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Digital twin software provider: key players, rankings and trends

Lutz Sommer
Department of Industrial Engineering, Faculty of Engineering, Albstadt-Sigmaringen University, Albstadt, Germany

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ABSTRACT

Current studies about digital twins (DT) generally provide little support to interested parties in selecting suitable providers. The aim of the present study is, on the one hand, to ask whether existing rankings could be used to derive a quick, cost-efficient decision. On the other hand, it is to be questioned how the provider market is developing. Therefore, the study based on the one hand on 10 provider rankings of DT and the other hand on detailed research of n=153 providers was included for a detailed analysis of trends. The following findings were obtained: i) The selected top 10 rankings can serve as a fast, cost-efficient selection approach for providers; ii) the DT market is dominated by established, large top providers with North American locations; and iii) Since 2010 there has been a trend in the form of a disproportionately large number of new providers.

Corresponding Author:

Lutz Sommer
Department of Industrial Engineering, Faculty of Engineering, Albstadt-Sigmaringen University
Jakobstrasse 1-6, 72458 Albstadt, Germany
Email: sommer@hs-albsig.de

1. INTRODUCTION

The main text format digital twins (DT) are increasingly used to simulate productions, production-related areas, and also completely new areas. The number of companies dealing with DT is growing continuously. Sales of € 183 billion are expected by 2031 [1]. But science is also working intensively on this topic. A "state-of-the-art survey of digital twins" showed that publications on this topic are increasing significantly, especially in China, USA, and Europe [2]. To put it simply, DT represents a virtual representation of objects, processes, and systems as well as information [3]. With this virtual representation, one is able to model, simulate, monitor, analyze, and optimize physical systems [4]. Overall, one can say that both science and companies are interested in this topic. But who are the key players on the supplier side?; What is the importance of the individual providers?; Where is the trend going?

In order to answer the above questions, however, it must first be clarified what a digital twin is in detail. The definitions range from a virtual representation to digital copies of a physical system to a virtual model [2], [5]. Weber and Grosser [6] has presented a comprehensive definition: "a digital twin is the virtual representation of a physical object using operating data and other data sources to enable monitoring and dynamic control of the object. This covers the full scope from a life cycle phase to the complete product life cycle. The maturity of a digital twin is defined as dependence on the level of communication and the degree of standardization. The degree of communication describes the connection between the digital twin and the physical object. The degree of standardization reflects the modeling of the data and data sources" [6].

Based on this definition, it is possible to derive a "digital twin maturity model" [6], which takes into account the degree of communication as well as the degree of standardization in relation to the modeling [6]: "i) Representative: there is no communication of any kind between the physical object and the virtual

representation; ii) Simulator: communication is unidirectional, i.e., it is limited to the direction from the physical object to the virtual representation; iii) Monitor: communication serves the monitoring of the physical object and travels from the object to the virtual representation. In this case, sensor data are visualized first and foremost; iv) Smart monitor: smart monitoring is an extension of the monitor level and encompasses the linking of received data and enriching these data to gain new insights (smart data) and to visualize them; v) Digital twin: at the digital twin level, additional communication travels from the virtual representation to the physical object, i.e., bi-directional communication that controls (for example) an actuator based on the collected smart data. The interaction with the virtual model has a direct effect on the physical object" [6].

In addition to the definition of a DT and its level of maturity, there are classification approaches. Authors have collected various literature approaches and analyzed DT from the perspective of various classification terms [3]. The following classification terms could be derived [3]: i) hierarchical level, ii) life-cycle phase, iii) functional use, and iv) data type/data flow.

As a result, it can be stated that the number of 37 manifestations or variants based on the above classification is large and may continue to grow [3]. Further growth can also be seen in the area of application for DT [7]. In a comprehensive study, authors compare individual sectors, the associated applications, and the respective advantages. The most important applications include [8]: i) optimization, ii) decision-making, iii) remote access, iv) training and documentation, v) designing and planning, and vi) real-time monitoring.

Furthermore, authors identify 13x relevant sectors for the use of DT [8]: i) aerospace and aeronautics, ii) manufacturing, iii) healthcare, iv) energy, v) automotive, vi) oil and gas, vii) smart city, viii) mining, ix) maritime, x) agriculture, xi) education, xii) construction, and xiii) retail. This assessment is also consistent with other studies [9]–[13]. The list could be expanded to include the logistics sector [14], [15]. In other words, DT are primarily used in companies that have a manufacturing character.

It is clear from the available studies and publications that there is extensive information about DT in general. Definitions, classifications, applications, sectors, and pros and cons have already been extensively researched. Special information on software products and solution approaches of the respective providers, evaluations or rankings [16] as well as market analyses can often only be found on special internet portals, homepages of the software providers, or studies [17]. Trends in the field of providers of DT, such as the inclusion of the topic "sustainability and manufacturing", can often only be understood with great effort by researching the respective homepages of the providers or, if necessary, by purchasing studies that are subject to a fee. While previous studies have dealt extensively with definitions, classifications, applications, and sector-specific uses of DT, they lack detailed insights into specific software products, vendor evaluations, and market trends. Furthermore, findings on practical implementation, longitudinal studies, and regional differences are insufficiently explored, suggesting a need for more accessible and comprehensive information on these aspects.

Therefore, the first part of the study aims to record the freely accessible sources with special information on providers of DT and to create a meta-ranking from the individual rankings that allows potential buyers and scientists to get an initial overview more easily about the most important top providers, their software and solutions as well as trends. The following research question (RQ) is derived from this:

RQ-1: Are there enough freely accessible sources that enable a comparative analysis of providers of DT and what are the characteristics of these companies?

The corresponding hypotheses are as follows:

H-1.1.: It is possible to derive a meaningful meta-ranking from 10 rankings.

H-1.2.: The top providers of DT are characterized by strong similarities in terms of the characteristics of provider size, areas of application, provider foundation, and provider headquarters.

To examine the trend behavior of providers, the mega-trend "manufacturing and sustainability" will be considered as an example:

H-1.3.: All top DT providers offer solution concepts for manufacturing as well as for the megatrend "manufacturing and sustainability/energy".

The second part will examine to what extent the above findings of the top providers coincide with a more extensive sample of n=153 providers of DT. Considering the top providers is sufficient to draw relevant conclusions on the market for providers of DT from a demand or scientific perspective. The following RQ is derived from this:

RQ-2: Do the findings on DT of the top providers match those of the n=153 providers in terms of the number of companies in the market, geographical origin, provider size, time of foundation, areas of application, and trends?

To answer the RQ, the following hypotheses were formulated:

H-2.1.: The evaluation of the sample of n=153 providers of DT confirms that the number of providers of DT according to the sample increases proportionally.
H-2.2.: The evaluation of the sample of n=153 DT providers shows that a disproportionately large number of providers from the sample come from the USA.
H-2.3.: The evaluation of the sample of n=153 DT providers confirms that the majority of the providers in the sample are large companies.
H-2.4.: The evaluation of the sample of n=153 providers of DT confirms that at least 9 out of 13 areas of application-according to the study by Singh *et al.* [8], were offered by the providers in the sample.
H-2.5.: The evaluation of the sample of n=153 providers of DT confirms that megatrends like "manufacturing and sustainability/energy" can be also found in the majority of the providers in the sample.

2. RESEARCH METHOD

The implementation of the RQ-1 and RQ-2 took place based on literature research and internet research. Studies and journals were used for the literature research. The internet research was based on the ten rankings listed follow.

RQ-1: The following ten rankings were used for the RQ-1, displayed in Table 1. All providers that were named in at least 3 out of 10 rankings considered were included in the ranking. Due to the different evaluation criteria of the individual rankings, the comparability of the results is limited, but the position in the respective ranking indicates its importance.

Table 1. Overview of the used digital twin rankings

Rankings	Sources
Ranking 1: Best digital twin software in 2022	[18]
Ranking 2: Top 10 digital twin companies impacting I 4.0. innovations 2021	[19]
Ranking 3: Compare the top digital twin software in 2022	[20]
Ranking 4: Top 10 digital twin solution companies 2020	[21]
Ranking 5: Digital twin software market size forecast 2025	[22]
Ranking 6: The best digital twin solution providers 2022	[23]
Ranking 7: Key players in the global digital twin market	[24]
Ranking 8: Top 5 digital twin companies in the market	[25]
Ranking 9: Top 10 digital twin vendors for 2019	[26]
Ranking 10: Top 10 digital twin solutions companies 2022	[27]

RQ-2: The ten rankings were also used to determine a sample of the most frequently mentioned providers with n=153. The selection is based on the frequency of mentions in the respective rankings. The internet portal Sourceforge [28] has proven to be the most comprehensive platform for DT. This is a platform that is defined as follows: "our business software directory lists over 79,000 software titles, and offers robust tools for business software and service comparisons and buying decisions, which allows B2B professionals to compare software and services by price, user reviews, integrations, deployment, region, support and training offerings, and more" [28]. Under the search term "digital twin", the search query returned 107 providers of software and solutions. The other nine ranking providers also provided ranking information, albeit less detailed. Missing information, such as founding date, areas of application, provider size, location-insofar as this was not available via the ten rankings-was researched via the homepages of the individual providers or via the online platform Crunchbase [29].

3. RESULTS

3.1. In research question RQ-1-meta ranking

The aim of the hypotheses H-1.1. considered is the implementation and evaluation of a meta-ranking (H-1.1.). According to Table 2, 10 rankings of DT providers were analyzed in a period from 2019 to 2022. Based on this, a meta-ranking was carried out in which the mention in the respective ranking was summed up as a sum. The maximum value was 10 out of 10 mentions, i.e. a provider was named "significant" in 10 out of 10 rankings-10 of 10. The minimum value was 1 out of 10 mentions, i.e. the provider was mentioned in at least 1 out of 10 rankings-1 of 10. The ranking that was determined in a few rankings could not be taken into account because the majority of the 10 rankings did not define a ranking. The results can be summarized as follows, based on the rankings 1-10 according to Table 2.

Table 2. Results of the meta-ranking

Ranking	Provider	Nominations
1	Siemens	7 of 10
2	Ansys/Microsoft/Bosch	6 of 10
3	IBM/Oracle/PTC	5 of 10
4	GE Digital	4 of 10
5	Akselos/Aveva/Cisco Systems/Dassault Systems	3 of 10

Note. ranking results according to ranking 1–10 (Source: Table 1)

The results hypothesis H-1.2. with regard to the analysis of the similarities of the top providers can be summarized as follows: i) 9 out of 10 top providers are large companies (=exception Akselos) with more than "249 employees or over 50 million euros in sales" [30]; ii) The companies have been in the market for many years and do not have the character of a start-up; iii) Predominantly North American companies; iv) The areas of application of the software or solutions from these providers are extensive, i.e. include at least 9 out of 13 areas of application [8]; and v) The trend manufacturing and sustainability is usually offered.

Hypothesis H-1.3. try to figure out whether the top providers follow common trends. For this purpose, the areas of application manufacturing (M), sustainability (S), and/or energy efficiency (E) were considered. The results show that the top providers–again except for Akselos–focus their offerings on the application areas of manufacturing and sustainability/energy efficiency. The extent to which these providers are pursuing a holistic approach in terms of production, sustainability, and energy efficiency could not be conclusively assessed based on the providers' websites. Table 3 provides an overview based on rankings 1 to 10 from Table 1 and the Crunchbase [29] database.

Table 3. Detailed information about the top provider

Provider	Ranking	Founded in	Country	Size	Sectors
Siemens	1	1847	GER	Large	M+S+E
Ansys	2	1970	USA	Large	M+S+E
Microsoft Azure	2	1975	USA	Large	M+S+E
Bosch	2	1886	GER	Large	M+S+E
IBM	3	1911	USA	Large	M+S+E
Oracle	3	1977	USA	Large	M+S+E
PTC	3	1985	USA	Large	M+S+E
GE Digital	4	2015	USA	Large	M+S+E
Akselos	5	2012	CHE	Medium	S
Aveva	5	1967	UK	Large	M+S-E
Cisco Systems	5	1984	USA	Large	M+S+E
Dassault Systems	5	1981	FRA	Large	M+S+E

Note. results according to ranking 1–10 (Source: Table 1 and Crunchbase [29])

3.2. Research question RQ-2–detailed analysis of n=153 provider

The subject of hypothesis H-2.1. is a comparison between the results of the top providers and those of the extensive sample of n=153 providers. If one looks at the dynamics in the market for providers of DT, one can use the "timeline of the evolution of the definition of a DT" [31] as a benchmark to check whether there were specific points in time for unusual growth [31]: i) 1970: DT concept appeared first time; ii) 2003: DT concept theorization; iii) 2010: DT first definition appears; and iv) 2016: DT consolidates. The results show a connection between the "Timeline of the evolution" [31] and the founding dates of the n=153 providers: i) In the period up to 1970, only 14 of the 153 providers examined had already been founded, with the corporate goal "digital twin" was not in focus; ii) Up until 2010, the increase in start-ups showed a linear trend; and iii) From 2010 onwards, the curve for start-ups of providers related to DT will increase disproportionately, as shown in Figure 1.

In other words, from 2010 to 2022 the number of companies in the sample n=153 almost doubled from 78 to 153. This coincides with the first definition of a digital twin by NASA in 2010 [31]. In the next step, the geographic origin of the provider–according to hypothesis H-2.2.-was considered. The results of the random sample n=153 show that, at 44.4%, a disproportionately large number of providers come from the USA, as shown in Figure 2. However, if one only considers foundations after the "DT concept consolidation" according to the "timeline of the evolution of the definition of a DT" [31]-from 2016, a different picture emerges as shown in Figure 3.

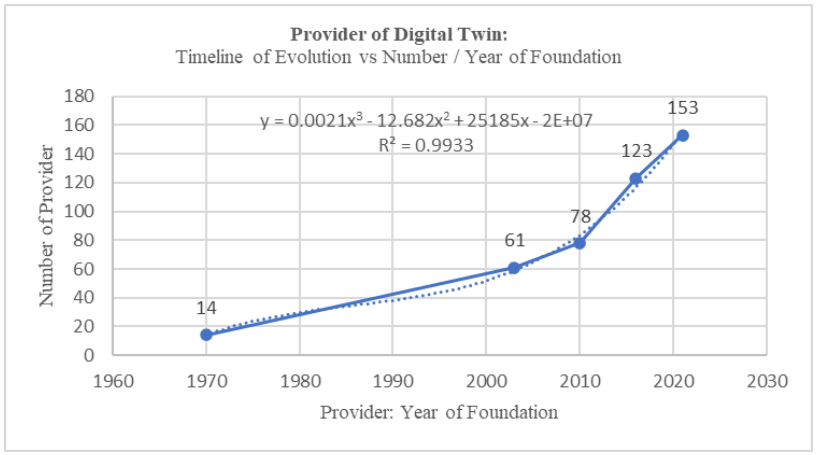

Figure 1. Relationship between date of foundation and number of providers–based on ranking 1 to 10 (see Table 1 and Crunchbase [29]) with the timeline of the evolution of DT [31]

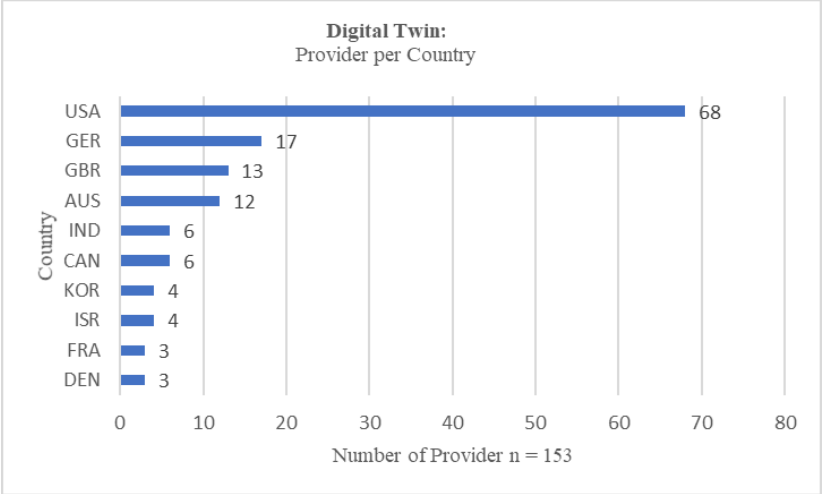

Figure 2. Provider DT, broken down by country–based on ranking 1 to 10 (see Table 1 and Crunchbase [29])

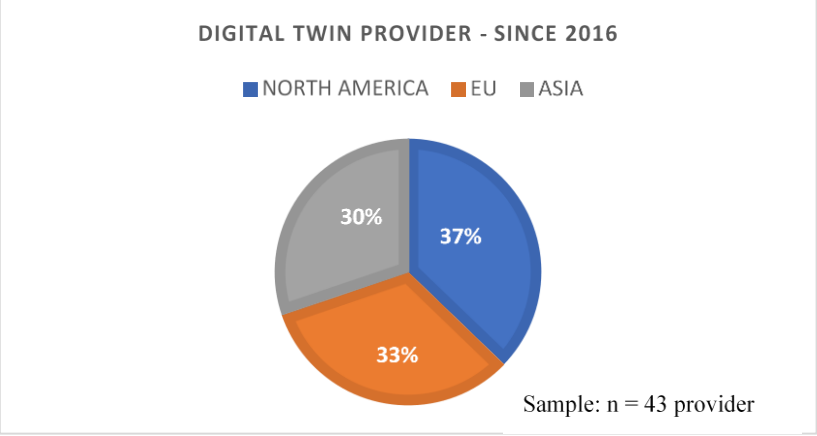

Figure 3. Provider DT, broken down by region–based on ranking 1 to 10 (see Table 1 and Crunchbase [29])

According to this, the number of start-ups is more or less equally distributed among the regions of North America, Europe, and Asia. In other words, according to the sample n=153, the dominance of

American providers is decreasing. In addition to the geographical origin of the providers, hypothesis H-2.3. investigates the characteristics of provider size according to the EU definition [30] and the time of founding. The combination of both criteria gives an indication of whether the provider tends to be a classic start-up. Figure 4 provides an insight.

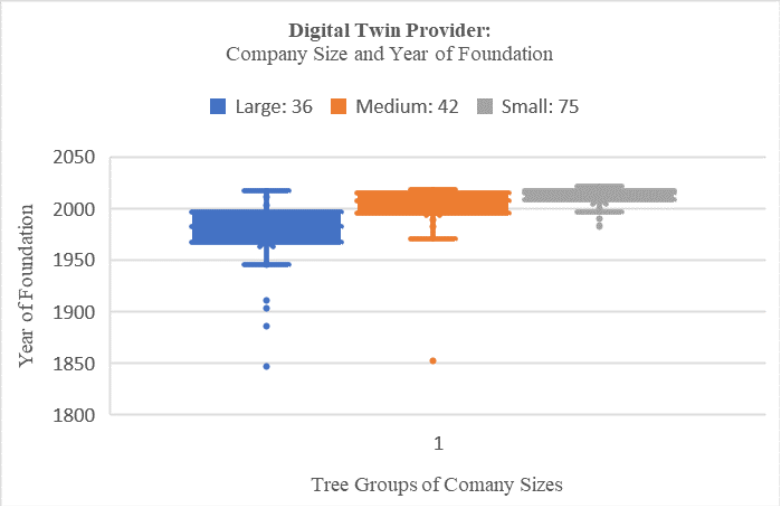

Figure 4. Provider DT, broken down by provider size [20] and year of foundation according to ranking 1 to 10 (see Table 1 and Crunchbase [29])

The results show that the identified 36 large companies tended to be founded before the year 2000 and thus tended to represent more established companies. In contrast, the majority of the 75 small companies were founded in 2010 or later, in addition to their small size. In other words, these companies have a start-up character. The subject of hypothesis H-2.4. is the question of whether the areas of application of the 153 providers examined correlate highly with the areas of application of DT on the basis of relevant studies and publications or top providers (H-2.4.). Due to a large number of identical or similar terms for certain areas of application, collective terms had to be defined (=the original terms are in brackets). The results can be summarized as follows based on the ranking 1-10 according to Table 4.

Table 4. Overview of identified new areas of application (sectors)

DT Sectors according to Singh *et al.* [8]	DT Sectors based on n=153 providers according to ranking 1-10 (see Table 1)	Comments
1. Aerospace/Aeronautics	Aerospace	
2. Agriculture	Agriculture	
3. Automotive	Automotive (Mobility)	
4. Smart City	City	
5. Construction	Construction (Buildings/Facilities/Smart Home)	
	Defense	New Sector
6. Education	Education	
7. Energy	Energy & Power Plants	
	Fashion	New Sector
	Finance & Insurance	New Sector
	Government	New Sector
8. Healthcare	Healthcare (Medical Devices)	
	Life Science (Chemical/Pharma/Food)	New Sector
9. Manufacturing	Manufacturing (Robotics/Electric)	
10. Maritime	Marine (Shipbuilding)	
11. Mining	Mining (Metal)	
12. Oil and Gas	Oil and Gas	
13. Retail	Retail & Logistics (Transportation)	
	Roads and Highways (Travel/Hospitality)	New Sector
	Safety & Security	New Sector
	Sustainability (Weather/Climate/Water)	New Sector
	Telecommunication (Media)	New Sector

Note. new areas of applications (source: Table 1)

The results of the n=153 providers show deviations between the studies/publications or top providers. The 13 areas of application from studies and publications [8], the providers examined in sample 9 add further areas of application according to Table 4. A look at the newly added sectors makes it clear that more and more new areas of application are emerging alongside production.

Hypothesis H-2.5. dealt with the question of whether the areas of application "manufacturing and sustainability/energy efficiency" [32]–[34] are represented more strongly by the providers examined (sample n=153). Based on Table 1, the results can be summarized as shown in Figure 5.

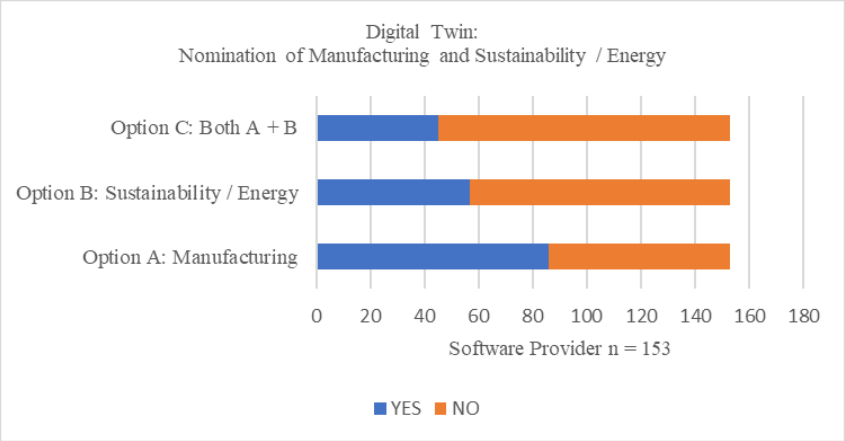

Figure 5. Selected areas of applications (sectors), broken down by options A, B, and C based on ranking 1–10 (see Table 1)

The results show that 86 of 153 providers offered the manufacturing area and 57 the sustainability/energy area. These results support the assumption that the providers of DT still see production as the most important area of application. The combination of both–option C–is offered by 45 providers. However, according to the providers' websites, it is not clear whether the "manufacturing and sustainability/energy" offer is a coordinated software module or whether it is a question of two independent software modules.

The key findings of the research conducted can be summarized as follows. In section 3.1, we found that the importance in the ranking of DT vendors correlates with the frequency of mention in several rankings, as frequently mentioned vendors were categorized as important. The proposed meta-ranking method tended to show an excessively high proportion of large, established North American companies, suggesting market dominance by these companies. However, Akselos, a smaller company, was a notable exception. Further analysis revealed that the focus areas of the leading vendors correlate strongly with the trend topics of manufacturing and sustainability/energy efficiency, although the extent to which these areas are holistically integrated is not conclusive based on the available data.

When examining the broader sample of 153 providers in section 3.2, a significant correlation was found between the development time of the digital twin concept and the founding dates of these providers. The geographic analysis found that American providers initially dominated, while the post-2016 landscape shows a more even distribution of new companies in North America, Europe, and Asia. In addition, the analysis revealed that larger companies were generally founded before 2000 and smaller, start-up-like companies predominantly emerged after 2010. The application areas of the digital twin vendors are largely consistent with existing studies but also introduce new sectors, indicating expanding and diversified use cases. However, manufacturing and sustainability/energy efficiency were found to remain the main areas of focus.

4. DISCUSSION

4.1. Hypothesis testing

RQ-1 dealt with freely available rankings for providers of DT with the aim of creating a meta-ranking. Hypothesis H-1.1. is confirmed, as certain providers appear disproportionately often as so-called top providers in the 10 rankings examined, making it easy to derive a meta-ranking. These providers were mostly larger companies with experience in the software sector and strong financial resources, such as Siemens,

Microsoft, international business machines (IBM), and general electric (GE). This result is not surprising considering that these companies have been successfully developing software products for many years. In this respect, the DT is the logical continuation of previous business activities, which also explains the dominance of these companies in the ranking. Regarding H-1.2. the question arose as to whether certain trends-such as manufacturing and sustainability/energy as an area of application be identified among the top providers. The answer to the question can be yes, i.e. with the exception of one provider, all of them had the areas of application "manufacturing" and "manufacturing and sustainability/energy" in their portfolio. The relevance of sustainability is also supported by the various literature reviews [35]–[37]. To sum up, this hypothesis is confirmed. Whether current trends can also be mapped in this way remains unanswered.

With the RQ-2, the findings of the top providers were compared with those from the sample n=153 in order to check whether the consideration of the top providers is sufficient to draw relevant conclusions for the market of DT providers. Hypothesis H-2.1. could not be confirmed, i.e. since 2010 the number of providers of software and solutions for DT has actually increased disproportionately. From 2010, the number of providers almost doubled from 78 to 153. In this respect, the top providers are not a reference standard for the growth of the provider in the DT market. The second hypothesis H-2.2. could be confirmed. Of 153 providers examined, 68 were from the USA, in other words, a disproportionately large number of providers. However, if you only analyze the providers who have entered the market for DT since 2016, it is noticeable that these-divided into the regions of North America, Europe, and Asia no longer primarily come from North America. Although 37% of the providers still come from the USA, 63% are already from Europe and Asia. Hypothesis H-2.3. dealt with the question of the provider size of the providers. The results show a significant increase in start-ups from 2010, i.e. 75 of the 153 providers examined are smaller, young companies with a start-up character. Only 36 companies were classic large companies. This makes it clear that the market for providers of DT is in a state of upheaval, which is also reflected in the new areas of application. All in all, the hypothesis cannot be confirmed that the majority of providers as with the top providers are large companies. A more detailed look at the areas of application according to hypothesis H-2.4. indicates a change or broadening of the offer. The current review of the areas of application of DT identified 13 areas of application on the basis of a comprehensive literature search [8]. However, a comparison with the providers of DT examined was able to identify 9 other areas of application, based on a ranking of 1-10 according to Table 1: i) defense, ii) fashion, iii) finance and insurance, iv) government, v) life science chemical/pharma/food, vi) roads and highways, and vii) safety and security.

In sum, it can be stated that the hypothesis H-2.4. could not be confirmed. On the one hand, in the majority of cases, the n=153 providers did not form 9 of 13 areas of application according to Singh *et al*. [8], on the other hand, 9 other areas of application were added [38]–[40]. The last hypothesis H-2.5. questions whether the majority of providers of DT map the areas of application "manufacturing and sustainability/energy". The results for the three selected options show that option A-manufacturing-is offered by the vendors in 56.2% of all cases, whereas option B-sustainability/energy in only 37.3%, and the combination of options A and B is present in 29.4% of cases.

4.2. Limitation and implication

This study investigated a comprehensive set of rankings and sample providers to evaluate the market for DT. However, the following factors limit the meaningfulness of the study: i) The limited sample size with n=153 and the lack of random selection of the providers, since the 153 selected companies come from the meta-ranking of the 10 rankings examined. This limited sample size and the non-random selection may affect the generalizability of the results; ii) The lack of subdivision or clear demarcation of the providers of DT between software on the one hand and solutions on the other poses a challenge in accurately assessing market trends and provider capabilities. These limitations suggest that while the findings provide valuable insights, additional and in-depth research is required to confirm their validity, particularly regarding the segmentation of the DT market.

4.3. Implication

This research highlights key trends and characteristics of digital twin providers and illustrates the dynamics and evolving focus areas of the market. Future research should expand the sample size and use random sampling to ensure broader representation. In addition, a more detailed analysis of the features and functionalities of DT software versus complete solutions is required. Examining the specific contributions of start-ups versus incumbents in the DT space can further shed light on market dynamics. Practical methods for holistic integration of manufacturing and sustainability/energy efficiency applications should also be explored to gain deeper insights into vendor offerings and market needs.

5. CONCLUSION

The following conclusions can be drawn from the results of this work. With regard to research question RQ-1, the following conclusions could be drawn: i) Yes, it is easily possible to create a meta-ranking with available data sources whose companies have a comparable profile and ii) According to the meta-ranking, there is a group of well-established providers that currently dominate the market. Typically, these are larger US companies or their subsidiaries with a connection to the creation of software, which have been active in the market for many years and, in some cases, reflect important trends.

RQ-2 provided insights into the question of whether the top providers of DT are suitable for market mapping. Depending on your perspective-whether you are looking for DT or scientists–our findings offer different conclusions: i) From a customer's point of view, a look at the top providers provides a portfolio of companies that offer at least 9 out of 13 areas of application, have many years of experience, reflect relevant trends and, due to their provider size, bring a low risk to the business relationship. In this respect, the top providers can be a useful orientation for a person looking for DT; ii) From the point of view of a scientist, however, these top providers are not suitable as a guide to depicting the market and its dynamics. This observation is also reflected in the hypotheses since 4 out of 5 hypotheses were not confirmed by the sample n=153: H-2.1. (market growth), H-2.3. (provider size), H-2.4. (areas of application) and H-2.5. (trends); iii) Production-related DT dominate the provider market; and iv) The observations indicate that combining sustainability and production is becoming increasingly important for DT providers.

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BIOGRAPHIES OF AUTHORS

Prof. Dr. Lutz Sommer teaches at the Albstadt-Sigmaringen University of Applied Sciences in the Department of Engineering. He studied engineering and economics in Germany, Italy, and Poland and graduated as a Dipl.-Ing. (Univ.) from the TU Berlin, as a Dipl.-Wirt.Ing. (Univ.) from the FU Hagen/TU Berlin and as a Dipl.-Kfm. (Univ.) from the FU Hagen with a focus on economics, technical chemistry, and production management. He received a doctorate in economics as part of a German-Polish EU-funded project at the University of Danzig/Gdansk and a doctorate from the International Telematic University UNINETTUNO/Rome. Previously, he held various positions, including Assistant to the Management Board (BESO Group-Germany), Export Officer-Middle East & Asia (Jungheinrich AG/WAP-Germany), and Head of the Detergents Division (NKT-Holding A/S-Denmark). He is currently a member of the Flex4Fact research project. He can be contacted at email: sommer@hs-albsig.de.