

# **Knowledge Representation for Ecosystems of Digital Twins**



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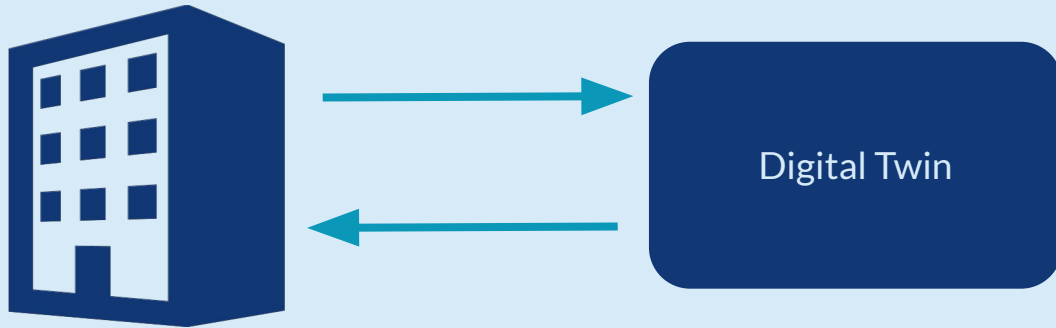
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# Background



# What is a Digital Twin?

A DT is a comprehensive software representation of an individual physical object. It includes the properties, conditions, and behavior(s) of the real-life object through models and data. [...] The DT represents and reflects its physical twin and remains its virtual counterpart across the object's entire lifecycle.<sup>[1]</sup>



[1] Minerva, Roberto, Gyu Myoung Lee, and Noel Crespi. "Digital twin in the IoT context: A survey on technical features, scenarios, and architectural models." Proceedings of the IEEE 108.10 (2020): 1785-1824.



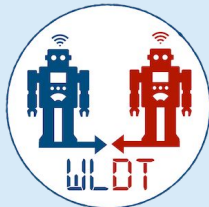
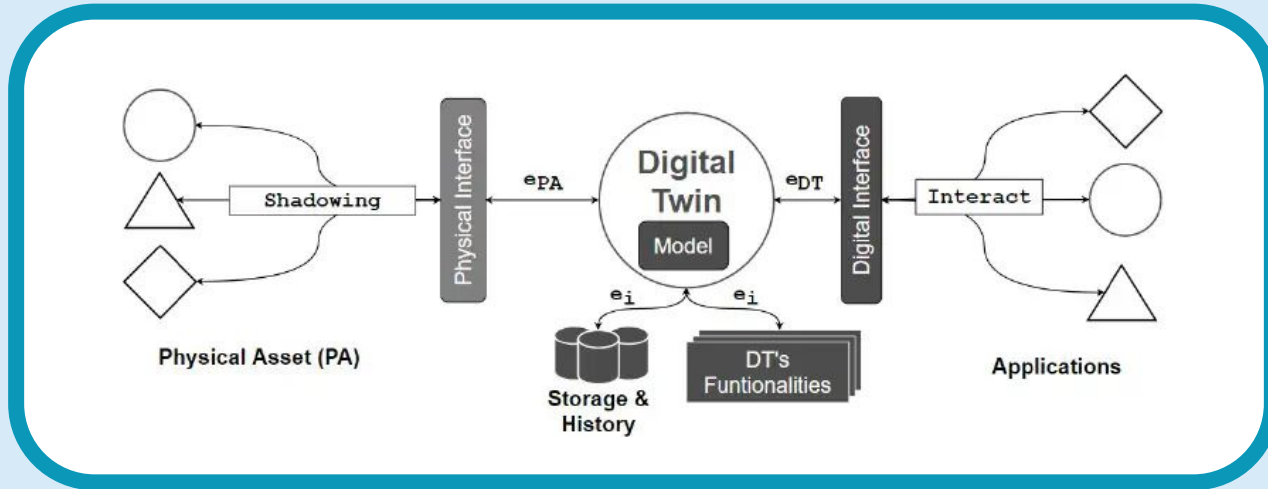
# 5 Dimensions for DTs

We can view a Digital Twin as composed of 5 dimensions<sup>[2]</sup>

- **Physical Entities:** the object and sensors that collect measurements in the real world
- **Connections:** the bi-directional data streams between real world and digital space
- **Virtual Models:** the geometrical, physical, behavioural and rule models that digitally represent the object
- **Data:** the data collected and generated by the DT over its lifecycle
- **Services:** what the DT offers to other applications, including simulation, prediction, monitoring, optimization...

[2] Qi, Qinglin, Fei Tao, Tianliang Hu, Nabil Anwer, Ang Liu, Yongli Wei, Lihui Wang, and Andrew YC Nee. "Enabling technologies and tools for digital twin." *Journal of Manufacturing Systems* 58 (2021): 3-21.

# Implementing Digital Twins



We are developing a library to build Digital Twins as software processes that can gather information from physical sources.

Check out <https://wldt.github.io>

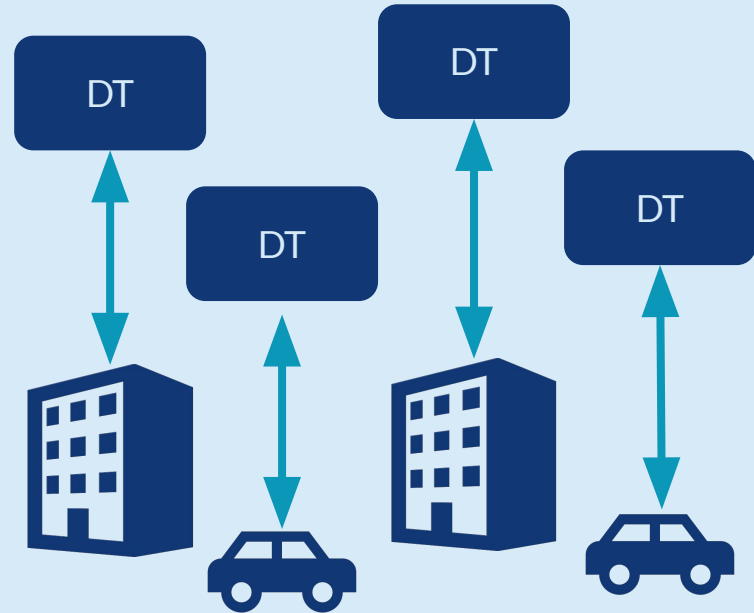
# What is an Ecosystem of DTs?

Imagine a world in which every object have a Digital Twin.

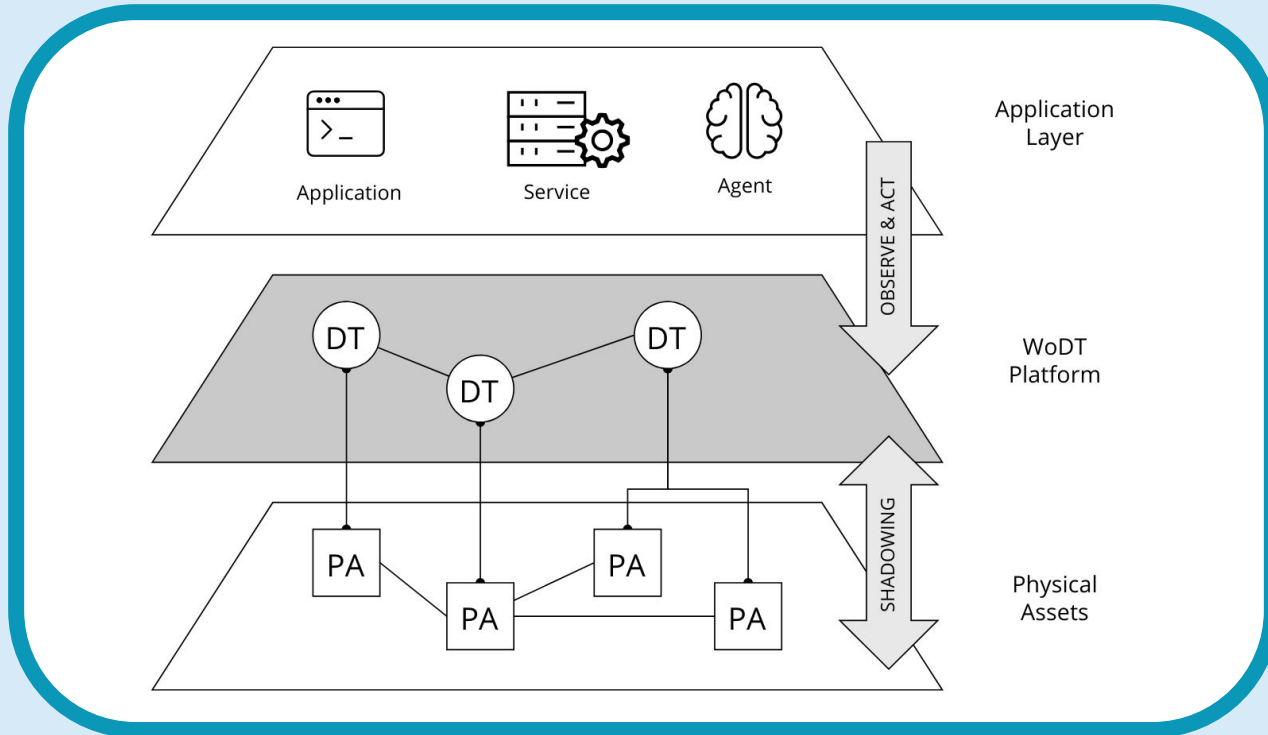
It would be useful to have a coherent view on all the Digital Twin and have them connected with each other.

This is an **Ecosystem of Digital Twins**:

- Assets are digitalized
- Relationships of the real world are shown in the Digital World
- Applications can traverse the ecosystem



# The Web of Digital Twins



[3] Ricci, Alessandro, Angelo Croatti, Stefano Mariani, Sara Montagna, and Marco Picone. "Web of digital twins." ACM Transactions on Internet Technology 22, no. 4 (2022): 1-30.





# Why do we want it?

The **Web of Digital Twins** can help in:

- Digitalization of complex domains
- Sharing of knowledge about the world
- Creation of applications connecting assets of different stakeholders

## **DT Producers**

Can approach the digitalization in a modular way. They can also share their DT and data and get more insights on the whole ecosystem.

## **DT Consumers**

Can discover DTs and interact with them in a dynamic open environment. This allow intelligent applications to leverage different sources of knowledge.



# What do we need?

To build the **Web of Digital Twins** we need to:

- Represent information about the DTs in an interoperable format
- Have rich descriptions of data
- Ideally reuse Web standards that have proven effective in the past

We want to be able to:

- **discover** DTs connected together by relationships
- **describe** the DTs and the assets they are connected to
- **describe** available interactions with DTs
- **query**, and **observe** DTs as well as the whole ecosystem
- **add** and **remove** DTs dynamically



# Knowledge Graphs

A Knowledge Graph is a collection of statements that express **facts** in the form of relationships between entities and data.

Knowledge Graphs can be encoded using the **Resource Description Framework (RDF)** to express such facts as **triples** of <subject> <predicate> <object>

## Fact:

- The sky is blue.
- Alice is a Person.
- Alice knows Bob.
- All Kitchens are also Rooms.

## RDF triple:

- <sky> ex:hasColor "blue".
- <Alice> a foaf:Person.
- <Alice> foaf:knows <Bob>.
- <Kitchen> rdfs:subClassOf <Room>.



# WoDT & Knowledge Graphs

How to combine?

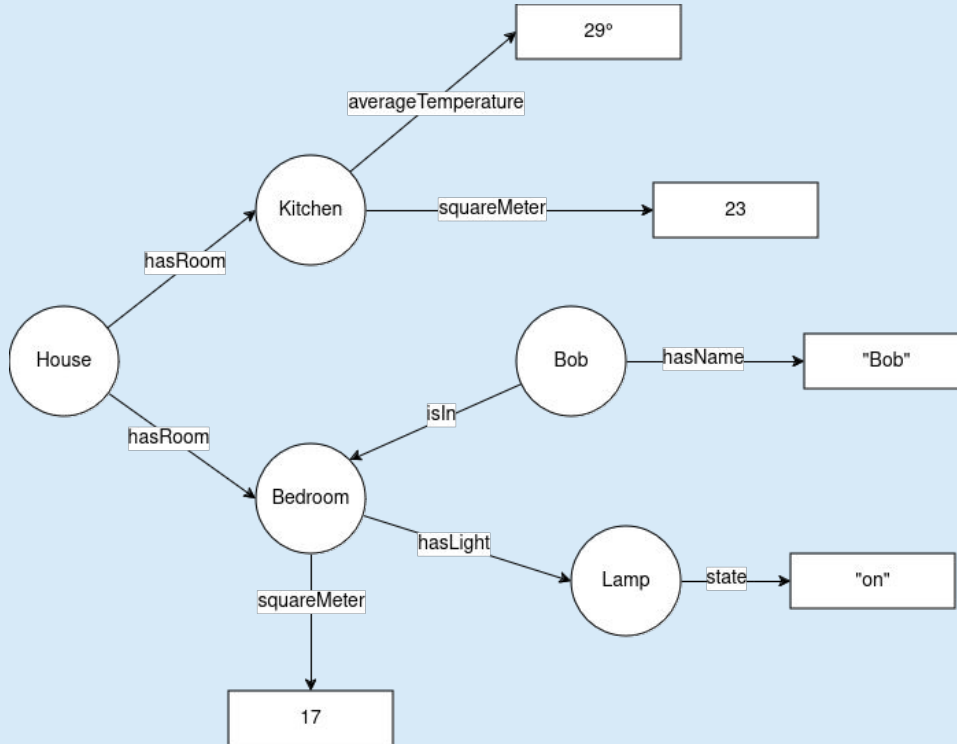
1. Each Digital Twin is described with triples
2. Digital Twins create together a Knowledge Graph

Consumers can:

- Query the DT Graph
- Discover relationships
- Get the current state of entities

**How to Describe Digital Twins?**

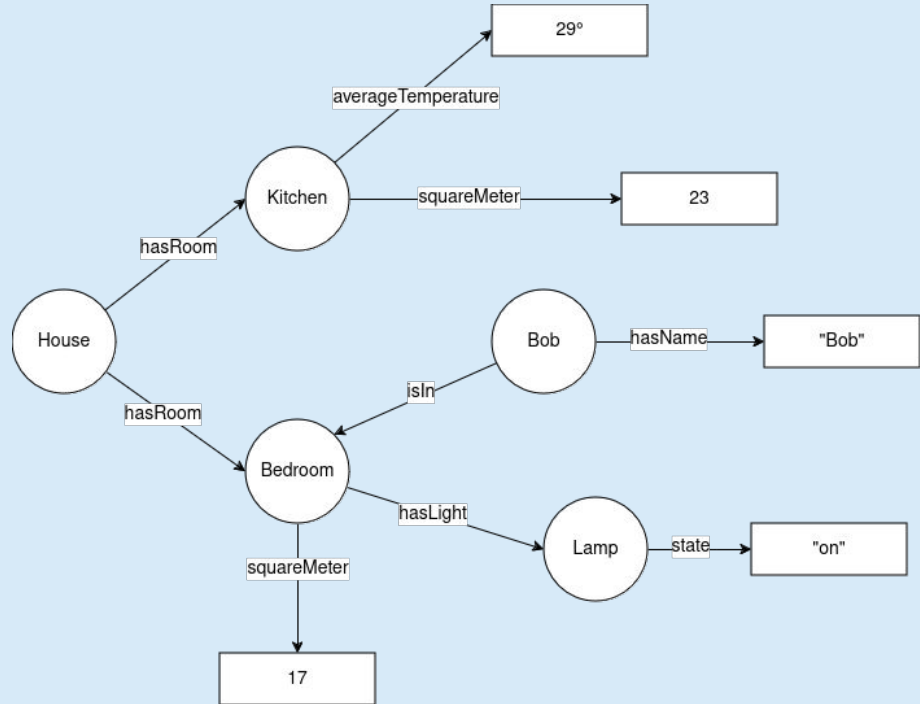
# A Smart Building KG



# Where are the Digital Twins?

The KG is a **digital representation of the real world...**

But it is not really saying anything about the **Digital Twins**.



# Describing Digital Twins



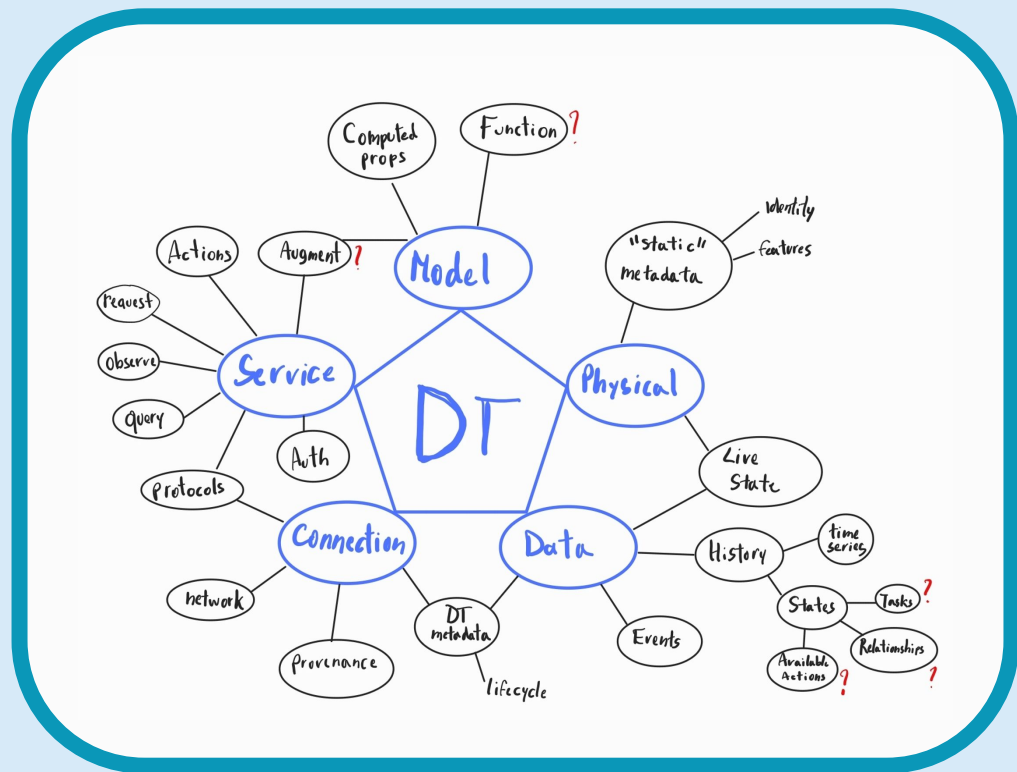
# What can we represent?

There is value in capturing all the sides of a DT in a **uniform** description.

## Why?

This might enable:

- better reasoning
- managing of DT ecosystems
- interoperability







# Static and Dynamic Data

## Static Data

- PA static knowledge
- Connections (e.g. protocols)
- Services (API, auth)
- DT metadata (versioning, authors)
- Data Schemas

## Dynamic Data

- PA current state
- Augmented computed properties
- History
- Current relationships
- Currently performable actions
- DT lifecycle (connected, etc..)

**Ideally we would like to access all of this data from a single endpoint**



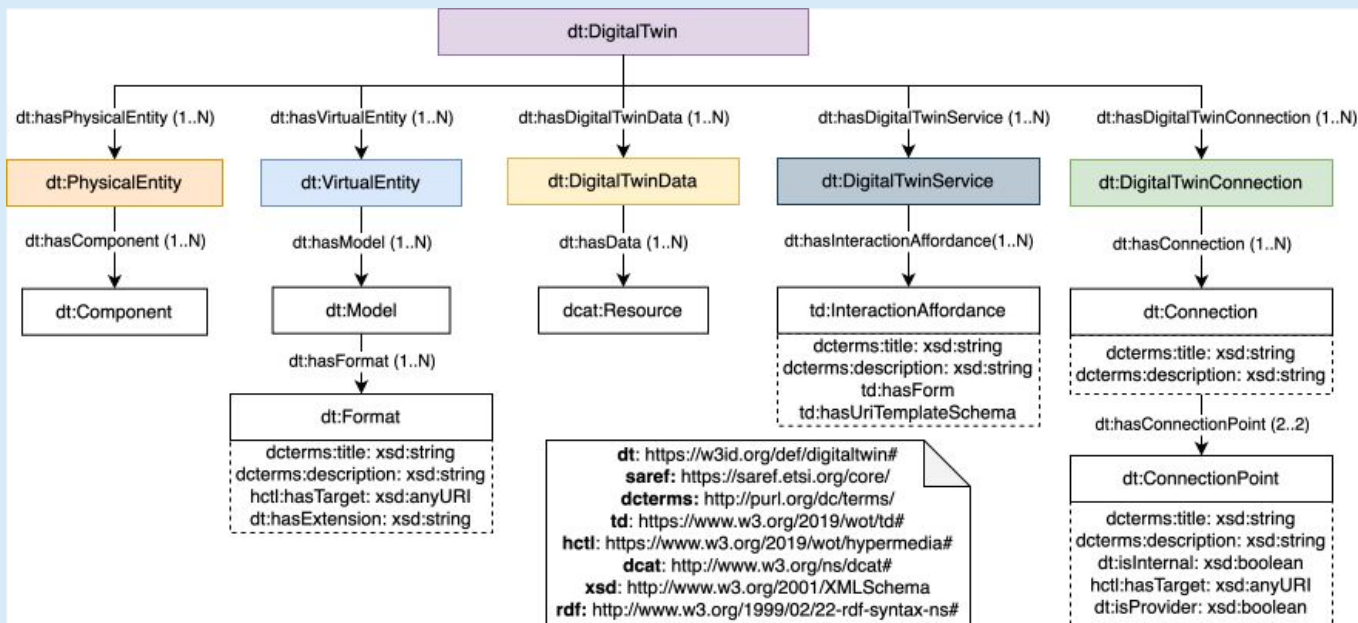
# Existing Ontologies

- Web of Things
  - connections
  - services (partially)
  - data (only schemas)
- DTD
  - physical asset
  - data (partially, no storage)
- SAREF
  - physical object
  - data
  - services (partially)
- Barros et al.
  - virtual models
  - (very high level description)
- Barth et al.
  - data (very broad)
  - connections (partially)
  - “value” for business

No existing representation captures all the different dimensions of Digital Twins

# WoT DT Ontology

A [recent proposal](#) is trying to address this issue explicitly representing the DT dimensions. This is still an early prototype.



**What's next?**

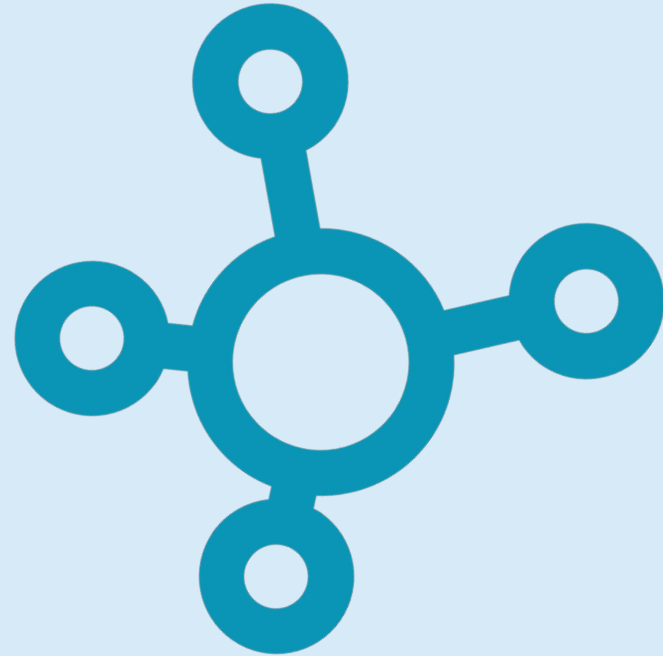




# A “Digital Twin Ontology”

Since existing ontologies seem inadequate to cover the full spectrum of DT dimensions we’re moving towards developing a “Digital Twin Ontology”

- Assimilating useful patterns from other descriptions
- Promoting interoperability and alignment with existing standards
- Trying to create a fully domain agnostic model
- With an initial minimal core model (to be potentially expanded with time)

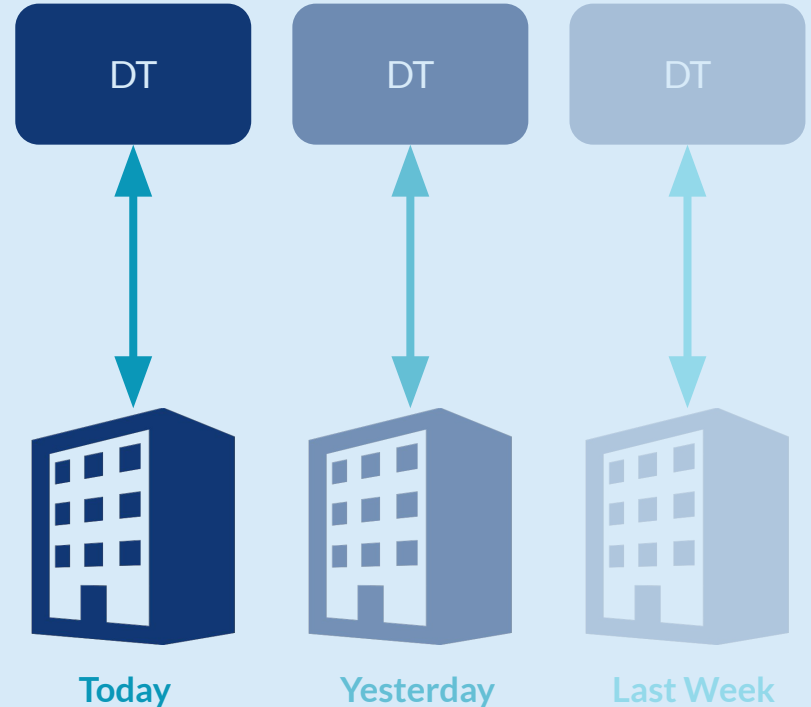


# Snapshot Graphs

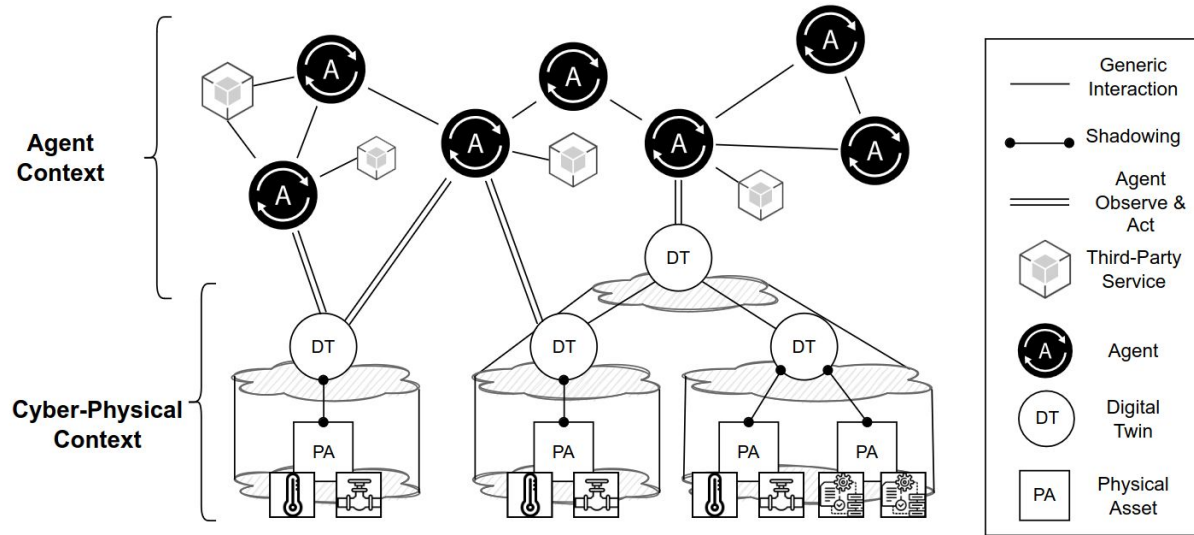
How to maintain the evolution of the Digital Twin graph over time?

We're looking into specializing Linked Data Platform Containers to represent snapshot in time of the same resource.

This can allow us to keep meaningful representations of DT snapshots over time.



# Agents and Digital Twins



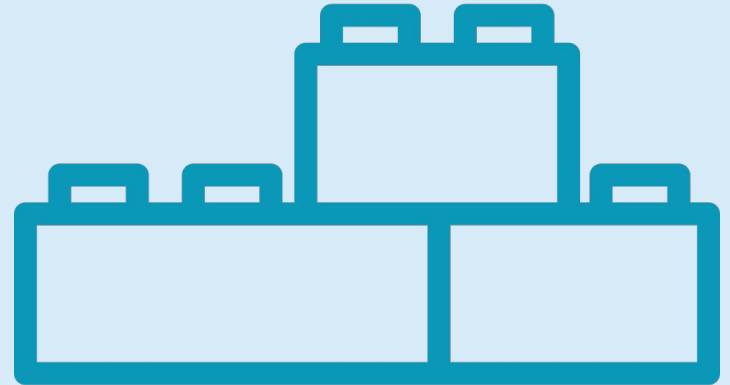
[5] Mariani, Stefano, Marco Picone, and Alessandro Ricci. "About digital twins, agents, and multiagent systems: a cross-fertilisation journey." In International Conference on Autonomous Agents and Multiagent Systems, pp. 114-129. Cham: Springer International Publishing, 2022.



# What is the end goal?

To have an infrastructure to build:

- Digital Twins capable of generating semantically rich descriptions
- Ecosystems connecting multiple Digital Twins together
- Autonomous Software Agents capable of using the DT knowledge to manage complex ecosystems







# Thank you!

Samuele Burattini - Alma Mater Studiorum University of  
Bologna

[samuele.burattini@unibo.it](mailto:samuele.burattini@unibo.it)