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Are practitioners and literature aligned about digital twin?

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Abstract

The attention of practitioner and research on the concept digital twin is constantly growing: many companies have already in their offer a so-called digital twin and literature have seen in the recent years a strong increase of contributions on the topic, nevertheless, none of them ever stated if it is the same thing to which the professionals are referring to. For this reason, the purpose of this paper is to understand whether literature and practitioners are aligned about the digital twin paradigm, eventually identifying which are the differences and so define what are the possible developments for future research.

Keywords: Digital twin, servitization, literature review

Introduction

Worldwide, the new national development strategies for the industry – such as Industrie 4.0 in Germany, Industria 4.0 in Italia , Made in China 2025 in China and Smart Manufacturing in the USA – have the common goal of smart manufacturing (Kang et al., 2016), an emerging form of production integrating manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, control, simulation, data intensive modelling and predictive engineering (Kusiak, 2018). Based on that, an intensive and articulated application of networked information-based technologies throughout the manufacturing and supply chain enterprise is needed (Davis et al., 2012). Such technologies, such as sensors, cloud computing, augmented/virtual reality, additive manufacturing, machine learning, artificial intelligence, robots etc. produce, share and use big amounts of data that manufacturing companies and organizations need to transform in useful informations with the help of gaining richer and deeper insights and getting an advantage over the competition (Sagiroglu and Sinanc, 2013). One way to seize such opportunities is the concept of digital twin.

The concept of digital twin is born in order to add value and efficiency of both the data collected from the physical manufacturing sites and the data generated or existing in these deployed information systems (Cheng et al., 2018). It has found increasing attention by both industry and academic as the number of applications, on one hand, and contributions, on the other, has strongly

increased in the recent years: in the industry, numerous companies offer a so-called digital twin to their customers; in the literature, the number of contributions on the topic has greatly increased since 2017 (as the following literature review demonstrates). To this high number of contributions correspond a similarly high variety of definitions and interpretations of digital twin, depending on the type of industry involved and the field in which is implemented (Tao, Sui, et al., 2018).

Considering such a high number of applications, it is evident that the possibilities in business terms need to be addressed, not just from a technical point of view, but also from a business model point of view, in particular the integration of the digital twin and service represents a promising research direction which should be addressed in future paradigms (Tao, 2018): servitization, the concept that refers to the transformation in which manufacturers are increasingly offering services that are directly coupled to their products (Baines and W. Lightfoot, 2013), is a topic for which there is a growing interest among academia, business and government because it is thought that a move towards servitization is a mean to create additional value adding capabilities for traditional manufacturers (Baines et al., 2009).

There is the need for studies in such direction but in order to seize such opportunities, it is fundamental that literature and practitioners are aligned about the digital twin concept; this is the reason why this paper aims to answer the following research question (RQ): *are the practitioners and the literature aligned about the concept of digital twin?*

In order to give an answer to this question, the definitions of digital twins that can be distinctly obtained analyzing the literature and the results coming off the combination of a survey with the interviews done with the practitioners, are compare.

The paper is structured as follow: first the method and results of the analysis of the literature review made on the Scopus database are presented, to which the genesis of the concept and its definition are deduced; then the results of a systematic combining of the results of the survey made on a sample of about 60 professionals, with in-depth interviews carried out on 15% of the same sample and therefore, are presented with its correspondent definition. Then the findings are discussed and so conclusions are made, The paper finishes with the definition of possible future works and the limitations of the research are pointed out.

Literature review

Approach

A literature review was conducted on the Scopus database searching for the “digital twin” term in the keywords: it resulted in 255 results of different types (articles, conference papers, etc.), distributed from 1993 (Koren et al., 1993) to March 2019 (Figure 1) and mainly focused in subject areas of *computer science* and *engineering*.

Based on a cross-referenced analysis of the results, 4 more papers have been added to the selection and included to point out the following definition of digital twin, for a total of 259 papers.

The analysis and the selection of the papers that have been considered the most relevant for the purpose to address the RQ, have been done reading in order the title, abstract and finally the entire paper; then, the selected ones (21 in total) have been used to obtain a general and common definition of digital twin.

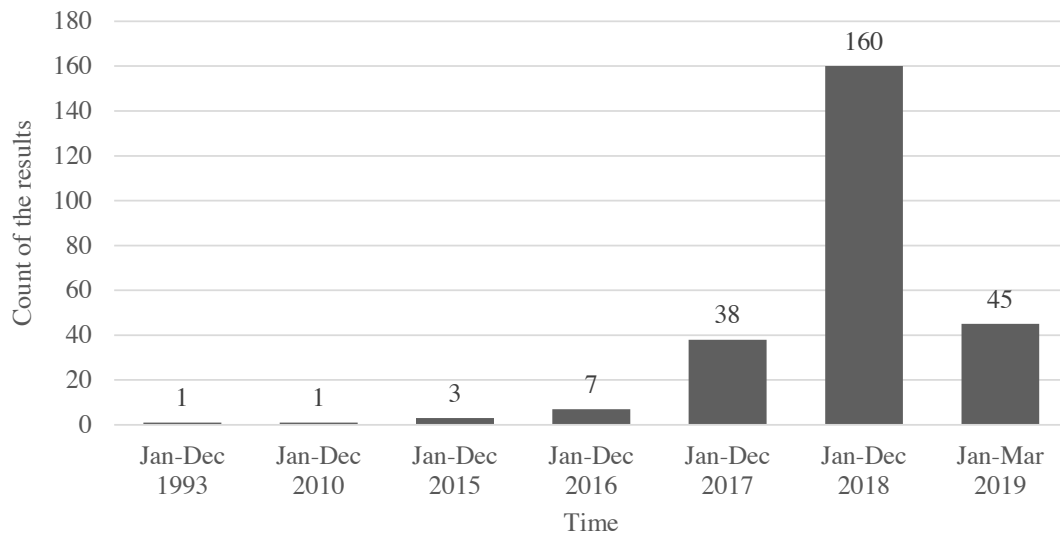


Figure 1: Histogram representing the count of contributions found in the Scopus database from January 1993 to March 2019.

Evolution of the digital twin concept

A first intuitive digital twin concept was introduced for the NASA's Apollo project in the late 1960s, when NASA created two identical space vehicles where the ones left on earth was called "the twin" and was used to mirror the condition of the space vehicle that performed the mission, so a prototype that mirrored the real operating condition for the simulation of real-time behaviour; the NASA then evolved its concept of digital twin as an integrated multiphysics, multiscale simulation of a vehicle or system that uses the best available physicals models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin (Glaessgen and Stargel, 2012). By the way, it is generally accepted (Cheng et al., 2018; Glaessgen and Stargel, 2012; Haag and Anderl, 2018; Padovano et al., 2018; Tao, Cheng, et al., 2018; Tao, Sui, et al., 2018; Zheng et al., 2018a, 2019) that the concept of digital twin was firstly presented by Grieves in a conference about PLM in 2003 as made of three parts, i.e. physical product in real space, virtual product in virtual space and the connection of data and information that ties two spaces together (Grieves, 2014). From Grieves, the concept of digital twin evolved in the years: until 2014, the different definitions given referred to the aeronautical field, with the digital twin concept that maintains the characteristic bi-part composition (i.e. virtual and physical) and integration (i.e. with data) but the concept of simulation is introduced (Glaessgen and Stargel, 2012; Hochhalter et al., 2014; Reifsnider and Majumdar, 2013); then, with the introduction of the Industrie 4.0 plan in Germany (Rosen et al., 2015), the concept of digital twin becomes broader, moving from products to processes (Rosen et al., 2015); from real-time representation to optimization and prediction (Tao and Zhang, 2017; Zhuang et al., 2018); from simulation to real-time and continuous evolution (Haag and Anderl, 2018; Tao, Cheng, et al., 2018; Tao, Sui, et al., 2018; Tao and Zhang, 2017).

The definition of digital twin from the literature

Based on the results of the research, literature defines the digital twin as a way to combine (Tao and Zhang, 2017), integrate and realize the interaction (Cheng et al., 2018; Shubenkova et al., 2018) between physical and virtual worlds. It can have different granularity since the physical object can be a system (Tao and Zhang, 2017) or a sub-system (Glaessgen and Stargel, 2012; Zhuang et al., 2018) and can be a product (Grieves, 2014) or a process (Rosen et al., 2015). The integration and interaction between physical and virtual worlds means that there is a bi-directional connection between the two parts: on one direction, various types of data are collected from the physical world and elaborated in the virtual world (Cheng et al., 2018; Shubenkova et al., 2018;

Zhuang et al., 2018); then, the results are fed back to the physical part for its management and optimization (Zhuang et al., 2018). The connection is in real-time and enables the co-evolution of the virtual part with its physical *twin* (Haag and Anderl, 2018; Tao, Cheng, et al., 2018), since it is not only the representation of the current and past status of the physical part but of all its entire lifecycle (Cheng et al., 2018; Tao, Cheng, et al., 2018). In addition to this, the digital twin is not only a tool to manage, control and monitor the physical object but also to support the decisional making process as it can perform optimization and predictions of its future status (Cheng et al., 2018; Shubenkova et al., 2018).

Digital twin possible uses

The research gave also several results in term of possible uses of the digital twin as a base or enabler for different purposes: in (Rosen et al., 2015), the authors consider the digital twin as a key enabler for the *autonomous systems*, i.e. intelligent machines that execute high-level tasks without detailed programming and without human control; for (Zhuang et al., 2018), the digital twin provides a new solution to data management, acting as a single data source throughout the product lifecycle: first, the manufacturing connected resources generate real-time data; then, the data are real-time processed in order to guide the managers to dynamically optimize the production activity plans; finally, the newly production activity plan is fed back to the physical assembly shop-floor and guides the production second round.

In terms of service proposition, for (Padovano et al., 2018), the digital twin can be used as a based service oriented application for a 4.0 knowledge navigation in the smart factory (a *KaaS*, Knowledge as a Service model), as an holistic software platform that works as a service-oriented knowledge-aware expert system that offers a full set of services (diagnostics and condition monitoring service, prognostics and decision support service,...) designed as a separately-maintained and deployed apps accessible over standard internet protocols; (Tao, Cheng, et al., 2018) specify nine categories of services that can be develop thanks to the digital twin: service of real-time state monitoring, service of energy consumption analysis and forecast, service of user management and behavior analysis, service of user operation guide, service of intelligent optimization and update, service of product failure analysis and prediction, service of product maintenance strategy, service of product virtual maintenance, service of product virtual operation.

Practitioners analysis

Approach

In order to extract a general definition of digital twin from the practitioner perspective, the following approach was applied: a survey to different company managers and practioners have been launched based on three core questions (what is a digital twin, what could be its purposes and which are its potential benefits); then, a semi-structured interviews to provide deeper insights into the digital twin; finally, a systematic combining of the results to provide a framework that describes the expectations of the community of the digital twin and to link the digital twin back to the literature.

Based on the research question detailed before, this was considered to be the most effective approach to gain insights from practitioners as it was conceived that the data (both ranking and open questions were used) from the survey results would help to show the gap between theory and practice with digital twins. This is confirmed by (Forza, 2002), who states that surveys are an effective tool to poll a population, which was from our own lists plus a self-selecting population from social media. The screening of the results was undertaken to ensure that industrial inputs were assessed.

The use of semi-structured interview is often used to provide deeper insights than from simple surveys, their applicability has been confirmed by (Barriball et al., 1994). The interview script -

focused on questions of the survey plus one open question - was built up based on the initial analysis of the survey results and made to 15% of the survey respondents.

We adopted systematic combining, in line with (Dubois and Gadde, 2002), in order to elaborate the framework that is presented in Table 1. In doing this, we moved back and forth between the empirical data and the extant literature, following a nonlinear analysis process (Eisenhardt, 1989): the open answers collected with the survey were transcribed, and enriched with the information coming from the interviews; we analysed the data qualitatively and the complexity was reduced through successive categorization of primary data (Bryman, 2004), in particular the content analysis was conducted by using ad hoc codes (manifestation of the findings recovered from the literature, around the conceptual definition of what a digital twin is, why a digital twin exist, how and what a digital twin does) that were converted into more meaningful “in vivo” codes, that were foundational to the development of the first-order categories; then, we moved back and forth to examine, compare, group, and find in-depth relationships among first-order categories and codes; doing this way, we reduced first-order categories to the most salient categories; finally, we established the 2nd order themes, that constitutes the pillars of the working definition of the digital twin.

During the mentioned stages we always referred to the literature to verify the explicative power of the working definition of the digital twin, to check for missing concepts, contradictions, and to improve the overall quality and internal consistency. We extensively used memos and affinity diagrams. We also shared the findings between the paper’s authors that initially had worked independently. Any discrepancy was analysed until we mutually agreed upon general and common definition of digital twin.

Results

Based on the 53 answers of the survey and the 9 interviews conducted, the results of the approach previously explained are shown in Table 1.

Table 1: The results of the systematic combining analysis applied on the answers of the survey and the interviews.

Second-order theme	First-order category	Representative code	Representative quote
A digital twin can collect – even in real time – field data of different kinds coming from the object it represents, to integrate them and show the object status (e.g. the contextual or environmental conditions, the operational conditions, the service activity) in a more meaningful way; the data trol and change it’s current status.	Data integration	Operational/ process data	<i>Digital twin collects real-time data coming from the product or process.</i>
		Service/ maintenance data	<i>What service life it has, what work has been done to it, what new parts have been fitted, etc..</i>
		Contextual/enviro- nmental data	<i>The usage is rated as well as the environmental conditions.</i>
		Semantic integration	<i>A digital twin is a representation of all characteristics of a physical asset in the digital world.</i>
	Data communication and remote control	Real time feedback	<i>A digital twin is a virtual representation of a real environment [...] that provides real-time feedback.</i>
		Bidirectional communication	<i>The flow of data can be bi-directional since they are not just only to represent the reality but also to manipulate it.</i>

Second-order theme	First-order category	Representative code	Representative quote
<p>A digital twin can be used to track the life cycle status of an object, make simulation and scenario analysis (what-if?) that are feed by real data (data driven analysis), to predict and simulate events, to show opportunity for improvement, to take decision and optimize.</p> <p>The environment for analysis and simulation is created through Industrial Internet platforms, that integrate applications, resources and skills coming from different fields and actors of the ecosystem.</p>	<p>Life cycle analysis, condition monitoring and resource integration</p>	<p>Aging, wear, degradation</p>	<p><i>A computational model that simulates aging at the same rate as a physical part.</i></p>
		<p>Resource integration</p>	<p><i>Promoting a product lifecycle analysis by enriching the combination of different engineering expertise.</i></p>
	<p>Decisional support and optimisation</p>	<p>Simulation models</p>	<p><i>A dynamic system, comprising of physical, operational and simulation data.</i></p>
		<p>Predictive models</p>	<p><i>On this platform analytics solutions are deployed to monitor, predict and optimize physical assets.</i></p>
<p>The digital twin is a virtual model of a real system or process, that can have different granularity.</p>	<p>Digital model of a real physical asset, product, component or system</p>	<p>System</p>	<p><i>A virtual representation of a real environment (for example, a production system).</i></p>
		<p>Sub-system</p>	<p><i>A digital representation of a physical asset, such as an installation, equipment, or subcomponent.</i></p>
	<p>Digital model of a process, a service, a maintenance activity</p>	<p>Process</p>	<p><i>A digital twin is the digital mirror of a real process.</i></p>
		<p>Maintenance</p>	<p><i>Maintenance will be done on the real system but is virtually also "added" to the virtual simulation environment.</i></p>
<p>The digital twin uses I4.0 techniques and technologies (i.e. VR, AR, 3D modeling, cloud, ML, IoT, numerical methods (CFD, FEA), etc.) to collect and elaborate data and acts on the physical counterpart thanks to the use of actuators.</p>	<p>Data transfer and elaboration tools</p>	<p>Transfer data</p>	<p><i>IoT based platforms enable the data transfer.</i></p>
		<p>Data collection/elaboration</p>	<p><i>ML, AR, VR, discrete event modeling, CAD, CFD, Cloud,... enable the data collection and elaboration.</i></p>
	<p>Cyber remote control</p>	<p>Remote control and manipulation</p>	<p><i>Digital twin can act as a remote controller of actuators placed on the product or on the objects etc of the process.</i></p>

The definition of digital twin given by the practitioners

Summarizing the results previously showed, we can say that for the practitioners a digital twin is a virtual model of a real system or process, that can have different granularity; it can collect – even in real time and thanks to I4.0 techniques and technologies (i.e. VR, AR, 3D modeling, cloud, ML, IoT, numerical methods (CFD, FEA), etc.) - field data of different kinds coming from the object it represents, in order to integrate them and show the object status during its entire lifecycle (e.g. the contextual or environmental conditions, the operational conditions, the service activity) in a more meaningful way; the data are used not only to represent the status of the object but also to predict and optimize – thanks to simulation and scenario analysis (what-if?) that are feed by real data (data driven analysis) coming from Industrial Internet platforms, that integrate applications, resources and skills coming from different fields and actors of the ecosystem – the decision-making process. A digital twin can also send data to the real object, to control and change its current status.

Discussion

With the support of Table 2, we discuss the differences between the literature and practitioner definition of digital twin.

Table 2. Comparison between the literature and practitioner definition of digital twin.

Characteristic	Literature	Practitioner	Different
<i>What is</i>	A “way”	Virtual model	•
<i>Different realities</i>	Real and virtual	Real and virtual	
<i>Digital twin object</i>	Product or process	Product or process	
<i>Granularity</i>	System or sub-system	System or sub-system	
<i>Communication between the realities</i>	Bidirectional	Bidirectional	
<i>Type of communication</i>	Real-time integration and interaction	Real-time integration and interaction	
<i>Actions on data</i>	Collection and elaboration	Collection and elaboration	
<i>Types of data</i>	Various	Various	
<i>Data time horizon</i>	Past, present and future (lifecycle)	Past, present and future (lifecycle)	
<i>Data enables</i>	Management, control, optimization, prediction	Management, control, optimization, prediction	
<i>Relationship between physical and virtual world</i>	Co-evolutionary and the virtual can act & control the physical	Virtual can act & control the physical	•
<i>Tools used</i>	I4.0 techniques and technologies	I4.0 techniques and technologies	

Starting from what is a digital twin, literature does not specify which kind of element (i.e. model, object, etc.) it is, and uses a more general term (“way”), instead practitioners specify that it is a model of a product or process with different granularity (system, sub-system); as previously described within the results of the literature review, in different use-cases and other papers we found instead a direct reference to simulation and/or modeling of products and/or processes.

In terms of what the digital twin does, it is commonly recognized that it realizes the interaction and integration between physical and virtual world in a real-time manner, along all of the lifecycle of the physical part, by a bidirectional flow of data: the data coming from the physical object are first collected in the virtual world; then, they are elaborated in order to predict and optimize its behaviour and to define a plan (Zhuang et al., 2018) that finally guides the user or the the virtual part on how to act on the physical part. The main difference to highlight is that if the practitioners intend the digital twin as a model/simulation of the reality and so something that simulates it, literature explicitly states that both worlds co-evolve together, just like they would be two “twins”.

About how the digital twin does that, even if in the definition of the literature there is not an explicit reference to how the interaction and integration between the two worlds is done – also because, we assume, of the more general definition of what is a digital twin (a “way”) –, we found many different use-cases in literature that refer to the same technologies and techniques specified by the practitioners .

Conclusions

Based on the previous discussion of the results, we can conclude that literature and practitioners seem to be generally aligned on the digital twin paradigm; nevertheless, even if the practitioners are aware of the possibility to develop customized, punctual and fast services based on the actual status of product/process thanks to the digital twin, literature rather neglect – considering the total 255 results of the literature review – its plausible key role in the service strategy of product-based companies, claiming only that it can enable the development of new and smart product-service solutions (Tao, Cheng, et al., 2018; Zheng et al., 2018b) or making manufacturing as on-demand cloud services (Lu and Xu, 2019; Padovano et al., 2018). In particular, (Tao, Cheng, et al., 2018) specify nine categories of services that can be provided to product users and manufacturers but still state as a possible future work the development of smart service analysis method based on digital.

Considering that servitization is a data-intensive process and effective approaches should be adopted to exploit data for new revenue stream in manufacturing companies (Opresnik and Taisch, 2015); that massive user/product generated data serves as the key for value creation, while effective data analytics tools enable its success (Rymaszewska et al., 2017); that adopting a platform approach with modular architecture is very effective for overcoming the servitization paradox (Cenamor et al., 2017), as the general definition of digital twin highlights how much effective it should be to bring the data into action, we can conclude that apart the obvious need for future research works on relevant industrial applications (Negri et al., 2017; Tao, Cheng, et al., 2018) to develop the *how-to* part of the definition (considering also what has been done so far from a regulatory aspect), particular attention should be given to investigate how the digital twin enables the service growth of manufacturing firms and to demonstrate how much they would benefit from them.

The limitations of this research can be found both in the literature and practitioners analysis: the literature review was done based only on the Scopus database and does not consider papers that could use different terms of digital twin (i.e. digital shadow); instead, the survey and the interviews could be conducted in a more structured way (i.e. carefully planning the selection of the respondents) and it lacks of a deep analysis of the documents, magazine articles, etc. where is the explained the digital twin concept for manufacturing – but not only – companies.

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