächste Abschnitt befasst sich mit den aktuellen Implementierungen von digitalen Zwillingen in verschiedenen Bereichen, wobei der Schwerpunkt auf dem maritimen Bereich liegt. Diese Projekte werden dann anhand unserer Definition bewertet. Der letzte Abschnitt konzentriert sich auf zukünftige Implementierungen und die Herausforderungen, die angegangen werden müssen, um die versprochene Revolution zu gewährleisten.

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Introduction

In recent years, the concept of digital twins has gained significant attention due to its potential to transform various industries. Digital twins promise a way to holistically manage and use information to enhance value. This approach is based on information extracted from sensor data. With the digitisation process in the context of Industry 4.0, more frequent and enriched data from sensors is made available. However, only the surface of their potential is being utilised, and the full potential can be achieved by combining heterogeneous information of various sources and formats. Multiple studies explored the current state-of-the-art in various domains, ranging from manufacturing to whole cities, covering infrastructure and various marine applications (Liu et al. 2023; Ferré-Bigorra et al. 2022; Madusanka et al. 2023). The results were consistent with our own previous research and show that digital twins are still in development (Bauer et al. 2022). The aforementioned studies show that many systems today, even though they are labelled as a digital twin, only employ partial solutions that require a human-in-the-loop. Evaluating the current state of digital twins is further hampered by the misuse of the term itself.

Definition of digital twins

The term digital twin is ambiguous and may be already used in another context describing something remotely similar. To counteract misunderstandings, a definition of digital twins in the context of Industry 4.0 will be given. Briefly spoken, a digital twin is a virtual representation that can be assigned to a concrete real object (Bauer et al. 2022). However, it is much more than a 3D model of an object. It is a collection of heterogeneous data associated with an object and their respective data and process models. It interacts with the mirrored object through a continuous and bidirectional data exchange. Its three main functions are the provision, linkage and use of information. The main components are the digital master, digital shadow and the linkage of information between the two (Fig. 1; Bauer et al. 2022). The digital master includes all information from the definition phase, including the associated object and its attributes such as weight or year of manufacture. The digital shadow includes the operation, process and condition data from the entire product life cycle of the associated object. This includes sensor data, service work performed and production data. Together, the two components form the data basis of the digital twin. The last component is the linkage of information of this data basis, creating solutions for specific use cases (Bauer et al. 2022). As shown in Fig. 1, a feedback loop can be implemented to influence the associated object, which can reduce the need of a human-in-the-loop. As an object can consist out of other objects, a digital twin can consist of other digital twins. For example, the digital twin of a vessel can be composed of the digital twins of the engines, the bridge systems and other components. At this point it is important to emphasise that it is not expedient from an economic and a technical point of view to mirror an object completely and that it should always be purpose oriented. Nevertheless, it is reasonable to selectively collect unused data to enable future applications to use this data. Applying digital twins to improve efficiency and reduce costs is promising for many domains like civil engineering, aerospace, the automotive industry, urban planning and the maritime sector. For example, predictive maintenance assistance through anomaly detection has the potential to decrease the expense of new components or processes can be optimised through investigation of the utilisation rate. This article shows examples that already apply this concept and explores potential applications of digital twins with a focus on the maritime sector. Readers will gain a better understanding of the potential of digital twins, but also of the challenges involved.

Current implementations of digital twins

The next few paragraphs describe projects that are in the process of implementing a digital twin according to our definition.

The construction industry has already taken the first step towards digital twin, by starting their building process with a digital master. This is known as building information modelling (BIM) (Albrecht 2013). This is a digital model that contains information about the whole design and all the construction details needed, including structural elements as well as pipes and electrical installations. Especially large projects often require such a digital master to organise the construction process efficiently. One example of such a project, that is close to being a digital twin, is the Shipyard Infrastructure Optimization Program (Lagana 2021). The aim is to improve the infrastructure of multiple US Navy shipyards. The project has a budget of $21 billion over a 20-year period. The planning started with 3D models of the planned infrastructures, which were then used to simulate commodity and worker movements and travel times. This led to various improvements in the layout of the whole area. However, they did not state how data generated during the operation of the shipyard is used, or even if it is used at all. Overall, this project is an example where the flow of information is only from the digital representation to the real object, but not back to the digital model.

The manufacturing industry faces different challenges compared to the construction industry. Aside from the construction of the factory itself, the more important decisions concern the layout of the manufacturing line inside the factory itself. Since the production requires large volumes with many different customisation options, the automotive manufacturing is a prime example of manufacturing line configurations. One such example is the collaboration between NVIDIA and BMW (Caulfield 2021). A digital model combined with sophisticated simulations is used to plan the shop floor layout. It is not only used to optimise the workflow of the human workers, but also autonomous robots that work across the shop floor. This model can then be updated with new information about the current state of the factory and used to

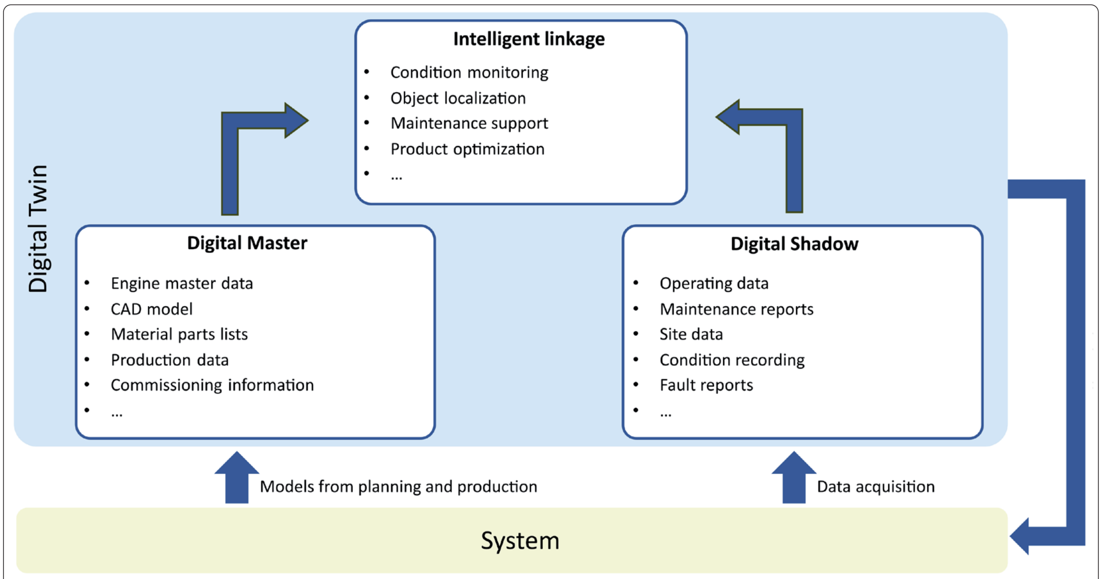

Fig. 1: Components of a digital twin (adapted from Bauer et al. 2022)

simulate the factory in real time. This comes close to our definition of the digital twin. Predictive maintenance is one benefit of such an elaborate implementation. Nevertheless, the information is drawn from advertisement material and should be treated with some scepticism.

A domain in which digital twins nearly fulfil our definition of a digital twin, at least according to advertisements, is the aerospace sector. Airbus is promoting the data platform »Skywise« as a solution for the whole life cycle of an aeroplane. The development process is similar to manufacturing and construction, starting with a digital master. However, instead of dismissing the data after the aircraft is constructed, it is used as the basis for further updates based on maintenance and usage. Safety is a top priority in the aerospace industry and therefore, topics like predictive maintenance receive a lot of interest. Aside from the data that corresponds directly to the aeroplane itself, information about the crew schedules and flight schedules are used as well to complement the digital shadow. One deciding factor that is revolutionising about this system is the transition from data silos, that is data stored at each individual company, to a dataspace that encompassed all the data corresponding to the whole lifetime of all managed aircraft. The digital shadow is then utilised by Skywise Apps that transform this data and combine it with external sources to provide all the information a human operator needs to make an informed decision (Skywise 2023).

The maritime domain is different from the previously mentioned industries, since it not only includes human creations but also an enormous ecosystem, which is a highly complex and dynamic system. Another caveat is the absence of a digital master of the ocean, which is usually the first step towards a digital twin. This stems from the fact, that the digital twin of the ocean is one of the first to focus on a natural object, instead of an artificial one. The United Nations declared the UN Ocean Decade to provide a better and broader understanding and digitisation of the ocean by supporting various projects hosted by the program Digital Twins of the Ocean (DITTO 2023; Heymans et al. 2020). One such project is ensuring the compatibility of the data exchange between all actors (TURTLE 2023). These range from the sensors, that are deployed in the oceans, covering the data transformation services and finally the data visualisation. At the same time, the EU is promoting projects for the ocean data management, distribution and visualisation. A goal of the ILIAD project is a simulation and visualisation of the data captured during the observation and measurement of the ocean (ILIAD 2023). The data itself needs to flow between various actors seamlessly, which is ensured, firstly by the aforementioned initiatives for compatible data exchange, and secondly by a framework for the infrastructure of a dataspace. The EU wide initiative for this data exchange without borders is Gaia-X (Gaia-X 2023). This is also the foundation for the maritime dataspace, that is currently being worked on in the Marispace-X project (Marispace-X 2023). Based on these projects and initiatives, the next step, towards the digital twin of the ocean, is the newly created Digital Ocean Lab in the Baltic Sea off the coast near Rostock (Digital Ocean Lab 2023). This test environment provides the means to employ the whole data pipeline required for a digital twin. Currently, sensors have been deployed and the data pipeline is being implemented. Furthermore, the known environment is an ideal use case for fast fluid simulations (Freiherr von Lukas 2023). The first implementations focus on artificial objects like vessels and harbours. One such project with a focus on vessels is MARIA (MARIA 2023). The project is centred around the condition of shipboard systems and helps the crew and service personnel during the documentation and maintenance. The combination of these projects will enable a secure and sustainable measurement, observation and evaluation of the ecosystem ocean. A plethora of sensors will be employed, e.g., temperature, salinity, wave direction and height, and even DNA and chemical analysis of the water composition (OTC-Genomics 2023). Future work will focus on the transformation, visualisation and further analysis of the data. All involved projects work towards compatibility between the corresponding parties and full automation.

Vision and further challenges

As can be seen from the digital twins implemented so far, there are no limits to the enthusiasm for possible use cases and business models, because the design, networking and complexity of digital twins can be expanded at will. However, agreeing on a common definition is still one of the most fundamental challenges (Wagner et al. 2019). This further hinders the advancement of theoretical frameworks, required for future and long-term research as well as investments.

At the moment there are several challenges that urgently need to be addressed. Some of those challenges are data homogenisation, data transport, data security and ownership. At the development level, common interfaces and data exchange formats must be found to homogenise the heterogeneous sensor data for further processing (Wagner et al. 2019). This can quickly become complex if data is to be made comparable that has already been modified with various filters beforehand and one no longer has access to the raw data. Since Digital Twins are often required to be real-time capable, the latency is another challenge. It is important to transport the data as quickly and efficiently as possible for further processing. This requires even more effort in the maritime domain, where the data connection between offshore and onshore is often slow and unstable (Wagner et al. 2019; Bauer et al. 2022; Fuller et al. 2020).

The collected data are often very valuable for the owner and therefore data security must be ensured throughout the entire pipeline. It is highly advisable that the data is transmitted exclusively in end-to-end encryption (Fuller et al. 2020). When it comes to data ownership, there is always the question of who is allowed to use the data and how (Bauer et al. 2022; Fuller et al. 2020). This requires transparency to create understanding and trust between the stakeholders. This is not necessarily about open data, but rather a targeted release of data for a suitable financial compensation (Fuller et al. 2020).

In conclusion, the digital twin is currently a very relevant concept, that many strive to achieve, but few actually manage to implement. Nevertheless, crucial progress is being made at this moment, and fully functioning digital twins are to be expected in the near future. //

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