Challenges and Possible Approaches for Sustainable Digital Twinning

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ABSTRACT

The advance in digital twin technology is creating value for lots of companies. We look at the digital twin design and operation from a sustainability perspective. We identify some challenges related to a digital twin's sustainable design and operation. Finally, we look at some possible approaches, grounded in multi-paradigm modelling to help us create and deploy more sustainable twins.

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1 INTRODUCTION

The advance of Digital Twin technology is creating a lot of value for companies But designing, making, and deploying these digital twins can cost a lot of energy. Computing as an industry is currently responsible for 2% to 6% of the emissions of greenhouse gasses globally with a predicted share of 6% to 22% in 2030 [6]. So the challenge of sustainable digital twins is a very relevant one.

2 ADDITIVE MODEL

To understand the problem of sustainable digital twinning, we need to understand where energy is consumed during the life-cycle of the system and its twin. We break down energy consumption into an additive model where the consumption of the energy occurs: $E_{total} = E_{design} + E_{local} + E_{networking} + E_{cloud} + E_{update}$. With

- E_design is the energy consumed when creating the twin.
- E_local is the energy consumption by executing the twin on the local hardware.
- E_networking is the system's energy consumption by sending and receiving messages on the network.
- E_cloud is the energy consumption by executing the twin in the cloud environment.
- E_update is the energy necessary to redesign and update the model during the system's life-cycle.

This additive model allows us to reason on the impact developers have during the design and deployment of digital twins.

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3 CHALLENGES

There are several challenges in creating a digital twin in a sustainable way. In the following paragraphs, we summarize some of these challenges.

3.1 Formalism Selection

The first challenge is about choosing a formalism for the digital twin. Different formalisms and workflows exist to create a twin model to use in the digital twin architecture. Most of the techniques transform the model into an approximate model or a model that is only valid within a certain context [2].

On one side of the spectrum, there are the fully data-driven digital twins. Engineers create these twins by combining big data together with machine learning algorithms. An example is the use of classification and clustering for predictive maintenance. On the other end of the spectrum, we have physics-based or simulation-based digital twins. These digital twins run simulations of the system to reason about the system's behavior. The simulation model can be modeled using several formalisms and levels of abstraction and approximation. For example projection-based methods lower the state space dimensions of the problem and can so model the system more efficiently. The nonlinear terms will still need to be evaluated in an efficient way [1]. Another means to trade run-time and energetic performance with accuracy is to model a simplified model by hand. The modeller needs to have sufficient domain knowledge to do this.

The challenge for sustainable twinning is to create a model that explains and predicts the energy consumption of all possible digital twin architectures created during the system's design. Furthermore, the model should also predict the ramifications of this architectural choice on the energy consumption in the operational phase of the system. The plethora of methods and techniques for creating surrogate models makes this especially challenging. Furthermore, the possible transformations are highly domain-dependent.

3.2 Value Proposition

In the previous challenge, we neglect several important concepts. The foremost concept is that of the purpose of the twin. Each twin is made for a specific purpose for example the monitoring of the system's health, and the online optimisation of the system. Based on the purpose, a company gains a certain amount of value from the twin.

The value proposition and the allowed uncertainty introduced by the model are related. If the twin decision maker is tolerant to more uncertainty, then an approximate model with more uncertainty results in the same value as a twin with a detailed model. This allowable uncertainty can be exploited by selecting a model that

has the lowest energetic cost that still is valid in the context where the system operates.
Estimating how much uncertainty the decision-maker can tolerate while gaining enough value from the digital twin is a difficult problem. Furthermore, once we know the allowable tolerance, we still need to include this in the formalism selection process of the first challenge.

3.3 System Evolution

The Next challenge is system evolution. To allow for the long and continuous operation of the digital twin, we need insight into the range of validity of the model in combination with insights into the system's evolution.
Different forms of evolution exist in systems and their digital twin you can have a change in boundary conditions, a change in a component of the system, or a change in the purpose of the system all of the evolutions of the system require that the validity of the simulation twin model is checked for the new context of the system or for the changes in the system operation.
Including the dimension of evolution within the formalism selection process is needed. Having a good estimate of these evolutions in frequency and severity helps determine the needed boundary conditions and validity of the model. If not taken into account, a new model needs to be used, possibly a model that consumes more energy. In data-driven models, it could be that a new model needs to be trained, adding significant overhead to the total energetic cost of the setup.

3.4 Twin Deployment Architecture

The last challenge is about deployment. A digital twin is a complex system on its own. A twin deployment architecture thus needs to consider all different parts of the system.
So this challenge is to reason on the deployment choices related to the deployment architecture used for the digital twin. Most choices are impacted by the system's requirements, which in turn depend on the value proposition of the twin. Integrating these value and sustainability-related questions into the requirements and architecture phase is needed but challenging as requirements and constraints can change.

4 POSSIBLE APPROACHES

The proposed approaches are very much grounded in the philosophy of Multi-Paradigm Modelling [5]. The additive model shown before is already the beginning of examining the models required to solve the proposed challenges.
Selecting a twin-model architecture is perhaps the most difficult challenge presented here. The different dimensions of the problem make the problem very difficult as most of the information is or might not be available to the twin designers. As the design space of the problem is quite big, design-space exploration techniques have to be employed to solve the problem. Sensitivity information is particularly interesting between the different choices and the model's energy consumption. We want to fix the choices with the highest impact first. we also need detailed information on the validity of each model used. Validity frames are needed to capture such information [4, 7].
To take the value of the choices into account for the formalism selection, we need to fix how much uncertainty brings an optimized value for the designer of the digital twin. To quantify the allowable uncertainty, models of the decision maker need to be co-simulated with the model of the simulation augmented with uncertainty. The results of these evaluations should be combined with value models from economics.
For the prediction of design consumption, we make a distinction between data-driven models and physics-based twins. Physics-based twins do not use a huge amount of energy during design time. Most energy consumption is involved in techniques for calibration and validation of the models. However, a lot of manual effort is involved in the design of abstractions and approximations. Estimation models for the other criteria are also thus very much needed.
For data-driven twins, the situation is different. Training black box models do take a lot of computation and energy. This part of the research still has very foundational aspects. We, therefore, want to establish the relationship between metrics of the dynamic behaviour and energy consumption of the training. If these metrics correlate, we create a data fit model to estimate the needed energetic cost.
For each technique to create the twin model, an estimate of how much energy is required to update the twin is needed. For projective techniques, we need to estimate the non-linear terms. For the other methods, we might be able to relate metrics to the energetic cost (e.g., the number of equations). Energy consumption during operation for black box models already has some techniques available [3].
Finally, for all the deployed components, we need prediction models on the energy consumption at a different level of detail.

5 CONCLUSION

Advances in digital twin technology is creating value for many companies. In this paper, we looked at the digital twin design and operation from the sustainability perspective. We identified some challenges related to the sustainable design and operation of a digital twin: (a) formalism selection, (b) twin value proposition, (c) system and twin evolution, and (d) twin deployment. Finally, we looked at some possible approaches, grounded in multi-paradigm modelling, to help us create and deploy more sustainable twins.

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