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The Potential of Digital Twins in Product Development.

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1 Introduction - What are Digital Twins?

A digital twin is a computer simulated copy of an existing, physical object, device or other similar entity. The physical object transmits its state and status back to the simulated copy which then updates itself accordingly. The physical twin object can be anything from a small and hard to reach sensor, to a large car or a massive cargo ship.

A fully functional real-time updated digital twin could allow for the manufacturer or other maintenance crew to detect problems, faults and other issues which need fixing even before the user knows anything is wrong.

Although the concept digital twins was formally invented in 2002 [1], similar approaches have been used since at least 1960s. During the Apollo 13 project in 1970, the mission control scientists used a replica of the spacecraft to quickly develop and test a solution for how to deal with a damaged oxygen tank in the original spacecraft. There are two very different types of digital twins, data-driven digital twins and model-driven digital twins.

A data-driven digital twin is a model created from data transmitted by the physical object. Sensors in the product gather data and send it back to the twin where this data is used to simulate the product. A model-driven digital twin does not require a fully developed and constructed physical product. The simulated twin is created from the original plans and the design can be tested before manufacturing has to be started. This can be very useful if it would be too expensive or complicated to build and modify several prototypes before the design if finalized. There are many industries where digital twins offer substantial benefits in productivity and efficiency.

In manufacturing, the digital twin allows for the manufacturer to collect large amounts of data on the effects of the manufacturing process and its efficiency. This data can then be used to simulate and optimize the entire process.

In urban planning, digital twins can be used with augmented reality technologies to simulate planned construction projects. Projected augmented reality maps are used to enable urban planning engineers to view highly detailed maps in collaborative projects.

In healthcare, it is possible to use data gathered from patients to maintain a live model of a patient, which could easily be used to predict health risks and other issues. This virtual patient can be compared to the entire population and thus the real patient could be given more accurate care and a treatment which is better tailored for the individual. With enough data, the personalized virtual patient could theoretically be used to predict and track illnesses and issues faster and easier than physical inspections could.

2 Advantages and Disadvantages of using Digital Twins

2.1 Advantages

There is huge untapped potential of DT, digital twin in product development and design. It acts as a bridge between the real world and the digital world, as for that the physical products can be enhanced to be smarter by adapting its real-time behavior with recommendations made by the digital twin. Contrary the virtual products can be made more realistic to mimic the real-world state of the product from physical world.

This enables communication and collaboration without middlemen between physical space and virtual space more accurately and effectively. [2] As for this DT can reflect new and old information onto serviceability of components and new simulations, diagnostics, and predictions [3]. This enables designers to understand not only where the possible contradictions are but how and how large scale of the contradictions are. [3] Thus, using digital twins, designers can create elaborated simulations and scenarios, effectively apply these tests to prototypes, and accurately predict the actual performance of physical products as accurately as possible. Moreover, a digital twin can be accessible anywhere and regardless of the size of the product or system [3]. As for this, DT's can be utilized even to be used to train operators in accountable simulations [4].

With decisive analysis of data, warn of any future breakdown, incident or anomaly or faults in the system can be detected much in advance [2]. So in this sense DT can accelerate cycles of development also by avoiding lengthy testing periods [3].

DT brings also better intra- and inter-team synergy and collaborations in between. All the information is close by and available, so different parties can assess their time in improving synergies and collaborations leading to greater productivity [2]. DT's can also make contextually smart decisions and would easy up amount of engineering related decisions. DT also can be reflected to the whole lifecycle of the product.

Lastly there most likely will be better documentation. Digitalized data will improve for example of informing stakeholders and thereby improving overall transparency. [2]
DT enables also to have complete digital footprint of products through design.

Overall DT enables detecting problems in advance and resolving them more quickly than with its physical counterpart. This helps overall in schedule assessment and might transform to greater productivity, synergy, faster development, decision making circumspect decisions, and even profitability. [5]

2.2 Disadvantages

It takes several steps to create a fully functional digital twin;
cad modelling, analyzing, integrating and visualizing data, simulations, controlling behavior, communicating with virtual product and measuring and collecting all data available.
As for with DT's design process becomes increasingly digital. There might be underlined problems if development phase isn't already fully digital and ready for DT's.
Data protection laws now require that the decisions made for humans should also be explainable to humans. There might be confrontations while using DT's. While AI is expanding and developing worldwide there are also lots of moral decisions to be made by virtual counterparts.
Successful DT's depends on a real-time two-way stream between the physical product and its DT. High probability challenges related to this are spatio-temporal resolution of sensor data, large data volume, large data generation rate, latency, variety of data, archival retrieval and online processing of data.
As the physical product wears or evolves in time it requires a corresponding response of the virtual models while still maintaining backward compatibility. DT's require high level of safety and security, there will be a need for greater transparency and interpretability of the decisions taken based on digital twins. This will require models which are interpretable and physically consistent. [2][3] Following table 1 enlightens the advantage and disadvantages of the different DT's:

Table 1: Advantages and disadvantages of different DT's

Physics based modeling	Data-driven modeling
+ Solid foundation based on physics and reasoning	− So far most of the advanced algorithms work like black-boxes
− Difficult to assimilate very long term historical data into the computational models	+ Takes into account long term historical data and experiences
− Sensitive and susceptible to numerical instability due to a range of reasons (boundary conditions, initial conditions, uncertainties in the input parameters)	+ Once the model is trained, it is very stable for making predictions / inferences
+ Errors / uncertainties can be bounded and estimated	− Not possible to bound errors / uncertainties
+ Less susceptible to bias	− Bias in data is reflected in the model prediction
+ Generalizes well to new problems with similar physics	− Poor generalization on unseen problems

As for these DT's require past data, present data, real time data, sensors, future data, machine learning, real time modelling, continuous model updates, modelling the unknown - it is a large scale computation interaction with physical assets or products. This means constant inputs from engineers is needed. And if company does not have products which used DT's before, designing novel solutions with new DT's might be overlapped with development of the DT's.

3 Example case 1: DigiTwin Project

Digital twins are widely used in the field of academia for teaching, research and innovation purposes. A prime example of this is the Aalto DigiTwin project which is being undertaken in collaboration with several industry partners such as Konecranes and Siemens Oy. Let us focus here on a research project which was being developed in the Aalto Industrial Internal Campus (AIIC) environment where the aim was to couple an actual crane and its digital twin in accordance to its product configuration, product design and the product life cycle.

The digital twin developed was for a type of overhead crane developed by Konecranes that was nicknamed as the Ilmatar crane. The crane platform was installed within the AIIC laboratory back in 2016 for mechatronics education and its digital twin was developed with the hope of influencing the manner by which practical learning exercises are implemented with respect to Industrial Internet technologies and other areas of automation [6]. Thereby, any successful research results could be transformed or utilized towards commercial products as well as services of the industry partners. Such research would typically take a longer time span if not for the existence of the digital twin since the digital twin enables the researcher to simulate more possible scenarios that revolves around the changes of a multitude of parameter combinations. Moreover, the researcher can do so without worrying about the risk of having to deal with severe consequences of failure since it is much easier and faster to revert back to the original point as the trials are being done digitally and not on the actual product during the initial phases. This is quite important in the field of education and research since the students are encouraged to try out new things and observe the outcome themselves in the process of learning. Under ordinary circumstances they might not have the liberty and freedom to do so since there is always a risk of damaging or breaking the actual product which costs millions to begin with.

Figure 1 presents an image of the Ilmatar crane installed within AIIC. I will not go into details with respect to the software and physical characteristics of the crane, but it available freely on the web as well as the Aalto Digitwin domain. In essence, this unit is a form of Cyber-Physical System (CPS) and the cyber part is basically represented by the Digital Twin.

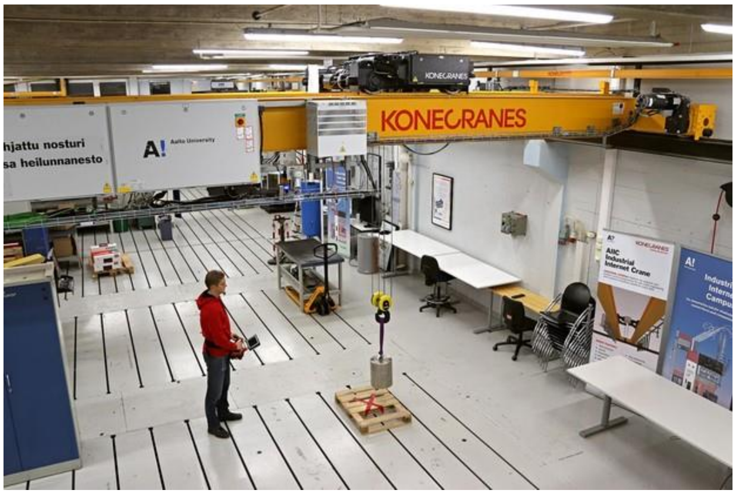

FIGURE 1: ILMATAR CRANE IN THE AALTO INDUSTRIAL INTERNET CAMPUS

More importantly, there have been many use cases of the digital twin of the Ilmatar crane since its implementation. One of the most interesting projects we found was a mixed reality project which was a part of a Master's thesis project of an Aalto student. Mixed reality, in its broadest terms, is a composition of the physical and digital worlds. Henceforth, the project was focused on instigating mixed reality centered visualization and manipulation of the Ilmatar crane. The digital twin was therefore used to enhance connectivity of the other devices with the Ilmatar crane (specifically, the Microsoft HoloLens for this project). The digital twin comprises of a database containing the real time crane positions as well as its history and it subsequently sends this information to the mixed reality device. Additionally, the digital twin also relays control signals from the mixed reality device to the crane in order to manipulate it as desired. All in all, by implementing certain selected segments of the digital twin within a real time environment as well as its related applications, students can obtain valuable hands-on experience [6].

The following link corresponds to a video which presents some of the cool highlights of what was organized as the Digitwin Demo Day which was held in November, 2019 within the Aalto Industrial Internet Campus [7]:
https://www.youtube.com/watch?v=J641MyVfxTc&ab_channel=AaltoUniversityIndustrialInternetCampusAIIC

4 Example case 2 – Digital Twin-models in the Car Industry

Another example of the benefits of using Digital Twin-Models can be found in the car industry. This has been very common for developing prototype models, digital twins of individual production cars are becoming increasingly common, especially among electric cars [8]. The usage of digital twins in the car industry can be divided to model- and data-driven digital twins.

4.1 Model-Driven Digital Twins – Prototyping and Car Racing

The model-driven digital twin gathers data from computer simulations and calculations. This can be beneficial, if physical testing is limited, costly or lack accuracy. Calculating engine loads can be simple with a CAD-model, while physical testing can be challenging [9].

For example, in Formula 1, the cars have digital models that accurately represent the behavior of the physical car during various loads and configurations, without bringing the car to the track at all [8].

Another benefit of using model-driven digital twins are crash tests. A crash test performed on a CAD model will greatly reduce costs, compared to a physical crash test.

4.2 Data-Driven Digital Twins – Modern Production Cars

Modern production cars may have individual data-driven digital twin models. This means, that the physical car has a sensors and other measurement devices, that measures tire wear, ride height, damper stiffness, spring loads and offsets, and engine oil quality in real time [8]. This data will be used to perform computer simulations and predictions about maintenance requirements and real-time lifespan prediction and performance of individual components [8].

References

[1] Grieves, Michael; Vickers, John. (2016). Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. Available at: https://www.researchgate.net/publication/307509727_Origins_of_the_Digital_Twin_Concept

[2] Rasheed, Adil & San, Omer & Kvamsdal, Trond. (2019). Digital Twin: Values, Challenges and Enablers. Available at: https://www.researchgate.net/publication/336304126_Digital_Twin_Values_Challenges_and_Enablers

[3] Fei Tao, Fangyuan Sui, Ang Liu, Qinglin Qi, Meng Zhang, Boyang Song, Zirong Guo, Stephen C.-Y. Lu & A. Y. C. Nee (2019) Digital twin-driven product design framework, International Journal of Production Research, 57:12, 3935-3953, DOI: 10.1080/00207543.2018.1443229

[4] Burghardt, Andrzej; Szybicki, Dariusz; Gierlak, Piotr; Kurc, Krzystof; Pietrus, Paulina; Gygan, Rafal. (2020). Programming of Industrial Robots Using Virtual Reality and Digital Twins. Applied Sciences. 10(2):486. Available at: https://www.mdpi.com/2076-3417/10/2/486/htm

[5] Murphy, Charlie. (2018). What is Digital Twin Technology And How Can It Benefit Manufacturing?. Available at: https://slcontrols.com/what-is-digital-twin-technology-and-how-can-it-benefit-manufacturing/

[6] Autiosalo, Juuso. (2018). Platform for industrial internet and digital twin focused education, research, and innovation: Ilmatar the overhead crane. 241-244. DOI: 10.1109/WF-IoT.2018.8355217.

[7] https://www.aalto.fi/en/aiic/digitwin

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[8] Ahlam, Rais. (2019). Digital twin in the automobile industy. Available at: https://www.maschinenmarkt.international/digital-twin-in-the-automobile-industry-a-851549/

[9] Barnard, Aenne. (2015). Full speed on the production line. Siemens. Available at: https://new.siemens.com/global/en/company/stories/research-technologies/digitaltwin/digital-twin-cars-production-line.html

[10] Digital Twin in the Automotive Industry: Driving Physical-Digital Convergence. Tata consultancy services. Available at: https://www.tcs.com/content/dam/tcs/pdf/Industries/manufacturing/abstract/industry-4-0-and-digital-twin.pdf