SYNCHRONICITY

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Executive Summary

The availability of shared, well-adopted information models is a key interoperability mechanism for enabling a global market for IoT-enabled urban services. Such models provide an essential element in the common technical ground needed for standards-based innovation and procurement, by making replicability and portability of smart city solutions practical. Global convergence is needed to attract investments. This document describes the activities conducted in Synchronicity towards defining a catalogue of shared data models, taking a multiple baseline approach based on and extending the OASC Minimal Interoperability Mechanisms (MIMs). The report references concrete, domain-specific data models ready to be used by OASC cities.

Abbreviations

CIM	Context Information Management
D	Deliverable
EC	European Commission
ETSI	European Telecommunications Standards Institute
GSMA	GSM Industry Association
HTTP	Hypertext Transfer Protocol
ISG	Industry Specification Group
JSON	Javascript Object Notation
MIMs	Minimal Interoperability Mechanisms
NGSI	Next Generation Service Interface
NGSI-LD	NGSI-Linked Data
OMA	Open Mobile Alliance
OASC	Open & Agile Smart Cities
RZ	Reference Zone
SAREF	Smart Appliances REFerence ontology
WP	Work Package
WT	Work Task

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1 Introduction

The following document is intended to summarize the activities conducted by the SynchroniCity project concerning the analysis, adoption and development of shared data models. SynchroniCity Data Models are a concrete extension of the OASC Minimal Interoperability Mechanisms (MIMs).

The main audience are open data publishers, service developers, smart city administrators or other stakeholders.

The document starts by explaining and helping readers to understand the necessity of a harmonised set of data models in the context of the SynchroniCity Architecture (described by Deliverable D2.10 [1]). Following that, a description of the baseline data models (the FIWARE Data Models [2]) is provided, together with their relationship with related industry initiatives. The FIWARE Data Models have been adopted as starting point (baseline) by SynchroniCity.

Then, a report is presented that describes the approach and results obtained concerning the adoption and development of new SynchroniCity Data Models, based on the OASC MIMs. Additionally, the way of working and collaborating with related initiatives is described. A gap analysis is also included, which has been used as an agile tool to find out the missing parts in the referred baseline. Such gap analysis has been driven by the real needs stated by the Reference Zones and related stakeholders.

Finally, as a roadmap-related activity, an overview is given of how the referred SynchroniCity Data Models can be later migrated to the information model proposed by ETSI, NGSI-LD.

1.1 Architectural considerations

Section 1.2 of the Deliverable D2.10 introduces the system, data management, service, security and privacy requirements of the SynchroniCity platform that will guide the design of its architecture and support the development of a digital single market for cities.

In particular, with regards to data management, the requirements state that the system has to support and reuse open and standard data models and metadata by providing pre-built taxonomies to describe different assets. The final aim is to facilitate replicability of solutions across RZs while avoiding vendor lock-in.

Thus, in the SynchroniCity architecture, Data Models play a crucial role because they define the harmonised representation formats and semantics that will be used both by city applications to consume data (through the northbound interfaces) and by data sources at the southbound (sensors, existing information systems or city databases) to publish data. Furthermore, Data Models are one of the fundamental "interoperability points" (Deliverable 2.10, Section 2.3), enabling the participation in a digital single market. The implementation of the SynchroniCity Data Models, together with other interoperability points will ensure that each of the 8 heterogeneous RZs and further OASC cities following the MIMs can be compliant. SynchroniCity atomic services are built on top of the SynchroniCity common data models and interoperability points, and it will further enable SMEs and smart city service providers provide a common service to multiple OASC cities.

2 Baseline Data Model

This chapter gives an overview of the baseline SynchroniCity Data Model that is based, as a starting point, on the FIWARE Data Models, including the main verticals and entity types involved.

2.1 Baseline Data Model Selection Rationale

In order to determine the baseline for Data Models, The SynchroniCity project has analysed:

- The IoT Big Data Harmonised Data Models developed by **GSMA** [3].
- The FIWARE Data Models developed by the **FIWARE Community** [2].
- The **schema.org** [4] Data Models developed by the Browser and search engine communities
- Ontologies promoted by the European standards community, particularly **SAREF** [5].

The first two initiatives are closely related and in general well synchronized. However, there are some Data Models developed by FIWARE not yet adopted by GSMA and vice versa. And there are some GSMA data models that were extended by FIWARE. In addition, FIWARE Data Models have adopted certain vocabularies terms and concepts coming from schema.org and SAREF.

The rationale for selecting FIWARE Data Models as a baseline for the OASC SynchroniCity Data Models can be summarised in the following points:

- They are based on the OMA NGSI information model and ready to be consumed by using the NGSI API, the Context Information API already adopted by SynchroniCity.
- They leverage Data Models already published by GSMA and reuse concepts coming from schema.org and SAREF, thus enabling interoperability and reusability.
- At least 5 of the Reference Zones are already exposing data using NGSI APIs and/or the FIWARE Data Models.
- The FIWARE Data Models provide a powerful but simple, well-known approach for modelling data. Experience demonstrates that instantiations of these data models can be easily mapped / implemented using a wide variety of data stores including NoSQL, SQL or Graph Databases.
- The FIWARE Data Models are defined using JSON Schema and can be encoded by means of simple JSON structures (key-value structures).
- The FIWARE Data Models have a community behind them, so that the work being done by SynchroniCity can be further contributed, ensuring long-term sustainability.
- Future-wise, it ensures a seamless transition to the ETSI standard, NGSI-LD, as it defines an information model with direct mappings to OMA NGSI.

It is important to underline that the adoption of the FIWARE Data Models as baseline for SynchroniCity does not preclude further adoptions and integrations of other data models and ontologies complementary to the FIWARE ones; in particular, the scope of the Task 2.2 is to develop new common data models and extend the existing ones to fit the needs of Reference Zones involved in the project in relation with particular application domains covered by the pilot applications. Fulfilling the task objective, SynchroniCity consortium has collected RZs' requirements, analysed gaps on the existing data models for the RZs applications and services, and have been actively contributing on the extension of existing data models. As a result, new common data models have been defined and are ready to be adopted by all the cities in the project. This iterative process will continue for the whole duration of SynchroniCity.

2.2 FIWARE Data Models overview

The FIWARE Data Models are based on the NGSI meta-model. As already described by deliverable D2.2 [6], such meta-model is based on *Entities, Attributes and Metadata*. An entity represents a thing, i.e., any physical or logical object (e.g., a sensor, a person, a room, an issue in a ticketing system, etc.). Each entity has an entity id. Attributes represent properties of entities or pointers to associated entities. For example, the current speed of a car could be modelled as attribute "speed" of entity "car-104". The *attribute value,* contains the actual data and there is optional metadata describing properties of the attribute value like e.g. *accuracy, provider, or a timestamp*.

An entity is represented by a JSON object which can be encoded using the NGSI normalized format or the key-value simplified format. The geospatial properties of an entity are represented using GeoJSON [7].

The FIWARE Data Models are specified using JSON Schema.

Table 1 summarizes the status of the FIWARE Data Models that were available when SynchroniCity started to adopt them (October 2017). As stated in the previous section, SynchroniCity is actively contributing on the extension of these data models to cover the gaps between the existing custom data models already adopted in the RZs and the new common ones to be adopted by all the cities in the project.

Vertical	Data Model	Original Source
Building	Building	GSMA
Building	BuildingType	GSMA
Building	BuildingOperation	GSMA
Civic Issue Tracking	Open311:ServiceType	FIWARE / Open311
Civic Issue Tracking	Open311:ServiceRequest	FIWARE / Open311
Devices	Device	GSMA - SAREF Extended by FIWARE
Devices	DeviceModel	GSMA - Extended by FIWARE
Devices	DeviceOperation	GSMA
Environment	AirQualityObserved	GSMA
Environment	WaterQualityObserved	GSMA
Environment	NoiseLevelObserved	FIWARE

Indicators	KeyPerformanceIndicator	FIWARE
Parking	OffStreetParking	FIWARE
Parking	OnStreetParking	FIWARE
Parking	ParkingGroup	FIWARE
Parking	ParkingAccess	FIWARE
Parking	ParkingSpot	FIWARE
Parks & Gardens	Garden	FIWARE
Parks & Gardens	GreenspaceRecord	FIWARE
Parks & Gardens	Flowerbed	FIWARE
PointOfInterest	PointOfInterest	GSMA
PointOfInterest	Museum	FIWARE
PointOfInterest	Beach	FIWARE
PointOfInterest	TouristInformationCenter	schema.org
PointOfInteraction	SmartPointOfInteraction	FIWARE
PointOfInteraction	SmartSpot	FIWARE
Street Lighting	Streetlight	FIWARE
Street Lighting	StreetlightModel	FIWARE
Street Lighting	StreetlightGroup	FIWARE
Street Lighting	StreetlightControlCabinet	FIWARE
Transportation	BikeHireDockingStation	FIWARE
Transportation	Road	GSMA
Transportation	RoadSegment	GSMA

Transportation	TrafficFlowObserved	FIWARE
Transportation	Vehicle	GSMA - Extended by FIWARE
Transportation	VehicleModel	FIWARE
Transportation	VehicleFault	GSMA
Weather	WeatherObserved	GSMA - Extended by FIWARE
Weather	WeatherForecast	GSMA - Extended by FIWARE
Waste Management	WasteContainerIsle	FIWARE
Waste Management	WasteContainerModel	FIWARE
Waste Management	WasteContainer	FIWARE
Events	Event	schema.org

Table 1 - FIWARE data models overview

2.3 FIWARE Data Models Examples

2.3.1 Data Model Definition

Below an excerpt of a Domain Specific Data Model for Weather can be found that has been specified using JSON-Schema. The vocabulary of attributes used is defined by the FIWARE Data Models for Weather, which is ultimately based on the work done by the GSMA under the IoT Big Data Project [8].

```json
{
    "properties": {
      "type": {
        "type": "string",
        "enum": [
          "WeatherObserved"
        ],
        "description": "NGSI Entity type"
      },
      "dateObserved": {
        "type": "string",
        "format": "date-time"
      },
      "precipitation": {
        "type": "number",
        "minimum": 0
      },
      "barometricPressure": {
        "type": "number",
        "minimum": 0
      },
      "temperature": {
        "type": "number"
      },
      "pressureTendency": {
        "oneOf": [
          {
            "type": "string",
            "enum": [
              "raising",
              "falling",
              "steady"
            ]
          },
          {
```

```
                "type": "number"
              }
          ]
        },
        "dewPoint": {
          "type": "number"
        }
      }
    }
  ],
  "required": [
    "id",
    "type",
    "dateObserved",
    "location"
  ]
}
```

Figure 1 - JSON-Schema excerpt (FIWARE Data Models)

The example above describes an excerpt of the schema for a weather observation entity. It is noteworthy that such schema is only modelling the key-value representation of the data model. Similarly, a schema for the NGSI normalized model could be devised.

First of all, the different NGSI attributes are defined as properties of the JSON object. In addition, there are four elements required in this data model:

- *id*: corresponding to the entity id (automatically generated by data providers)
- *type*: corresponding to the entity type which shall be equal to "WeatherObserved"
- *dateObserved*: which is the date and time at which the observation was made. Please note how this attribute was defined (format=date-time)
- *location*: which is a GeoJSON geometry which defines the location associated to the weather observation

2.3.2 Data Model Instantiation

Below there are some examples of instantiations of the common information meta-model using the key-values representation format.

In the first example, an entity of type 'WeatherObserved' is represented.

In the second example, an entity of type "OffStreetParking" is represented.

```
{
  "id": "Spain-WeatherObserved-Valladolid-2018-11-30T07:00:00.00Z",
  "type": "WeatherObserved",
  "barometricPressure": 938.9,
  "dateObserved": "2018-11-30T07:00:00.00Z",
```

```
  "location": {
    "type": "Point",
    "coordinates": [
      -4.754444444,
      41.640833333
    ]
  },
  "precipitation": 0,
  "pressureTendency": "raising",
  "relativeHumidity": 1,
  "temperature": 3.3
 }
```

Figure 2 - WeatherObserved entity instance

Apart from the mandatory entity type and id, there are different attributes and values in accordance with the JSON Schema described previously. The format shown is very compact and can be consumed very easily by different applications or services.

```
{
  "id": "porto-ParkingLot-23889",
  "type": "OffStreetParking",
  "name": "Parque de estacionamento Trindade",
  "category": [
    "underground",
    "public",
    "feeCharged",
    "mediumTerm",
    "barrierAccess"
  ],
  "chargeType": [
    "temporaryPrice"
  ],
  "layout": [
    "multiLevel"
  ],
  "maximumParkingDuration": "PT8H",
  "location": {
    "coordinates": [
      -8.60961198807,
      41.150691773
    ],
    "type": "Point"
  },
  "allowedVehicleType": [
```

```
    "car"
  ],
  "totalSpotNumber": 414,
  "availableSpotNumber": 132,
  "address": {
    "streetAddress": "Rua de Fernandes Tomás",
    "addressLocality": "Porto",
    "addressCountry": "Portugal"
  },
  "description": "Municipal car park located near the Trindade"
  }
```

Figure 3 - OffStreetParking entity instance

The example above shows an entity of type 'OffStreetParking' which includes different attributes. In this case there is one attribute, named 'category', which is multivalued and represented as an array. Another point to be noted is that there is a property which denotes a duration 'maximumParkingDuration' and is represented using a text string following the ISO8601 format [9] for representing durations.

3 SynchroniCity Data Models Development

This chapter is intended to report about the results obtained during the Data Models development for SynchroniCity at the time of writing. It also describes the way of working agreed concerning the development of Data Models and the gap analysis conducted.

The gap analysis is aimed at analysing the existing data models adopted in the RZs and identifying possible gaps with respect to proposed common data models to eventually extend them or develop new ones.

The description of the way of working is intended to provide the main guidelines for the data model development and to clarify what is the relationship between SynchroniCity and related initiatives, particularly those which provide baseline data models to the project.

3.1 Way of working

During the first phase of the Data Models activity within SynchroniCity, the way of working concerning the development of Data Models has been defined and is summarised as follows:

- The main source of truth of the SynchroniCity Data Models is the public Gitlab Repository https://gitlab.com/synchronicity-iot/synchronicity-data-models.
- Change requests, bugs or extension proposals have to be reported by RZs, concerned cities or other stakeholders through Gitlab issues raised on the SynchroniCity Data Models Repository.
- Gitlab merge requests against the SynchroniCity Data Models Repository [10] is the mechanism to be used when it comes to solving issues.
- Baseline data models (namely FIWARE Data Models) are referenced (not forked, nor copied) from the SynchroniCity Gitlab Repository. Any change or addition request to a baseline data model shall be done through the specific repository of the referred baseline (https://github.com/FIWARE/data-models in the particular case of FIWARE).
- New Data Models (see below) proposed by SynchroniCity are hosted by the Gitlab SynchroniCity Data Model Repository.
- For each data model proposed by SynchroniCity there is an owner (city, RZ, technological partner, etc.).
- Data model owners will be responsible for reviewing and approving merge requests, however, anybody can also review and contribute.
- Technological partners should help to ensure that the needs, concerning data models, of their RZs of interest are satisfied.
- The overall lifecycle of a SynchroniCity Data Model is:
  - o *Draft*. The data model has been proposed and is under revision by the cities, communities, application developers or any other interested party.
  - o *Stable*. The data model is in stable state and only extensions or backward compatible changes are expected.
  - o *Approved*. The data model has been versioned and approved by the corresponding stakeholders.

3.2 Gap Analysis methodology

The gap analysis methodology that has been followed is largely based on the OASC principles: open, agile and implementation-driven. As a result, a study was conducted with the RZs in order to determine the Data Models from the baseline that were useful (i.e. they have available data) for them (or that were already being used) and other Data Models potentially needed.

An internal working document[1] has been used to conduct the analysis with the RZs. At row level the different Data Models under study are arranged. At column level the different RZs are enumerated. "R" indicates that the RZ has already implemented the Data Model in their SynchroniCity instance. "P" indicates that the RZ is planning to use the Data Model for data publication and a question mark (?) conveys that the RZ is studying the inclusion of instances of the Data Model.

After the execution of this study it was determined what Data Models from the baseline had a minimum adoption threshold so that they could be added to the SynchroniCity, OASC Catalogue of shared Data Models.

3.3 Recommendations on new Data Models

Apart from the Data Models described above, some Reference Zones have made recommendations on the development of additional Data Models for the following verticals:

- Traffic
  - Restricted areas
  - Maintenance works
  - Traffic Alerts (accidents, etc.)
- City Information
  - Events
  - Public office queue status
- Points of interest
  - Store
  - Public Toilet
- Transportation
  - Cycle Paths
  - Cycle Hubs
  - Status of metro lines
  - Car sharing stations
- Urban Mobility
  - Public transport lines
  - Public transport routes
  - Public transport stops

---

[1] https://docs.google.com/spreadsheets/d/1BeXStnd2pNtrY6GdalKtsFE_946XS1Ia3FHhTcNmkr0/edit#gid=0

    o Interoperability with GTFS

    o Crowd flows

  • Energy

    o Device energy measurements

Those new Data Models have been developed and improved during whole project duration.

In addition, the Project Consortium has committed to work on additional data models adapted or directly taken from other initiatives, namely INSPIRE, EuroCities or SAREF.

For each of these initiatives, a brief introduction is presented in the next sections together with an overview of their data models, and finally, some considerations on the possible adoption/adaption of (a subset of) such data models in SynchroniCity, in order to meet the needs of the RZs, not yet covered by the existing models. Whenever a data model will be chosen to be adopted, its own model schema must be adapted to a JSON Schema, in order to fit into the NGSI meta-model.

3.3.1 INSPIRE initiative

Inspire, Infrastructure for Spatial Information in Europe [11], is the European Community directive [12] that aims to create an infrastructure for sharing environmental spatial data between public authorities of the European States. Each State produces and uses geospatial data, especially in the environment scope, such as groundwater, pollution, land-use, population and so on. In addition, each country has its own specific convention to describe these data; but often some of them, regarding for instance river flows or mountains, cross the country borders, thus requiring a common way of representation.

Furthermore, an important aspect is related to critical events, such as natural disasters, when actions have to be executed very quickly in coordination among different European countries. Such data are not always readily available and created using the same standards and technologies; hence, the need to create a common standard representation. In addition, Inspire, with its own standards, allows collecting spatial information for the first time in an efficient way and facilitates public access to the available spatial data, from different countries, through the online geoportal [13].

The Directive, which came into force in 2007, will be fully implemented by 2021.

3.3.1.1 INSPIRE Data Models

The common Data Models defined in the initiative are called Inspire objects and are referred to specific environmental applications, with a total amount of 338 spatial objects grouped in 34 application data themes [14]. Some themes that are not strictly related to City aspects in terms of the contexts, such as Geology, Elevation, Agriculture facilities and so on, will not primarily be taken into consideration in the context of the SynchroniCity project. Table 2 reports the data themes identified and the relevant objects for each theme.

Theme	Description	Relevant Objects
Addresses	Fixed location of a property and its components	Address, AddressComponent, GeographicPosition, Postal Descriptor
Administrative units	Units of administration with jurisdictional rights, separated by administrative boundaries.	Administrative Unit, Administrative Boundary, Condominium, Maritime Units
Cadastral parcels	Areas defined by cadastral registers or equivalent.	Cadastral parcels
GeographicalNames	Names of areas, regions, localities, cities, suburbs, or any geographical or topographical feature	GeographicalName
Hydrography	Marine areas and all related other water bodies	Sea Regions, Hydro Network, Hydro Physical Waters (Shore, Falls, etc.)
Transport networks	Road, rail, air and water transport networks and related infrastructure. Includes links between different networks.	Common Transport Elements (Transport Node, Link, Area, etc.), Road, Railway, Air, Cable and Water Transport Network
Area management/restriction regulation zones	Areas managed and regulated under specific restrictions: dumping sites and areas, regulated fairways at sea, noise restriction zones, etc.	ManagementRestriction OrRegulationZone
Energy Resources	Energy resources including hydrocarbons, hydropower, bio-energy, solar, wind, etc.	FossilFuelValue, RenewableAndWasteValue, VerticalReferenceValue
Environmental monitoring facilities	Location and operation of environmental monitoring, e.g., observation and measurement of emissions.	EnvironmentalMonitoring Activity, Facility, Network, Programme

Atmospheric and Meteorological conditions	Physical conditions in the atmosphere: spatial data based on measurements	Observation (Point, MultiPoint, Grid), ObservedProperty
Buildings	Geographical location of buildings	BuildingGeometry2D, buildingNature, horizontal and vertical Geometry
Human health and safety	Geographical distribution of dominance of pathologies, the effect on health linked to the quality of the environment.	Disease, Noise Measure, Biomarker, Safety (TrafficRelatedEvent, NaturalHazardRelatedEvent, etc.)
Natural Risk zones	Vulnerable areas characterised according to natural hazards	HazardArea, RiskZone, Natural Hazard Classification
Utility and governmental services	Facilities such as sewage, waste management, energy supply and water supply, administrative and social governmental services	GovernmentalService, Utility Networks (Water, Oil-Gas, Thermal, Sewer, Electricity, etc.)

Table 2- Relevant Inspire data Themes and Objects

The Data Models are defined through UML Models (Class Diagram) [15], also with related XML Schemas [16], representing relationships between the different themes, object types, data type classes and their properties.

3.3.1.2 Application of INSPIRE data models in SynchroniCity

The use of such data models is under investigation, in those cases in which the RZs have data in contexts not represented or difficult to adapt with the data models already adopted. For instance, specific objects, such as the ones of Administrative Units theme, could be used to define RZ's entities in a more specialized way than simply using *PointOfInterest*. The applicability is depending on particular concepts to be modelled by an RZ application. In the Milan RZ, for instance, spatial data about different Municipality government areas are mapped using Point of Interest data model. Instead, a specialized data model, such as the Administrative Unit, which has specific fields and relative well-defined data types can better describe the custom data used in Municipality systems.

Another relevant example is the Utility and Governmental Services theme, which represents facilities such as sewerage, waste management, energy and water supply, public administrative and social services such as public administrations, civil protection sites, schools and hospitals. Not all of these concepts have been modelled by the currently adopted data models in SynchroniCity, thus a one-to-one investigation is ongoing.

A particular mention is needed regarding the Transport network theme. The included objects may collide with the already adopted Urban Mobility ones. In this case, for colliding concepts, a deeper analysis will be conducted on the new and existing properties, in order to identify which properties

or relationship can be integrated in the existing models. For instance, the *speedLimit* property, in the Common Transport Elements of INSPIRE Network object, could be conceptually related to the adopted GtfsRoute model.

Atmospheric and Meteorological conditions and Human Health themes could extend the existing entities like *AirQualityObserved* and *WeatherObserved.*

Furthermore, regarding the Area Management theme, relevant properties such as *designationPeriod*, *competentAuthority*, *environmentDomain*, LegislationCitation and *zoneType* could extend the *RestrictedTrafficArea* [17] developed within SynchroniCity.

3.3.2 EuroCities

The Eurocities initiative [18], founded in 1986, is a network of the local governments of major European cities. It brings together the local governments of over 140 cities across 39 countries, offering a platform for sharing knowledge and exchanging ideas in the economic, political, social and cultural scopes. Through six thematic forums, a wide range of working groups, projects, activities and events, collaborate with EU institutions to respond to common issues that affect the lives of citizens. Therefore, the main focus is to reinforce the important role that local governments should play in a multilevel governance structure; connecting cities enables exchanging common issues and solutions, in order to learn from one another.

In particular, the Data working group [19] deals with topics like data management, collection and storage. One of its main objectives is to find equitable solutions for public data and data from private sources, to create 'shared urban data schemes'. The Standards and Interoperability working group [20], instead, is more focused on developing common standards in order to improve the interoperability of city systems with the target of maximising the accessibility and usability of data.

3.3.2.1 Application of EuroCities in SynchroniCity

The EUROCITIES Standards Interoperability Guide [21] underlines the importance of having well agreed common standards and indicates the three European Standardisation Organisations (ESOs) as responsible for European Standards: CEN, CENELEC and ETSI. The activities of ETSI fit better within the scope of SynchroniCity, and, as already anticipated in Section 2.1, the migration to NGSI-LD [22] is under investigation.

Furthermore, the EUROCITIES initiative is involved [8] in the Sharing Cites project [23]. This project aims to demonstrate the effectiveness of new technologies in improving urban mobility, increasing the energy efficiency of buildings and reducing carbon emissions. The focus is to engage society in new ways (e.g. gamification) to enable them to play an active role in the transformation of the city communities.

Municipality of Milan RZ is also involved in the Sharing Cites project and legacy data coming from their deployed sensors for Sharing Cities, such as Lamppost Weather measurements and smart-parking availability sensors, are being used and already mapped to the agreed SynchroniCity data models (*WeatherObserved* and *OffStreetParking*).

3.3.3 SAREF

The Smart Appliances REFerence (SAREF) ontology [5] is a common shared model to bring together semantics and data from different smart appliances in buildings and households. This reference ontology, representing the main outcome of the Smart Appliances project [24], can be used to match the data coming from different sites and organizations. In particular, ontology can be defined as a formal specification of a conceptualization, used to explicitly capture the semantics of a certain real concept, its properties and relationships with other concepts [25].

In detail, the following appliances are covered by the project:

- Home and building sensors (temperature, humidity, water quality, CO2 sensors and in general environment sensors.
- Actuators (windows, doors, etc).
- White goods (Refrigerating, Freezing, Cooking, Washing, etc.)
- HVAC: heating, ventilation, air conditioning, plumbing, etc.
- Lighting
- Micro renewable home solutions (solar panels, solar heaters, etc.)

The study conducted on existing semantic assets, led to a short-list of 24, which took the basis for OWL reasoning, in order to develop the final common SAREF ontology.

3.3.3.1 SAREF Data Models

The basic concept of SAREF is generic Device. Devices are real objects designed to accomplish a particular task in households, common public buildings or offices. In order to accomplish this task, the device performs one or more functions. The ontology provides a list of basic functions that can be considered as building blocks to be combined, in order to have more complex functions in a single device. The device, when connected to a network, offers a service, which is the representation of one or more functions to a network, making them discoverable, registerable and remotely controllable by other devices in the network. Figure 4 depicts an overview of the Device, the main class of the ontology, and its properties.


```
                         ● saref:Device
■ saref:IsUsedFor : saref:Commodity or saref:Property or saref:BuildingObject
■ saref:accomplishes : saref:Task (min 1 saref:Task)
■ saref:consistsOf : saref:Device
■ saref:hasCategory : saref:DeviceCategory
■ saref:hasFunction : saref:Function (min 1 saref:Function)
■ saref:hasProfile : saref:Profile
■ saref:hasState : saref:State
■ saref:hasTypicalConsumption : saref:Energy or saref:Power
■ saref:isLocatedIn : saref:BuildingSpace
■ saref:offers : saref:Service
■ saref:hasDescription : string[0..1]
■ saref:hasManufacturer : string[1..1]
■ saref:hasModel : string[1..1]
```
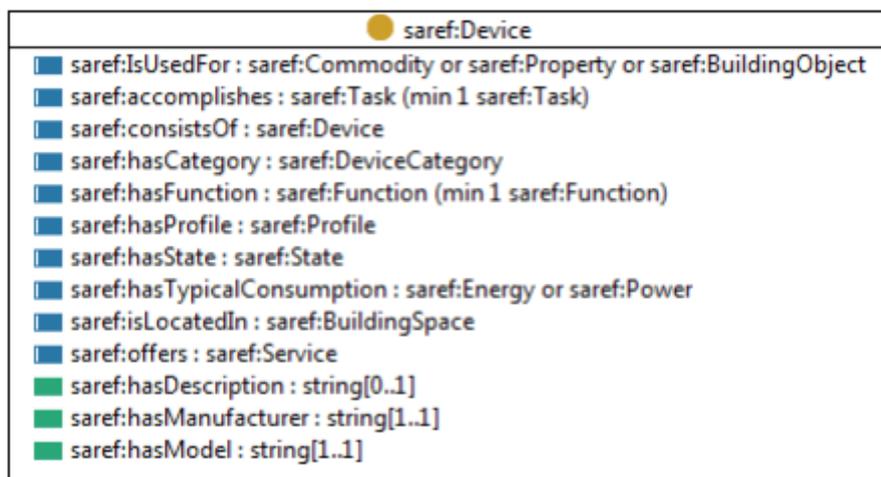
Figure 4 - SAREF - Device class

3.3.3.2 Application of the SAREF ontology in SynchroniCity

Since the SAREF ontology is represented as a Turtle OWL file [26], the specific concepts to be used in SynchroniCity have been identified. In order to apply the identified concepts, processes are needed in charge of flattening the intrinsic triples structure of the ontology to a structured representation through JSON Schema. In particular, the relationships between concepts should be mapped as entity properties, with the right semantics and cardinalities defined in the original SAREF ontology.

The main focus, on identifying which concepts to reuse or adapt for the SynchroniCity data models, is in the SAREF semantic coverage regarding devices, sensors and their specification in terms of functions and states. This consideration leads to the extension of the already adopted Device model (from FIWARE), since it already reuses concepts coming from SAREF [27].

The ontology provides a list of properties that can be used to further specialize the functioning of a device, and the investigation is ongoing to identify those which can be useful for RZs and are not already included in the current Device model. For instance, the "function" property could point to a new dedicated entity, if further details for each function of a specific device are needed, like specific Command classes provided by SAREF. Furthermore, a specific device on an RZ could have the information about the power consumption of the device itself, which could be modelled with the *saref:hasTypicalConsumption* property and related Energy or Power concepts. Definitively, those needs could lead to also adopt the concept of *saref:Profile*, intended as a specification associated to a device to collect information about a certain Property (e.g. Energy) or commodity (e.g. Water) for optimizing its usage.

As a first attempt of bringing SAREF to the domain of Smart Cities, in June 2019 ETSI has made an initial release of an extension of SAREF [28], known as SAREF4City.

3.4 Development process

For collaborative development, SynchroniCity Data Model documentation is drafted using the markdown format. The recommended documentation template can be found at [29]

New data model specifications are uploaded to the SynchroniCity GitLab data models project [10]. They can later be contributed to upstream projects of reference, such as the FIWARE Data Models project.

For each data model, the following elements are included in the documentation:
- A general description of the data model and the main entities modelled.
- A description of the attributes of the data model that are formalised using JSON Schema.
- An example of a data model instance encoded as a JSON code fragment.
- A description of reference / example endpoints that offer data following the specified data model (if there are any available).
- A list of activities yet to be completed on the data model or open issues.

The folder structure for each Data Model is the one that was formerly described in D2.2 [6]:

EntityTypeName/
- doc/
  - spec.md: Data model description based on the data model template
- README.md: A summary file
- schema.json: The JSON Schema definition

● example.json: Example file including an instance encoded in JSON format (as key values)

● example-normalized.json: Example file including an instance encoded in JSON format (as normalized NGSIv2 format).

In the near future, and once NGSI-LD is being adopted, extra examples will be included with an NGSI-LD representation of the different entities.

3.5 Results

Table 3 summarizes the current status of the catalogue of OASC shared Data Models. It includes the FIWARE Data Models already adopted by SynchroniCity and new Data Models that have been developed in the project.

Vertical	Data Model	Description	Status
Environment	AirQualityObserved	It represents an observation of air quality conditions at a certain place and time	Taken from baseline
Environment	NoiseLevelObserved	It represents an observation of those parameters that estimate noise pressure levels at a certain place and time	Taken from baseline and extended by SynchroniCity
PointOfInterest	PointOfInterest	A harmonised geographic description of a Point of Interest	Taken from baseline and changes proposed by SynchroniCity
PointOfInterest	Museum	A harmonised geographic description of a museum	Taken from baseline
PointOfInterest	Beach	A harmonised geographic description of a beach	Taken from baseline
PointOfInterest	Store	A harmonised geographic description of a store	Developed by SynchroniCity
Transportation	BikeHireDockingStation	A bike hire docking station where	Taken from baseline

		subscribed users can hire and return a bike.	
Transportation	TrafficFlowObserved	An observation of traffic flow conditions at a certain place and time.	Taken from baseline and extended by SynchroniCity
Transportation	EVChargingStation	A public charging station supplying energy to electrical vehicles.	Developed by SynchroniCity
Transportation	CrowdFlowObserved	An observation of people movement at a certain place and time.	Developed by Synchronicity
Transportation	CarSharingStation	A public Car Sharing Station where it is possible to rent a car, with either direct access from a road or with suitable and clearly marked access points.	Developed by Synchronicity
Transportation	RestrictedTrafficArea	An area of a city in which the traffic generated by cars or any other kind of vehicles is subjected to limitation.	Developed by Synchronicity
Transportation	Vehicle	Real time tracking of the vehicles that are used for public transportation (buses, trains, etc.)	Taken from baseline
Transportation	Road	This entity contains a harmonised geographic and contextual description of a road.	Taken from baseline
Transportation	RoadSegment	This entity contains a harmonised geographic description of a road segment. A collection of road segments are used to describe a Road.	Taken from baseline

Transportation	RoadAccident	Describes road accidents giving description and information about causes, casualties and aftermath.	Developed by SynchroniCity
Weather	WeatherObserved	An observation of weather conditions at a certain place and time.	Taken from baseline and extended by SynchroniCity
Weather	WeatherForecast	Harmonised description of a Weather Forecast.	Taken from baseline
Parking	OffStreetParking	An off street parking site with explicit entries and exits	Taken from baseline
Parking	OnStreetParking	An on street, free entry (but might be metered) parking zone which contains at least one or more adjacent parking spots	Taken from baseline
Parking	ParkingSpot	An individual, usually monitored, parking spot/parking lot	Taken from baseline
Urban Mobility (GTFS mapping)	12 Entity Types (Agency, Stop, Route, Trip, …)	The General Transit Feed Specification (GTFS) defines a common format for public transportation schedules and associated geographic information.	Developed by SynchroniCity
Urban Mobility	ArrivalEstimation	It captures the estimated arrival time of a public transport vehicle reaching a particular stop, whilst the vehicle is	Developed by SynchroniCity

		servicing a particular route.	
UrbanMobility	GtfsTransitFeedFile	Provides the Location (URL) of the ZIP file containing a valid GTFS transit feed.	Developed by SynchroniCity
UrbanMobility	PublicTransportRoute	A route is a journey, offered by one public transport service, that goes through a set of stops.	Developed by SynchroniCity
UrbanMobility	PublicTransportStop	Generic model for a public transport stop	Developed by SynchroniCity
Waste Management	WasteContainerModel	Static properties of a waste container	Taken from baseline
Waste Management	WasteContainer	A waste container	Taken from baseline
Parks and Gardens	GreenSpaceRecord	Harmonised description of the conditions recorded on a particular area or point inside a greenspace (flower bed, garden, etc.)	Taken from baseline
Parks and Gardens	Garden	A garden is a distinguishable planned space, usually outdoors, set aside for the display, cultivation, and enjoyment of plants and other forms of nature.	Taken from baseline
Device	Device	A device	Taken from baseline
Energy	ThreePhaseMultiCircuitAcMeasurement	A measurement from an electrical sub-metering system	Developed by SynchroniCity

		that monitors three-phase alternating current across multiple circuits	
Energy	GreenEnergyGenerator	A station which is able to generate energy from green sources such as solar, eolic, hydropower, biomass, geothermal	Developed by SynchroniCity
Energy	GreenEnergyMeasurement	A measurement of power generation using green energies in specific datetime	Developed by SynchroniCity
Privacy	PrivacyObject	A device or an object with the point of view of the privacy.	Developed by SynchroniCity
Public Offices	QueueMonitor	Describes an office counter queue system on a daily run	Developed by SynchroniCity

Table 3 - OASC shared Data Models

4   Roadmap

The roadmap of SynchroniCity has two major targets: migration to NGSI-LD [22] and consolidation of SynchroniCity Data Models as part of the catalogue of recommendations made by relevant industry associations, namely TM Forum.

4.1 Migration path to NGSI-LD

The OMA NGSI information model (currently adopted by SynchroniCity) has been evolved to better support linked data (entity relationships), property graphs and semantics (exploiting the capabilities offered by JSON-LD). This work has been conducted under the ETSI ISG CIM initiative and has been branded as NGSI-LD [22]. D2.2 [6] provided an overview of NGSI-LD and its information model. This chapter is intended to show in practical terms how the SynchroniCity Data Models can be eventually migrated to NGSI-LD.

The main constructs of NGSI-LD are: Entity, Property and Relationship. NGSI-LD Entities (instances) can be the subject of Properties or Relationships.

In terms of the traditional NGSI data model, Properties can be seen as the combination of an attribute and its value. Relationships allow establishing associations between instances using linked data. In practice, they are conveyed by means of an NGSI attribute, but with a special value (relationship's object) which happens to be a URI which points to another entity. They are similar to the "ref" attributes recommended by the D2.2 guidelines.

Properties and Relationships can be the subject of other Properties or Relationships. Thus, in the NGSI-LD information model there are no attribute's metadata, but just "properties of properties" or "properties of relationships". It is not expected to have infinite graphs, and in practice, only one or two levels of Property or Relationship "chaining" will happen. Typically, there will be one, equivalent to the NGSI metadata abstraction.

NGSI-LD Entities are represented using JSON-LD, a JSON-based serialization format for Linked Data. The main advantage of JSON-LD is that it offers the capability of expanding JSON terms to URIs, so that vocabularies can define terms unambiguously.

4.2 Steps to migrate to NGSI-LD

The migration steps to NGSI-LD have been documented at https://gitlab.com/synchronicity-iot/synchronicity-data-models/blob/master/NGSI-LD_Guide.md and are summarized by the following paragraphs.

First of all, each Data Model shall have a JSON-LD @context [30], providing an unambiguous definition by mapping terms to URIs. For practical reasons, it is recommended to have a unique @context resource, containing all terms, subject to be used in every SynchroniCity Data Model, the same way as schema.org does. The following steps have to be followed in order to migrate existing NGSI instantiations of the SynchroniCity Data Models to NGSI-LD:

- Entity ids have to be converted to URIs, preferably using the NGSI-LD URN namespace.
- Regular entity attributes have to be converted to JSON-LD nodes of type "Property".
- ref attributes (pointing to other entities) have to be converted to JSON-LD nodes of type "Relationship".

- The timestamp metadata item has to be mapped to the "observedAt" member of a Property node.

- The unitCode metadata item has to be mapped to the "unitCode" member of a Property node.

- The NGSI DateTime type has to be properly encoded as per the JSON-LD rules.

- The NGSI geo:json type has to be renamed to "GeoProperty".

The FIWARE Community, in collaboration with SynchroniCity, has already provided a simple script to migrate FIWARE NGSI entity representations to NGSI-LD, see https://github.com/FIWARE/data-models/blob/master/tools/normalized2LD.py

4.3 Example of migration to NGSI-LD

Figure 5 and Figure 6 show how air quality information at a certain point of interest can be conveyed using the Synchronicity Data Models (involving the entity types *AirQualityObserved*, *PointOfInterest*) in NGSI (JSON) format.

```json
{
        "id": "AirQualityObserved:RZ:Obsv4567",
        "type": "AirQualityObserved",
        "dateObserved": {
                "type": "DateTime",
                "value": "2018-08-07T12:00:00"
        },
        "NO2": {
                "type": "Number",
                "value": 22,
                "metadata": {
                        "unitCode": {
                                "type": "Text",
                                "value": "GP"
                        }
                }
        },
        "refPointOfInterest": {
                "type": "Reference",
                "value": "PointOfInterest:RZ:MainSquare"
        }
}
```

Figure 5 - JSON NGSI Representation of an entity of type AirQualityObserved

```
{
      "id": "PointOfInterest:RZ:MainSquare ",
      "type": "PointOfInterest",
      "category": {
            "type": "List",
            "value": ["113"]
      },
      "description": {
            "type": "Text",
            "value": "Beach of RZ"
      },
      "location": {
            "type": "geo:json",
            "value": {
                  "type": "Point",
                  "coordinates": [-8,44]
            }
      }
}
```

Figure 6 - JSON NGSI Representation of an entity of type PointOfInterest

Figure 7 and Figure 8 show how air quality information, at a certain point of interest, can be conveyed using the Synchronicity Data Models (involving the entity types *AirQualityObserved*, *PointOfInterest*) in **NGSI-LD** format. The new representation has been obtained by applying the conversion rules described before.

Please note that the referred JSON-LD @context could be eventually published by SynchroniCity at the suggested URL, or, for instance, the one that FIWARE would eventually publish could be reused.

```
{
      "id": "urn:ngsi-ld:AirQualityObserved:RZ:Obsv4567",
      "type": "AirQualityObserved",
      "dateObserved": {
            "type": "Property",
            "value": {
              "@type": "DateTime",
              "@value": "2018-08-07T12:00:00Z"
            }
      },
      "NO2": {
```

```
        "type": "Property",

        "value": 22,

        "unitCode": "GP"

    },

    "refPointOfInterest": {

        "type": "Relationship",

        "object": "urn:ngsi-ld:PointOfInterest:RZ:MainSquare"

    },

    "@context": [

      "https://gitlab.com/synchronicity-iot/synchronicity-data-
models/raw/master/context.jsonld",

      "https://uri.etsi.org/ngsi-ld/ngsi-ld-core-context.jsonld"

    ]

}
```

Figure 7 - JSON-LD NGSI Representation of an entity of type AirQualityObserved

```
{

    "id": "urn:ngsi-ld:PointOfInterest:RZ:MainSquare ",

    "type": "PointOfInterest",

    "category": {

        "type": "Property",

        "value": ["113"]

    },

    "description": {

        "type": "Property",

        "value": "Beach of RZ"

    },

    "location": {

        "type": "GeoProperty",

        "value": {

            "type": "Point",

            "coordinates": [-8,44]

        }

    },

    "@context": [

        "https://gitlab.com/synchronicity-iot/synchronicity-data-
models/raw/master/context.jsonld",

        "https://uri.etsi.org/ngsi-ld/ngsi-ld-core-context.jsonld"

    ]
```

```
}
```

Figure 8 - JSON-LD NGSI Representation of an entity of type PointOfInterest

The content of the JSON-LD @context could contain the mappings enumerated in Figure 9. Observe that "refPointOfInterest" is labelled as an @id, as it is actually pointing to another Entity (linked data). On the other hand, there are certain terms such as "location" or "unitCode" which are not included in the @context, as they pertain to the Core JSON-LD @context which is always implicitly given (and cannot be overwritten).

```
{
  "@context": {
      "dateObserved": "https://uri.fiware.org/ns/data-models#dateObserved",
      "NO2": "https://uri.fiware.org/ns/data-models#NO2",
      "refPointOfInterest": {
          "@type": "@id"
          "@id": "https://uri.fiware.org/ns/data-models#refPointOfInterest"
      },
      "category": "https://uri.fiware.org/ns/data-models#category",
      "description": "https://schema.org/description"
  }
}
```

Figure 9 - JSON-LD @context content

4.4 TM Forum – Front Runner Smart Cities

The joint initiative TM Forum – FIWARE Foundation, named "Front Runner Smart Cities", is intended to accelerate the adoption and implementation of Common Information Models for the smart city domain.

TM Forum and FIWARE Foundation intend to publish these Common Information Models as TM Forum Recommendations under a Github organization, https://github.com/smart-data-models. The starting point will be the FIWARE Data Models.

The idea is that cities participating in the programme will approve and endorse data models once they are validated in real applications or pilots. As the initiative follows the OASC principles of agility and being implementation driven, it is also supported by SynchroniCity and by the main OASC cities initiative.

This initiative and others that could be put in place, in the end, will foster the sustainability and scalability of the SynchroniCity project, maximizing the impact beyond the lifetime of the project.

More details about this initiative can be found at https://github.com/smart-data-models/data-models/blob/master/README.md

5 Conclusions

This deliverable has summarized the development activities of new Data Models for SynchroniCity. These activities are sustained by the following principles:

- Promoting reuse of existing Data Models wherever possible, by following a baseline approach, adopting Data Models already developed by the FIWARE Community or GSMA.
- Adhering to the Data Models Guidelines previously developed and summarized in D2.2 [6].
- Open and Agile development listening to the real needs and data availability from the Reference Zones.
- Using NGSI and NGSI-LD as the main meta-model formalisms.
- Using collaborative development tools (*gitlab*) to publish new Data Model specifications.
- Ensuring a sustainable approach by contributing to upstream development communities, such as FIWARE.
- Participating in global industry initiatives, namely the "Front Runner Smart Cities" initiative with TMForum, so that a sustainable and scalable approach is followed, maximizing the impact beyond the lifetime of the SynchroniCity project.

Defining and using the common data models are pivotal for achieving SynchroniCity objectives, and it continues the activities and efforts to develop and enhance the wide set of data models covering large area of Smart City application domains, particularly in a way to ensure the sustainable development.

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