

# *Sunfish*: Enabling Predictive Analytics for Datacenters Through Digital Twinning

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## Context

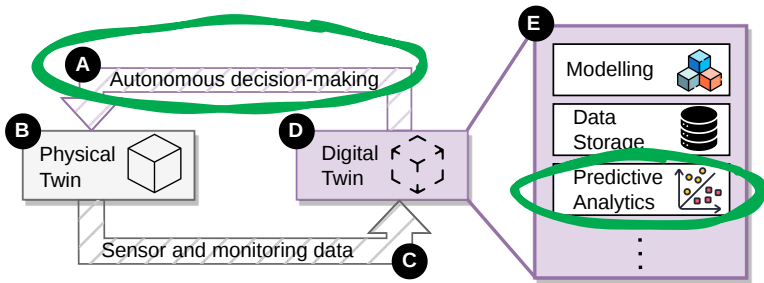
21<sup>st</sup> century datacenters (DC) are mostly heterogeneous [10] and modern computational needs of AI drive managers to diversify datacenters even more [1]. In result datacenters become extremely complex and hard to operate with millions of CPU's, GPU's etc.



**Figure 1.1:** Society depends on datacenters to keep running, and therefore we cannot afford to let these systems break down or experience significant performance-related issues. With millions of servers in the largest datacenters, real-time management becomes very difficult. Left to right: a Google datacenter, server racks, Ada Lovelace AD102 GPU architecture.

## DCDT's lack predictive analytics

We need Datacenter Digital Twins (DCDT) to be better able to detect and solve issues in critical ICT infrastructure [1]. However, DCDT's are still actively developed and lack crucial features such as predictive analytics [11] to *e.g.*, prevent unexpected failures.



**Figure 1.2:** Datacenter Digital Twin Diagram. There are 5 core elements to any Digital Twin: **A** The Digital → Physical Twin link, **B** the Physical Twin (*e.g.*, the datacenter), **C** the Physical → Digital Twin link, **D** the Digital Twin, **E** the features necessary to any Digital Twin. **Highlighted areas are the contributions from this thesis, which include the autonomous actions resulting from predictive insights **A** and the predictive analysis (including simple storage capabilities) within **E**.**

## Main Research Question

How to enable predictive analytics for datacenters through digital twinning?

## Research Question 1

How to assess the current state-of-the-art of digital twinning for datacenters?

## Research Question 2

How to design a reference architecture for a predictive datacenter digital twin using discrete-event simulation?

## Research Question 3

How to validate and evaluate a datacenter digital twin architecture in relation to system requirements?

## Main Finding I

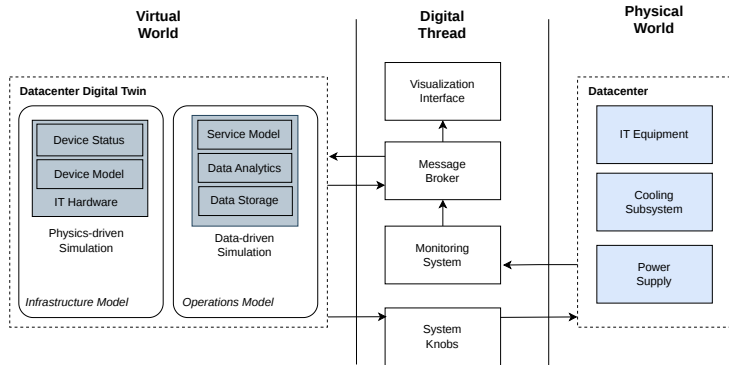
The literature on DCDTs is sparse. Some systems barely classify as DTs (e.g., Kalibre [15], ChatTwin [8]). Existing deployments specialize in **Cooling and Heat Modelling**, together with **3D visualizations**. Most lack predictive modelling of DC operations.

Project	Simulation Technique	Focus	Stakeholders	Modelling Capability
ExaDigiT [2]	CFD/HT, AI/ML	Energy Loss Prediction, Heat Modelling	HPC Engineers and Operators	3D*, CH*, VP*, PE*, RA, SE‡
SmartDC [16]	CFD/HT, BIM, AI/ML	Heat Modelling, PUE optimization	Cloud Datacenter Engineers	CH‡, PE, 3D*
DyTwin [12]	Gaussian Process Regression, AI/ML	Anomaly Detection	Cloud Datacenter Operators	A*, FD, VP*, SE‡
ChatTwin [8]	?	Digital Twin Definition Language	Cloud Datacenter Engineers	3D*
Reducio [3]	POD, Gaussian Process Modelling (ML)	Heat Modelling	Edge and Hyper-scale Datacenter Operators	CH*, 3D*, SE
NetGraph [5]	Graphs	Network Management	Cloud Datacenter Operators	VP*, RA*, N*, SE‡
Kalibre [15]	CFD/HT, ML	Heat Modelling	Cloud Datacenter Engineers	CH*, 3D*

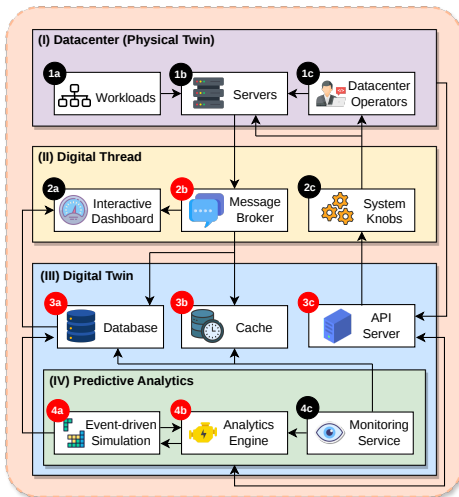
**Table 1.1:** Comparison of selected datacenter digital twins. **Modelling capability:** 3D = Visualizations; CH = Cooling/Heat, PE = Power/Energy Consumption, A = Anomaly Detection, N = Network Modelling, SE = Scenario Exploration, VP = Virtual Prototyping, FD = Federation, RA = Resource Allocation; **Data Analytics:** \* = Predictive Analysis; ★ = Descriptive Analysis, ‡ = Prescriptive Analysis.

## A holistic DCDT system model

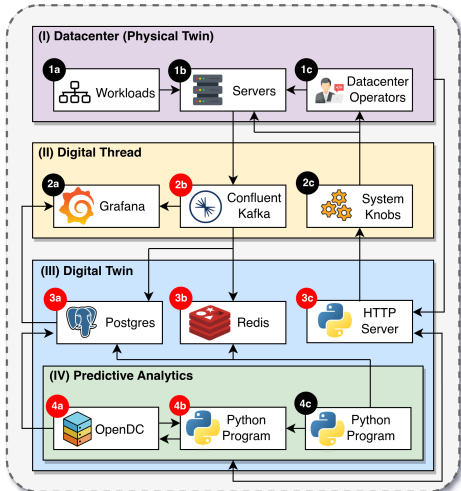
We propose a generic model of datacenter digital twinning that can be mapped to each system from **Table 1.1**. Within this model (see **Fig. 1.3**) we introduce a concept of the *Digital Thread*: a bridge between the DCDT and the physical DC equipment.



**Figure 1.3:** To answer **RQ1** we designed a generic datacenter digital twin system model based on a comprehensive literature review and findings from **Table 1.1**. The *Infrastructure Model* simulates the structure of the DC and the *Operations Model* simulates the behaviour of the DC.



**Figure 1.4:** The predictive datacenter digital twin reference architecture. The architecture was designed with the *AtLarge Design Process* [7] over several iterations in the past months.



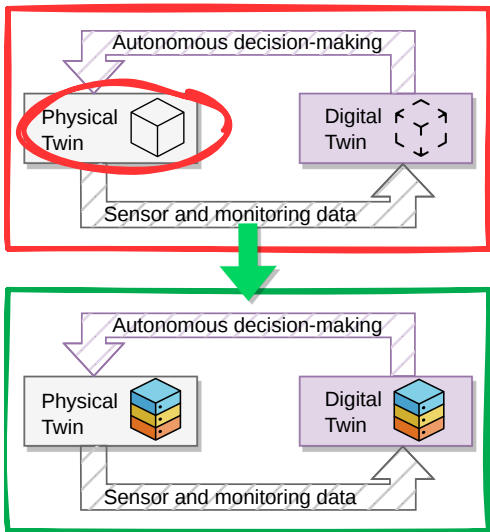
**Figure 1.5:** The prototype – *Sunfish*, and its components based on **Figure 1.4**. The time-series data flows first to the Grafana dashboard, PostgreSQL database and Redis cache [12].

## Problem

We cannot just go and test digital twins on large systems, because we do not have large systems at hand. Moreover, real-world experimentation is costly and unsustainable in the long run [9].

## Solution

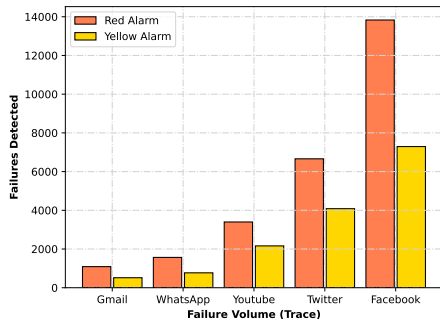
The way we test our reference architecture prototype is by using multiple simulators. We use an additional OpenDC process to play the role of a real datacenter.



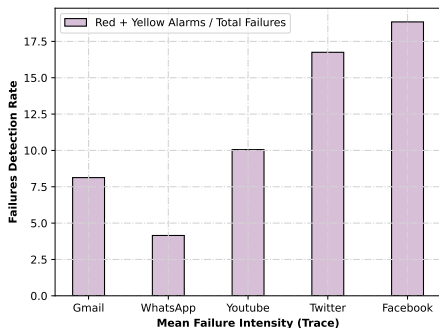
**Figure 1.6:** The experimental setup. Answering RQ3 we provide a novel way to evaluate datacenter digital twins through discrete-event simulation.

## Main Finding II

We posit digital twinning can be used for failure detection to the benefit of DC operators. We replicate an experiment from DyTwin [12] designed by Milojevic *et al.* to show our system can reliably detect *unexpected* host failures.



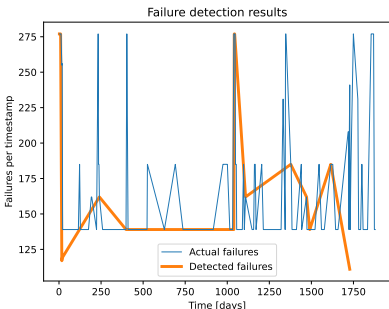
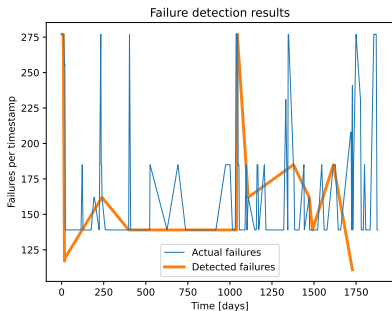
**Figure 1.7a:** Experiment 1a. In this experiment we use red and yellow alarms to notify datacenter operators of unexpected failures. We use a threshold based on predictions done by the simulator and a statistical distribution.



**Figure 1.7b:** Experiment 1b. The mean failure detection rate is around 15%. Even though this seems low, if we look at Fig. E.1 (see Extra Slides), this simply means around 15% of failures are unexpected.

## Main Finding III

*Sunfish* is capable of dynamic adjustments to the physical twin at runtime, and can lower the mean number of failed tasks.



**Figure 1.8a:** Experiment 2a. We can see in this plot which failure distribution is the most likely to be the true distribution while the simulation is running.

**Figure 1.8b:** Experiment 2b. The gains in number of failures from turning faulty hosts in advance.

## Societal Context

Datacenter manageability is a top-priority for the digital society. Over 3 million jobs in the Netherlands directly depend on cloud services, which are hosted in datacenters [6].

## Problem Statement

DCDT's, still under development, lack crucial features such as predictive analytics to manage datacenters well. The entire DCDT design space remains largely unexplored.

## Contributions

(1) A thorough literature survey with a system model, (2) a DCDT reference architecture, and (3) prototype-based experiments via a novel evaluation method.

## Main Findings

*Sunfish* can reliably detect unexpected failures based on discrete-event predictions, and can serve as a foundation for additional research and future work.

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# Extra Slides: Technical Setup

## What is the simulation workload?

The compute workload is BitBrainsSmall. The failure traces include user reports from Gmail, WhatsApp, Facebook and Twitter. For predictions we use prefabs [14].

## What is the experiment environment?

A commodity laptop: Framework Laptop 13, with 32GB of DDR5 RAM and an AMD Ryzen 7840U processor and an ArchLinux OS with Linux 7.0.13-arch1-1 kernel.

## How did we adjust OpenDC (Physical Twin)?

We use a SURF [14] datacenter topology with 277 hosts. We wrote a custom Kotlin ComputeMonitor to export live-metrics into Kafka, and a custom Kotlin HTTPClient to talk to the digital twin. We add a new scheduling mechanism, the SmartScheduler.

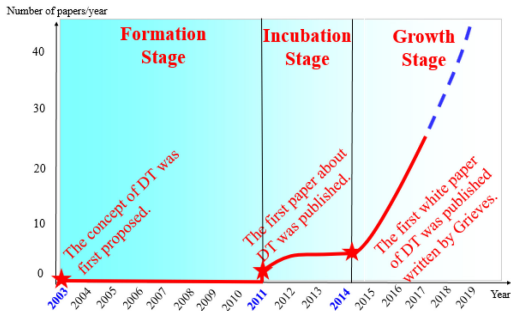
## Which metrics do we measure?

Timestamps, host names, uptime, downtime, CPU utilization *etc.*

# Extra Slides: Why Digital Twinning?

## Definition

A DCDT mirrors the structure, context and behaviour of a datacenter [1]. The prerequisite to any digital twin is good monitoring and sensing capabilities in the physical entity. Datacenters meet this requirement easily because they already connect hundreds of monitoring sensors.

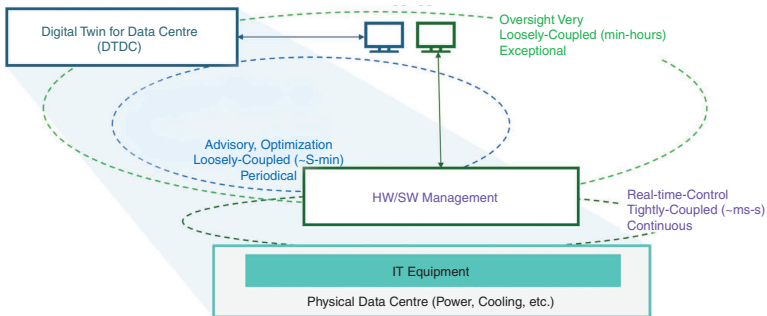


**Figure E.2:** Due to insufficient technological foundations, little work is available on DTs between 2003 and 2018, and it is only with the rapid growth of cloud computing, Internet-of-Things and Big Data analytics that DTs have reemerged [13]. That is why nobody used digital twins to mirror datacenters earlier.

# Extra Slides: Why not pure simulation?

## Predicting job failures

Preventing failure-caused outages in advance can reduce huge operational costs, as over 20% of all reported outages amount to more than 1 million US\$ [4]. Only a constant bi-directional interaction (digital twin  $\leftrightarrow$  physical entity) can achieve this.



**Figure E.3:** Real-time control that is tightly-coupled with the IT equipment is a prerequisite for timely predictions within seconds/minutes [1].