My Digital Sibling

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Abstract - Digital twins show enormous promise in terms of support to decision making and through life optimisation of systems. A fully responsive, automated holistic system can however, be costly to implement and have a number of technical, cultural and commercial challenges. A digital twin maturity spectrum has been identified which could help decision makers define the requirements for their digital twin and support its agile development. Ultimately, this research asks the question, should we specify at the outset a perfect digital twin replica or start our journey with a less representative "digital sibling"?

1 What is a Digital Twin?

In Lewis Carroll's 1871 novel "Through the Looking-Glass" Humpty Dumpty says "*When I use a word, it means just what I choose it to mean - neither more nor less*". The term digital twin is increasingly used across many industry sectors and perhaps as a result there is no definitive definition. Wikipedia states it as "a virtual representation that serves as the real-time digital counterpart of a physical object or process" [1]. As a wider vision, the built environment services company ARUP states it as "the combination of a computational model and a real-world system, designed to monitor, control and optimise its functionality. Through data and feedback, both simulated and real, a digital twin can develop capacities for autonomy and to learn from and reason about its environment." [2]. What such definitions point to is that a Digital Twin is characterised by:

- a model of the object,
- an evolving set of data relating to the object,
- a means of dynamically updating or adjusting the model in accordance with the data, and
- being associated with an entity that actually exists (a digital twin without a physical twin is a model) [3]

Although such definitions describe a physical system or thing, we are also seeing digital twin approaches being applied to humans with digital models dynamically interacting with human data such as physiological data.

2 What are the Benefits of Digital Twins?

As a dynamic, up-to-date representation of an object, system or human, a digital twin can provide a collection of data in one place and evolve with the flow of real-time input from sensors and more. This connection between the digital and physical worlds offers enhanced lifecycles, informed decision-making, and predictive capabilities.

2.1 Benefits Now

<u>Optimized Performance.</u> Actionable insights, simulations, and a connected view of all online and offline data enhances decision making and the optimization of performance and efficiency.

<u>Data Visibility.</u> Unlock data silos across a project's lifecycle with both historical and real-time data in one place.

<u>Predictive Insights.</u> Data can support machine learning and artificial intelligence, with the potential to better understand trends.

<u>Managing Complexity.</u> Creating digital twins of complex assets and processes can help better understand and optimise the interdependencies and interactions.

2.2 Why now?

Over the course of the last decade, digital twin capabilities have improved due to a number of factors [4]:

<u>Simulation.</u> The tools for building digital twins are growing in power and sophistication and techniques such as machine learning are enhancing analytical capability.

<u>New sources of data.</u> New sources of data such as Lidar can be incorporated into digital twin simulations.

<u>Interoperability.</u> The ability to integrate digital technology with the real world has improved dramatically, much of which has been driven by enhanced industry standards.

<u>Visualization.</u> Advanced data visualization can help meet this challenge of the large volumes of data required to create digital twin simulations.

Instrumentation. IoT sensors, networked, embedded and external, are becoming smaller, more accurate, cheaper, and more powerful.

Computing. Increased availability of and access to powerful and inexpensive computing power, network, and storage are key enablers of digital twins.

2.3 Benefits Future

Beyond these more immediate benefits, there is the potential for entities and systems with automated systems to learn and optimise their own operation. A digital twin that can learn from and then shape the workings of its physical sibling. As AI techniques improve over time, the machine learning that will enable this level of self-optimisation. When a company builds a digital replica of its products, the environments in which they operate and the systems that produce them, it can predict virtually everything that will happen in the physical world.

3 Digital Twin Challenges

3.1 Commercial, Cultural and Technological

Digital twins and the concepts around them have been in existence for some time, so what are the current challenges? The UK's Digital Catapult [5] has made the case that digital twin challenges are commercial (eg. Multi-stakeholder ecosystems, cost), cultural (eg. complex cross-silo collaboration, and technical (eg. legacy systems). The non-technical aspects can be critical but for this paper we will highlight 5 technical orientated challenges [6]:

Accurate Capturing of Physical Properties Digital twin technology should be able to model both simple objects and complex systems by accurately capturing their physical properties.

Project Collaboration Digital twin technology should be able to collaborate and connect with other digital twins in a variety of contexts.

Automatic Updates in Real-Time It should be self-informed of its functionality in real-time and change or alter when required.

Conflict Detection and Resolving It should be able to detect and react to changes in a real-time environment.

Interaction with Digital and Physical things It can communicate with other virtual objects or digital twins in an immersive manner.

3.2 Cost Drivers

Irrespective of the challenges above, the cost, complexity and difficulty of sustaining a digital twin will very much depend on the fidelity of the models that support the digital twin. As an example, Arnold Engineering Development Complex research [7] claimed that the cost to develop and sustain a robust digital thread/digital twin models for the USAF Next Generation Air Dominance (NGAD) aircraft would be in excess of $1 trillion. These very high costs were attributed to the required computational power required, software costs, and the training of the workforce. In another example, "Destination Earth" is a joint project between the number of European scientific organisations to develop a highly accurate digital twin, or replica, of Earth. Researchers have estimated [8] that they will need a supercomputer with 20,000 graphics processors consuming around 20MW of power to create the highly complex model. Do we always need to have the highest fidelity digital twin models and data to improve decision making?

4 Digital Twin Fidelity

4.1 Digital Twin Maturity Spectrum

It is compelling to implement immediately a fully implemented digital twin, but this may prove very challenging and costly, especially applied to legacy systems or where there is not a conducive organisational digital culture. Instead, we could more usefully focus on the purpose, understanding the benefits of each milestone towards full implementation and how value is increasing along the journey to maturity. The IET have proposed [9] an industry-agnostic maturity spectrum which as a twin digital develops, each element increases in complexity and connectivity, and subsequently value. The maturity spectrum is at Table 1 with bias towards building digital twins. The ability to run simulations answering 'what if' questions, and to interrogate and analyse the data is a key part of the digital twin and this remains possible across every element of the maturity spectrum, albeit with different degrees of analytical evidence.

Table 1. IET digital twin maturity spectrum defining principles and outline usage

Maturity element (Logarithmic scale of complexity & connectedness)	Defining principle	Outline usage
0	Reality Capture	As built survey
1	2D map/system or 3D model	Design/asset optimisation and coordination
2	Connect model to persistent (static) data	Design/asset management.
3	Enrich with real-time data (e.g. IoT, sensors)	Operational efficiency

4	Two-way data integration and interaction	Remote and immersive operations
5	Autonomous operations and maintenance	Complete self-governance with total oversight and transparency

4.2 Digital Twin Maturity Spectrum and Defence

The acquisition lifecycle of a product, system or service is typically linear in approach with a clear start to the process and a clear end. There are many lifecycle models with the UK MoD using [10] the 6 phase CADMID/T Lifecycle: Concept, Assessment, Demonstration, Manufacture, In-Service, Disposal/Termination. Many systems in defence are legacy and hence it is challenging to introduce a fully mature digital twin, but nevertheless a lower level of maturity may be appropriate and better than no digital twin at all. Decision makers could decide what level of maturity they are aiming for, and Table 2 provides an illustration of this.

Table 2. Example mapping digital twin maturity against life cycle

	Phase	Legacy System	New System
C	Concept		1
A	Assessment		2
D	Demonstration		3
M	Manufacture		4
I	In-Service	1	5
D/I	Disposal/ Termination	0	1

5 Conclusion

Digital twins show enormous promise in terms of support to decision making and through life optimisation of systems. They represent a convergence of the real and digital worlds as sensors proliferate and computing and networking get ever better and more cost effective, alongside improved analytical techniques such as machine learning. A full implementation of a digital twin that is a fully responsive, automated holistic system is not straightforward, however. The appropriate validation of such a system would be required, especially if it is safety critical and/or complex with emergent properties. Costs can also spiral as computational power, software costs, and the training of the workforce are taken into account.

The challenges can not only be technical, with also potentially significant cultural and commercial issues, especially for an organisation where digital transformation is already problematic. It is hence important that when a digital twin approach is chosen the desired outcomes are clearly expressed and that its creation and management are a journey. Further, while a digital twin can be developed at any point in an asset's life, it's most effective when deployed at an early stage, so that captured data adds value for longer.

To address the aforementioned issues and assist decision makers, this paper has suggested that a digital twin maturity spectrum is used that provides a guide to all stakeholders as to what level of maturity or fidelity the twin might be. Further work would need to be carried out to refine this spectrum for the defence community. However, it is important to start a conversation and communicate to decision makers, who may not be subject matters experts, that a full digital twin approach may not be the most cost-effective way forward. A better starting point might be a less sophisticated approach that starts the journey. Less of a digital twin, more of a "digital sibling".

References

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Andy Fawkes is an independent consultant and engineer working in the field of training and simulation. He previously presented at ITEC 2018 "Simulation Based Acquisition - Has its Time Come?". Formerly he was head of simulation policy for the UK MoD and Chair of the NATO M&S Group. He is a Fellow of the Institution of Mechanical Engineers (FIMechE).