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Context Information Management (CIM); Feasibility of NGSI-LD for Digital Twins

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Reference

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) cross-cutting Context Information Management (CIM).

Modal verbs terminology

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Executive summary

The present document analyses the use of NGSI-LD information model and API for representation and handling of digital twins. It starts with a description of actual digital twin use cases, in several vertical domains. Then it provides an identification of relevant external technical initiatives. Finally, the present document provides concrete views on the definition of Digital Twins in an NGSI-LD ecosystem including identification of Digital Twin capabilities and life cycle stages. The final clauses analyse how, taking inspiration from actuation mechanisms, a service execution API could be defined to handle Digital Twin capabilities.

Introduction

The present document advocates the use of NGSI-LD property graphs as holistic Digital Twins, maintaining multi-level and multi-scale descriptions of complete environments, such as cities, buildings or factories. The nodes of the proposed multilevel graph stand for any real-assets, which can be a physical asset or a concept. The arcs of the graph represent relationships between these entities, which capture the physical and information structure of a system. They can capture top-down and bottom-up system composition relationships, or transversal connectors (like cables, pipes, etc.) in a distributed network-like system. A further level of description captures distributed or loosely coupled "systems of systems" as "graphs of graphs", i.e. graphs, whose "hypernodes" encapsulate other graphs). By maintaining this shared context, the graph makes it possible for different applications in these environments to locate and share their data sources on the basis of the consolidated information stored in the graph, much as the knowledge graph of as search engine does for the Web. The graph platform can play the role of a Digital Twin, in the sense of a one-stop-shop for applications operating upon these environments. The NGSI-LD specification is thus already an actor in the Digital Twins area and the present document aims at exploring its current usage, positioning within the overall Digital Twins technical landscape and providing recommendations for NGSI-LD specification evolution.

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1 Scope

The purpose of the present document is to show to what extent various Digital Twin types can be realized or facilitated by NGSI-LD and to identify new features for NGSI-LD which would make it more useful for such areas of usage.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Grieves, Michael, et John Vickers: "Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems". In Transdisciplinary Perspectives on Complex Systems, edited by Franz-Josef Kahlen, Shannon Flumerfelt, and Anabela Alves, 85-113. Cham: Springer International Publishing, 2017.

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[i.2] Gilles Privat: "Phenotropic and stigmergic webs: The new reach of networks". Universal Access in the Information Society 08/2012; 11(3):1-13., DOI:10.1007/s10209-011-0240-1.

[i.3] Gilles Privat: "The "Systems of Systems". Viewpoint in telecommunications", Orange Research Blog, September 2018.

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[i.5] Tuegel, Eric, Ingraffea, Anthony, Eason, Thomas, et Spottswood, Stephen. (2011): "Reengineering Aircraft Structural Life Prediction Using a Digital Twin". In International Journal of Aerospace Engineering, 2011.

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[i.6] Boss, Birgit & Malakuti, Somayeh & Lin, Shi-Wan & Usländer, Thomas & Clauer, Erich & Hoffmeister, Michael & Stojanovic, Ljiljana & Flubacher, Björn. (2020): "Digital Twin and Asset Administration Shell Concepts and Application in the Industrial Internet and Industrie 4.0". An Industrial Internet Consortium and Plattform Industrie 4.0 Joint Whitepaper.

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[i.7] ETSI GS CIM 009: "Context Information Management (CIM); NGSI-LD API".

[i.8] ETSI GS CIM 006: "Context Information Management (CIM); Information Model (MOD0)".

[i.9] "PackML language for the control of packaging machines".

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[i.11] ISO 23247-1:2021: "Automation systems and integration -- Digital twin framework for manufacturing -- Part 1: Overview and general principles".

NOTE: Available at https://www.iso.org/standard/75066.html.

[i.12] ISO 23247-2:2021: "Automation systems and integration -- Digital twin framework for manufacturing -- Part 2: Reference architecture".

NOTE: Available at https://www.iso.org/standard/78743.html.

[i.13] ISO 23247-3:2021: "Automation systems and integration -- Digital twin framework for manufacturing -- Part 3: Digital representation of manufacturing elements".

NOTE: Available at https://www.iso.org/standard/78744.html.

[i.14] ISO 23247-4:2021: "Automation systems and integration -- Digital twin framework for manufacturing -- Part 4: Information exchange".

NOTE: Available at https://www.iso.org/standard/78745.html.

[i.15] ETSI TS 103 828: "SmartM2M; SAREF: Ontology Support for Urban Digital Twins and usage guidelines".

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[i.16] ISO/IEC AWI 30173: "Digital twin -- Concepts and terminology".

NOTE: Available at https://www.iso.org/standard/81442.html.

[i.17] IEC Technology report: "City information modelling and urban digital twins".

NOTE: Available at https://www.iec.ch/basecamp/city-information-modelling-and-urban-digital-twins.

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AASX	Asset Administration Shell Explorer
AEC	Architecture, Engineering, Construction
AI	Artificial Intelligence
AMR	Autonomous Mobile Robots
API	Application Programming Interface
AR	Augmented Reality

ARF	Augmented Reality Framework
BIM	Building Information Management
DMA	District Metered Area
DT	Digital Twin
DTDL	Digital Twin Description Language
EC	European Commission
EPANET	Environmental Protection Agency Network Evaluation Tool
F6G	Fixed 6G
GIS	Geographic Information System
HiL	Hardware in the Loop
HTTP	HyperText Transfer Protocol
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
IIoT	Industrial Internet of Things
IoT	Internet of Things
IOWN	Innovative Optical and Wireless Network
IT	Information Technology
JSON	JavaScript Object Notation
JTC	Joint Technical Committee
LD	Linked Data
LWM2M	Lightweight Machine To Machine
M2M	Machine To Machine
ML	Machine Learning
MLS	Machine Learning Service
MQTT	Message Queuing Telemetry Transport
NGSI	Next Generation Service Interfaces
OASCs	Open and Agile Smart Cities
OGC	Open Geospatial Consortium
PackML	Packaging Machine Language
QoS	Quality of Service
RAMI	Reference Architectural Model Industry
RFID	Radio Frequency IDentification
ROS	Robot Operating System
RWA	Real World Asset
SAREF	Smart Applications REFerence
SCADA	Supervisory Control and Data Acquisition
SiL	Software in the Loop
SMS	Short Message Service
SoSTs	Systems of systems Twins
ST	System Twin
STF	Specialist Task Force
STs	System-Twins
UDT	Urban Digital Twins
UI/UX	User interface/User experience
UL	Ultra Light
URI	Universal Resource Identifier
WDS	Water Distribution System
WoT	Web of Things

4 Illustrative use cases

4.0 Introduction

Clause 4 describes some of the on-going initiatives making use of NGSI-LD information model and API to define and interact with Digital Twins. The concept of Digital Twins is not elaborated here, because many variations are explained in the literature [i.1], [i.2], [i.5],[i.6], [i.11], [i.15], [i.16], [i.17].

4.1 Water distribution network

4.1.1 Usage

Management of Water Distribution Systems (WDSs) is an area where DTs have significant potential, and they are already starting to be implemented to address issues such as optimizing operation of the system, asset management and water leak localisation. However, development of DTs for WDSs can be complex, with the need for any hydraulic and/or quality model to be constantly paired with data and information from multiple sources in the physical world, including, for example, Supervisory Control and Data Acquisition (SCADA) and consumption metering systems. Transmission, conversion, storage and protection of this data are all important issues for consideration and are currently complicated by a lack of standardization. However, standardization, along with interoperability and integration are fundamental features of a successful DT. The described research integrates the WDS simulation toolkit, OWA-EPANET [i.4], within a FIWARE NGSI-LD environment.

The functionalities foreseen from that integration focus on the system in operation and include:

- **Simpler interface to a composed system:** such as exposing the "equivalent water pump" of N water pumps connected in parallel. This equivalent pump can thus be queried and configured as if it would be a real water pump.
- **Predictive analytics:** to provide a prediction of the system state in the future (T1), based on the current state (T0).
- **Outliers/anomaly detection:** to raise alerts in case the network deviates from its anticipated state.

EXAMPLE 1: By comparing the actual state of the system at T1 with the simulation T1 executed at T0.

EXAMPLE 2: By comparing the state of a subnetwork with expected state calculated using simulation based on other part of the system.

- **What-if scenario:** how will the system evolve if an action is taken starting from the current state, modifying some parameters in the model (i.e. close a valve).
- **Network optimisation:** starting from the current state, identify the optimum functioning point (i.e. reduce water pump energy consumption while maintaining requested pressure). When combined with actuation (not mandatory), this functionality provides automated management.

4.1.2 Challenges

Several challenges have been identified:

- Sharing a common data model representation between the target EPANET simulator and the NGSI-LD representation.
- Having a model which allows the selection of only sub-parts of the water network (i.e. DMA - District Metered Area level) to be used within the simulation.
- To provide a service feeding the simulator with appropriate values and configuration parameters and storing the resulting state without storing the whole simulated result, so as to avoid overloading the system storage.

4.1.3 Solution proposal

A NGSI-LD data model for water network, aligned with the definition of the EPANET hydraulic simulator has been proposed (https://github.com/smart-data-models/dataModel.WaterDistributionManagementEPANET). An overview is provided in the picture below. All parts of the network are considered of equal importance from a modelling point of view so they have all been modelled as entities, including pipes. In addition, most of the network entities are directed, so connections are made through *startsAt* and *endsAt* relationships.

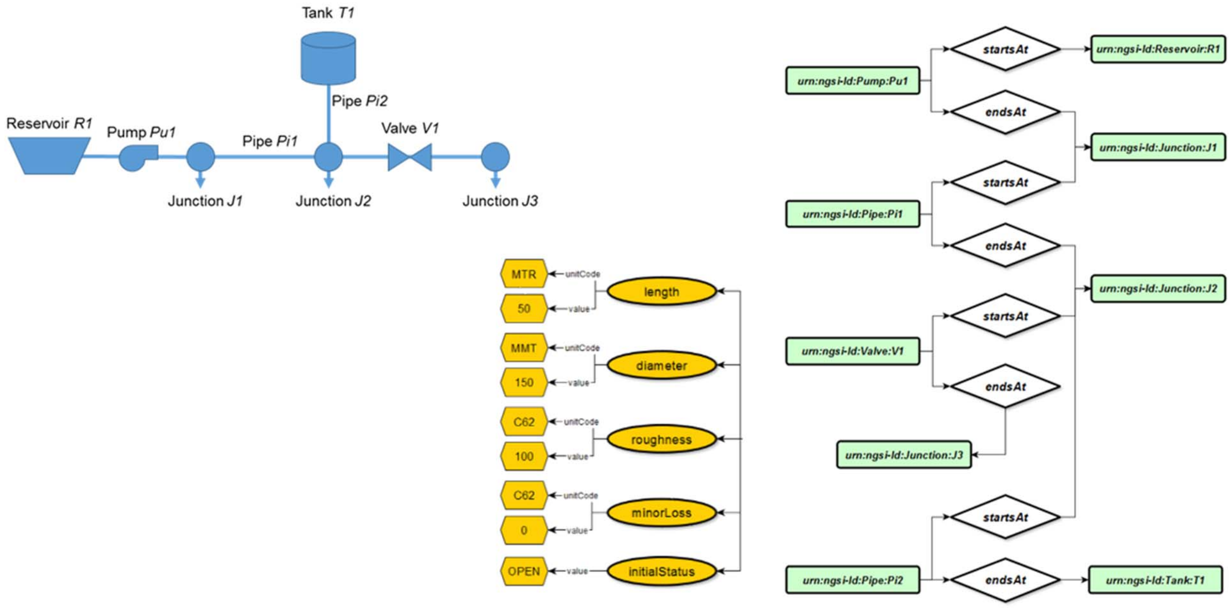

Figure 4.1.3-1: NGSI-LD model of a water distribution network

In addition, as seen on the next picture, a system composition approach has been made by defining entities representing the different DMAs. This allows a simulation to handle only one specific DMA. Any simulation is associated to a NGSI-LD entity which holds through its attributes: the simulator configuration options, possibly, a list of value to be changed change from actual values (to run a "what-if" scenario) and the list of points in the water network to be controlled so not all the network state needs to be saved.

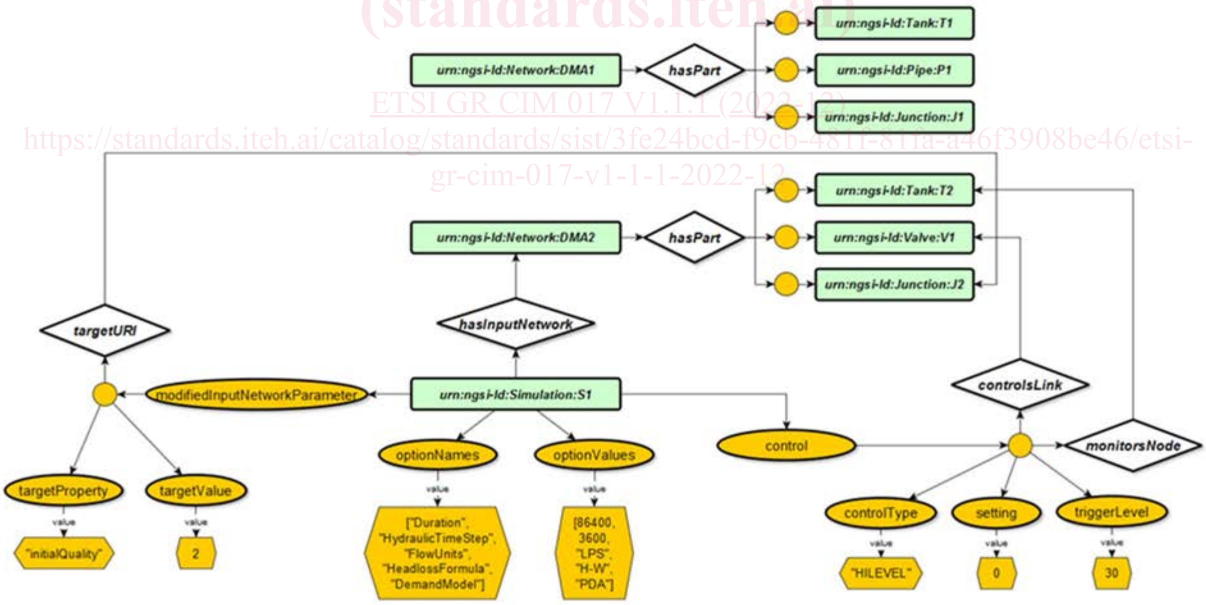

Figure 4.1.3-2: Handling of simulation parameters within a NGSI-LD representation

To facilitate the integration of the NGSI-LD context information and EPANET, a new interface has been developed. The key functionalities provided by this are:

a) translation of existing EPANET model data into the requisite NGSI-LD format;

b) posting of this information to a NGSI-LD context broker;

c) retrieval of all data necessary to generate an up-to-date network model for simulation (capturing real-time network data supplied to the context broker from other sources such as IoT platforms); and

d) as and when required, running hydraulic and quality simulations of the network.

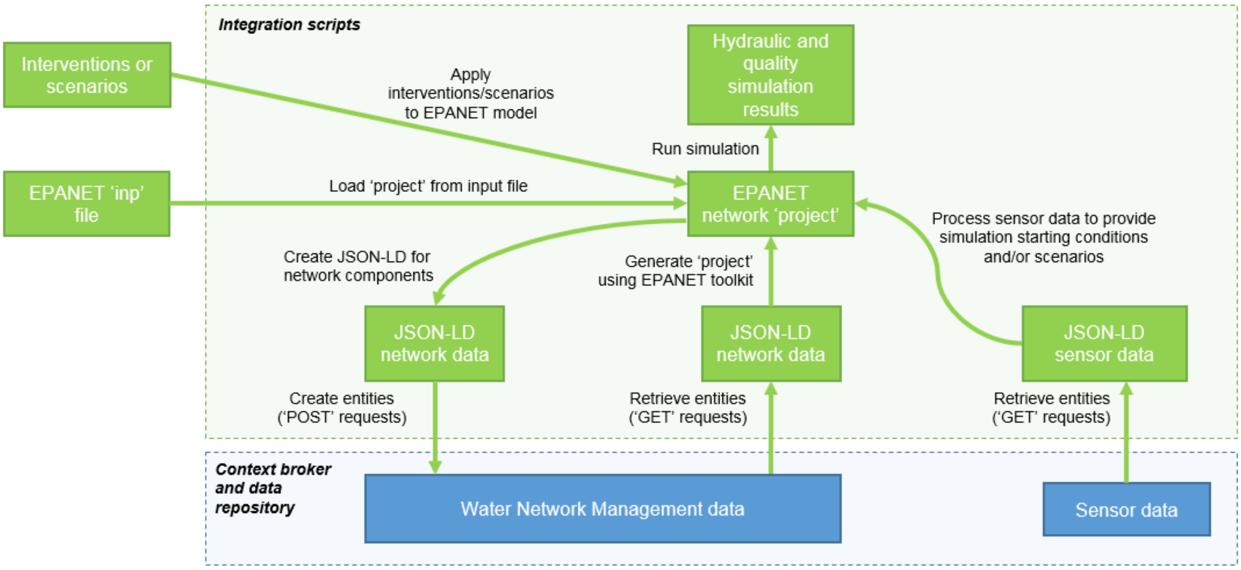

Figure 4.1.3-3: Architecture and functionalities provided in the EPANET-FIWARE integration module

The new NGSI-LD-integrated implementation of EPANET outlined in the previous sections has been applied to a case study water distribution network from the South West of England to test and demonstrate some of the functionalities offered. The network is a small, gravity-fed system, with the EPANET model containing only one source (modelled as a reservoir), 1 005 nodes and 1 035 links. It also contains 91 household level smart meters, which provide daily water consumption measurements for individual houses. Data from these meters is posted to a Stellio context broker in accordance with the 'WaterSmartMeter' data model.

In this case study, historical smart meter data is used to adjust and extend the demand patterns in the EPANET model to capture daily variations in demand and enable more realistic simulation of hydraulic performance under historical conditions. To illustrate the impact of using smart meter data instead of the default demands defined in the EPANET input file on the hydraulic simulation results. Figure 4.1.3-4a) compares the results of pressure time series for one junction with an associated smart meter, Figure 4.1.3-4b) shows the flow rate in the pipe supplying this node.

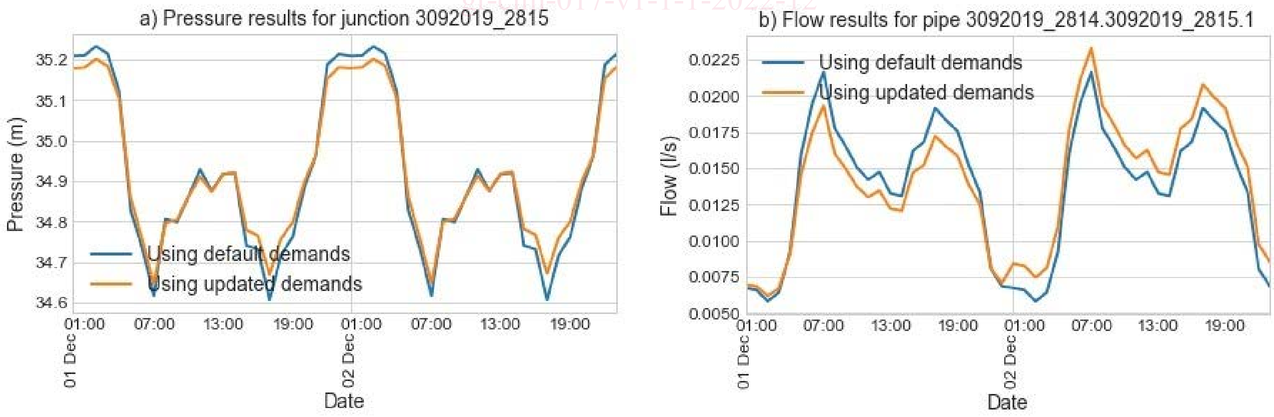

Figure 4.1.3-4: Example of hydraulic results obtained with the default network model demands and with demands updated based on data retrieved from smart meters

4.1.4 Gaps

It appeared that in its current version the NGSI-LD specification is fully relevant for definition and management of Digital Twins, even, in the context of a water distribution network made of several sub-systems. Still, some improvement could be made:

- Improved handling of system composition to avoid multiplying relationships toward all entities of a sub-system.

- Improve management of relationships to make them first class citizen as are the entities in the NGSI-LD API to allow more traditional modelling of a water distribution network. Nevertheless, handling the fact that a pipe is not directed (water can flow in both way) within a directed graph would require additional investigations.
- Provide capabilities to ease handling of a simulator within a NGSI-LD based deployment. This includes configuration of the simulator, handling of some special scenarios (e.g. What-if) and storage of the key results.

4.2 Digital Twins in robotics

4.2.1 Usage

Two basic but essential core robotics scenarios should be explored as application enablers:

- 2D Robot Navigation (e.g. autonomous robot navigation for intra-logistics).
- Pick and Place Operations (e.g. palletization, packaging, product sorting, etc.).

An advanced scenario is the 3D navigation of drones. In turn, many features of this scenario may be simplified and represented as a 2D Navigation.

EXAMPLE: Autonomous Mobile Robot for Warehouse Automation:

- **Robot Entity:** AMR (Transportation Robot) → Autonomous Navigation System (Interfaces to Automated Path Planning Module, trajectory planning and obstacle avoidance are opaque).
- **Robot Task:** Move 'Item X' from 'Loc A' to 'Loc B'.
- **EnvModel:** Layout of the factory with annotatedLocations, **Personnel:** Warehouse Operator.
- **IIoT Device:** RFID Reader; **User Interface:** Stock Transfer Order Request.

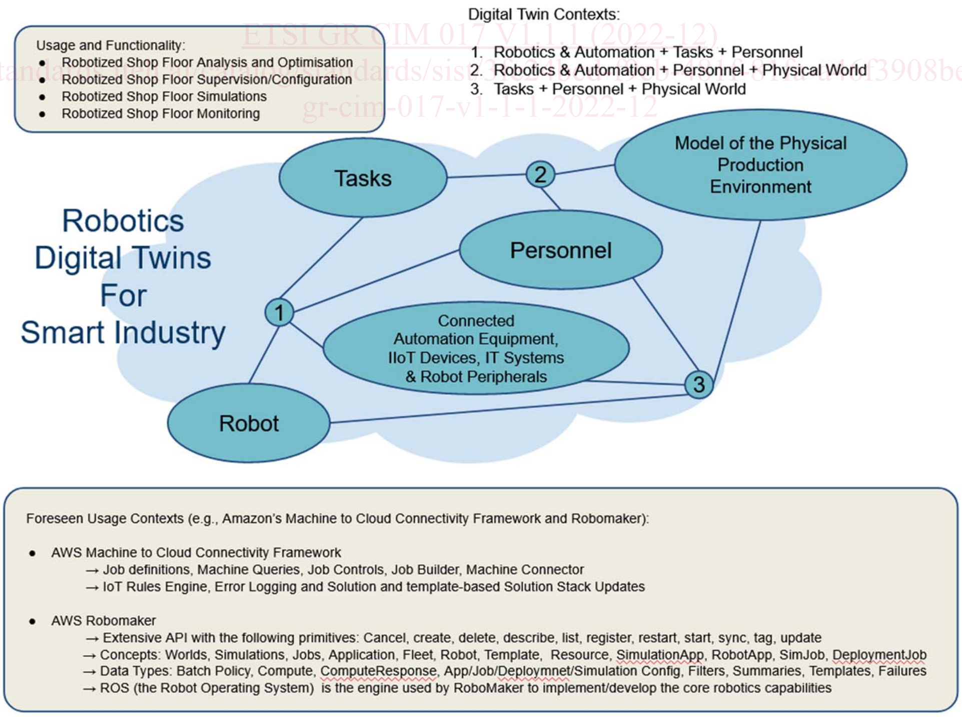

Figure 4.2.1-1: Foreseen usage and expected functionalities from a DT deployment

4.2.2 Challenges

The main challenges Identified for NGSI-based Digital Twins of Robotics Systems are:

- The software architecture of robotics systems is often a complex, monolithic architecture and largely conditioned by mechatronic requirements. Robustness and efficiency are often at a premium. Reusability, modularity, interoperability as they are understood in the IT world have been, in general, secondary aspects within the robotics domain.

- Even at higher levels of discrete control and plan execution the interfaces are extremely heterogeneous. Almost every robot manufacturer has its own framework/programming suite to develop applications and relies on an ad/hoc communication protocol to integrate them.

- The Robot Operating System has been trying (and still tries) to offer a common framework for open-source robotics application development. The adoption in real-world scenarios out of prototypes, laboratories, and experimental settings is still limited. This invites exploring the robotics frameworks developed by robot manufacturers and those developed by widespread system integrators and application simulators (Visual Components). Probably, our space to create value for robotics applications is the implementation of capabilities that easily integrate on top of these frameworks.

4.2.3 Solution proposal

The proposed solution is made of the following:

1) Smart Gateway on Top of the Native Robot Middleware.

2) NGSI-LD Compliant Digital Twin.

3) Smart Cloud for Accessible and Scalable Robotics Applications.

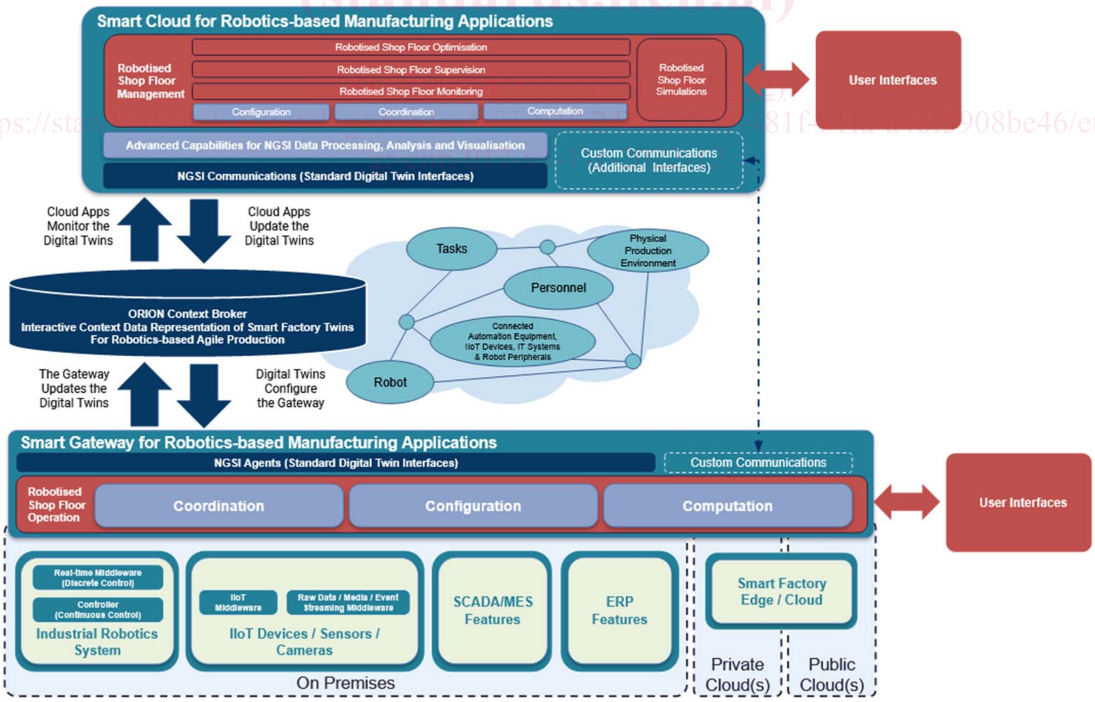

Figure 4.2.3-1: High level architecture for Digital Twins in robotics

Data: ROS Messages already define a number of properties and structures for core robotics applications that have remained constant for long. One need to adopt additional data models from industry standards, in particular those modelling real-world environments and devices and with the monitoring/configuration of automated jobs and simulations.

Security: Since the robot interacts with the physical world, every scenario that considers an application scenario that goes beyond the typical hard-coded behaviours for standalone robotics faces a number of security and safety issues.

Services beyond v1.3 of API: Robot entities should advertise their special capabilities and their current hardware state/configuration. Ideally the Digital Twin should automatically update its state when some end-effectors, sensors or peripherals are connected, changed, replaced or removed from the base robot.

4.2.4 Gaps

NGSI-LD has potential to implement powerful robotics twins at the "integrated planning and execution levels" in which context semantics play relevant roles. Objective is then to provide a common context data layer for heterogeneous robot twins based on standardized context information management.

The main gap to be filled is the integration of NGSI-LD based robotics capabilities within the native executive features of base robotics platforms. The design of criteria to conveniently monitor/sample/configure the discrete control loop of the actual robot is not straightforward and still lack mechanisms to implement smart integration behaviours. Even in simple robotics scenarios, the real-time monitoring of robot resources and capabilities as well as the maintenance of right-time synchronized representation of the robot world is a challenging task.

4.3 Use of Digital Twins in the aeronautic sector

4.3.1 Usage

The Aeronautical sector is one of the many sectors in which large amounts of data are generated and, consequently, they can be exploited by the implementation of Digital Twins, improving the performance of processes through the communication between the physical and the virtual world. This use case presents an Airport Digital Twin Reference used to improve turnaround process.

Airports are one of the infrastructures that require more organization and security protocols since they have to deal with a high density of passengers, staff, aircrafts, baggage, data, etc. In particular, flight delays are a common problem affecting airports, airlines and passengers. The lack of digitalization has made the turnaround process a bottleneck in airport operations and a common cause of delays. This process is made up of several tasks, and in most airports, their operations are coordinated through radio communications and paper forms completed by workers.

This use case shows how to improve the turnaround process thanks to context information management provided by different sources, and how to take advantage of web services and 3D representations instead of printed version forms.

4.3.2 Challenges

DTs have been very prolific in the Aeronautics sector, in fact, one of the first DT use cases was developed in this domain in the year 2011 [i.5]. Recently the interest of building DTs has increased in this sector, for both specific purposes (e.g. modelling aircraft turbines and engines), and for general ones (e.g. modelling the whole airport). The present document describes a DT of a commercial, with the objective of deploying a 2D/3D view application fed with information in (pseudo)real-time about the airport, including, the stand occupancy, flight information, turnaround events, etc., together with an operator's application that registers the flight tasks.

Examples of usage:

- Operator: 2D/3D navigation viewing the pending and completed tasks regarding the aircraft "W", placed in the stand "X", related to the flight "Y" that is scheduled to depart in "Z" minutes.
- Passenger: 2D/3D navigation following its own luggage position in the airport.

The main challenge is on data ingestion and modelling from external sources: each source provides its data in its own format, using its own protocols and standards. In the Aeronautics sector there are several widely disseminated standards (e.g. ICAO, IATA). As a consequence, in some cases it is difficult to establish relationships between entities. As an example, an API that identifies a flight with the ICAO format while another identifies it using the IATA designator.

4.3.3 Solution proposal

Figure 4.3.3-1 shows all the agents present in the Airport Digital Twin use case, including the data source/sink entities, which interact with a NGSI-LD compliant platform.