CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2023

4th Conference on Production Systems and Logistics

Method For Identifying And Evaluating The Fields Of Application Of A Digital Twin

Fabio Oettl[1], Sebastian Dietl[1], Christian Göltl[2], Daniel Müssig[2], Johannes Schilp[1, 3]

[1]*Chair of Digital Manufacturing, Faculty of Applied Computer Science, Augsburg University, Augsburg, Germany*
[2]*WEISS GmbH, Buchen, Germany*
[3]*Fraunhofer Research Institution for Casting, Composite and Processing Technology – IGCV, Augsburg, Germany*

Abstract

In the context of Industry 4.0, digital technologies and concepts are becoming more and more important in companies, as they can provide solutions to current challenges. The digital twin in particular can be used in various fields of application and thus create added value. However, the variety of different application possibilities as well as the difficult evaluation of the added value of the digital twin poses great challenges for companies. This publication therefore presents a method that offers companies a structured approach to identifying and subsequently evaluating possible uses of the digital twin based on their digital maturity. First, the digital maturity of a company is determined by means of a point-based questionnaire and a suitable identification method is proposed based on the result of the digital maturity. If a field of application could be identified with the proposed method, it is evaluated by a self-developed "Digital Twin Canvas" and, depending on the field of application, by a suitable simulation. By applying the method in various companies from different sectors, the method's functionality has been validated.

Keywords

Digital Twin; Digital Shadow; Digital Readiness; Digital Maturity; Evaluation; Identification; Simulation

1. Introduction

Competitive pressure on companies is increasing due to globalisation, as well as the rising demand for individual products with simultaneously shorter product life cycles [1]. In this environment, companies are confronted with strong price and efficiency pressures [2]. At the same time, technological progress in recent years and the accompanying digitalisation give companies the opportunity to make their processes more efficient through the automation and networking of their production and thus maintaining their competitiveness [3]. One technology that has great potential for connecting the real world with the virtual world is the digital twin (DT) [4]. This technology has a variety of application fields in the life cycle of a product.

For example, the DT can already be used in the design phase of a product to identify and reduce potential problems with products before they are produced [5]. It also enables a virtual commissioning of machinery, which speeds up the real commissioning and enables the detection of potential defects [6]. In addition, with the help of a DT, the training of employees can be carried out on a digital image, thus avoiding a stop in production or the generation of rejects [7]. If a product has sensors and the operating data generated by them are transferred to a DT, the condition of the product can be recorded and, if necessary, condition-based maintenance can be performed [8]. If this collected data is stored over a longer period, anomalies can be detected using various methods of data analysis, such as algorithms from machine learning [9]. Furthermore,

DOI: https://doi.org/10.15488/13448
ISSN: 2701-6277

the use of these methods in combination with a DT can determine the probability of failure of components if the database is adequate, thereby enabling predictive maintenance [10]. The collected data in the DT of a product provides information about the stresses during its life cycle and allows optimisation of the individual components of the product in order to extend its lifespan [11]. The use of a DT can also offer benefits for companies in the application areas of reuse, remanufacturing, and recycling of the product [12].

The fields of application of the DT listed here represent only a small part of the variety of different fields of application. Since it is often difficult for companies to identify the most suitable fields of application, this paper presents an approach that supports companies in identifying and evaluating the fields of application of a DT. This method is discussed in this paper after the introduction and the state of the art. The approach presented here is divided into 3 parts. First, the digital maturity level of the company is determined. Based on this result, suitable methods for identifying application fields are presented. After the successful identification, the selected application fields are evaluated to check whether the use of a DT is profitable in this application field. Subsequently, the method presented here is validated on an application example. Afterwards, the advantages and limitations of the method are shown in the discussion and, finally, the conclusion summarises the most important findings and gives an outlook on the need for further research.

2. State of the Art

This section presents various works in the areas of "Digital Maturity Level in Companies", "Identification of Application Fields of a Digital Twin" as well as "Evaluation of Application Fields of a Digital Twin".

To determine the digital maturity level of companies, Bastos et al (2021) developed a questionnaire. After evaluating this questionnaire, an index is calculated based on the points awarded and, with the help of this index, companies are classified in terms of their digital maturity [13]. Next, depending on the classification, measures are identified to increase digital maturity [13–15]. Gill et al. (2016) and Lödding et al. (2017) have also developed a questionnaire to determine the digital maturity of companies. In addition to these quantitative approaches, there are also qualitative approaches to determine the digital maturity of companies [16]. In many works, the term digital readiness is used instead of digital maturity. This will also be the case in this paper. Overall, there are some papers that determine the digital readiness of companies, but most approaches are very general and do not focus on the assessment of digital readiness for a DT. In 2020, the MSG Group published a study in cooperation with Fraunhofer IPK called "Digital Twin Readiness Assessment" [17]. In this study, the authors investigated how far the companies are regarding the use of a DT and which use cases are being pursued. However, an identification and evaluation of use cases did not take place but will be done in this paper alongside the determination of Digital Twin Readiness (DTR).

The life cycle of a product is often considered for the classification and identification of application fields of a DT [6,18]. Through the enrichment of data and models during the product life cycle, the DT of the real image is expanded and can thus be used for several application fields [19]. The classification of the different application fields can be based on the criteria of hierarchy, data flow type and functional benefit [20]. Other works refer to Industry 4.0 concepts to find application fields for the DT [21]. These concepts are sometimes extended to include the interdependence between the real and virtual image, in order to better classify the fields of application [22]. These works classify existing application fields and do not consider the identification of new application fields in their work. In contrast to these works, this paper provides an approach that presents different methods for identification and classification.

There are various possibilities for evaluating the fields of application of a DT. One possibility is the evaluation based on the aspects of business models, which can be done, for example, using the Business Model Canvas according to Osterwalder [23]. This model was used to evaluate a DT, but the model was not adapted to the application fields of the DT [24]. In addition to the aspects of a business model, the evaluation of the DT in the Data Science Canvas also involves the data situation in the company [25]. Simulations can be used to evaluate the possible effects of a DT when it is introduced and, in addition, interactions can be recognised [26,27]. The application field of a DT can also be evaluated via quality criteria such as extensibility, interoperability, transferability, and reusability [28]. The approach presented here represents a mixture of the evaluation opportunities presented here to be able to provide the appropriate evaluation depending on the field of application of the DT.

3. Method

For a generic identification and evaluation of application fields of a DT a modular system was developed. The aim of this system is to be able to respond to the digital readiness for a DT of different companies. The user is guided through steps A, B and C (see Figure 1). Each module contains sub-modules. The initial situation in the company is evaluated by determining the degree of digital readiness in all sub-modules of A. Based on the score of the assessment, a sub-module of module B is chosen by using a decision tree. These sub-modules aim to suit the needs of the company and provide a method to identify an application field of a DT. After an application has been identified using module B, the application is evaluated in module C.

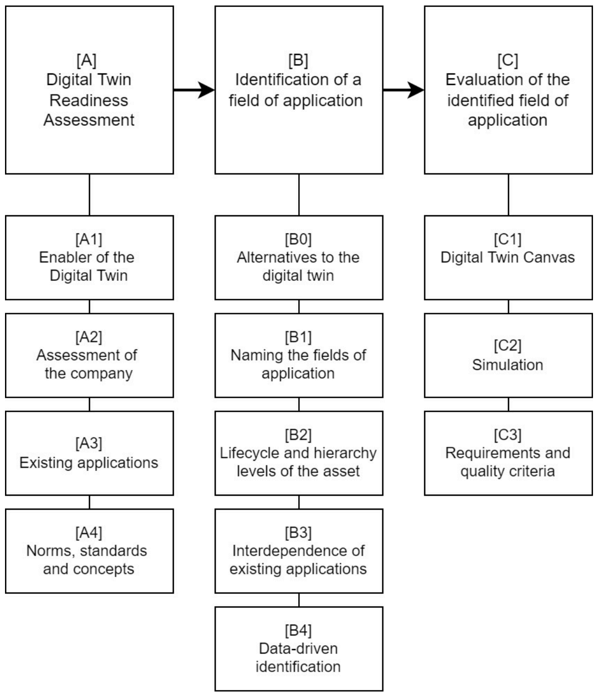

Figure 1: A modular system to identify and evaluate the application fields of a DT

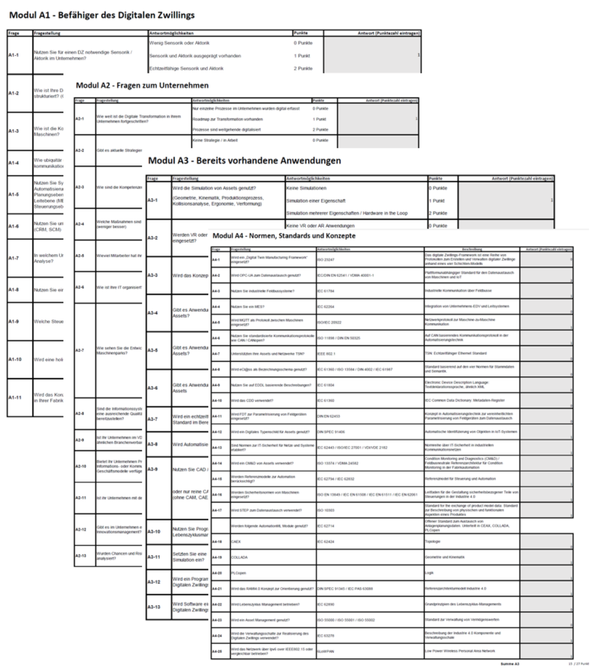

Figure 2: DT readiness assessment with point-based questionnaires

The module system ensures that:

- The method can easily be adopted by companies.
- The modular system allows to present different approaches to identify applications based on the digital readiness of various companies.
- Different perspectives can be taken.
- Companies can process the system in a short amount of time or in more detail.
- A further development of the modules and sub-modules can easily be adopted by adding modules.

Module A: Digital Twin Readiness Assessment:

The realisation of a DT can only be successful if the company has reached a high level of digital readiness in all areas - this requires increased agility and holistic thinking [17]. To determine the DTR, four point-based questionnaires are provided (see Figure 2):

A1 - Enabler of the DT: The enablers of Industry 4.0 were evaluated for the properties of a DT (the questionaries are inspired by [29,17,30]). Further questions regarding the enablers of a DT were explored.

A2 - Assessment of the company: The Digital Twin Readiness Assessment study [17] deals with questions in three "maturity areas" (understanding and commitment, targeting and concept, implementation of a DT). These questions are adapted to the assessed company and its structure. The questions were evaluated, and further questions were added.

A3 - Existing applications: Simulations, visualizations, digital models, and shadows can be completed to a DT by increasing the interdependence of the physical and the digital object. This block of questions also considers the whole spectrum of automation technologies and software like Profinet, Automation Studio, Siemens TIA, Ansys Twin Builder, AWS IoT TwinMaker, MS Azure DT, ISG-viruos, Mnestix and many more. The naming of technologies helps companies to get an overview of the market.

A4 - Norms, standards and concepts: Norms and standards that already have been introduced in companies provide information about the digital readiness of the company for a DT. The questions in this module are based on a list of norms of the DIN [31] , Platform Industrie 4.0 [32] and IEEE [13]. Only norms and standards that are relevant to the introduction of a DT were considered, like OPC-UA (IEC/DIN 62541), MQTT (IEC 20922), TSN (IEEE 802.1), eCl@ss (IEC 61360), AutomationML (IEC 62714), AAS (IEC 63278) and more.

Module B: Identification of a field of application:

The aim of module B is to identify one or more fields of application for the DT that does already exist in the company. Based on the result of the DTR a corresponding sub-module of B is chosen by a decision tree (B0 - B4). In these sub-modules, a perspective on the fields of application of the DT that corresponds to the degree of DTR is taken. Each sub-module thus represents one of several different perspectives on the fields of application of the DT.

B0 - Alternatives to the digital twin, initial situation: low DTR. Regarding the degree of the DTR, this module focuses on alternatives to the DT. The requirements for a company to introduce a digital shadow or model are lower than the requirements for introducing a DT. The perspective of this module is based on the decreasing interdependence (see Figure 5). These alternatives are a more sensible decision for companies with a low DTR. The aim should be to expand the application field in future by adding interdependence.
B1 - Naming the fields of application, initial situation: few DTR. It can be assumed that the company has little knowledge of the application fields of a DT. It is therefore useful to name and describe application fields to familiarize the companies with the spectrum of applications of a DT. Therefore, a table describing the application fields of a DT is provided. This method is often to be found if companies are looking for an identification in literature and web [33]. In addition to naming application fields, reflective questions are used to help the companies to understand and identify the applications of a DT.
B2 - Lifecycle and hierarchy levels of the asset, initial situation: average DTR. The decision tree also a check about the result in module A3 (existing applications of the DT). An average DTR means that a company usually has knowledge of application fields of the DT but has few or no applications of a digital model, shadow or twin. With the architecture model RAMI4.0 / DT a perspective on the life cycle and hierarchy axis can help companies to identify new applications with a provided template (see Figure 3). This represents a horizontal layer of the RAMI4.0 / DT model.

B3 - Interdependence of existing applications, initial situation: above average DTR. Applications and knowledge of a digital model or shadow are available. The perspective of this module is based on the increasing interdependence of existing applications (see Figure 5). The goal is to expand the dependencies between the physical and the digital object. An existing application of a digital model or shadow needs to be checked for the expandability of the interdependences successively to generate new applications. Maintenance of a machine prior based on condition monitoring can then be transformed into predictive maintenance by realising the bidirectional automated dataflow (and the corresponding algorithms for prediction).

B4 - Data driven identification, initial situation: high DTR. Applications of a digital model, shadow or twin are available. In this module the perspective of the company focuses on the dataflow. Companies with a high DTR are facing and solving the issues of big data. Therefore, a data-, a simulation- and a control-twin are considered in data mining, process mining and machine learning applications. For example, a data-twin can be used in machine learning applications for predictive maintenance. Another example could be a simulation-twin in data mining application for virtual commissioning.

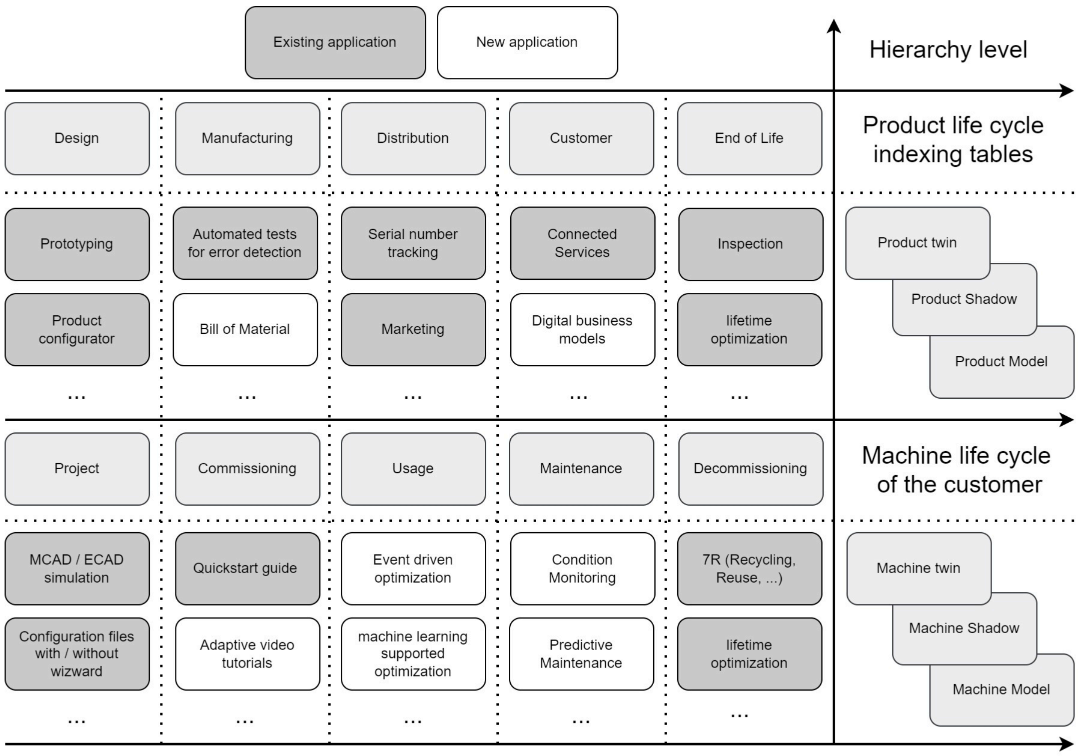

Figure 3: Module B2 - Lifecycle and hierarchy levels of the asset

Module C: Evaluation of the identified field of application

After one or more applications of a DT were identified, the aim of this module is to evaluate the application. An evaluation can be done under serval aspects: business model, investment, trend, functionality, requirements, and implementation.

C1 - Digital Twin Canvas: A canvas is an intuitive model for evaluating different aspects. The Digital Twin canvas addresses the aspects of business model, investment, and trend of an application. Different already existing canvases were evaluated regarding their applicability to the subject of a DT:

- Business Modell Canvas [23]
- Data Science Canvas [34]
- Trendmicrocosmos [35]

To meet the requirements of evaluating a DT, individual elements were taken and supplemented. The Digital Twin Canvas covers the following aspects seen in Figure 6:

Driver, Disruptors, Digital Readiness, Key Resources, Value Propositions, Implementation, Customer, Data, Key Resources, Synergies, Channels, Cost Structure, Revenue Streams.

C2 - Simulation: A simulation can validate the functionality of an application field. A simulation can also be used to evaluate the effects of realizing an application. The concepts developed during a simulation can be used in the implementation of the DT.

C3 - Requirements and quality criteria: This module is considering all aspects regarding the requirements [28] and quality criteria (ISO/IEC 25000) of an application if implemented.

4. Use Case

To evaluate the applicability of the method a study was carried out with eight different companies between May and September 2022. The company WEISS GmbH processed all modules of the method.

About the WEISS Group:

With its automation solutions, WEISS GmbH is one of the world's leading system suppliers in the automotive industry, machine and plant manufacturing, life science, and electronics. The reliable and durable rotary indexing tables (see Figure 4), handling units, delta robots, and linear transfer systems are making the industrial production of tomorrow a reality. By applying their engineering expertise, knowledge of industries and processes, and high affinity for serving customers, the experts assist system integrators and producers in designing and operating innovative and sustainable production plants. Founded in 1967, WEISS now has a staff of around 700 employees in its sales, service, and manufacturing locations in 49 countries.

Module A:

The DTR of the company was determined in cooperation with a product manager for controls and digitalization and also the development engineer for advanced development. The DTR result was above average and knowledge about the application fields of the DT was available. Therefore, the decision tree directed the company to proceed with module B3, the increasing of the interdependency of existing applications.

Module B:

The Weiss GmbH already has existing applications in the preliminary stages of a DT. By extending bidirectional data exchange, these offer potential for new applications of a DT. Thus, the sub-module B3 is ideally suited to the company´s initial situation. Here, new applications for the DT can be identified (see Figure 5): Condition-based Maintenance with the possibility of further development to predictive maintenance with anomaly detection, an event-controlled optimization with the possibility of further development for artificial intelligence and a hardware agnostic commissioning.

Module C:

Digital Twin Canvas: Condition-based maintenance was selected for the evaluation from several identified applications, since WEISS GmbH aims to introduce condition-based maintenance for different components in a timely manner. With the Digital Twin Canvas, the application was evaluated according to various aspects. In 45 minutes, the drivers, disruptors, the digital readiness, the key resources, the value proposition, the implementation, potential customers, the data situation, the key activities, synergies, channels, the costs and the revenues of condition-based maintenance in the company could be evaluated (see Figure 6). This increased the understanding of the different aspects of the new application.

Figure 4: WEISS indexing table

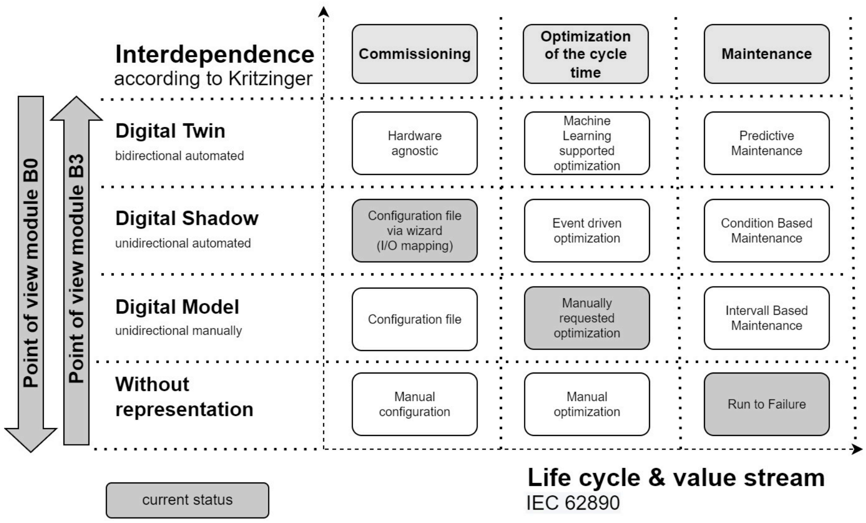

Figure 5: Improving the interdependence of an asset

Digital Twin Canvas: Application Condition Monitoring - Weiss GmbH

Driver
Fewer and fewer people are working in production facilities and robots are replacing staff. The human senses (seeing, hearing, etc.) need to be digitized. Data-driven business models enable a secure future. Differentiation from the competition is necessary. Customer expect Condition Monitoring in future products.

Disruptor
Incorrect interpretations / messages lead to increased downtimes and thus to higher costs and a loss of image. Customer acceptance is lower than expected. Customers may not want Condition Monitoring. A crowding out from the market by "big players" in the field of Condition Monitoring is possible.

DT Readiness
New development in the company - but skills have been improved through education and training. The domain knowledge was strengthened. The infrastructure was created. The company's mindset regarding CM was strengthened.

Key Resources
- sensors
- infrastructure
- data preparation and analysis
- human skills

Value Proposition
- a data collection that describes the state of the component
- domain knowledge for customers
- increase the availability of the system
- production peaks analyses are better assessable
- increased transparency in the production
- data for future projects
- deeper insights into the production process

Implementation
- hardware development (measuring technologies)
- software development (data acquisition, preprocessing)
- product development (link mechanics and measurement technology)
- integration into the service landscape
- and business model

Potential Customers
- external customers (machine builders / integrators / operators)
- internal customers (service, development, quality assurance)

Data
- Machines are already operating in a test field
- data is used to develop artificial intelligence applications
- validation for algorithm

Key Activities
- data driven developed business models
- training of the sales staff
- service development

Synergies
- process optimizations
- ERP notifications at events
- improved ability to communicate for the components
- know-how generation
- more insights into the use of the components

Channels
- new deliveries
- retrofit existing products
- retrofit for repairs as a service
- magazines
- lectures
- trade fairs
- automation platforms
- associations

Cost Structure
- hardware / software development costs
- manufacturing costs
- infrastructure costs
- operating costs
- employee training
- IT security costs

Revenue Streams
- hardware (measurement technology, sales indexing tables)
- training for customers
- data-driven business models
- service contracts

Figure 6: Digital Twin Canvas for evaluating different aspects of the application

Simulation: An important step in evaluating an identified application is a comparison of possible improvements with the current state. The simulation offers an opportunity to illustrate complex relationships and interactions. Furthermore, customers can also benefit from the evaluation of the application through a simulation. The WEISS GmbH agreed to carry out a simulation of Run to Failure, Condition-based and predictive maintenance based on data from their service work.

5. Discussion

To validate the developed method structured expert interviews were designed and conducted to examine whether the modular system can help companies to identify as well as evaluate the application of a DT and is therefore useful in practice. These are the results:

- Module A is seen as a good introduction to the topic for companies. Some have already been able to identify first applications based on the questions and the gaps that have been identified. Clarity about the status quo is created.
- Companies that have already identified applications of a DT before, see their decision confirmed. The method can therefore be used to validate existing applications.
- Repeated processing of the modular system by using different personas can provide new insights.
- For all participating companies the development of norms and standards is essential in the future.
- The Simulation showed that Condition-based and predictive maintenance have a positive effect on the detection time of a defect, the number of fatal defectives, the total disruption time and enables remote maintenance.

Limitations:

- The method is limited to applications for manufacturing companies. Considering the twin of a person, the weather or the environment would meet the generic claim of the method but reduce the quality of the work. Many companies gave feedback that an industry-specific approach to identifying and assessing DT application can provide better solutions than a generic approach. For this reason, an even more detailed method is more sensible than a general one.
- The implementation of an identified and evaluated application was not considered in this work. However, there is sufficient literature in the form of frameworks or standard software for e.g., virtual commissioning, condition monitoring, predictive maintenance or asset administration shell. However, a method that takes all steps into account would be of great value in practice.

The modular system can be used in practice for a management consultancy. However, companies are also able to use this work as a guide to familiarize themselves independently with the topic of identification and evaluation, to determine their degree of maturity, and to identify and evaluate new applications of a DT. Individual concepts of this work can be useful for further research and in practice. The determination of the DTR for the DT, the RAMI4.0/DT model and the Digital Twin Canvas offer many possible applications due to their generic approach. The modular principle of the method also allows modules or sub-modules to be exchanged or supplemented.

6. Conclusion

In this paper, a method has been introduced with which application fields of a DT for a company can be identified and evaluated. The method is divided into 3 modules, which were presented after the introduction and the state of the art. In Module A, the DTR of a company is derived with the help of a questionnaire and the score calculated from it. In Module B, various approaches are used to identify areas of application for a DT based on the company's DTR. Finally, Module C evaluates the identified fields of application. Subsequently, the results of the application of the developed method in cooperation with WEISS GmbH are described. Finally, the advantages and limitations of the method were shown in the discussion.

There is a need for further research, especially in the adaptation and evaluation of the sub-modules of the method, as the research field of DT’s is continuously developing. In addition, standards and norms are constantly being revised or further ones published. Due to the expandability and adaptability of the method, these changes can be considered, and the modules can be adapted accordingly. The evaluation of the application fields of the DT should also be expanded to include ecological criteria, as the evaluation is mainly based on economic and qualitative criteria. Due to the increasing consequences of climate change, an evaluation from an ecological point of view will become essential for companies in the future, as the various possible uses of the DT can save resources and energy and enable an efficient recycling.

References

[1] Pistorius, J., 2020. Industrie 4.0 – Schlüsseltechnologien für die Produktion: Grundlagen • Potenziale • Anwendungen. Springer Vieweg, Berlin, Heidelberg, 2 pp.

[2] Ciupek, M., 2022. Diese sechs Megatrends entscheiden über die Wettbewerbsfähigkeit der Industrie. https://www.vdi-nachrichten.com/technik/produktion/diese-sechs-megatrends-entscheiden-ueber-die-wettbewerbsfaehigkeit-der-industrie/. Accessed 22 April 2022.

[3] Schebek, L., Kannengießer, J., Campitelli, A., Fischer, J., Abele, E., Bauerdick, C., Anderl, R., Haag, S., Sauer, A., Mandel, J., Lucke, D., Bogdanov, I., Nuffer, A.-K., Steinhilper, R., Böhner, J., Lothes, G., Schock, C., Zühlke, D., Plociennik, C., Bergweiler, S., 2017. Ressourceneffizienz durch Industrie 4.0: Potenziale für KMU des verarbeitenden Gewerbes. https://www.ressource-deutschland.de/fileadmin/Redaktion/Bilder/Newsroom/Studie_Ressourceneffizienz_durch_Industrie_4.0.pdf. Accessed 22 April 2022.

[4] Barwasser, A., 2021. Resiliente Wertschöpfung: mit Digitalem Zwilling zu Transparenz und Krisenfestigkeit. Fraunhofer IAO. https://blog.iao.fraunhofer.de/resiliente-wertschoepfung-mit-digitalem-zwilling-zu-transparenz-und-krisenfestigkeit/. Accessed 24 April 2022.

[5] Kennel, M., Juhasz, T., 2017. Engineering mit VINCENT – Der digitale Zwilling für die Entwicklungsphase. https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9605af7f-a040-4181-bbb9-4ee789c8b5e0/content. Accessed 21 October 2022.

[6] Güntner, G., Hoher, S., 2020. Digital Twins im Anlagen-Lebenszyklus.

[7] Back, M., 2020. So funktioniert der digitale Zwilling: Voraussetzungen, Möglichkeiten und ein 5-Schritte-Programm. https://www.technik-und-wissen.ch/digitaler-zwilling-voraussetzung-und-moeglichkeiten.html. Accessed 21 October 2022.

[8] Aivaliotis, P., Georgoulias, K., Arkouli, Z., Makris, S., 2019. Methodology for enabling Digital Twin using advanced physics-based modelling in predictive maintenance. Procedia CIRP 81, 417–422.

[9] Thiele, C.-D., Brötzmann, J., Huyeng, T.-J., Rüppel, U., Lorenzen, S.R., Berthold, H., Schneider, J., 2021. A Digital Twin as a framework for a machine learning based predictive maintenance system, in: Semenov, V., Scherer, R.J. (Eds.), ECPPM 2021 – eWork and eBusiness in Architecture, Engineering and Construction. CRC Press, London, pp. 313–319.

[10] Classens, K., Heemels, W.M., Oomen, T., 2021. Digital Twins in Mechatronics: From Model-based Control to Predictive Maintenance, in: Proceedings, 2021 IEEE 1st International Conference on Digital Twins and Parallel Intelligence (DTPI 2021). Jul. 15-Aug. 15, 2021, Beijing, China. 2021 IEEE 1st International Conference on Digital Twins and Parallel Intelligence (DTPI), Beijing, China. 7/15/2021 - 8/15/2021. IEEE, Piscataway, NJ, pp. 336–339.

[11] Schmitt, J., Richter, R., Deuse, J., Zarges, J.-C., Heim, H.-P., 2021. Digitaler Zwilling in der Kunststofftechnik: Lebensdaueroptimierte Herstellung technischer Bauteile durch Einsatz datengetriebener Methoden.

[12] Wang, X.V., Wang, L., 2019. Digital twin-based WEEE recycling, recovery and remanufacturing in the background of Industry 4.0. International Journal of Production Research 57 (12), 3892–3902.

[13] Bastos, A., Sguario Coelho De Andrade, M.L., Yoshino, R.T., Santos, M.M.D., 2021. Industry 4.0 Readiness Assessment Method Based on RAMI 4.0 Standards. IEEE Access 9, 119778–119799.

[14] Gill, M., VanBoskirk, S., 2016. The Digital Maturity Model 4.0: Benchmarks: Digital Business Transformation Playbook.

[15] Lödding, H., Riedel, R., Thoben, K.-D., Cieminski, G. von, Kiritsis, D., 2017. Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing. Springer International Publishing, Cham.

[16] Schuh, G., Anderl, R., Dumitrescu, R., Krüger, A., ten Hompel, M., 2020. Der Industrie 4.0 Maturity Index in der betrieblichen Anwendung: Aktuelle Herausforderungen, Fallbeispiele und Entwicklungstrends. acatech KOOPERATION.

[17] Samarajiwa, M., Kai Lindow, David Salamon, Rainer Stark, 2020. Digital Twin Readiness Assessment: Eine Studie zum Digitalen Zwilling in der fertigenden Industrie, 1st ed. Fraunhofer Verlag, 2 pp.

[18] Massonet, A., Kiesel, R., Schmitt, R.H., 2020. Der Digitale Zwilling über den Produktlebenszyklus. Zeitschrift für wirtschaftlichen Fabrikbetrieb 115 (s1), 97–100.

[19] Mandolla, C., Petruzzelli, A.M., Percoco, G., Urbinati, A., 2019. Building a digital twin for additive manufacturing through the exploitation of blockchain: A case analysis of the aircraft industry. Computers in Industry 109, 134–152.

[20] Newrzella, S.R., Franklin, D.W., Haider, S., 2021. 5-Dimension Cross-Industry Digital Twin Applications Model and Analysis of Digital Twin Classification Terms and Models. IEEE Access 9, 131306–131321.

[21] Deuter, A., Pethig, F., 2019. The Digital Twin Theory. I40M 2019 (1), 27–30.

[22] Kerber Florian, Eichinger Peter, Förster, F., Händel, G., 2022. Der Digitale Zwilling im industriellen Kontext - Eine regionale Perspektive. TTZ Flexible Automation.

[23] Osterwalder, A., 2013. Business model generation: A handbook for visionaries, game changers, and challengers, 1st ed. Wiley & Sons, New York, 278 pp.

[24] Klostermeier, R., Haag, S., Benlian, A., 2020. Geschäftsmodelle digitaler Zwillinge. Springer Fachmedien Wiesbaden, Wiesbaden.

[25] Stevens, G., Bossauer, P., Esau, M., Neifer, T., 2020. Data Science Canvas: Ein Instrument zur Operationalisierung von Daten. https://www.kompetenzzentrum-usability.digital/kos/WNetz?art=News.show&id=985. Accessed 21 October 2022.

[26] Oppermann, I., 2021. Von der Simulation bis zur virtuellen Inbetriebnahme. CITplus 24 (7), 38–39.

[27] Schluse, M., Roßmann, H.-J., 2021. Von der Simulation zum Experimentierbaren Digitalen Zwilling und zurück, in: Franke, J., Schuderer, P. (Eds.), Simulation in Produktion und Logistik 2021. Erlangen, 15.-17. September 2021, 1. Auflage ed. Cuvillier Verlag, Göttingen.

[28] Moyne, J., Qamsane, Y., Balta, E.C., Kovalenko, I., Faris, J., Barton, K., Tilbury, D.M., 2020. A Requirements Driven Digital Twin Framework: Specification and Opportunities. IEEE Access 8, 107781–107801.

[29] Martinelli, A., Mina, A., Moggi, M., 2019. The Enabling Technolgies of Industrie 4.0: Examining the seeds of the fourth industrial revolution. Industrial and Corporate Change (30).

[30] VDMA, RWTH Universität Aachen, IW Consult GmbH, 2022. Industrie 4.0-Readiness-Check: Where does your business stand? Check your readiness for Industry 4.0! https://www.industrie40-readiness.de/?lang=en. Accessed 19 September 2022.

[31] Deutsches Institut für Normung e. V., 2022. Normen und Standards - Industrie 4.0. https://www.din.de/de/forschung-und-innovation/themen/industrie4-0/normen-und-standards. Accessed 19 September 2022.

[32] Adolphs, P., Auer, S., Bedenbender, H., Billmann, M., Hankel, M., Heidel, R., Hoffmeister, M., Huhle, H., Jochem, M., Kiele-Dunsche, M., 2016. Struktur der Verwaltungsschale: Fortentwicklung des Referenzmodells für die Industrie 4.0-Komponente. Ergebnispapier der Plattform Industrie 4.0.

[33] Fuller, A., Fan, Z., Day, C., Barlow, C., 2020. Digital Twin: Enabling Technologies, Challenges and Open Research. IEEE Access 8, 108952–108971.

[34] Stevens, G., Bossner, P., Esau, M., Neifer, T., 2022. Data Science Canvas: Ein Instrument zur Operationalisierung von Daten. https://www.kompetenzzentrum-usability.digital/kos/WNetz?art=News.show&id=985. Accessed 19 September 2022.

[35] Blechschmidt, J., 2021. Quick Guide Trendmanagement: Wie Sie Trendwissen in Ihrem Unternehmen wirksam nutzen, 1st ed. Springer Heidelberg, Berlin, Heidelberg, 116 pp.

Biography

Fabio Oettl (*1994) is a research assistant at the Digital Manufacturing Group at the University of Augsburg since 2019. From 2013 to 2018 he studied Industrial Engineering. His main research focuses is one the identification and evaluation of application fields of the digital twin and their introduction in companies.

Sebastian Dietl (*1988) researches the applications fields of the digital twin. His focus is on the bidirectional data exchange of components with different protocols. From this he develops IoT applications such as dashboards, stream processing, condition monitoring, anomaly detection and predictive maintenance.

Christian Göltl (*1983) has been Product Manager at the Weiss Group since 2018. He is responsible for drive technology, software and digitalization. His focus is on creating smart Weiss products and new business models. He is member of VDMA IAS working group and the TwinStore community.

Daniel Müssig (*1993) has been Development Engineer - Advanced Development at the Weiss Group since 2018. His focus is on creating smart solutions for existing as well as new products in digitization. With his studies in Mechanical Engineering he connects the gathered data with the mechanical products.

Johannes Schilp (*1976) has been Chair of Digital Manufacturing since 2015. He is also head of the processing department at the Fraunhofer Research Institution for Casting, Composite and Processing Technology and member of scientific networks like WG MHI and automation research groups (VDMA).