Smart City Platform Enabling Digital Twin

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***Abstract*— Visual 3D models are being deployed in smart cities around the world. While earlier the motivation was mostly to visualize the buildings, the latest developments will turn the 3D models into a rich source of information related to the urban landscape and built environment. The models can be used to compare the energy consumption between similar buildings or to display the potential solar panels had if mounted on certain district. The models have soon become elemental in not only managing a smart city but also as a platform for co-design and development together with the citizens.**

Keywords*— *data platform; smart city; user participation; data model; sensor ontologies

I. Introduction

Virtual 3D models of the cities have been used for a while already for visualization purposes, allowing users to graphically explore cityscapes. Typically, such earlier models were based on point clouds or polygon geometries. In semantic 3D city models the objects are decomposed into parts due to logical criteria and not graphical considerations [1]. This approach will open up new opportunities to associate not only metadata but also processes and events with the city model objects.

The semantic 3D city models consume various data sets in order to provide a rich view on the city functions. This will raise the expectations on data quality and interoperability, including semantic interoperability. In the smart city context, virtually any type of data includes or should include spatial information of the area of coverage. Data, whether that is a decision or an observation made of something, is referencing to a certain spot, block or district. In order to be useful, the data should include the location information in early stages in order to be useful.

Parallel to the 3D city model developments the cities are also developing their urban platforms. The term refers to a collection of web services, interconnected by data interfaces, and sharing information with others. A key service on urban platform is the open data catalog, which in Helsinki was opened in 2011. Currently it hosts about 800 data sets created and published by various organizations within the city and its neighboring cities. The city is also working on API guidelines and governance models for the data.

The next step in open data is to introduce more live data sources such as sensors and the data points of building automation systems. As with the data sets, the semantic interoperability is critical in order to be able to utilize the data on services. In order to do that, the urban platform will adopt many of the functions currently available in IoT platforms.

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II. Objectives and Actions

The City of Helsinki has been experimenting with 3D models since the 1980's. In 1999 the city introduced a 3D Simulator, a 3D model based on RealImation game engine. In 2002, the thoroughly revised city plan was introduced to the citizens using a 3D model, as was the case in 2003 when the new Pasila district area plan was illustrated with several design options. The 3D model became quickly a tool for the city planning. The 1999 Land Use and Building Act had already introduced requirements on how to interact with the persons and bodies impacted on and how to later on organize planning reviews and development negotiations.

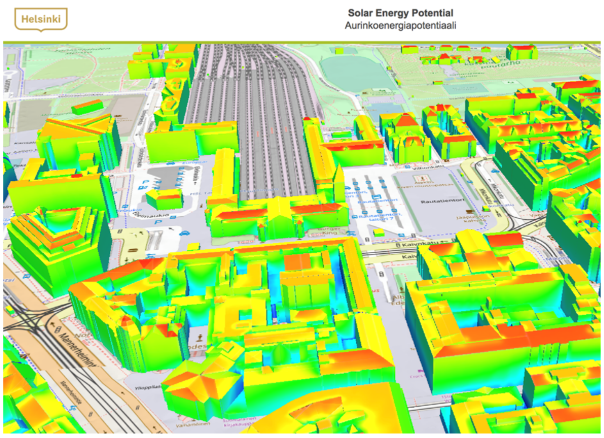

Figure 1: Solar Energy Model on Helsinki 3D+

A. Open Standards

The primary organization for geospatial standardization is Open Geospatial Consortium, OGC. It is a consortium of over 500 companies, government agencies, research organizations and universities that are participating in a consensus process to develop publicly available geospatial standards. The standards are available free of charge and the organization is open for new members to participate with the process. The OGC has taken the role of geospatial standardization in a coordinated effort to support other standardization organizations, e.g. ISO and W3C.

The key standard for the 3D city models is CityGML. It is based on Geography Markup Language (GML), an XML grammar written in XML schema for the modeling, transport and storage of geographic information. The GML is based on the OGC Abstract Specification that models the world in terms of features [4]. A feature in that context is an abstraction of a real-world phenomenon and a geographic feature then can be any real-world object that is somehow associated with a location.

The CityGML represents the physical world objects with four aspects: semantics, geometry, topology and appearance. All objects can be represented in up to five different levels of details (LoD). The different levels of details can also co-exist in the same model in the next version, allowing maintaining a good user experience with lower bandwidth and processing capacity terminals.

Functionally the CityGML is partitioned into modules. These modules provide support for the definitions of different thematic models such as building, land use, city furniture and so on. Further thematic extensions can be added without having to release a new version of the data model. That approach has been utilized when extending the use of the model towards solar energy potential, noise emission simulations or testing the effect of flooding. The following figure illustrates the modular structure of the model:

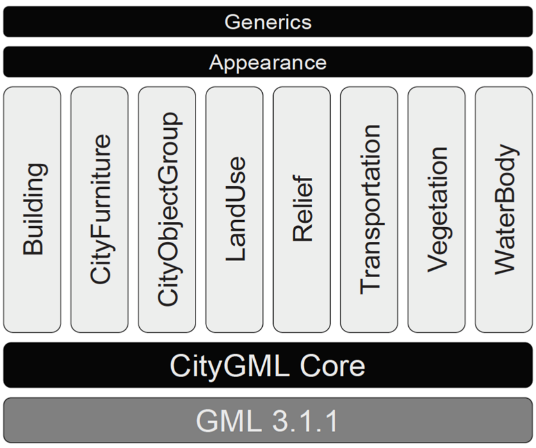

Figure 2: CityGML Modularization

For the appearance of the surface of an object, CityGML provides various options. Appearances are considered an integral part of virtual 3D models to provide a better experience on city exploration. The future applications of augmented reality (AR) and virtual reality (VR) will naturally also benefit on detailed surfaces. Appearances are not however only limited to visual data but they can also contain arbitrary categories called *themes* such as infrared radiation, noise or sunlight emission or even earthquake-induced structural stress [6].

The upcoming new version 3.0 of CityGML will introduce new methods to update contents on the entire model or in parts of it. This would allow the objects having dynamic properties, e.g. a number of persons inside the building at current moment or the reading of water meter at the time of loading the model. The new version will also have better support for mapping data with the IFC models generated as part of planning in CAD – application [7].

B. Helsinki 3D+ City Model

In mySMARTLife project Helsinki has opened several energy related datasets in the 3D model and in open access data. The goal is to increase the knowledge of possibilities to increase energy efficiency and renewable energy production especially in renovation stage to help to reach Helsinki's ambitious climate goals. There are several recognized international experiences that show that open energy data motivates all stakeholders to action when relevant information is available. The benefits for different target groups are:

1. Data increases building owner's interest on the performance of their buildings when they can compare their consumption and renovation need and they can see the potential for energy improvements

2. Data supports especially smart and clean technology related businesses when the building stock's energy related data can be found easily and used for business purposes. In example businesses can estimate if the roof renovation is coming soon which can be combined with solar panel installation

3. Investors can get better access on the information of building stock, which eases making the financial decisions related to energy renovation projects

4. Data and 3D model eases the city planners to concentrate on the most beneficial areas in energy renovation efforts when all the data can be processed simultaneously

In previous EU-funded projects the Helsinki Region Environmental Authority HSY has produced the following datasets including all buildings in Helsinki:

1) Solar power potential: solar irradiation on the roofs, suitable locations for PV installations and estimated yearly electricity yield

2) Roof heat loss thermal map

3) Green roofs: existing (built and spontaneous) and potential

These datasets listed above are freely available through HSY open data interface and utilised by other models. The services are provided on Web Feature Service API (WFS), making them compliant with other city model initiatives, although being modelled on 2D.

As a follow-up the tools developed in mySMARTLife are the comprehensive building heat loss visualisation tool "Kattohukka" which was launched in April 2018 and the Region Climate Atlas that will be launched later in 2018. Kattohukka is an easy-to-use web-based map service that visualises thermal losses from the buildings in Helsinki. The heat loss map is a completely open data interface which features a thermography map acquired on a clear, cold winter night. The map represents the surface thermal radiation measured from each roof using a thermal imaging camera.

In Kattohukka, the user answers questions about the shape and material of the roof and whether the space directly below the roof is heated. The tool then presents a legend explaining the colours in terms of roof insulation quality. The service can be used by property owners as well as companies when planning renovations. The service also includes information on building heat losses and tips how to improve energy efficiency.

The Regional Climate Atlas data covers the Helsinki Region cities (Helsinki, Espoo, Vantaa and Kauniainen) and it is equally all open data also available via API for further use. The service features building-level energy data such as modelled energy consumption, yearly solar power potential and green roof potential. It also features basic building information such as fuel used in heating, number of floors, floor area, volume, and building purpose of use. There are several search criteria for the buildings but data can also be retrieved by clicking on the map and downloading the selected buildings information. Particular building detail can also be filled in as added information such as measured energy consumption, data on solar panels or air source heat pump installation or planned renovations.

C. *Digital Twin*

While the data catalog datasets provide data from the past and the IoT sensors from the present, the future outlook is provided with a concept called digital twin. The term refers to a digital replica of physical assets. In the smart city context, the digital twin can be of a specific block or district. It is created in order to support co-creation and test scenarios with city parameters, as an example what would be the impact on noise levels and air quality if speed limit would be lowered on a street or how the people flows would work on different setups. The digital twin requires a large amount of observations that interact, in order to define the causality and mathematical model. Since the amount of data can be large and relationships unknown, machine learning algorithms can be useful when creating simulation models.

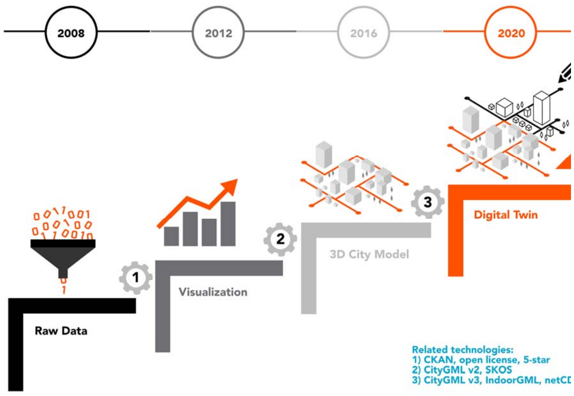

Figure 3: Data Requirements

Figure 3 illustrates the increased requirements for data and data quality the more advanced the services and 3D model is. The release of open datasets in 2008-2009 soon resulted with the first visualization applications being released. As an example, the expense data of the city was visualized as a live diagram. At this point, the requirements for the data were not that hard since visualizations were based on a single or few datasets that were manipulated by hand in order to fulfill the task.

The 3D models increased the requirements for the data. A simple model was constructed of several datasets that still required plenty of manual work, the data being inconsistent and missing some values, including key fields that broke the relations with other data sources. Because of this, the release of the first 3D model was resource intensive, resources being consumed on cleansing and preparing the data.

D. *Energy and Climate Atlas*

The modularity of the CityGML model was utilized in the first application created on top of that, the Energy and Climate Atlas. The data generated as part of the mySMARTLife Helsinki is being visualized and processed into spatial data in building level using the thematic extension options for the CityGML model. The open data services complement each other and the HSY visual tools can be utilized and they work side by side with the 3D city model.

The 3D Map and its Energy and Climate Atlas services are linked to REMA calculation model developed by VTT. The REMA tool was created for information management and for evaluating the impacts of repairs to be made to individual buildings and the building stock as whole.

The model will help to analyse a variety of technological scenarios, evaluating factors such as the technological potential for reducing carbon dioxide emissions from the building stock. The tool has also been used to outline cost impact scenarios for the most effective measures.

The REMA model uses as inputs the energetic properties of each building type and sub-type in Figure 2. For existing buildings, the combined living area of the type is included and a linear annual decrease in that area over time due to demolitions or abandonment. For new buildings, a linear increase in the amount of each particular building type is assumed over time until it is replaced with a newer building type. In this case, REMA is used to provide a reference level of energy efficiency for buildings of various type and age that can then be visualized in a map view. REMA is also used to produce forecasts of energy savings in the building stock with energy improvements included in renovations. [8].

E. *City as a Platform*

The socio-economical function of the digital platform is important to include in development projects. The technical core of the platform is surrounded with synchronous collaboration, coordinated work practices and institutional and cultural framework. Co-creation together with various stakeholders will generate new opportunities and service concepts. The platform and the city model will also be part of the city functions.

The first services such as the Energy Atlas were developed with the motivation of being part of the city's energy renaissance program, aiming at changing the behavior of the citizens in order to reduce carbon footprint and primary energy consumption. The visual model can be a useful tool to pinpoint buildings that would require retrofitting, motivating their owners to begin with action.

F. *Open Data*

A key function of the Urban Platform is the sharing of data. A key to a successful open data service is in the creation of a citywide culture of *data being open as a method*. Open data refers to information that has been made available for free for anyone to use.

Several aspects can define the level of openness. The data is expected to be technically accessible, free to access, have license that permits reusing, be findable and be understandable. It should be noted that the use of data can also be restricted unintentionally. Dataset has been published in good faith but the data in it is not understood without knowing the context. The goal is that all the data is self-explanatory and doesn't require any additional metadata addition at the publishing stage.

In order to provide a method to categorize published data, Tim Berners-Lee has suggested a 5-star deployment scheme for open data. The following diagram illustrates the method:

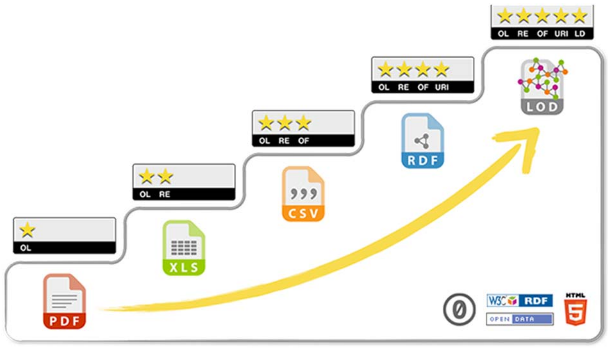

Figure 4: 5-Star Scheme

The first star is achieved when the data is made available online under an open license. The next star requires, that the data is in structured format, as an example as an Excel file. Three stars will require that the data file is non-proprietary, e.g. using CSV instead of Excel. Four stars introduce elements of linked data, using URI's as external references. Finally, a 5-star assessment is given to data that is linked with other data to provide deeper context.

G. *IoT on Urban Platform*

The Smart City is about creating, sharing and presenting data. Useful data services will depend on actual data, even presented in real time. In order to accomplish that, the smart city platforms are supported with a layer to manage incoming data feeds. The data feeds will be based on sensors or gateway products that would as an example send selected data points from building automation system into open data platform. It is essential that the smart city platform will utilize all the available sensors of building automation systems and not build overlapping sensor networks.

In the smart city context, the majority of information is linked to a location. The information is about a location or referencing to one. This will have an effect on the requirements of urban platform components. It is expected, that any data is associated with a location, therefore the sensors and automation API's should be capable of associating a location with the data. Also, since the urban platform server a number of service domains, the data models are expected to be generic, not use case specific. This will cause a requirement of utilizing linked data and hierarchical ontology-based reference libraries instead of fixed schemas.

The Open Geospatial Consortium has been working on the data models of observations and measurements for long and they also have introduced a comprehensive API for sensor connectivity under the name of SensorThings API. The following diagram illustrates they key features of SensorThings:

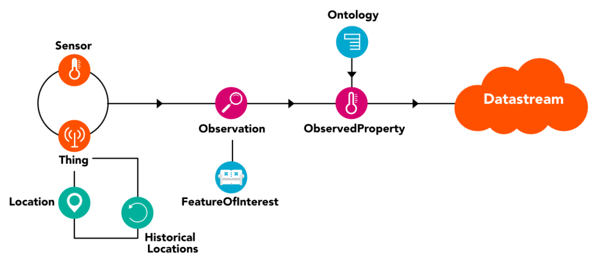

Figure 5: SensorThings Data Model

The sensor device is split into two logical parts: the thing that connects to network and the sensor(s) that make the observations. In many cases the thing is the enclosure and backplane that supports the sensors. The thing has a location property and if it has changed place, it also has historical locations.

The observations made by the sensors are stored as an ObservedProperty. Its definition is retrieved from a reference server in JSON-LD format. In Helsinki, most of the definitions will be managed in a hierarchical ontology, maintained in SKOSMOS -server. The server has been developed as a joint effort between the Finnish National Library and Aalto University. The SKOSMOS -server implements the SPARQL -query mechanism and SKOS -protocol, which is a W3C standard. The top-level ontology for physical observations will be based on ISO 80000 (the SI System) and extended with some domain -specific derived units and indicators [9]. The key benefit of ontology-approach compared to domain specific schema the generality of it: The urban platform will cover hundreds of use cases and by nature it is multi-domain. The hierarchical ontology also provides a structure that has a logical and consistent placeholder for future additions.

The observation can be given context information as FeatureOfInterest. It is good to notice that the concept of feature here is similar than in CityGML: in SensorThings, a feature is an abstraction of a physical phenomenon. An example of FeatureOfInterest could be the area observed when it is not the same as the location of the Thing. This is useful in the large systems of smart cities. As an example, a public streetlight system may have tens of thousands of lamp posts (=sensor) but only one gateway and API (=thing). In such case, the FeatureOfInterest could be the location of each lamp post or the area a single lamp will illuminate.

The output of the SensorThing objects described earlier is a self-explanatory data stream, that can provide real time data with high semantic interoperability and reliability. Because of the nature of how context information is embedded, SensorThings also makes it easier to create dynamic discovery services in larger scale.

H. GDPR and Privacy

In May 2018, the European General Data Protection Regulation (GDPR) became applicable. It is seen as an important component in building the European Digital Single Market. All member states of the Union harmonized their data privacy laws. The way how the regulation reached its expansive territorial scope of application has been unusual, since the jurisdiction is constructed beyond and regardless of national or EU territory. The impact of the regulation and the national regulations supplementing it has thus been significant [2]. According to the Article 50, the protection of personal data is declared not as an absolute right but in balance with other fundamental rights in order to emphasize the importance of precedence of the law.

While the new privacy laws are strict and the penalties harsh, the impact on data handling and processing can be manageable also on public service data platforms. The key principle in the regulation is that the data is processed lawfully, fairly and in a transparent manner in relation to the data subject. The data is to be collected for specified, explicit and legitimate purposes only. Data is to be minimized, meaning that only data that is adequate, relevant and limited to what is necessary in relation to purposes for which they are processed may be processed.

The definition of personal data under GDPR is “any information relating to an identified or identifiable natural person (‘data subject’); an identifiable person is one who can be identified directly or indirectly, in particular by reference to an identifier such as name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person” [3].

An urban platform with 3D city model may have applications that would process personal data because location data is involved. The platform as a system must then include features to let the data subject to decide what data sources can be published and to which service. A platform that can be trusted on handling data will also support co-creation activities where the citizens are encouraged to share their data for common cause. The more detailed this consent management service is, the less there is a risk that the GDPR would become a liability.

Parallel to the discussion on privacy and proper methods on the implementation of the GDPR -requirements, the Ministry of Transport and Communications of Finland published a white paper on Nordic MyData Model [10]. It presents a framework and principles of a model for a human-centric approach to the managing and processing of personal information. The GDPR and MyData ultimately reach out for the same goals: transparency and ownership of the personal data.

The MyData Model focuses on three main principles:

- *Human centric control and privacy*
- *Usable data*
- *Open business environment*

The MyData model supports the smart city approach of collecting data for the citizens and not of them. The citizens are treated as empowered actors and co-creation partners, not as passive targets. The smart city should not be seen as a top-down organization and this approach should be a core principle on urban data platforms. The platforms are expected to provide an easy access and use of data to catalyst new data-driven services that will help the citizens to manage their lives.

As a business environment, the MyData -focused data platform is decentralized, has a high level of interoperability and make it easier for the companies to comply with regulations such as the GDPR.

III. RESULTS

The Energy and Climate Atlas as part of the Helsinki 3D city model was launched in February 2018 through mySMARTLife project. It contains extensive real and calculated data on buildings for example completed energy-efficiency upgrades, energy performance classifications, and the energy sources used for heating and shows the estimated energy consumption of buildings were calculated by the Technical Research Centre of Finland VTT.

The service has generated a lot of interest within the city and in professional media. When real and simulated data was combined, the first release model was already able to provide a complete view on the buildings in the city. In the future, a larger number of the buildings will have an API to provide real-time data, replacing simulations with real measurements. This process has been intensified by the lot assignment stipulations in the Kalasatama district that have set the requirement of the buildings to be equipped with an API with a defined set of attributes to monitor. The protocol requirement for the energy data is the CIM -protocol for energy management (IEC 61850). It is mainly used in smart grids but because of that it contains all the necessary elements for automatic meter reading. In case of Kalasatama, the electrical energy consumption is metered on nine consumption types and the CIM –based interface will then include submeters as addition to the smart meter. The same protocol enables the building system to take part on demand management market directly or through an aggregation service. Other types of remote controls of specific equipment are also available, although not implemented.

The development on the 3D city model is running on two parallel paths: visual details and textures are getting more detailed and the model is connected to new data sources, the outcome being more detailed both visually and semantically. The developments of the semantic properties also include the utilization of application domain extension (ADE) –concepts, that can extend the core data model and introduce new objects and attributes into the model. As an example, the current Energy ADE extension defines the buildings energy related characteristics using the following new objects: Occupant Behaviour, Material and Construction, Energy Systems and Building Physics.

The next step of the development is labelled as Digital Twin and it focuses onto area of Kalasatama District. Some video samples of the next version of the reality mesh model have been published on YouTube: https://fvh.io/digitaltwin

The following picture is a screen capture of the video linked above, illustrating the 3D+ -model visualizing both built and planned environment. The model can also be used to illustrate the upcoming plans and to co-create new city functions together with the citizens.

Figure 6: Kalasatama Digital Twin

New co-creation activities on top of the city model are currently being planned with Agency9, a company that has created the CityPlanner -product. The product visualizes the plans and built models in user friendly way, allowing moving in the model, measuring areas and changing attributes like lighting to provide an understanding of the plan in different conditions.

The CityPlanner product has been used in various co-development activities. It can be used to collect feedback for features of interest but also to have dialogue with citizens on the different options and versions. In Denmark, the tool was used to arrange architectural design contest for the new museum Jorn og Søtorv. All submissions were published as 3D models. Citizens were able to compare the designs by their design, impact on the city skyline and the shadow effect. It is expected that soon such models could be provided in IFC -format which for the architect would cause very little extra effort, since the IFC can be exported from the design from almost any CAD -program available. It is also expected that the IFC file format would be used in the building permit process, thus making it possible to enhance the 3D model as part of the process.

To improve the semantic interoperability, both SensorThings and CityGML rely on linked data instead of static data models. The observations and objects are described by referencing the attributes from external sources. In the smart city context, relying on use case specific domains is a limitation since data is to be shared across domains as well. The approach taken in mySMARTLife was to look for a common nominator for all the sensor data, which are mostly about observations of physical phenomena. It was assumed, that a good starting point for such data model would be the ISO 80000, the SI system.

Unfortunately, standards sometimes have restrictions and after long communication with the standardization organization it became evident that the contents of ISO 80000 could not be used in publicly available server. As an example, it may have been possible to provide browsing access to the contents but file downloads would not be allowed. In order to link the data stream with JSON-LD such download process would be mandatory and preventing it would render the service useless. To solve the copyright issue, the UCUM -project was used as a source instead. It maintains a copy of ISO 80000 standard but with a more open license.

Currently the Finnish National Library is working on converting the UCUM -definitions into a SKOS -ontology. It is expected, that the service would be part of the Finnish Finto national ontology. The expertise of the experienced ontologists from the Finnish National Library is expected to be needed in the future projects as well when the supporting ontology is to contain more derived units and taxonomies. It will also be studied then how mathematical functions could be provided as part of the data flow, likely using the MathML format. An example of UCUM -based controlled vocabulary to define the term 'hertz' can be seen at https://fvh.io/skosexample

When planning for the first sensor data collection services, the documentation of the SensorThings API seemed complete. Later when planning for the first professional grade sensor pilot, new requirements were identified to manage the sensor calibration information and other sensor metadata, e.g. accuracy, noise levels and thresholds. As far as we know, there is currently not a widely accepted standard that could be used as a basis for data model or schema design for such information. There is an ongoing standardization effort that should provide some useful information. Since the information is to be linked with the observation data stream as JSON-LD structure, it is expected that the initial model could later on be replaced when the standardization process proceeds.

Some of the new live data sources may fall in the category of personal data. To make the data usage compliant with the GDPR -regulation, a privacy proxy was created for the SensorThings server, allowing to link together the data stream and the owner of data. These are prerequisites for dynamic consent management according to the regulation. The owner of the data thus has the opportunity to give and revoke consent from a service using the data. Such services can also provide data storage function, as an example a MyData Wallet as a service. The approach of linking data stream with the authority has already raised interest from other projects and service developers and it is likely to be implemented as part of another project by the end of 2018.

IV. CONCLUSION

The mySMARTLife has been a good initiative to improve the city of Helsinki capabilities on urban platform and 3D model development. The practical interventions and detailed indicators to measure success have been directing the city as a platform -approach into a good direction, enhancing the role of data on both the management of the city and co-creation with the citizens.

Focusing on open standards has helped the project to make more general systems and to utilize the effort on another projects. The easy access to standardization organization has helped to implement the standards in a consistent way.

Work on the 3D data model has quickly evolved into semantic data models, turning a visual tool into a data platform and providing a logical placeholder for any type of data related to smart city.

The Energy Atlas and Kattohukka -services have provided a useful example and case study on applications that can run on top of spatial city model, extended with information from legacy systems such as the building permit database. It is expected that these systems will have a significant role when educating the citizens on understanding the needs and benefits on the renovation of their apartment buildings.

Linking the sensor data with city model is seen as a basis of digital twin, collecting open data with high semantic interoperability into one place. The platform forms an ecosystem for the analytics companies to build their services onto.

With citizen-centric approach and by providing the tools and means to manage personal data streams, the privacy issues have been tackled, thus making it easier to manage the services on GDPR -compliant way. The GDPR has helped to root the MyData concept of personal data ownership as part of the privacy expectations.

The CityGML data model, being part of the larger OGC family of standard data models, is the cornerstone of the smart city data modeling. It is expected that some simple legacy IT systems can soon be merged into the data platform. The GML family also contains ready data models for defining other infrastructure and civil engineering activities. Merged together with the asset management extension, the data model can evolve into an operational system for various uses.

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