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Comparative Analysis of Digital Twin and Cyber-Physical System Concepts

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Abstract

The terms Digital Twin (DT) and Cyber Physical System (CPS) are becoming more and more popular topics for scientific research as connectivity technologies are evolving boosting new use cases with digital data about physical assets. Both terms gained popularity after the year 2017 and are seen as the key drivers for automating processes. In the growing number of research papers, both terms are also more frequently used together. Though in many research papers, there are no defined differences between the terms, and they are even used with the same meaning or in many cases also with a different meaning for the same term by different scientists.
This research paper aims to evaluate state of the art of how those two terms with growing importance in scientific research are explained when used together in research papers by other scientists in recent years. And considering insight from this literature review clusters of key differences and interactions between the two terms is presented.

Keywords: Digital twin; cyber physical system; Industry 4.0

1. Introduction

The term DT as a concept was proposed more than 20 years ago by Michael Grieves who introduced its conceptual idea for Product Lifecycle Management in 2002 (Lektauers et al., 2021). However there still is no international standard for the term DT and scientific literature reviews about DT show that among scientists there are different views on how to define it (Duan et al., 2022; Durão et al., 2021; Fuller et al., 2020; Jeong et al., 2022; Semeraro et al., 2021).

Initially the DT concept first introduced by Grieves was defined as a virtual, digital equivalent to a physical product (Grieves, 2015). Through the years' connectivity technologies have opened a lot of new DT use cases in various industries and there are new methods introduced of how to use data also in real-time. (Tao et al., 2018) defines DT as "a comprehensive virtual replica of a physical entity that integrates real-time data from sensors, IoT devices, and other sources to monitor and optimize its performance and enable predictive maintenance".

CPS as a term was proposed in the year 2006 by Helen Gill at the National Science Foundation (NSF) (Tao et al., 2019). And NSF defines the term of cyber-physical systems referring to the tight conjoining of and coordination between computational and physical resources (National Science Foundation, 2009). Lee and Seshia (2014) describe CPS as "an integration of computation with physical processes", and emphasize that CPS is "about the intersection, not the union, of the physical and the cyber" (Lee and Seshia, 2017).

Both terms are used more and more together in research papers. From the data of the yearly amount of all the scientific publications in databases Scopus on search string "digital twin* AND cyber* AND physical*" (see Figure 1) it can be seen that the trend is growing.

As the use of DT and CPS continues to expand in different industries, it further accentuates the need for a clearer and unified definition to foster consistent understanding and communication within the scientific community. (?) conducted a systematic review of DT technology and applications, highlighting its wide-ranging utility in aerospace, bridge construction, transportation,

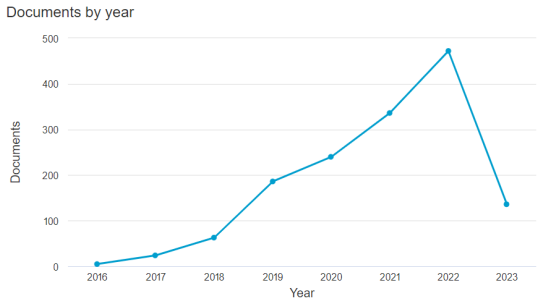

Figure 1. Statistics from "Scopus" (Elsevier B.V., 2023) about DT and CPS research papers

healthcare, intelligent manufacturing, human-machine collaboration, metal smelting, physical networks, energy, power, as well as training and education industries. CPS as well is used in various industries, "including manufacturing, energy, infrastructure, consumer goods, military, robots, smart buildings, communications, healthcare, and transportation" (Javaid et al., 2023).

2. Comparison between DT and CPS

DT and CPS both concepts are based on cyber-physical connections. As they have many other similarities just already in the year 2019 published research (Tao et al., 2019) comparing those two concepts and the correlation between them. In this review and analysis CPS core element was distinguished as sensors and actuators and DT core elements – models and data (see Table 1 for other comparison parameters).

Nevertheless, even in recent research published by (Parnianifard and Wuttisittikulkij, 2022) authors emphasized that there is no systematic and complete investigation of the connections and relationships between these two concepts as was shown in previous research by (Yao et al., 2019). Also, the authors provided a schematic representation of CPS (Parnianifard and Wuttisittikulkij, 2022) shows a very similar picture of a conceptual model of Digital Twin. Figure 2 shows this CPS concept and DT concept visualization used in "Destination Earth" digital twin project in Europe (European Comission, 2021).

Both concepts are becoming more and more popular and have a greater impact on our everyday life and economics. With the development of more advanced wireless technologies such as 5G and 6G mobile communication networks, the role of CPS and DT is expected to rise (Gartner, 2023; Ericsson, 2022). Therefore, it is important to review how those concepts are used in scientific literature.

3. Research Method

Literature analyses were conducted to review scientific publications where both terms were used together in a title. See the Figure 3 describing process and results for conducted literature analyses. In "Scopus" data bases search string "Digital Twin* AND Cyber* AND Physical*" was used as there are different versions of how those terms are written, for example, digital twin as well as digital twins, cyber physical system as well as cyber physical systems and as cyber-physical system. The results were limited to search parameters - all open access, articles and conference papers, and English language. The search string for both terms was limited to the title because that means that authors see both terms as significant to emphasize and there is a correlation between them.

Of 68 papers one was found not available for open access. Therefore 67 full research papers were reviewed. The Scopus database data were used to examine the available scientific literature because it is the largest abstract and citation database of peer-reviewed literature (Elsevier B.V., 2023). For the same search string, it also showed the biggest amount of research papers among the most

Table 1. Data from (Tao et al., 2019) research on the correlation and comparison of CPS and DTs

Items	CPS	DTs
Origin	Coined by Helen Gill at the NSF around 2006	Presented by Michael Grieves in a presentation on PLM in 2003
Development	Industry 4.0 listed CPS as its core	Not much attention paid to DTs util 2012
Category	Akin to a scientific category	Akin to an engineering category
Composition	The physical world and the cyber world, CPS focus more on powerful 3C capabilities	The physical world and the cyber world, DTs focus more on virtual models
Cyber-physical mapping	One-to-many correspondence	One-to-one correspondence
Core elements	CPS emphasize sensors and actuator	DTs emphasize models and data
Control	Physical assets or processes affecting cyber representation, and cyber representation controlling physical assets or processes	Physical assets or processes affecting cyber representation, and cyber representation controlling physical assets or processes
Hierarchy	The unit level, system level, and SOS level. A smart production line, shop floor or factory are examples of system-level CPS and DTs; a service platform constitutes SOS-level CPS	The unit level, system level, and SOS level. A complex product can also be considered as a system-level DT; an SOS-level DT covers the product life-cycle
Integration with new IT	Be inseparable from new IT	Be inseparable from new IT. A DT is easier and faster to integrate with new IT compared with CPS

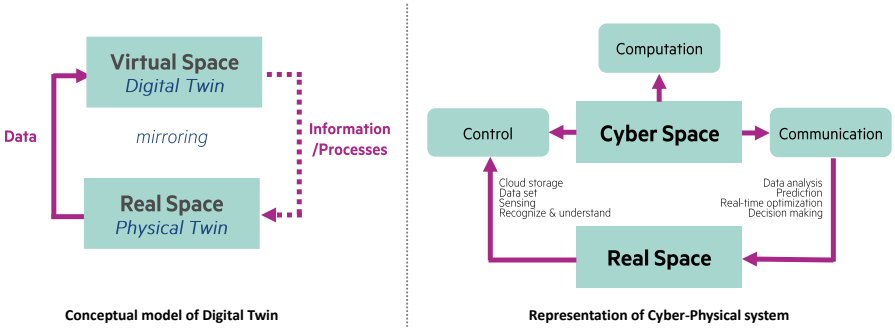

Figure 2. Concepts of Digital Twin and Cyber-Physical System

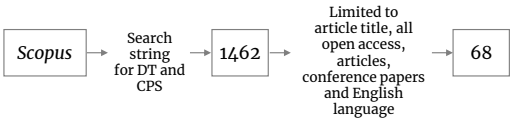

Figure 3. Scientific document search in Scopus database for literature review

frequently used database of scientific literature.

4. Results and Discussion

Reviewing all 67 research papers where in the title is mentioned DT and CPS it can be seen that those concepts still are used differently by various scientists. In many cases, the description of concrete boundaries what is CP part and what is DT part is very blurred or those concepts are explained just theoretically. In some cases, one concept or another is just mentioned in the article title, but then only a few times in the rest of the article.

Analyzing the wording used in those research papers regarding DT and CPS interconnection there can be 4 clusters allocated. And they all show how different in research papers DT and CPS concepts are used and described (see Figure 4). Regarding DT and CPS concept integration in some of the publications DT is seen as separate, but in others as integrated with CPS as well as part of CPS or even type of CPS. And at the same time, CPS is also seen as DT-based or assisted. There are different relationships between both concepts described – in some publications is mentioned that DT is controlling and orchestrating CPS, but in others, it is mentioned that CPS is embedding intelligence and CPS is only modelled as DT. In many of the papers that are using both concepts in the article title, in the publication it was described how DT could be used for CPS as a virtual representation or as modeling and simulations of CPS. And there is even a different view by various authors about DT as a virtual model, as an augmented reality solution.

Based on the results from this literature review the most various versions describing DT and CPS use cases is about the integration of those technologies and relationships between them. This could be the topic for future research defining more precise interaction and integration models for DT and CPS. For example, there could be DT without CPS and vice versa and there could also be DT and CPS integration models with CPS or DT based or driven approach.

4.1. Types of interaction between DT and CPS

Based on the results from this literature review there can be 5 types of CPS and DT interactions defined (see Figure 5). This classification could be the solution to the problem of distinguishing both concepts.

If there is just a system with sensors and actuators without DT model and data approach – it can be defined just as CPS. In cases where DT is a replica of CPS or a model for simulating CPS it could be defined as DT of CPS. It could be also that CPS is just providing data for DT and maybe even multiple CPS could be the providers of data for DT – then the interaction model could be defined as DT to CPS. In the cases where CPS is designed and controlled by DT the interaction model could be defined as DT-driven CPS. And there could also be situations where are no sensors and actuators, just data and models then it could be defined just as DT.

Both concepts are becoming more and more popular to use and technology is evolving Therefore this kind of DT and CPS interaction model could help to make clearer the usage of those concepts.

5. Conclusions

DT and CPS concepts are both based on cyber-physical connections. Even though those concepts are becoming more and more popular and more frequently used together

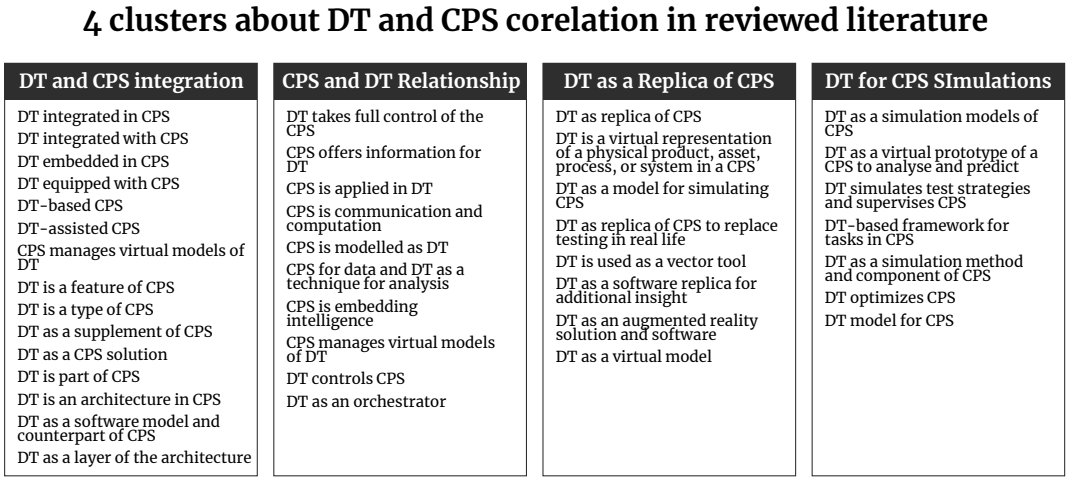

Figure 4. Clusters from literature analyses from research papers about DT and CSP about how those concepts are described in correlation

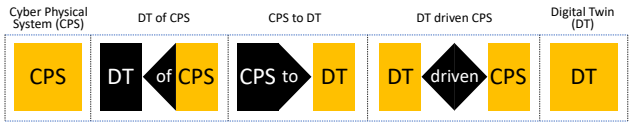

Figure 5. Five types of CPS and DT interactions

in scientific research papers literature analysis presented in this paper shows that there are different views among scientists on how to describe the correlation between both terms.

For more clear usage of those two terms, a model of five types of DT and CPS interactions is offered based on the results of the literature review in this paper. Using this classification model of interaction between DT and CPS could help to define those technologies more clearly.

Both of those technologies are evolving. Therefore, there is a need for further research to develop a more precise unified approach to how to distinguish DT and CPS concepts.

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