City of Things: An Open Smart City Vision and Architecture

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ABSTRACT

For a long time, cities were surrounded by big walls and gates for controlled access and protection. These days, cities are expanding quickly and are becoming heavily integrated into their surrounding region, country and even within the world. This de-fencing results in more dense cities where numerous challenges arise in the fields of mobility, safety, livability, sustainability and environment. Technology can assist in addressing the issues. Developments like the Internet of Things (IoT) and artificial intelligence (AI) enable us to make cities smarter. However, as with all new technological revolutions, the challenge is to make sure these are used for their primary goal, i.e. increasing the "urban wellness" of the citizens. In that context, we plead for an open smart city: a city which excels in its smartness by tearing down the walls and gates between the different silos of technology, data, processes and organizations. The open city offers a flexible framework for citizens, companies, research entities and governments to contribute within their domain and expertise to a smart city that can keep pace with the needs of its citizens in a rapidly changing world.

INTRODUCTION

The purpose of this paper is to give an introduction into the current imec City of Things (CoT) vision on an open smart city and its architecture. There is still a lot to explore in the CoT program in the next years and future work will be disseminated during the way. As such this paper serves as inspiration for the reader, is an open invitation for cooperation and feedback, and a snapshot in time in the search for delivering success in the smart city domain.

The primary meaning of "open" is to not close the eyes to what is happening around us in the context of smart cities and smart technology. This paper refers to some findings learned during the first half of the City of Things program, that make much sense as candidates for adoption in Flanders (and beyond) as a smart region. As you can see in the many references we point to, we have worked in close collaboration with CoT partners in our projects and beyond to bias our findings.

The paper starts with some definitions of Open Smart Cities that are ready for a data-centric approach, where data sharing is seen as the pivotal enabler. Turning lots of (big) data into usable information and knowledge that can be interpreted by machines is where smart data comes in.

After having touched the fundaments of a data-centric open city, this paper then introduces the Open City platform concept, listing the major challenges to overcome and some pointers to methods that can assist in addressing these. We present some viewpoints on the open city architecture and how data and applications find their place within.

To conclude, we mention some of the long-term promises of an open smart city and future work to be done.

DEFINITIONS

We like the staged definition of an open smart city delivered by the OpenNorth program [1]:

*A **city** is a complex and dynamic socio-biological-physical system. It is a territorially bound human settlement governed by public city officials who manage the grey (i.e., built form), blue (i.e., water) and green (i.e., land) environment and the people they serve as per their legal and jurisdictional responsibilities.*

***Smart Cities** in the common sense of the term and as per their current manifestations are "[technologically] instrumented and networked [cities], [with] systems [that are] interlinked and integrated, and [where] vast troves of big urban data are being generated [by sensors] and used to manage and control urban life in real-time". Public administrators and elected officials invest in smart city technologies and data analytical systems to inform how to innovatively, economically, efficiently and objectively run and manage the cities they govern. Predominantly, a smart city is about quantifying and managing infrastructure, mobility, business and online government services and a focus oriented toward technological solutionism.*

*An **Open Smart City** is where residents, civil society, academics, and the private sector collaborate with public officials to mobilize data and technologies when warranted in an ethical, accountable and transparent way to govern the city as a fair, viable and livable commons and balance economic development, social progress and environmental responsibility.*

A DATA-CENTRIC CITY

Datafication[20] of the city as a new (r)evolution is an analogy with its "electrification" counterpart from the past. Data is the new enabler, just like electricity has changed our lives forever. In literature, it is sometimes compared to "the new oil" [26]. However, this comparison may not be the right one for data within open smart cities. Of course, data is fuel for the algorithmic economy[44] and its applications. Algorithms,

defined as procedures or formulae for solving problems using data, become a key part of our lives.
Data makes it possible to use (amongst others) past trends to predict the future and check in real-time what is happening now, thereby continuously calibrating the model used for prediction. Data is much more complicated to work with and unleash its potential than oil and moreover is an "infinite" resource, which oil is clearly not. This makes the economic value of data also much more difficult to grasp.

Sharing data should make both the data producer or owner and the data consumer "richer". From an ideological point, data sharing could be compared to love. Love cannot just be "exchanged"; its full power is unleashed when it is shared. Of course, sharing data needs to be controlled as there are lots of pitfalls and hurdles to manage. Privacy, trust and "fear-inspired" (avoid sharing as it could cause damage) economic protection are some of the main challenges to overcome. However, the power of sharing within smart cities is much stronger than the trivial silo-based and fenced data handling approach and serves the main user (the citizen) much better. Applications can deliver more value to the citizen when they have easy access to different sources of data, e.g. for multi-modal mobility optimizations and combining environmental and traffic data into healthiest traffic routes.

Some examples from the algorithmic economy clearly illustrate the sharing power of data and some of the associated complexity. At this moment, your personal human genome can be analyzed for around 1000 euro [27], and this price is dropping rapidly. However, the result can be considered raw and essentially meaningless data. We need smart data that can deliver you information that leads to knowledge about possible genetic diseases, abilities, ... Sharing DNA sequences of many people is the only fast way to decode the embedded information into usable knowledge using Artificial Intelligence (AI) techniques. Of course, privacy is a crucial matter, as "your DNA knowledge can be used against you". But if we all keep the information to ourselves, progress for everybody will probably slow down a lot and we will keep on getting stuck with a limited view.

Smart solutions can accelerate the sharing of data. For example, a technique like privacy-preserving federated machine learning [5] enriches the knowledge of pharmaceutical organizations by smartly sharing each other's information of drug impact & efficiency on cell level, without compromising the Intellectual Property and business secrets of each party. This leads to better and more effective medicine for the patient, where the mapping of the drug to the patient and the attached risks are much more controlled. This approach is an example of how machine learning can make it possible to use data sources efficiently together, combining value for the patient within an economic context.

We illustrate this with city parking data. Enclosing off-street and on-street data within closed vertical applications and Application Programming Interfaces (APIs) is suboptimal. It can lead to some roadside signs indicating parking occupation but does not empower the real value of sharing all the parking data sources uniformly. Doing so and combining these with other (real-time) data mobility sources, would pave the way to multi-modal mobility. Moreover, parking spaces will transform into e-fueling stations, autonomous car vehicle bays, bicycle and e-step parking spaces, ... For such use cases, the sharing of data will be the key to success for flexible pricing models and efficient mobility applications, where real-time parking lot reservation becomes a key feature.

The examples above illustrate that sharing data is the real trigger for innovation, but that it is not a straightforward activity and needs to be stimulated & governed to maximize the potential of getting data out of its silos. As in the above DNA example, data sharing serves the patient. In cities, data sharing serves the citizen.

FROM BIG DATA TO SMART DATA

Big data is commonly described as using the four Vs[45] : variety, volume, velocity, veracity. Smart data is adding a fifth V: value. Collecting raw data from IoT and ICT silos within the city only yields basic knowledge. This raw data collection is just scratching the surface of the city data potential. We need less unstructured but more actionable data.

Smart data reduces the volume and augments the veracity [28]. As illustrated in figure 1, raw data should lead eventually to actionable intelligence, passing the stages of transforming this raw data into information and knowledge.

In the world of alert monitoring and operations, alert fatigue [29] is a huge issue. In smart cities, the complexity and isolation of big data at lots of different places can lead to **data fatigue** [30], putting at risk the very investments that were made obtaining the data.

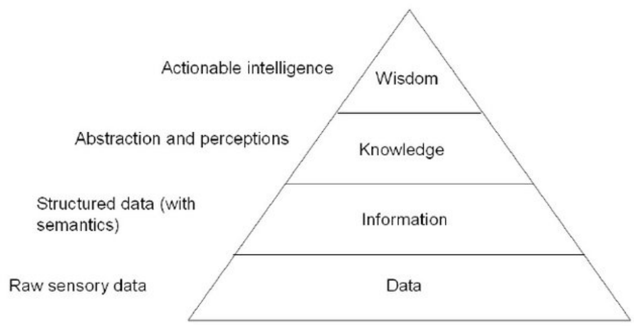

Fig. 1. *The data-information-knowledge-wisdom (DIKW) hierarchy (Rowley, 2007)* [39]

AN OPEN CITY PLATFORM

To realize an open city, an "Open Urban Platform" is needed. The European Innovation Platform (Smart Cities) and Communities (EIP-SCC/ESPRESSO) [2] defines an Urban Platform as:

- an implementation of a logical architecture or design that aggregates all data from city systems,
- that uses modern technologies (IoT/sensors, cloud, mobile, analytics, social media, ...),

- and provides building blocks which can be used by cities to rapidly evolve from fragmented services to more efficient and new services and interaction with the citizens,
- to change the city in a measurable way on local level.

In short, the Netherlands Standardization Institute (NEN) [3] defines this as a set of policy agreements, (inter)national legislation, standards and their technical implementation under the governance & control of the (local) government in cooperation with public and private partners (citizens, companies, researchers) to **rapidly and continuously** deliver data- and information-driven services in the city.

SOME MAJOR OPEN CITY CHALLENGES

An open smart city creates a diverse range of challenges. One of the biggest is unlocking the real value of the data that is present in its silos in different formats and quality.

Effective sharing of data does not happen out of the blue. It needs a process from the early stages of every project. This process has recently been termed as **DataOps** [32].

DataOps *is a collaborative data management practice focused on improving the communication, integration and automation of data flows between data managers and consumers across an organization. Much like DevOps, DataOps is not a rigid dogma, but a principles-based practice influencing how data can be provided and updated to meet the need of the organization's data consumers.*

The goal of DataOps is to create predictable delivery and change management of data, data models and related artifacts. It uses technology to automate data delivery with the appropriate levels of security, quality and metadata to improve the use and value of data in a dynamic environment.

Open cities need explicit data governance, where a horizontal organized smart city coordination layer can install DataOps processes in all of its vertical layers to make sure that big data can become smart data. However, DataOps is still in its infancy stage, as illustrated in the Gartner Hype Cycle for Data management curve (2018) listed in figure 2. As such, it should be one of the main points of attention for a successful smart city data governance and coordination.

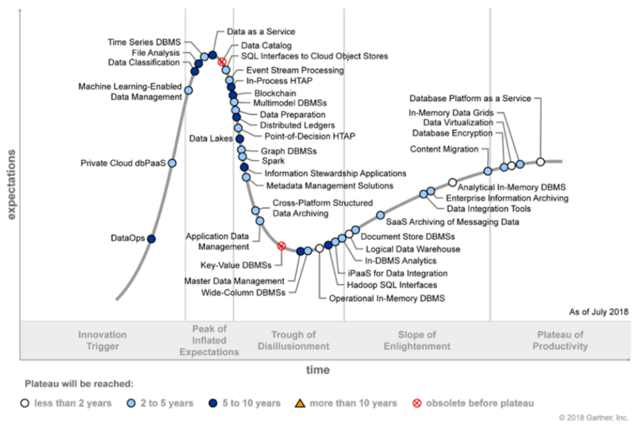

Fig.2. Gartner Hype Cycle for Data Management (Gartner, 2018)

Another big challenge is the **absence of easily accessible data brokers and data marketplaces**. These make it possible to offer data discovery, control and transfer methods, keeping data producers and consumers in full control. Figure 3 illustrates that data and API marketplaces for digital government are still in their innovation trigger phase. This makes it not straightforward for smart city executives to pick them off-the-shelf and make sure that they are open city compliant and ready for **future-proof data gravity** [33] principles.

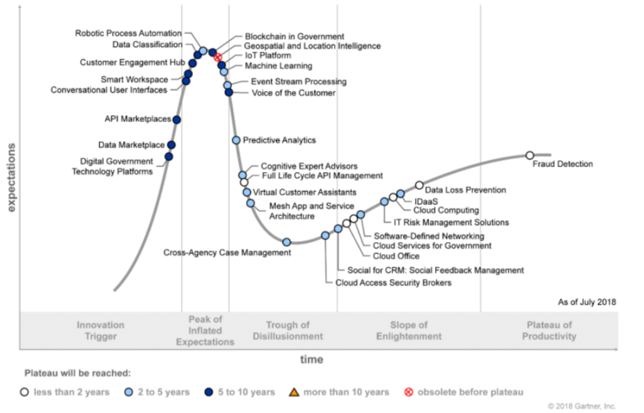

Fig.3. Gartner Hype Cycle for digital government (Gartner, 2018)

And finally, the challenge of interoperability (IOP) is huge in an open smart city. The European Commission defines IOP as the ability of organizations to share information and knowledge, through the business processes they support, by exchanging data between their ICT systems [40]. Different levels of interoperability need to be addressed:

- **Legal**: how can digital-friendly and agile legislation keep up with and stay aligned with the ever-increasing rhythm of change in the smart city. How can data licenses be used to promote maximum reuse? Privacy is an excellent example of this complexity. Again, we can compare to the DNA-decoding of the human genome, and all the usage concerns, which evolve so rapidly that legal evolutions cannot even predict the next use cases.
- **Organizational**: how can the processes between the different city departments and with their stakeholders (intra/extra muros) boost the promises of an open city? Business processes and their data sharing needs must be aligned and documented between different actors in the ecosystem. For example, Smart Flanders has setup a concrete way of organizing the sharing of open data with its open data charter [41].
- **Semantic**: How do we speak the same data-language? How to make sure that information can easily be used by lots of different parties by providing a unified meaning and structure? A nice reference from AIOTI[47] WG03 on semantic interoperability for the Web Of Things (and its vlaue) can be found in [49].
- **Technological**: how to link brown- and greenfield technology in such a way that they can solve the real

challenges of the open smart city? How should the APIs be designed in order to decouple the clients from different services and achieve seamless interoperability, where clients can discover the server's capabilities?

SOME INNOVATIVE WAYS TO ADDRESS THESE CHALLENGES

Creating an open city is only possible by applying a vision in the following domains:

1. **Open Governance**: Smart City projects and initiatives need to be governed socially and technically to make sure that the open urban platform embeds ethical, accountable and transparent data collection, infrastructure, algorithms and processes. In an open smart city, all actors of the quadruple helix [34] are included and the intent is to go for an inclusive, informative and collaborative "city-style". Finding the right and effective scale (city, regional, nation-wide, city-wide, ...) of governance is crucial in delivering the success of the open city.
2. **Open Technology & Standards:** Technology changes rapidly, and an open architecture needs to stimulate standardization at the connection surfaces between communication, interworking and data components. Open source code, open standards, open interfaces and an open supplier ecosystem are catalysts within this vision.
3. **Open 'Data Management':** Digital sovereignty is the ability of a natural or legal person to exclusively and sovereignly decide about the usage of data as an economic asset. Data sovereignty is a key concept to consider. It is about finding a balance between the need for protecting one's data and the need for sharing one's data with others. Create data management processes (DataOps) and stimulate data ownership methods to let the citizens retain control of their personal data (e.g. using principles like Solid [6]). Make sure that companies realize that data sovereignty is a crucial capability to develop in order to be successful in the data economy.
4. **'Open Data' Management.** Public data within the city is owned by the city. Making it publicly available and easy retrievable is necessary to make it reusable. Refer to the Smart Flanders [11] program on how this is handled within the Flanders region and to the European vision on high-value datasets within the Public Sector Information (PSI) directive [35]. Of course, these open data sets contribute highly to the goal of increasing the data gravity in an open smart city.

Not all cities and communities are organized to cover the four domains completely. To realize this vision, cities should define their strategy on how they want to impact the Open Urban Platform. They can choose to

1. Just set out some guidelines.
2. Facilitate the (technical) sharing of data.
3. Participate in the development within the ecosystem of platforms and applications.
4. Deliver connectivity, networks, data platforms and applications themselves.

Cities differ in size and technical support and will probably need to combine forces with other cities and with government to benefit from the economies of scale and ability to deploy IOP rules that form the base for data sharing and realization of the open smart city. Avoiding vertical silos and creating well-defined tenders in the market to do so can be a complex, costly and timely activity when not handled at the right scale.

One of the key components to install at the heart of these four domains, is a **City (or Urban) Data Exchange Marketplace (CDEM),** implemented and used at the right scale as described above. CDEM is the combination of a data broker with data retrieval facilities and a marketplace for data. It is advised to realize this with **standardized data connectors** (using, for example, the connectors and reference architecture defined by IDSA[4]) to the city brokers and IoT stacks. This CDEM will offer features like data discovery, API management, authentication, billing and contracting, documentation, identification and community management, policing, data quality and statistics, logging, ...

Figure 4 illustrates the McKinsey assessment of data marketplaces, which are still in their early stage. Making open cities connected, is one of the main challenges to overcome, knowing that e.g. some mobility and environmental issues do not stop at the borders of the city.

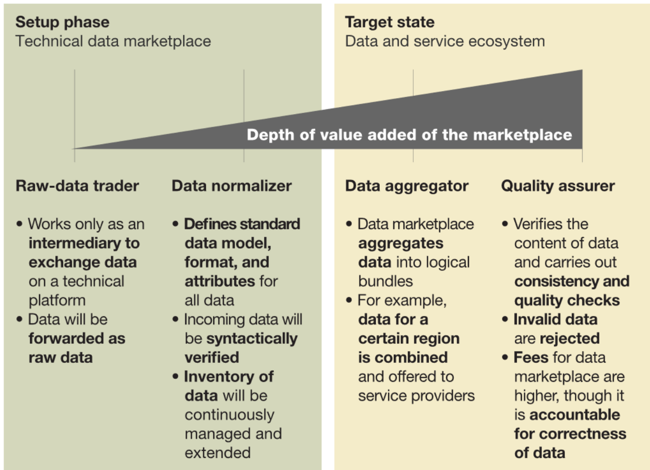

Fig.4. *McKinsey & Company : Creating a successful Internet of Things data marketplace* [42]

Setting up a raw data trader is the first step. It can be done by simply connecting the city IoT stacks to an API gateway. To make sure that applications can collect data independent of the specifics of the underlying IoT stacks, normalization of the data is needed. This also enables straightforward inventories to assist data listing and discovery. For example, if the IoT stacks send data in a standardized format to the data broker, broker agents cannot only immediately understand the data, but they could also auto-enumerate devices in the city by probing for the specific names within the city regions.

However, data marketplaces are still mostly in "setup phase". Cities mostly just have (a) data lake(s) [46], which makes it very difficult to scale. The real target should be to offer smart data in logical bundles for example based on the city location tiles and eventually to assure the quality of the data delivered.

Note that the IDSA reference architecture forms the foundation of an open, distributed marketplace ensuring data sovereignty for the creator of the data, proven data-provenance for the user of the data, audit-proof on request and based on European values [36].

AN OPEN SMART CITY ARCHITECTURAL AND PLATFORM VIEW

The minimum mechanism to create a connected city is **the machine-readable API** (as a result of an API-first strategy)**.** To realize this, some rules must be considered. A RESTful API with Swagger [37] documentation is a good start, for example. Of course, getting the link to these APIs is not always straightforward, as they open a communication channel to a controlled resource and thus are subject to economical and security issues. To tackle this, API gateways offer a good way to control the access and are a very useful tool to start sharing the knowledge, while remaining in control of the economics and security aspects. Example API features include authentication, call rate control, call logging, …

More advanced environments can also regulate API components and their behavior. The clients know what to expect for a result when they make calls to an API. Since operations and data contracts can be discovered, users of smart data can evolve independently from the API services themselves.

When API usage is heavily subjected to economic drivers, API gateways can evolve into **API marketplaces.** These focus on extra features to include monetization based on API usage. Flexible and dynamic monetization models can drive correct usage of APIs and control the technical complexity to build and maintain scalable infrastructure.

There are **push/pull** APIs where the consumer needs to get the data on his initiative, typically with HTTP APIs. Querying data can be done with GRAPHQL, SPARQL, SQL or other standard query languages.

However, for real-time city data, **pub/sub** APIs enable data to be pushed to the consumer automatically, and at the negotiated pace. In low-level IOT applications, Message Queuing Telemetry Transport (MQTT) is a de facto choice, but in general application space, Hypertext Transfer Protocol (HTTP) and Advanced Message Queuing Protocol (AMQP) could be the best candidates. Other solutions can be Web-Sockets and Server Sent Events.

From a high-level view, an open city (of things) infrastructure can be sketched in figure 5. A platform delivers application enablement, data aggregation/storage and compute and connectivity to sensors.

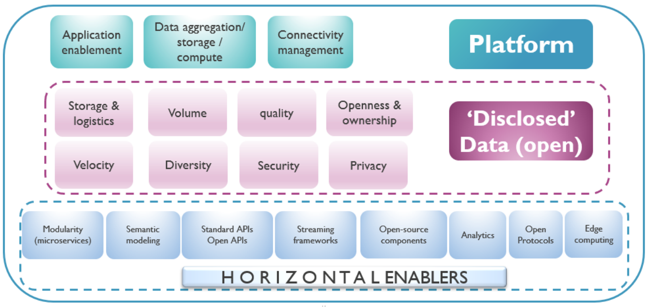

Fig.5. *exploring horizontal enablers in an open city platform*

In an open city, Data is the "Killer App" and its value is subject to Metcalfe's Law [21]. To optimize its value, the data produced by its sensor network needs to be fully disclosed. To be able to control the data ecosystem, the data parameters in figure 5 are of crucial importance and addressed in the following six data attribute groups.

1. **Data storage & logistics**. Big data needs to be stored before it can become smart data. Data can be stored at different places (cloud, on-prem, regional, @ the edge, …) and needs to move around. Cold and hot storage functions need to be clearly managed to control the financial cost of storing the Yesterday-Today-Tomorrow (YTT) data for the right application access.
2. **Volume.** Lots of data can be generated in a smart city. Controlling the volume (e.g. by interpretation and aggregation at the edge) and future scalability are essential.
3. **Quality & Integrity.** One of the biggest challenges is managing (i.e. also publishing) the quality of the different data sources. Data integrity is the maintenance and assurance of the accuracy and consistency of data over its entire lifecycle. In the end, the platform needs to produce valid information that leads to trustworthy knowledge even in the presence of possibly inaccurate sensing devices and complex data enrichment functions using machine learning techniques.
4. **Openness & Ownership.** To make data sharing a real success in an open city, data producers need to have the means (if they want) to still own their data. They need to be able to allow selective access, to retract their data from the server, to publish their data as full (linked) open data, … Data sovereignty is also used in this context.
5. **Security and Privacy.** Privacy rules should be embedded in any data gathering and publishing system. Setting up secure storage & access to the data is not to be forgotten.
6. **Velocity & Diversity.** Smart City applications differ profoundly in time and format. There are current-time sensors and actuators (such as intelligent traffic lights) but also applications that update their clients every hour, day, or ad-hoc with acceptable time delays. Mapping all of this to the right technology to be used is a real challenge.

The mere consideration of each of these parameters often is beyond the state of the art in most existing (IoT) stacks. This is a major obstacle in terms of accessibility.

Bridging the gap of smart city solutions to open smart city solutions needs components that address the horizontal enablement. Some of them are listed in figure 5, but the list is not exhaustive. **Semantic modeling** is very important to share domain data from different producers. **Edge computing** can address many of the problems mentioned above (such as privacy matters, addressing data volume concerns...) and simplify the complexity of the platform. **Open and standard APIs** promote quick adoption of other components to link with existing ones. The use of open source (under the hood or full applications) can bring trust and transparency. And of course, **AI components** (at the right places) prevent data-fatigue and turn big data into smart data.

A typical open city IoT platform (in our current vision), is built of a set of minimum components as illustrated in figure 6.

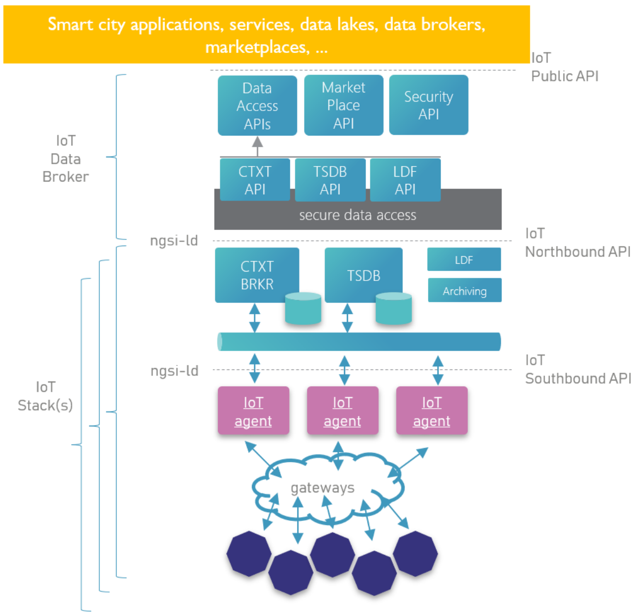

***Fig.6.** A simple view on the basic building blocks of an open smart city IoT platform*

The IoT stack contains some minimal blocks. These are connectivity components (hardware/software), IoT agents, a context broker and a time-series database to store historical data. To apply this to an open city, it is crucial to set rules and guidelines for the coupling of the different components together, especially for the northbound and southbound coupling surfaces. In the search for scalable data offering, Linked Data Fragments [25] (LDF) is a technique we explore more in-depth.

An IoT data broker is connected to multiple IoT stacks and aggregates their data. A data broker in the context above is a complex ecosystem of functionalities, offering data access facilities and marketplace features in a secure way. It facilitates the access of smart city applications, services and other data brokers/marketplaces to the YT(T) (Yesterday / Today / Tomorrow) data of the smart city, preventing vendor-locked-in access to each IoT stack individually.

Searching for solutions to implement the components, we have been looking at initiatives like Synchronicity [18], Open and Agile Smart Cities (OASC) [17], FIWARE [19], International Data Spaces Association (IDSA), Alliance for IOT Innovation (AIOTI) [47] ... The vision of the OASC - combining already more than 140 cities worldwide - is to create an open smart city market based on the needs of cities and communities. They strive to establish Minimal Interoperability Mechanisms (MIMs) [17] needed to create a smart city market. In practice, these MIMs are a set of common APIs to access data, context information to structure data. Examples can be found in the Synchronicity project.

We are experimenting with FIWARE building blocks to see how the choice for NGSIv2 and NGSI-LD [7] (as candidates for world-wide MIMs) could accelerate the adoption of standardized north- and southbound IOT stack interfaces. The FIWARE Catalogue is a curated framework of open source platform components which can be assembled to accelerate the development of Smart Solutions.

This **Context Broker** [48] has been added to the catalog of the Connecting European Facility (CEF), making NGSI-LD a *de facto* choice for connecting European IoT data contexts in the search for the realization of a European single digital market. FIWARE has set out a communication and information program and keeps aligned with other European initiatives like the IDSA and standardization organizations like ETSI-CIM [24] to make sure that NGSI-LD becomes an anchor in the smart IoT data disclosure landscape.

AN OPEN SMART CITY DATA VIEW

As already stated above, data sharing is a cumbersome task, mostly because of non-technical reasons. The IDSA has listed the major obstacles concerning the extensive sharing of data and tries to address them. Data producers

1. worry about revealing valuable data and business secrets. *Data security* should address this point.
2. fear loss of control of the data. Addressing *sovereignty* should mitigate this concern.
3. are very concerned about inconsistent processes and systems. *Optimizing processes* and cost structures can address this issue.
4. fear that platforms do not reach the critical mass for data exchange to remain interesting. As a solution, larger scale platforms following *standard connectors* (such as IDSA within the reference architecture) are preferred over small and vertical platforms.

An open city data management policy should address these fears to be successful.

In the previous section we already touched briefly upon six groups of important property attributes of data within smart cities. A lot of them require technical excellence when needed for deployment. In what follows, we focus on data formats and meaning: syntax and semantics.

Syntax defines how data is formatted. Two of the most commonly used structured data notations are XML and JSON. Fiware defines the NGSIv2 format for describing context information. ETSI-CIM is standardizing the NGSI-

LD format, which makes it possible to link NGSI data sets to each other and with other (standardized) vocabularies.
NGSI-LD (using JSON-LD[22]) has been created to support the setup of linked data. Linked data increases the power of browsing data (by machines), just like embedded HTTP links have increased the power of the Web. Using linked data can be a key to solve the data discovery problem within smart cities. It supports geo- and temporal queries which are mandatory for effectively using the smart city IoT data. Figure 7 illustrates how adding linking context using predefined URIs can lead to machines interpreting linked data sets and answering complex queries with limited technical effort. We are experimenting with this standard to assess its best place within the city platform, and using its linked properties in the context of a data broker (and in the chain of data discovery and access).

JSON

```
{
"voorkeursNaam": "Agentschap Informatie Vlaanderen",
"alternatieveNaam": "AIV"
}
```

JSON-LD

```
{
"@context": "http://data.vlaanderen.be/context/organisatie.jsonld",
"@id": "http://data.vlaanderen.be/id/organisatie/OVO002949",
"@type": "Organisatie",
"voorkeursNaam": "Agentschap Informatie Vlaanderen",
"alternatieveNaam": "AIV"
}
```

Fig.7. *Code snippet of a JSON-LD object, which adds context to the organization.*

Figure 8 shows a similar example transforming NGSIv2 type data into its linked ETSI-CIM NGSI-LD variant. Remark that the context can refer to any vocabulary.

NGSIv2

```
{
   "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"
   }
}
```

NGSI-LD

```
{
   "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://schema.lab.fiware.org/ld/context",
      "https://uri.etsi.org/ngsi-ld/v1/ngsi-ld-core-context.jsonld"
   ]
}
```

Fig.8. *Code snippets of NGSI-v2 and NGSI-LD for an AirQualityObserved measuring point.*

The **semantics** of data describes the meaning of the information. E.g., for temperature, it is mandatory to know if a value is expressed in degrees Celsius or Fahrenheit. In an open city, the notation and meaning of sensor data should be subjected to rules so that it can be interpreted by machines without the need for manual transformation and to minimize the amount of translating middleware.

The Flemish government runs an IOP program: Open Standards for Linked Organizations (OSLO) [8], which builds upon the principles of the European Interoperability Framework (EIF). The OSLO-program increases awareness on the need for semantic and technical interoperability. OSLO initiates short definition trajectories between domain experts from government, industry and academia to quickly adopt or define semantic agreements. They start from international standards including W3C, ISA and INSPIRE to assess what can be easily adopted or needs to be extended to get linked, machine readable definitions for smart city information. Note that linking data is a key focus for data-driven economy and new business models.

TMFORUM and the FiWare Foundation have recently launched the Front-Runner Smart Cities Program [23] with regular virtual and face-to-face meetings starting in 2019. It has the objective to support the adoption of a reference architecture and compatible common data models that underpin a digital market of interoperable and replicable solutions for smart cities. The common data models will address lots of smart city and urban region domains, and thus could be used as input for OSLO trajectories.

Output of OSLO trajectories are officialized for quick adoption in the Flemish region [9]. Lots of vocabularies already exist [10,16] and new OSLO sessions need to be set up to define more IoT data vocabularies, e.g. for air and water quality. Linked Open Data can be published with more adoption when the OSLO trajectory has produced a result.

When (public) open data is published, it should follow the principles of 5-star [31] open linked data so that it can easily be consumed by other applications.

In summary, a data-centric approach makes its data available in compliance with syntactical and semantic guidelines. Publishing this data is done via HTTP / RESTful based APIs. Scalability issues can be tackled with existing technologies, such as API gateways, or novel approaches such as Linked Data Fragments (LDF). The next step is to set up a data broker. IDSA defines it as a registration point for data endpoints offering lookup functions for data sources in terms of their content, structure quality, actuality and other attributes. Finally, data marketplaces offer mechanisms to trade data between consumers and producers.

AN OPEN SMART CITY APPLICATIONS AND SOLUTIONS VIEW

A city needs smart applications, and combinations of solutions. These applications are preferably built on top of the (reusable) data infrastructure that is offered by the city (or region). This is done by using platform and business APIs that assure reusability of business services and building blocks that use open city grade data APIs. Smart applications can be end applications or (reusable) intermediate agents such as data enriching applications (models, AI components) that turn normalized or raw data into actionable information and knowledge.

Access to smart solutions should also be organized from an open city perspective. And first and foremost, an open city access portal should group and rate actual solutions for specific smart city domains, describing what these problems entail and how they could be solved within open city guidelines. An example mockup has been built in [12]. Then open city marketplaces where solutions are offered, are linked to the city problem domains and are well-described with even user ratings, are really part of the solutions for cities to learn from their neighbors and have quick access to feedback on smart solutions.

These app and solutions stores can also assist in publishing the guidelines for open city platforms and crosschecking solutions to these guidelines. Such a marketplace needs to be governed to make sure that its minimal objective criteria are respected.

In summary, an information access point [12] for cities listing the ever-growing list of smart city domains and solutions like flooding, lighting, environment, mobility, culture, sport, ... should demystify the landscape and reduce the fear of cities to make a deliberate choice for open smart solutions. Linking this information access point and accessible solution descriptions to a solution marketplace that extends this into an economic dimension gives city officials a good entry point into the realization of smart city plans.

SUMMARY OF OPEN CITY PLATFORM ASPECTS

Finally, and for completeness sake, figure 8 summarizes the different heterogeneous aspects that open smart IoT platforms should address.

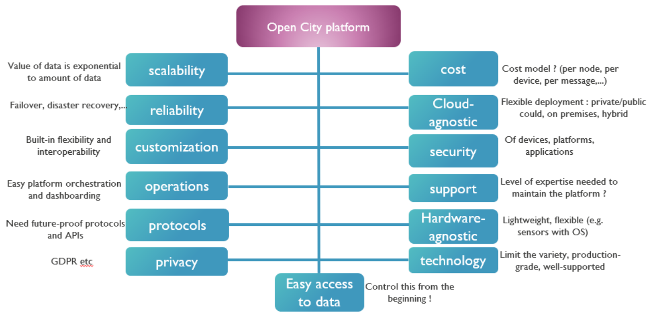

Fig.8. *Major aspects to be considered for an open city platform, with easy access to data as its backbone principle.*

As you can see, lots of parameters need to be considered in the search for a qualitative open city platform. Facilitated and controlled data access forms the backbone of the platform with data discovery, retrieval, injection, monetizing, sovereignty, ...

THE ROAD AHEAD : LONG-TERM PROMISES OF THE OPEN CITY

As described above, an Open Smart City is much more than a combination of city data and I(o)(C)T technology. To solve the complex city problems, a long-term vision on social, economic, political and organizational processes is needed. Cities need to organize themselves to become Open Cities. If they manage to do so, there are lots of opportunities lurking behind the corner that will deliver extra promises.

Cities are in **continuous and rapid motion**. Making cities smart is a complex challenge to keep up with the rhythm of change. A smart city that is built from vertical and fragmented solutions without clear and horizontal governance will quickly fail to deliver the pace that is needed. Open Cities are much more adapted to the pace of change as they embed speed of change into their architectural requirements and fundamental processes.

Setting out a clear data sharing vision ("*data is love*") using user-friendly and accessible data access points (data brokers & data marketplaces) with a balanced regulation of data producers and consumers, will yield a wealth of new applications to deliver value to the citizens. This will induce real **serendipity** in the city, where unplanned and emerging solutions will revolutionize the complex city-life. Citizen science solutions, advanced research solutions and innovative industrial solutions can go together and build solutions using each other's data and intelligence. Their solutions and data can cross-fertilize and deliver rapid and mature new solutions. This should not only lead to a better city for the citizen, but also boost the economical energy of the city.

Open Urban Platforms will also – because of their inherent process and tech nature – explicitly boost the **transparency** within the city. Citizens like to understand the behavior of their smart environment. Unlocking the data, using well-thought vocabularies, documenting the result of DataOps processes, ... will surely help in building transparency engines that explain the complexity of the city to its inhabitants. As becoming smart is a learning process, transparancy can boost the smartness by offering insights in the current smart reactions of the city.

This paper has focused mainly on data management and governance. In a real open city, **data gravity** will unleash the real smart applications. Data gravity as opposed to application gravity, where not the applications attract the data, but "open city compliant" data and data access attracts smart applications of all kinds, realizing complex and emerging citizen use cases at high velocity.

CONCLUSIONS AND FUTURE WORK

This paper summarizes some of the main interoperability principles of an Open Smart City of Things that we are exploring within the CoT program. We are exploring the use of NGSI-LD (and its predecessor NGSI-V2) as candidate MIM implementation within certain layers of the smart city platform since it has become an ETSI-CIM standard and we believe it can get enough traction to play an important role in Europe and beyond. The CEF context broker is an important building block to manage context as a crucial aspect of successful IoT data disclosure and usage. We will dessiminate important findings regularly in workshops, presentations and papers during the second half of our program.

We have become member of the IDSA as we believe that data sharing and sovereignty are at the heart of the open smart city. Making sure that the concepts are clear, and the problems are well identified with industrial and research partners is key to a good data sharing strategy and implementation. Open-source implementations of these concepts can boost the principles underlined in this paper.

We believe evidence-based policies [38] can play an important role to make a city more effective and transparent. Our digital twin of the city combines live and historical IoT sensor data with model-based simulation engines to offer a comprehensive geo- and temporal view on the city past, current and future behavior. For that, the data principles and requirements touched in this paper are of crucial importance. Could it be possible in the future to predict the impact of bike-friendly changes on the gentrification level of a part of the city (e.g. such as in Kopenhagen) using combined models in a digital twin ?

Data brokerage is a key function of the open smart city platform and needs to be able to offer and aggregate live IoT data with less volatile IT data to facilitate smart city applications. Data and API marketplaces and business services are key to successful implementations. We will explore further in our SmartZone the coupling of our projects and principles with the Antwerp City Platform as a Service (ACPaaS) [13]. Also in our other CoT projects we continuously aim to design and implement principles outlined in this text.

We will assist the Flemish government in the application of open smart city architectural principles in concrete projects like the VLAIO City of Things calls[14]. We also participate in European projects, e.g. [15], and are continuously trying to combine actors from the quadruple helix in different open smart city projects, programs and initiatives. We are also following and contributing to the Front-Runner Smart Cities program closely in our search for the open-source vocabularies for the open smart cities of the future. And finally, this is an open invitation for cooperation and new ideas to make the open smart city a reality.

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CONTACT

Imec City of Things invites all interested initiatives, governments and organizations from home and abroad to work together on the open smart city of tomorrow. Don't hesitate to contact us: cityofthings@imec.be, www.imeccityofthings.be

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