A survey on the industry's perception of digital twins – a follow-up to the digital twin workshop at the DESIGN Conference 2022

Citation for the original published paper (version of record):
Fett, M., Zwickler, J., Wilking, F. et al (2024). A survey on the industry's perception of digital twins – a follow-up to the digital twin
workshop at the DESIGN Conference 2022. Proceedings of the Design Society, 4: 2039-2048.
http://dx.doi.org/10.1017/pds.2024.206

INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.206

A survey on the industry's perception of digital twins – a follow-up to the digital twin workshop at the DESIGN Conference 2022

Michel Fett [1,✉], Julius Zwickler [1], Fabian Wilking [2], Stefan Goetz [2], Sebastian Schweigert-Recksiek [3], Ben Hicks [4], Oscar Nespoli [5], Kristina Wärmefjord [6], Sandro Wartzack [2] and Eckhard Kirchner [1]

[1] Technische Universität Darmstadt, Germany, [2] Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany, [3] :em engineering methods AG, Germany, [4] University of Bristol, United Kingdom, [5] University of Waterloo, Canada, [6] Chalmers University of Technology, Sweden

✉ michel.fett@tu-darmstadt.de

Abstract

Digital Twins are perceived differently between and within industry and academia regarding applications and potentials. For this reason, a round table was formed based on the Digital Twin Workshop of the Design Conference 2022. One of the results of this round table is this contribution, which deals with a survey within the industry. The survey captured the understanding of the different roles in the creation and use of Digital Twins, the requirements and hurdles as well as the perception of methodological support. In addition, factors that influence the perception were identified.

Keywords: digital twin, survey, design workshop, industry 4.0

1. Introduction

Digital Twins offer a multitude of potential benefits and are gaining popularity in both academic and industrial contexts. Prospective fields of application and research range from the recording of individual variables of interest for single components to the condition monitoring of an entire system. Despite this shared interest, a common understanding between and within industry and academia regarding application, definitions, and expectations of the concept of the Digital Twin hardly exists.

Thus, efforts are being made to consolidate and unify the understandings and expectations of the scientific community, for example through publications such as the WiGeP position paper, in which an association of German university professors plead for a uniform definition (Stark *et al.*, 2020). However, there are hardly any efforts in the literature to bridge the gap between the academic and the industrial perspective. For this reason, this contribution presents a survey to capture and interpret the industry's view. This is intended to strengthen communication and cooperation between industry and academia by

- capturing and formalizing the industrial perspective of Digital Twins, and
- establishing the factors that drive the industrial perspective.

2. Fundamentals

This section first explains the theoretical fundamentals of the Digital Twin concept, followed by a description of the Digital Twin workshop held at the DESIGN Conference 2022, which resulted in the roundtable on which this contribution is based.

2.1. Digital Twins

A Digital Twin (DT) is a digital representation of a system, which in this context is called a physical twin. Sensors are installed on the physical twin to record operating data. This data is transferred to the Digital Twin via a suitable IT infrastructure. The Digital Twin is based on simulation and calculation models that map the behaviour of the physical twin and are fed with the acquired sensor data. Virtually any behaviour and any property that can be modelled to a satisfactory extent can be represented. The results of the simulations and calculations are then fed back into the physical world, ensuring a bidirectional exchange of data (Stark *et al.*, 2020; Czwick *et al.*, 2020; Trauer *et al.*, 2020). The results of the simulations and calculations can then be used to display them to a user, who then makes decisions based on them. Alternatively, the Digital Twin can make decisions within a previously defined range and make recommendations for action, such as the replacement of critical components (Wilking *et al.*, 2021). Even though Digital Twins are based on models for calculation and simulation, the Digital Twin concept differs from conventional simulation. Differences are e.g. the bidirectional data exchange in real time and the additional logic for information processing. Digital Twins have a multitude of potentials for developers, manufacturers, and users of products. Some of these potentials are, for example, condition monitoring and predictive maintenance, monitoring of performance, and adjustments of the operating parameters of the product (Wilking *et al.*, 2021). Digital Twins can be applied to diverse industries and types of systems. These systems can be products, especially technical products, which is called a product DT. If several products are linked in a communicative network, this is known as the Internet of Things (IoT). This can also be represented by Digital Twins. Since the processes and interactions between the individual systems are often in the foreground, this is referred to as an IoT or process DT (Hoz Diego *et al.*, 2022; Li *et al.*, 2022). Spatial Digital Twins describe an even larger scope, namely a physical location or environment such as buildings, industry plants, but also botanical environments such as farmland or forests. A special case of spatial Digital Twins is the City DT (Ali *et al.*, 2023). Finally, biological systems can also be represented by DT. A prominent example is the creation of a Digital Twin from a human body to a human DT. Reasons for this can be the improvement of medical treatment (Wang *et al.*, 2022). The literature already contains initial surveys on the topic of Digital Twins. Biesinger et al. consider the necessity for a Digital Twin for the production in the automotive industry (Biesinger *et al.*, 2019). Udugama et al. ask about the application of big data and Digital Twin concepts in Denmark (Udugama *et al.*, 2021), while Lei et al. 2020 XXX record in their survey challenges of urban Digital Twins (Lei *et al.*, 2023).

2.2. DESIGN workshop 2022 on Digital Twins

As part of the DESIGN Conference 2022, a digital workshop was held on the topic of Digital Twins. The organizers of this workshop were Professor Ola Isaksson (Chalmers University), Professor Oscar Nespoli (University of Waterloo) and Professor Eckhard Kirchner (TU Darmstadt). The workshop started with six presentations on different Digital Twin related topics. Afterwards, the questions presented were discussed with around 50 participants in small groups and the results were exchanged. The high number of participants from academia and industry as well as the discussions encouraged further meetings with several participants, speakers, and organizers of the workshop in the form of a roundtable with about ten members. The members included an international selection of several professors and their staff, as well as industry representatives from an SME and a multinational corporation. During these roundtable meetings, the findings were further discussed, and key questions were formulated as a result. Since the results of this contribution were originally created during a workshop at the last DESIGN conference and were developed together with the organizers and participants of this workshop, the results will be submitted again at a DESIGN conference.

2.3. Creation, execution, and evaluation of the survey

The members of the roundtable have a strong academic background, which is why viewpoints, potentials and challenges facing the industry can mostly be considered indirectly. For this reason, it was decided to capture the industry's perspective with the help of an online survey. For this purpose, the key questions developed during the roundtable were adopted and translated into an online survey format. The questions

https://doi.org/10.1017/pds.2024.206 Published online by Cambridge University Press

were divided into four sets. First, demographic information was collected. Next, the roles necessary to create and implement Digital Twins were discussed, followed by the use cases and business models. The last set of questions dealt with challenges and opportunities. The specific questions and their assignment to the sets are presented in the following section. The survey was created in Tivia's survey software Unipark. The survey was then distributed to potential participants via the online platform LinkedIn, as it is primarily used by people from industry to exchange information about their experiences and to network. The target group were people who had mentioned experience with Digital Twins on their LinkedIn profile. A total of 82 people completed the survey. During the evaluation, the distributions of the answers were considered. The respondents were divided into distinct groups, allowing comparison across roles.

3. Results of the survey

This section describes the results of the survey. The demographic information of the respondents is discussed first, followed by a summary of their responses to the three remaining sets of questions.

3.1. Demographic information and categorization of responses

In terms of regions, Europe accounts for more than half of the respondents, with Asia and North America each accounting for about a fifth. In contrast, there are only a few respondents from South America and Australia, see Figure 1 (left). This distribution may be traced back to the fact, that the survey was carried out from Europe and, thus, does not represent the interest of the corresponding regions on the subject of the Digital Twin. Most of the study respondents have been working in a profession related to Digital Twins for 5 or fewer years (47%) or between 6 and 10 years (31%). Far fewer respondents have 11 to 15 years of experience (10%), 16 to 20 years (5%) or over 20 years (7%), see Figure 1 (right).

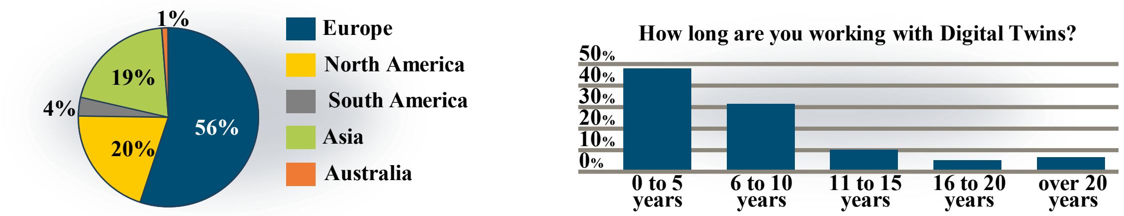

Figure 1. Origin of survey respondents (left) and their experience with Digital Twins (right)

First, the participants were asked **which types of Digital Twins are most relevant** to them. The type of the IOT/Process DT (54%) is relevant for most respondents, followed by Product DT (44%) and Spatial DT (43%). Only one third of the respondents are interested in City DT (33%) and only 11% in Human DT, see Figure 2 (left). As with all questions in this survey, respondents were able to make more than one selection, resulting in the sum of all answers being above 100%.

This is followed by the question of what the **purpose of a Digital Twin** is for the participants. For most respondents, the main purpose is optimization and efficiency (65%) or decision support (60%). 56% of the respondents see Digital Twins more in the context of simulation and analysis and 51% in monitoring and predictive maintenance. The least prominent, but still significant (41%), is the usage of Digital Twins in design and development, see Figure 2 (right).

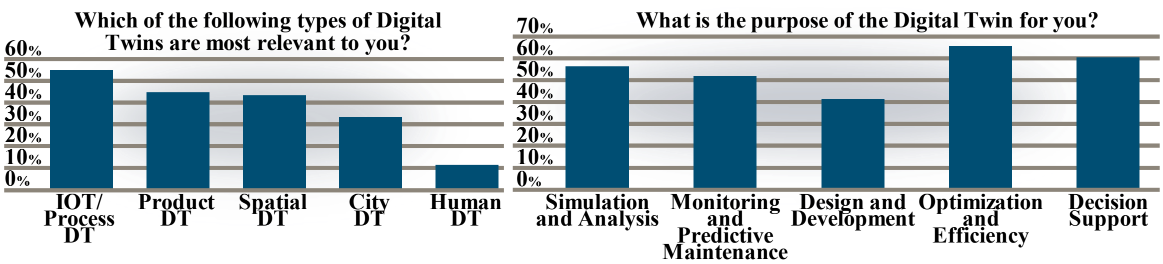

Figure 2. Distribution of answers on what type of Digital Twins the respondents use (left) and what purpose they serve (right)

https://doi.org/10.1017/pds.2024.206 Published online by Cambridge University Press

To structure the results of the survey and to enable the examination from different perspectives, two categorizations were derived from the previous questions. The first categorization was derived from the question about years of experience, which is divided into less and more than 10 years. The second categorization was derived from the question about the relevant type of DT. The answers "Product DT" and "Process DT" were grouped into the category "Technical DT". Similarly, the answers "Building DT" and "Human DT" were combined into "non-technical DT". In addition, options for other categorizations were examined, such as the influence of the stated purposes of the Digital Twin, see Figure 2 (right). However, these had no visible influence on the perception of the Digital Twin and are therefore not further discussed.
In the following sections, a selection of results of the survey are examined in detail. The graphs in the following sections show the distribution of the answers of all respondents in the survey in blue. In particular cases, significant differences can be seen between distinct groups of respondents. These are then shown as narrow bars above the wider bars of the overall averages. The assignment of the narrow bars to the individual groups can be seen in the legend of the respective figure.

3.2. Roles in the creation and implementation of Digital Twins (Who?)

The respondents of the study show no agreement on the question of who the ***key stakeholders*** are in the creation and implementation of Digital Twins. A large proportion of respondents report that these are engineering development (60%), followed by maintenance and operations teams (55%), management (51%), data scientists and analysts (51%), production and manufacturing (48%) or IT and technology professionals (48%). Far fewer see suppliers and vendors (28%) or regulatory authorities and compliance experts (26%) in this role. Of note is that respondents with more than 10 years of experience compared to those with fewer than 10 years select engineering development stakeholders at 75% compared to 56% and management at 75% compared to 45%. The same respondents also see vendors and suppliers as key stakeholders with 56% compared to 20%. This distribution can be seen in Figure 3 on the left.
The whole respondent group has a clear opinion on the question of who the ***most likely creators*** of the Digital Twin are. These are cross-disciplinary teams with engineering, IT, and data analytics expertise (74%), followed by engineering development (50%). Production and manufacturing (31%) and research institutions and universities (28%) are also worth mentioning. The respondents see collaborative initiatives and consortia (20%), IT (19%), management (13%), C-suite executives with responsibility for in-service and maintenance (10%), government agencies (9%) or investors and financial stakeholders (3%) as less likely creators. Notwithstanding the generally strong agreement, there is an observable influence of the years of experience on the perception of whether research institutions and universities are possible creators. Respondents with less than 10 years of experience see disproportionately often research institutions and universities (31% compared to 13% with more than 10 years of experience) as creators. Figure 3 on the right side shows this distribution.

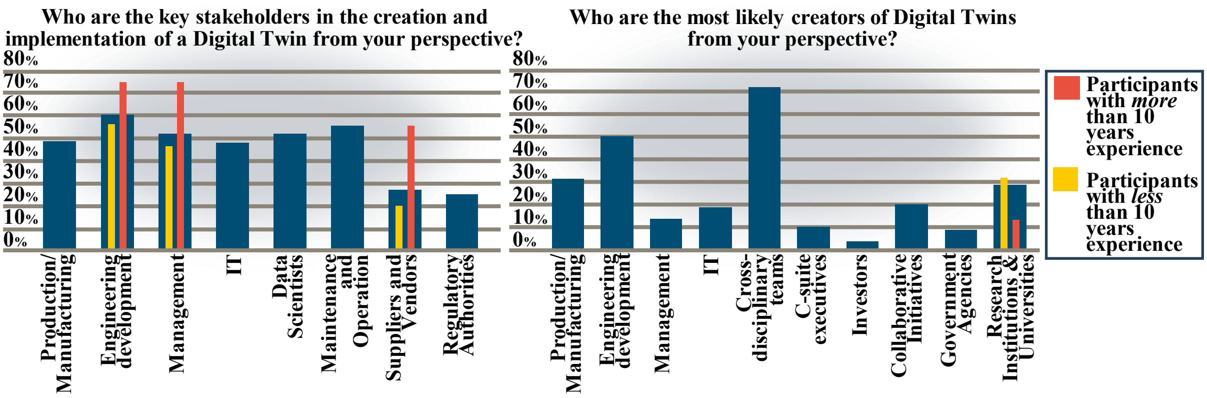

Figure 3. Distribution of answers regarding the key stakeholders (left) and most likely creators (right) of Digital Twins

https://doi.org/10.1017/pds.2024.206 Published online by Cambridge University Press

As ***most likely operators of the Digital Twin,*** the whole respondent group sees production or manufacturing employees (53%), followed by engineering development (43%) and cross-disciplinary teams with engineering, IT, and data analytics expertise (43%). Fewer see management (26%), C-suite executives with responsibility for in-service and maintenance (24%), government agencies (21%), IT (20%), collaborative initiatives and consortia (16%), research institutions and universities (16%) or investors and financial stakeholders (10%) as likely operators. Regarding the categorization of the type of the Digital Twin, differences can be seen between users of technical and non-technical DT. Users of technical DT are more likely to understand production or manufacturing personnel (61% compared to 37%) as operators. In comparison, users of non-technical DT are more likely to see government agencies (37% compared to 17%) in this role. In terms of experience groups, far more respondents with more than 10 years of experience see engineering development (69% compared to 36% with less than 10 years of experience) or cross-disciplinary teams (63% compared to 38%) as the most likely operators, see Figure 4 (left).

In terms of the ***most likely funders of the Digital Twin***, the whole respondent group sees the management (46%) as the primary funders. In second place are C-suite executives with responsibility for in-service and maintenance (38%) and in third place investors and financial stakeholders (36%) followed by government agencies (34%). Less likely to be considered as funders are production or manufacturing (25%), research institutions and universities (23%), engineering development (16%), cross-disciplinary teams with engineering, IT, and data analytics expertise (15%), collaborative initiatives and consortia (15%) or IT (4%). Users of non-technical DT see funding disproportionately on the side of government agencies (60%) compared to 33% for users of technical DT. Furthermore, users with less than 10 years of experience disproportionately see research institutions and universities (27%) in this role compared to 6% of users with more than 10 years of experience, see Figure 4 (right).

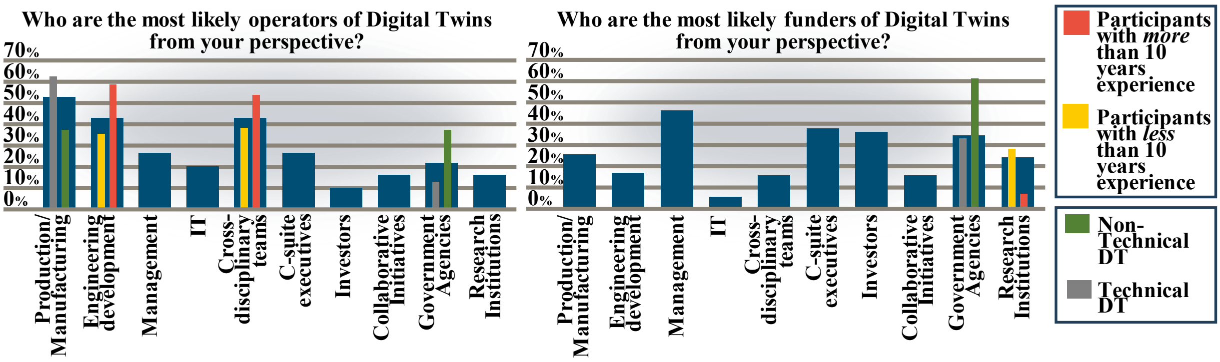

Figure 4. Distribution of answers regarding the most likely operators (left) and most likely funders (right) of Digital Twins

3.3. Use cases and business models (Why?)

The respondents of the study report ***current use cases of Digital Twins*** as being most common in condition monitoring and predictive maintenance (71%), followed by real-time performance analysis (69%), simulation-based design and virtual product development (66%) or optimization of manufacturing processes and supply chain management (64%). Virtual commissioning and testing of industrial equipment or systems (45%), case studies (40%) or network optimization (28%) are perceived as less common, see Figure 5 (left). The experience or the type of the Digital Twin which the respondents use have no considerable influence on this distribution.

Based on the use cases, the participants were asked which ***implemented (or known) business models*** they perceive. The participants see virtual training and education (63%) as most important. This is followed by Software as a Service (SaaS) (55%), consulting and integration services (50%) or data sharing and collaboration (50%). Data monetization (39%), product-service and function sales models (38%), performance-based contracts or equipment-as-a-service (26%) or licensing and intellectual property (18%) are rated lower. Respondents with more than 10 years of experience disproportionately value performance-based contracts or equipment-as-a-service (44% compared to 22% for respondents

https://doi.org/10.1017/pds.2024.206 Published online by Cambridge University Press

with less than 10 years of experience) and licensing and intellectual property (38% compared to 13%) as implemented or known business models, see Figure 5 (right).

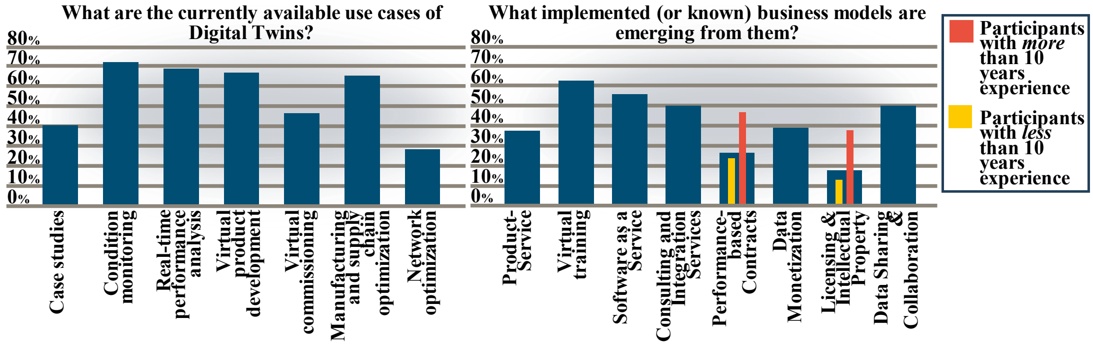

Figure 5. Distribution of answers regarding current use cases (left) and business models (right) of Digital Twins

The participants were also asked what they consider to be ***potential (but not yet implemented) use cases*** of the Digital Twin. The respondents consider complex and dynamic systems like infrastructure, airspace, space, shipping, and health (48%) and energy grid optimization (44%) to be particularly relevant. This is followed by usage in the context of natural disaster management and response (39%), smart cities and urban planning (39%), product improvement through geometrical variation reduction and field data utilization (36%), or climate modelling and environmental management (34%). Less relevant use cases are supplementing system models with real-world data (30%), healthcare and personalised medicine (28%), retail and customer experience (24%), performance-based contracts like equipment-as-a-service (24%), data monetization (24%) or data sharing and collaboration (23%). Less than one in five respondents selected product-service and function sales models (18%), virtual training and education (18%), Software as a Service (SaaS) (16%), licensing and intellectual property (15%), or consulting and integration services (14%). As mentioned above, respondents could select multiple responses. For this question, the years of experience of the respondents were observed to have a significant influence, as respondents with less than 10 years of experience select on average 50% more answers than respondents with more than 10 years of experience. Answers with a low overall proportion of less than 20% on average were almost exclusively selected by respondents with less than 10 years of experience. Respondents with more than 10 years of experience are more likely to select use cases that also correspond to the overall average, such as natural disaster management and response, complex and dynamic systems or smart cities and urban planning, see Figure 6.

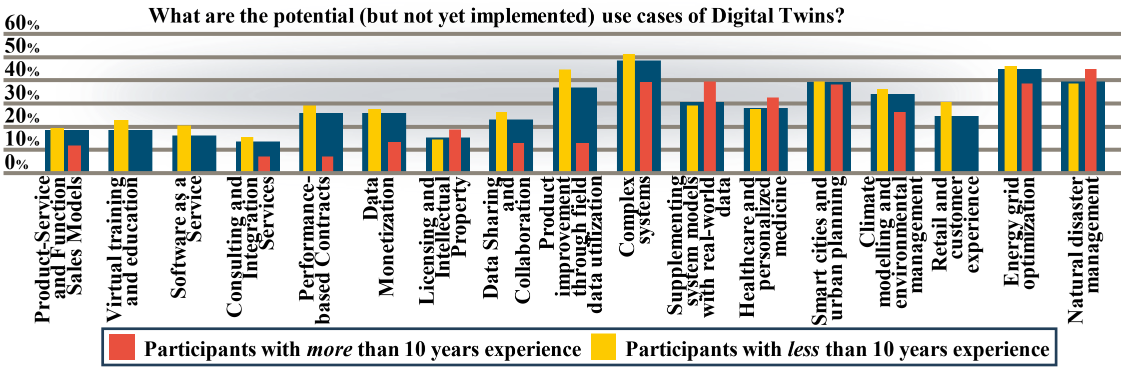

Figure 6. Distribution of answers regarding potential current use cases of Digital Twins

3.4. Challenges and opportunities (How?)

The opinions on ***obstacles in implementation*** are evenly distributed among the responses. The most commonly selected are limited determination of cost-benefit and value proposition (53%) and challenges with ownership and responsibilities (51%) followed by technical challenges with data

https://doi.org/10.1017/pds.2024.206 Published online by Cambridge University Press

management, computation times or model decay (49%) as well as confusion with other concepts (46%). Other perceived obstacles are legal aspects such as data privacy and security (41%) and missing concepts for a twin-ready IT landscape (38%). Legal aspects are seen as obstacles especially by respondents with less than 10 years of experience (47% compared to 19% for respondents with more than 10 years of experience) as well as challenges with ownership and responsibilities (55% compared to 38%). In contrast, the same group sees fewer obstacles in terms of confusion with other concepts (42% compared to 63%), see Figure 7.

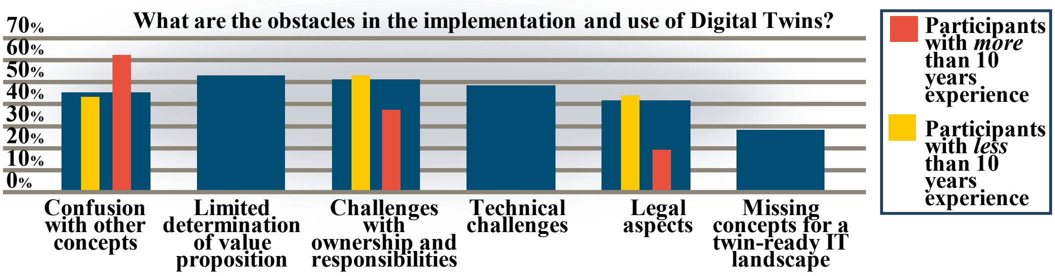

Figure 7. Distribution of answers to obstacles in the implementation and use of Digital Twins

The ***requirements*** that need to be fulfilled for the implementation of a Digital Twin are discussed next. Among the respondents, financial and personnel resources (69%) and a corresponding digitalization strategy (68%) are most commonly selected. Other relevant requirements are an appropriate concept for the introduction and operation of a Digital Twin (49%), a twin-ready IT landscape (44%) and implementation of use cases (36%). Less relevant are proper end-to-end tool chains (20%), legal and ethical considerations (20%), improved product quality and reliability (15%), and reduced physical tests (6%). Respondents with more than 10 years of experience see a disproportionately high number of financial and personnel resources (88% compared to 64% of respondents with less than 10 years of experience) and an appropriate concept for the introduction and operation of a Digital Twin (69% compared to 44%) as implementation requirements, see Figure 8 (left).

Factors for successful usage according to the study, are observed to be business value proposition (71%) followed by usability and accessibility (63%). A moderate number of respondents consider technological enabler of new business models (48%), enhanced production efficiency (45%) or improved efficiency and accuracy on Digital Twins (45%) as factors for successful usage. Other factors are cost reduction and scrap rate reduction (41%), streamlined maintenance and repair processes (40%) or reduced time to market (40%). Subordinate, according to the study respondents, are reduced physical testing requirements (25%). Respondents with more than 10 years of experience see enhanced production efficiency (63% compared to 41% of respondents with less than 10 years of experience) and streamlined maintenance and repair process (63% compared to 35%) as factors for successful usage, see Figure 8 (right).

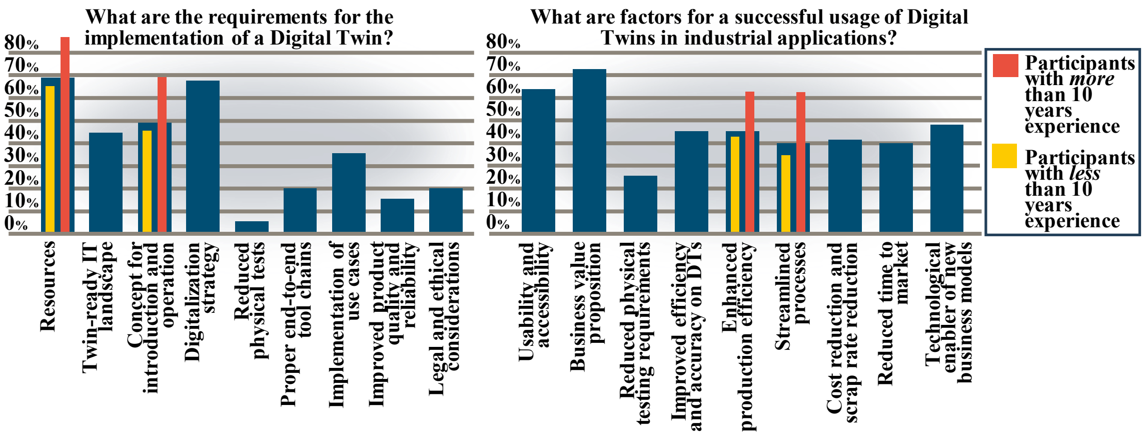

Figure 8. Distribution of responses regarding requirements for implementation (left) and success factors in the usage (right) of Digital Twins

https://doi.org/10.1017/pds.2024.206 Published online by Cambridge University Press

The participants were also asked in which areas they see ***comprehensive methodological support***. The three domains are models (58%), IT infrastructure (43%) and sensors (40%) and are rated relatively equally. Especially the categorization of experience has an influence on this perception. Respondents with less than 10 years of experience rated comprehensive methodical support in models (55%), sensors (44%) and IT infrastructure (39%) relatively equally. In comparison, respondents with more than 10 years of experience see comprehensive methodical support primarily in models (69%) and IT Infrastructure (56%), while this is less the case in sensors (25%), see Figure 9 (left).
Subsequently, the question was asked in which of the areas mentioned is ***more methodological support desired***. The respondents are most likely to demand more methodological support in the areas of models (45%) and IT infrastructure (41%) compared with 28% for sensors. For the creation of models, methodological support is more desired by respondents with more than 10 years of experience - 63% compared to 41% for respondents with less than 10 years of experience, see Figure 9 (right).

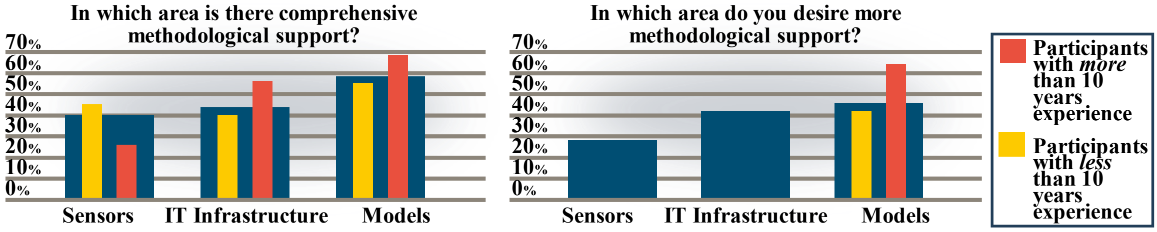

Figure 9. Distribution of answers regarding existing (right) and desired (right) methodological support for the creation of Digital Twins

4. Interpretation and findings

The survey participants' views from the industry can be summarized as follows:

- Main key stakeholders are equally employees in engineering development and employees in maintenance and operations teams.
- Creators are cross-disciplinary teams with engineering, IT, and data analytics expertise.
- Operators are production/manufacturing employees, followed by cross-disciplinary teams and employees from engineering development.
- Funding for the creation and use of Digital Twins is provided by management.
- The most prominent use cases are predictive maintenance and real-time performance analysis.
- Key requirements are financial and personnel resources and a corresponding digitalization strategy.
- Factors for a successful usage are business value proposition and a good usability and accessibility of the Digital Twin.
- In all three domains (sensors, IT infrastructure, and models), methodological support for the creation of Digital Twins is already available to a certain extent, but not completely sufficient.

Overall, the respondents in the survey have different views on the Digital Twin. The type of the Digital Twin and how the respondents use this Digital Twin have only a negligible influence on the view. In contrast, the experience of the respondents and the classification into the two categories based on less or more than 10 years of experience has a substantial influence. To assess the statistical significance of this influence, the Pearson-Chi-square test was applied. Here, the observed and expected responses are compared and expressed as χ^2 value. This value can be used to determine the probability P that a difference in response behaviour is a random phenomenon and, therefore, not statistically significant (Chernoff and Lehmann, 1954; Plackett, 1983). Since the size of this survey is on the boundary of few and moderately many respondents, an additional correction according to Yates was carried out (Yates, 1934). Table 1 lists the observations described above and assigns them to the results of the Pearson-Chi-Square test and the Yates's correction. The probability P was taken from statistical tables. If the probability of a random phenomenon is less than 5%, the effect is called statistically significant. These are highlighted by bold text in the table. The remaining effects cannot be neglected, but should be addressed again by a further survey with more precise questions.

https://doi.org/10.1017/pds.2024.206 Published online by Cambridge University Press

Table 1. Statistical significance of the influence of the years of experience

	Pearson-Chi-square		Yates's correction	
Effect	χ^2	P	χ^2	P
Engineering development as key stakeholder	1,875	< 20%	1,175	< 50%
Management as key stakeholder	4,515	**< 5%**	3,405	< 10%
Suppliers and vendors as key stakeholder	8,292	**< 0,5%**	6,587	**< 2%**
Research institutions and universities as creators	2,257	< 20%	1,415	< 50%
Engineering development as operators	5,640	**< 2%**	4,377	**<0,05%**
Cross-disciplinary teams as operators	3,274	< 10%	2,331	< 20%
Research Institutions and universities as funders	3,029	< 10%	1,976	< 20%
Performance-based contracts as business model	3,164	< 10%	2,135	< 20%
Licensing as business model	5,541	**< 2%**	3,945	**<0,05%**
Confusion with other concepts as obstacle	2,124	< 20%	1,386	< 50%
Ownership as obstacle	1,513	< 50%	0,904	< 50%
Legal aspects as obstacle	4,178	**< 5%**	3,098	< 10%
Resources as requirement	3,272	< 10%	2,273	< 20%
Concept for the introduction and operation as requirement	3,202	< 10%	2,280	< 20%
Enhanced productivity as factor for successful usage	2,475	< 20%	1,670	< 20%
Streamlined processes as factor for successful usage	4,219	**< 5%**	3,128	< 10%
Comprehensive methodical support with sensors	1,875	< 20%	1,175	< 50%
Comprehensive methodical support with IT Infrastructure	1,547	< 50%	0,924	< 50%
Comprehensive methodical support with models	1,036	< 50%	0,540	< 50%
More methodical support with models desired	2,475	< 20%	1,670	< 20%

In the following, the effects of the years of experience with a statistical significance are presented. Respondents with more than 10 years of experience…

- tend to see management and suppliers as the key stakeholder together with engineering development.
- tend to see engineering development employees rather than production/manufacturing employees as operators.
- Tend to see licensing and intellectual properties as a particularly interesting potential business model.
- tend to see streamlined maintenance and repair processes as an over-proportional factor for the successful usage of Digital Twins.

Respondents with fewer than 10 years of experience…

- tend to be significantly more optimistic and open about new use cases and select 50% more answers on average.
- tend to see more obstacles when it comes to secondary tasks, which have been topics of discussion in the recent past, like challenges with legal aspects, such as data privacy and security.

5. Conclusion and outlook

In the context of this contribution, a survey was conducted to capture the perception of industry on Digital Twins. This made it possible to achieve the initially declared goal of capturing and formalizing the industrial perspective of Digital Twins. Although there is no absolute agreement among the respondents, there are clear trends regarding the department or job roles responsible for the creation, utilization and financing of Digital Twins. Trends and preferences were observed for existing and potential use cases and perceived challenges and requirements for the implementation of Digital Twins were evaluated. Further, it was also determined how methodological support in the various domains is perceived and to what extent further support is desired. The factors that drive the industrial perspective were established. It can be seen that the years of experience of the respondents influence the perception of Digital Twins the most, while the type of Digital Twin used or its purpose has negligible influence. From these results, implications for future research into Digital Twins can be derived. The knowledge gained about the positions in the company that play a role in the creation and use of Digital Twins can be used to tailor the systematic support to specific target groups and adapt them to specific needs. With regard to methodological support, specific solutions can be offered for support in the domains of sensors, models and IT infrastructure. These domains are already partially addressed in the literature, as various reviews show (e.g. Fett *et al*., 2023). Nevertheless, holistic approaches can be developed that consider the interactions. However, this contribution only provides an initial overview of the topic. The results can be used to create further surveys, focusing on specific topics. For example, quantifiable response metrics could also be used, as well as targeted validation questions to back up the results. In this way, statistical statements can be made that go beyond those in this contribution.

References

Ali, M.E., Cheema, M.A., Hashem, T., Ulhaq, A. and Babar, M.A. (2023), "Enabling Spatial Digital Twins: Technologies, Challenges, and Future Research Directions."

Biesinger, F., Kras, B. and Weyrich, M. (2019), “A Survey on the Necessity for a Digital Twin of Production in the Automotive Industry”, *Proceeding of International Conference on Mechatronics Technology (ICMT)*, IEEE, Salerno, Italy, pp. 1–8. https://doi.org/ 10.1109/ICMECT.2019.8932144

Chernoff, H. and Lehmann, E.L. (1954), “The Use of Maximum Likelihood Estimates in Chi2 Tests for Goodness of Fit”, *The Annals of Mathematical Statistics*, Vol. 25 No. 3, pp. 579–586. https://doi.org/10.1007/978-1-4614-1412-4_47

Czwick, C., Martin, G., Anderl, R. and Kirchner, E. (2020), “Cyber-Physische Zwillinge”, *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, Vol. 115 No. 1, pp. 90–93. https://doi.org/10.3139/104.112310

Fett, M., Wilking, F., Goetz, S., Kirchner, E. and Wartzack, S. (2023a), "Sensor selection and integration for Cyber-Physical Systems in context of Digital Twins – A systematic review of requirements," 2023 *18th Annual System of Systems Engineering Conference (SoSe)*, pp. 1-7, https://dx.doi.org/10.1109/SoSE59841.2023.10178669.

Hoz Diego, J.D. de, Temperekidis, A., Katsaros, P. and Konstantinou, C. (2022), “An IoT Digital Twin for Cyber-Security Defence Based on Runtime Verification”, *International Symposium on Leveraging Applications of Formal Methods*, Springer, Cham, pp. 556–574. https://doi.org/10.1007/978-3-031-19849-6_31

Lei, B., Janssen, P., Stoter, J. and Biljecki, F. (2023), “Challenges of urban digital twins: A systematic review and a Delphi expert survey”, *Automation in Construction*, Vol. 147, p. 104716. https://doi.org/ 10.1016/j.autcon.2022.104716

Li, J., Zhou, G. and Zhang, C. (2022), “A twin data and knowledge-driven intelligent process planning framework of aviation parts”, *International Journal of Production Research*, Vol. 60 No. 17, pp. 5217–5234. https://doi.org/10.1080/00207543.2021.1951869

Plackett, R.L. (1983), “Karl Pearson and the Chi-Squared Test*”, International Statistical Review / Revue Internationale de Statistique*, Vol. 51 No. 1, p. 59-72. https://doi.org/10.2307/1402731

Stark, R., Anderl, R., Thoben, K.-D. and Wartzack, S. (2020), “WiGeP-Positionspapier: „Digitaler Zwilling“”, *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, Vol. 115 No. s1, pp. 47–50. https://doi.org/10.3139/104.112311

Trauer, J., Schweigert-Recksiek, S., Engel, C., Spreitzer, K. and Zimmermann, M. (2020), "What Is a Digital Twin? – Definitions and Insights from an Industrial Case Study in Technical Product Development," *Proceedings of the Design Society: DESIGN Conference*, Vol. 1, pp. 757–766. https://doi.org/10.1017/dsd.2020.15

Udugama, I., Öner, M., Lopez, P.C., Beenfeldt, C., Bayer, C., Huusom, J.K., Gernaey, K.V. and Sin, G. (2021), “Towards Digitalization in Bio-Manufacturing Operations: A Survey on Application of Big Data and Digital Twin Concepts in Denmark”, *Frontiers in Chemical Engineering*, Vol. 3. https://doi.org/ 10.3389/fceng.2021.727152

Wang, B., Zhou, H., Yang, G., Li, X. and Yang, H. (2022), “Human Digital Twin (HDT) Driven Human-Cyber-Physical Systems: Key Technologies and Applications”, *Chinese Journal of Mechanical Engineering*, Vol. 35 No. 1. https://doi.org/10.1186/s10033-022-00680-w

Wilking, F., Schleich, B. and Wartzack, S. (2021), “Digital Twins - Definitions, Classes and Business Scenarios for Different Industry Sectors”, *Proceedings of the Design Society*, Vol. 1, pp. 1293–1302. https://doi.org/10.1017/pds.2021.129

Yates, F. (1934), “Contingency Tables Involving Small Numbers and the χ 2 Test”, *Supplement to the Journal of the Royal Statistical Society*, Vol. 1 No. 2, p. 217. https://doi.org/10.2307/2983604