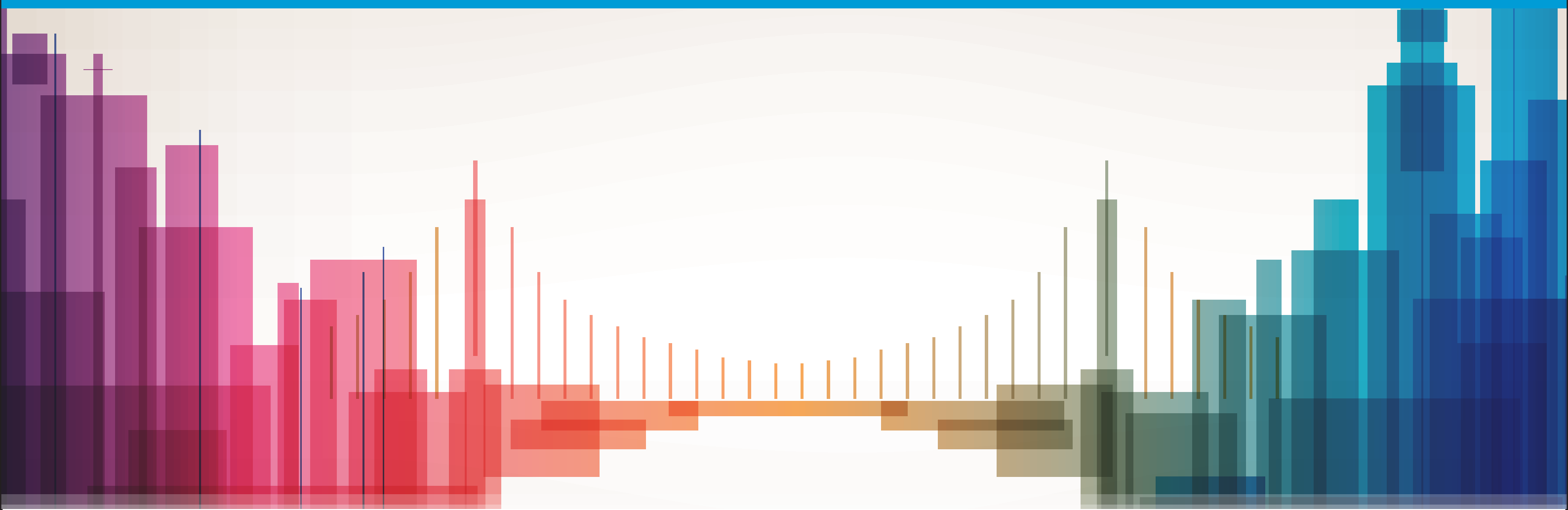
United 4 Smart Sustainable Cities

Redefining smart city platforms: Setting the stage for Minimal Interoperability Mechanisms

A U4SSC deliverable on city platforms



Convention on Biological Diversity

United Nations ECLAC

Food and Agriculture Organization of the United Nations

ITU

UNDP Empowered lives. Resilient nations.

United Nations Economic Commission for Africa

UNECE

UNESCO United Nations Educational, Scientific and Cultural Organization

UN environment programme

UNEP FINANCE INITIATIVE

United Nations Framework Convention on Climate Change

UN-HABITAT FOR A BETTER URBAN FUTURE

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Foreword

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Disclaimer

The opinions expressed in this publication are those of the authors and do not necessarily represent the views of their respective organizations or U4SSC members. In line with the U4SSC principles, this report does not promote the adoption and use of smart city technology. Rather, it advocates for policies encouraging responsible use of ICTs (information and communication technologies) that contribute to the economic, environmental and social sustainability of cities, as well as the advancement of the 2030 Agenda for Sustainable Development.

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Executive summary

As the world is witnessing urbanization at an unprecedented rate, urban stakeholders are increasingly exploring the concept of smart and sustainable cities as a means to deal with growing challenges associated with pollution, urban sprawl, climate change, among others. The success of a smart and sustainable city is largely dependent on having an effective smart city platform which serves as the channel to improve interoperability between different sectors, promote innovation, provide various services and allow inhabitants to provide feedback on the development of their surroundings and provision of utilities within the smart city domain.

In this context, this Report provides guidance to governments and cities at all levels – with a focus on the local and regional – on setting up smart city platforms, as well as on procuring the requisite elements for building them. It also illustrates the current state of the art of interoperable smart city platforms, and provides recommendations for technical specifications.

The Report also sets the premise for enhancing capacity in terms of the use of standards, architectural mechanisms, urban services, guidelines, and tools that enable the interoperability of data platforms for cities and communities, to speed up the delivery of services leading to innovation and positive local impact.

Furthermore, the Report delves into the evolving landscape of smart cities and communities, encompassing the different types of data in terms of data governance, interoperability requirements, standards, data lakes and data spaces, the impact of new technologies, data-enabled communities, and digital twins, while underscoring the role of Minimal Interoperability Mechanisms (MIMs) in supporting the management of these smart city platforms in line with Sustainable Development Goal (SDG) 11.

In keeping with its scope, this Report is intended primarily for digital managers in local administrations, for those who are involved in the procurement, development or regulation of digital platforms and services, and for those who use local data to improve the sustainability of their communities.

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List of abbreviations

Abbreviation	Full form
AI	Artificial intelligence
API	Application Programming Interface
CEF	Connect Europe Facility
CIM	Civil Information Modelling
CP	City platform
ETSI	European Telecommunications Standards Institute
EIRA	European Interoperability Reference Architecture
EU	European Union
GDPR	General Data Protection Regulation
GIS	Geographic information system
GQOL	Global Quality of Life
GSMA	Global System for Mobile Communications
ICT	Information Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
INSPIRE	Infrastructure for Spatial Information in Europe
IoT	Internet of Things
ISO	International Organization for Standardization
ITU	International Telecommunication Union
ML	Machine Learning
MIMs	Minimal Interoperability Mechanisms
NGSI-LD	Next Generation Service Interfaces
NIST	National Institute of Standards and Technology
OASC	Open & Agile Smart Cities
SAREF	Smart Applications REFerence Ontology developed by ETSI/OneM2M
SCP	Smart city platform
SDGs	Sustainable Development Goals
SDO	Standards Developing Organization
SQL	Structured Query Language
U4SSC	United for Smart Sustainable Cities
UNECE	United Nations Economic Commission for Europe
UDP	Urban Data Platform

1 Introduction: The challenges facing cities and communities

1.1 The need to manage increasing complexity

City and other local government administrations strive to improve the life of their inhabitants, increase the ease of doing business and facilitate the transition to a sustainable future.

It is proving increasingly difficult to achieve those goals comprehensively. This is partly due to the current situation and environment of cities and local communities, where resources are often limited, and where they face new challenges including extreme weather conditions, an aging population and rapid technological change. These are factors that generally lie beyond the ability of cities and communities to influence proactively.

However, there are two systemic problems where technology can help provide city and community administrations with solutions.

1.1.1 The siloed nature of city and community management

A city's systems are managed in order to best deliver on the goals of each individual systems. The challenge is that the goals of the different systems often seem to conflict with one another. For instance, the aim of one department to lower the carbon footprint of the city may seem to contradict the aims of other departments to develop the local economy or to provide services as cheaply as possible. These different aims mean that different systems within the city are likely to be managed in isolation, which could often lead to conflicts in the outputs of the different systems.

These problems could be exacerbated by the administrative situation within cities, with different stakeholders having differing priorities and with a short-term focus on the electoral cycle. Even establishing pacts between the different parties with a role in city governance is not the most effective way of delivering on long-term strategies as they are often constrained by the need to compromise between different visions.

1.1.2 The complexity of cities

As cities have evolved, they have become increasingly complex. Service managers have to rely on incomplete, out-of-date, inconsistent and unreliable information. Trial-and-error and best efforts are, therefore, a typical management style of cities.

As a result, management decisions to achieve the goals of the city often fail to deliver. They are also often not aligned with management decisions within other service areas of the city.

1.1.3 The solution

The solution to these two systemic problems is to exploit advances in data collection and data handling. This approach enables the collection and use of more accurate and comprehensive information about what is happening in the city, and uses it to model and better align the differing objectives and strategies of city departments.

Using a combination of off-the-shelf commercial enterprise management systems, along with loosely coupled components and services with minimal but sufficient interoperability, will enable the orchestration of a robust, efficient and holistic management of infrastructure and citizen engagement.

Thus, the city-as-a-system can employ digital transformation to continuously increase the level of orderliness of the city and, therefore, make the city easier to manage.

This report aims to provide practical guidance on the steps and processes needed to achieve this.

1.2 The need for affordable and transformative solutions

The second challenge facing cities and communities is that as they collect more and better data to enable new and transformative solutions to tackle city problems, they find that the products and services available are largely untried, resulting in significant risk and expense. This could be due to several factors, including the following:

- Cities and communities are trying to find solutions on their own.
- Companies are trying to sell proprietary solutions based on the strengths of their offerings and not necessarily on the needs of the city.
- Research and trials are taking place on an ad hoc basis, with no consistent approach that would allow comparison of different approaches.

If cities and communities adopt the same overall approaches to address their shared challenges, this could spur the development of an effective market. Competition would drive down prices, while wide-scale deployments of products and services would provide evidence on the efficacy of a solution, thus de-risking investment.

Cities require robust and scalable ICT architectures, managed and designed using international standards and free and open-source software, providing the socio-economic environment with valuable information to foster an evolution towards a knowledge economy.

This report describes an approach that will help create a market for smart, data-enabled services for cities and communities.

2 The evolving landscape of smart cities and communities

2.1 Data life cycle management by default

- A starting point for any smart city or community is to manage and utilize the data it collects in the most effective and appropriate way. Therefore, it is important to understand that these data fit into several key categories and that each needs to be dealt with differently. A typical way of classifying the data is as follows:

- Closed personal data: Data that are generated by individuals are private and this requires access control and masking techniques to be used or divulgated. It also requires consent for use and traceability.
- Closed organization data: Data that are generated and administered by public or private companies and that have to remain confidential for public security, privacy or commercial reasons.
- Shared data: Data that are either sensitive or commercially valuable but can be shared under strict conditions to authorized roles within other agencies or upon the payment of a fee to provide added value.
- Open data: Open data refers to any information that has been made available for anyone to access, alter, and share. It is open not only technically but also legally. It could be from a public source, e.g., government data, or from a business, e.g., company intelligence, and can be used for commercial and non-commercial purposes.

Open data are the easiest to manage and make available. Many cities have adopted a policy of "*Open Data by Default*", where the presumption is to make data freely available unless it can be shown that this is not appropriate. Cities around the world have adopted Open Data Portals to enable such data to be easily available for widespread use.[1]

However, it is important to recognize that even though sharing personal or other confidential data in an appropriate way is far more complex, that is where the greatest value can accrue to the city.

Cities and communities are learning that the key is to adopt a *"Sharing by Default"* policy. Such an approach refers not only to technology options but, more importantly, to a culture that helps the community be innovative and reach its goals in a collaborative manner that is beneficial for society, while ensuring that the digital rights of individuals and communities are properly protected.

It is vital that the appropriate data will be easily available and with the level of richness required to support whoever needs to take a political, strategic or operational decision in a city. This is one of the main objectives of the city platform. Open data are simply the public part of these data.

2.2 Interoperability

Interoperability is one of the main challenges – and opportunities – in the development of smart sustainable cities and communities, using digital technologies to become more resilient, liveable and attractive for inhabitants and businesses.

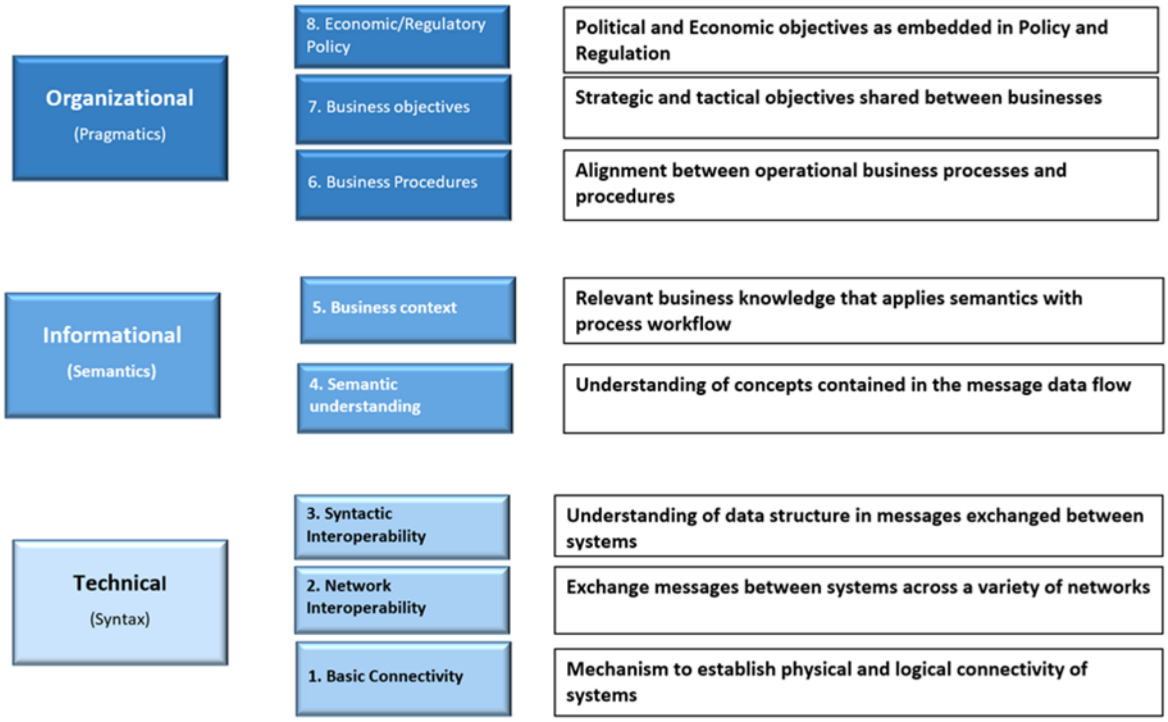
The goal is to develop platforms that can allow key stakeholders, including governments, businesses, knowledge institutions and inhabitants, to communicate and work together across domains. The key to achieving this goal is in defining modular and scalable, multi-layered ICT solutions to enable cross-domain interoperability, moving beyond existing siloed solutions that address specific challenges such as improvement of traffic flows, surveillance, smart lighting, among others.

There are also layers of interoperability, and a key concept is that of minimal interoperability as a practical way of dealing with the complexity and heterogeneity of IoT and data in smart cities and communities.

ITU defines minimal *interoperability* as: "The minimal sufficient degree needed to meet a certain requirement for data sharing, use and reuse".[2] It is an approach to establishing a set of modular mechanisms across multiple application domains and geographic territories, without having to specify everything in complete detail; and without requiring complete implementation of and compliance to the entire framework.

Examples are the MIMs (Minimal Interoperability Mechanisms).[3, 4] Complementary sources of potential interoperability requirements include the European Interoperability Framework[5] and the European Interoperability Reference Architecture.[6] It is also important to recognize that interoperability is not just related to digital technology. The GridWise Architecture Council's eight-layer stack can help in understanding the context for determining interoperability requirements and defining exchanges of information.[7]

Figure 1: The Gridwise 8-layer interoperability stack



Each of these layers needs to be addressed when committing to interoperability.

Comprehensive city management using a smart city platform requires a complex architecture based on smart enabling components that are safe and interoperable by default. The wide variety of situations in which cities currently find themselves points to the need to employ a set of modular minimal interoperability mechanisms such as the MIMs as key building blocks within the creation and governance of such architecture.

2.3 New technologies

Cities and communities aim to gain value from many new technologies that are coming to maturity.

Increasingly, the Internet of Things (IoT) is being used to gather different types of information about the performance of many aspects of city life.[8] Artificial Intelligence (AI) and decision-making algorithms are being used to support the provision of city services, making them better targeted and more efficiently delivered.[9] The use of blockchain is being explored in many areas of city life to support smart contracts and provide greater transparency in transactions.

These blockchains depend on the collection and use of large amounts of reliable data and require city administrations to have the ability to manage these data effectively.

2.4 Data-enabled cities and communities

Not only is it important for the local administration to become more effective users of data, it is just as vital for the city as a whole – for all its businesses, organizations and residents. A smart city or community is one in which increasing amounts of useful data within the city are collected and used wherever they can help the city work better.

Given the exponentially increasing amount of data being generated in cities and communities by many different agencies, and the fact that many of these data could be of value to other agencies, increasing numbers of cities and communities are setting up their smart city platforms to support a local data marketplace or ecosystem. The aim is to make it easy for organizations to offer up their data and easy for potential users of these data to find and access the data.

A whole range of processes are needed:

- To ensure that the data are in a format that can be used easily, and can be accessed easily by standardized APIs.
- To make it easy for any agency or individual to find out who has data that are useful to them.
- To set up a simple process to exchange these data and, specifically, to ensure that appropriate rights and obligations as to how these data should be used are complied with.
- To ensure that data protection regulations can be complied with, even if the data being "bought" are mashed up with other data.

To enable the city and its inhabitants to benefit fully from the enormous amount of useful data that is already being generated, or could potentially be generated, within the city, the smart city platform needs to be set up to allow the management of all of these processes.[10]

There may be many software platforms working together to make this possible. Different software platforms might be needed to manage the exchange of open data, the sharing of sensitive data with authorized agencies under carefully managed conditions, and the buying and selling of data, where this is appropriate.

However, all these software platforms could feed into a smart city platform providing a data exchange that offers a single gateway to city data. The more data that can be accessed from that gateway, the more it will be used by organizations and businesses within the city agencies to provide access to data useful to them, thus setting up a virtuous circle.

2.5 Data lakes and data spaces

A city administration that is serious about supporting greater use of data to support its service provision to its inhabitants will want to make sure that all the data it generates are easy to find and use. One way of doing this is to develop a data lake, which can be held either "on premises" (within an organization's own data centres) or "in the cloud".

A data lake is a centralized repository that allows an organization to store all its data, structured as well as unstructured, at any scale. It can store relational data from line-of- business applications, and non-relational data from mobile apps, IoT devices and social media. The key is that the structure of the data or schema does not need to be defined when the data are captured. This means that all a city's data can be stored without needing to know what questions it might need answers for in the future. Only when specific data sets need to be analysed are analytics like SQL queries, Big Data analytics, full text search, real-time analytics and machine learning brought in to provide the insights required.

For a data lake to make data usable, it needs to have defined mechanisms to catalogue and secure data to ensure semantic consistency, and to provide controls to manage access. Without these elements, data cannot be found, trusted or used resulting in a "data swamp."

A data space is very similar to a data lake, except that it is more focused on the need to share these data and to integrate different sets of data to provide new insights. Data spaces provide federated data ecosystems in which the participants can exchange data easily based on shared policies, standards, rules and economic models that protect their rights and guarantee transparency and fairness.

Data spaces can deal with all types of data, be it from smart objects, data marketplaces, cloud platforms, individuals or organizations, openly available or confidential. They enable interoperability among data sources, data intermediaries and services that consume data, and thereby open up novel uses.

Data spaces are still in their early days and a great deal of work is needed to develop consistent standards and architectures, and thus drive adoption. However, to take one example, the European Union considers data spaces as a key part of its ambition for the free flow of data in a Digital Single Market. Because of this, the Digital Europe Programme will support the development of an open-source, cloud-to-edge middleware infrastructure that can be used in the different data spaces to develop data interoperability within and across sectors.

Among the key data spaces being proposed by the European Commission is one that is focused on smart communities. This will bring together existing local data ecosystems, and relevant stakeholders, to join efforts and identify common principles for sharing large pools of data at the EU level.[11] The action will contribute to the definition of the technical infrastructure for data sharing across relevant sectors (e.g., mobility, energy, pollution, extreme weather events, waste) in a local context. The aim will be to develop a consortium of relevant supply and demand-side stakeholders to establish a cluster of data spaces between a large number of EU cities. The data spaces will consist of the same kind of datasets (including real time), from the local platforms of each city, making them accessible, re-usable and interoperable across borders and cities.

The need for cities to manage unified data repositories that allow inter-domain solutions to be offered where required is clear. The concept of data spaces seems to be a promising approach to enable cities to address the need for informational or semantic interoperability.

2.6 Local digital twins

The development of digital twins can play a pivotal role in the establishment of smart and sustainable cities by providing accurate, real-time, digital representations of the city to help with city planning and management.

In general, a digital twin can be considered as "a digital representation of a physical asset or the service delivered by it, used to make decisions that will affect the physical asset. Any changes to the physical assets will be reflected in the digital twin."[12]

The digital twin provides a means to simulate, predict outcomes, forecast behaviour, and possibly control the real-world entity where applicable. Digital twin models can help organize data and pull it into interoperable formats so that it can be used to optimize infrastructure use. Digital twins can also share these data, with defined levels of access, to inform better decisions about which future infrastructure to build and how to manage current and future infrastructure.

The digital twin concept has its origins in mechanical engineering and the use of digital models to represent a component or a machine in such a way that it does not simply look the same for visualization, but also behaves in the same way. As the model framework is spatially and temporally accurate, and also has dynamic properties that enable it to deal with the things that change for a system during operation, as well as changes that occur because of the effect of its environment, the digital twin can be used not only for visualization but also for interaction. In this way, it can enable simulation and prediction of what would happen to the physical asset based on the digital behaviour.

This has been brought across to support modelling at urban scales relating to urban environments.

The "Living-in EU" initiative defines local digital twins as: "a virtual representation of a city's physical assets, using data, data analytics and machine learning to help simulation models that can be updated and changed (real-time) as their physical equivalents change" (European Commission, n.d).[13]

A local digital twin could be a comparatively simple model used, for instance, to identify the impact on traffic flows in the city or help decide whether a major development site in the city would best be used for housing, retail, or offices. Or it could be a comprehensive and detailed model of the city, allowing the drilling down from an overall view of the city to the detail of individual pieces of street furniture. It may be focused on the physical assets and infrastructure of the city, or it may also include detailed information about the profiles and behaviours of the people and organizations that use those physical assets and infrastructures.

In short, a local digital twin cannot be considered to be a complete digital representation of a city or locality, as this would be impossibly complex. Rather, it is a digital representation that incorporates data about those specific features of the local area that are needed to solve specific problems to the level of completeness and accuracy required.

It is vital that the digital twins developed for different purposes can, over time, be added to or linked together to enable more and more problems to be solved. Consequently, the architecture needs to be designed so as to enable more and more data sets of different types to be incorporated, as and when needed.

The architecture needs to allow data about the physical assets and infrastructure in the city to be linked with data about the people in the city and how they live their lives. It also needs to allow linking at various levels of scale, so that it can provide a city-wide view, a neighbourhood-wide view, right down to an individual building, structure or piece-of- equipment view. It also needs to have the capability to link to even larger-scale models to show how the city fits within its local region, its nation, and potentially globally, so that it can take into account the flows of goods and people in and out of the city and set the city within its wider geopolitical context.

A city digital twin is not only an information model, it is, more concretely speaking, cloud-native software that represents the physical city across its life cycle, using real-time data to enable understanding, learning, and reasoning. This pairing of the digital and physical worlds allows analysis of data and monitoring of systems to head off problems before they even occur, prevent downtime, develop new opportunities, and even plan for the future by using simulations. With a digital twin of the city, the complexity and uncertainty of urban planning, design, construction, management and service can be managed through simulation, monitoring, diagnosis, prediction and control in the digital city.

However, there are still many challenges in implementing a digital twin-based smart city or community. The main problem is the nature of vertical city management. This means that data about different areas of city life are collected separately in different and often incompatible formats by different city agencies, which are often already developing their own digital twins using proprietary software and data models. This undermines any attempt to use digital twins to manage the city as a whole. As a consequence, a local territory would have a number of digital twins relating to it, including some that are closely modelling the actual physical dimensions and the geography, whereas others would be more semantic in nature and less precise physically. They bring different values, and most of the value comes from the semantic digital twins.

Imagine that a major fire breaks out in the city. To deal with it, it is vital to know where exactly the fire is, how extensive it is and how fast it is spreading, where people are in the area and what are their escape routes, how to deal with hazards such as gas pipes or dangerous chemicals, what is the best route for fire engines (given current congestion on the road network), what likely threats there might be to human life, and so on. It is also important to provide all the different agencies that are dealing with the fire with real-time information so that they can adjust their activity accordingly.

To address a challenge like this, the digital twin of a city or territory requires an interoperable platform to support co-construction, co-sharing, and co-governance, while maintaining the integrity and security of the related systems.

From a comprehensive city management perspective, the ICT architecture that supports it must have the spatial components embedded in its different layers.[14] The new AI-based technologies in the geospatial environment of cities or Building Information Modelling must be considered in these future ICT city architectures. The concept of the digital twin could show us the way for a comprehensive and effective management of the city, although now it may seem ambitious, incipient and hardly achievable. Its spatial simulation capabilities need to be well integrated with the city's information repository and its economic information could provide solutions and city services that were not on offer before its advent. In practice, once implemented, city operations will rely on linked local digital twins.

A smart city platform needs to be designed and built to be able to handle the evolving requirements of city digital twins.

3 Eight steps that cities and communities can take

Focusing now on the practical aspects, this section gives guidance on simple but essential steps that every city or community can follow to ensure that their investments in data platforms, and in related skills and capabilities, meet the requirements of the future.

Management aspects and technical requirements are addressed, but always together. While the focus here is on data platforms for cities and communities, most of the recommendations can be applied more widely to processes related to sustainable, digital development.[15]

3.1 Develop a roadmap

The first step would entail developing a roadmap with the following elements in mind:

What: A roadmap gives a clear route of how to get from where you are now to where you want to be in the next two to five years.

Why: This will enable you to have a clear sense of direction and to focus your resources effectively.

How: Start by assessing where your city or community is at the moment and develop a clear set of targets. There are a number of helpful maturity models that you can use to assess your city in a way that will also allow you to set some clear goals for where you want to be in the next two to five years.

The TM Forum Smart City Maturity and Benchmark Model provides a way to assess your city or community against statements of good practice.[16] The Maturity Model is broadly grouped into five dimensions, each representing a major aspect of smart city transformation:

1. Leadership and Governance
2. Stakeholder Engagement and Citizen Focus
3. Effective Use of Data
4. Integrated ICT Infrastructure
5. Existing Levels of Smartness

The first four dimensions allow a city to assess the city-wide capabilities that are necessary for the city to become a truly smart city, rather than being a collection of smart applications or "islands" of smartness. The final dimension allows the city to assess how far it has already integrated smartness into the different aspects of city life.

The **Leadership and Governance** dimension area reviews the breadth and depth of city leadership, the efficiency of city management, the commitment to learn from best practice, the strategic management of smart city initiatives and the transformational mindset in the city's approach.

The **Stakeholder Engagement and Citizen Focus** dimension area reviews the customer and stakeholder needs, the citizen and business engagement for smart city initiatives, the strength of communities and social equity, the collaboration with third parties, and how the business community is engaged.

The **Effective Use of Data** dimension area reviews the openness and sharing of data, data interoperability and use of common standards, privacy, security and data analytics.

The **Integrated ICT Infrastructure** dimension area reviews how assets are deployed and linked to deliver city services, the city-wide IT architecture, the commitment to open standards, the integration of IoT and how cloud computing is used by the city.

Finally, the **Existing Levels of Smartness** dimension area investigates how far the city is already using the power of data to transform the way it manages its core infrastructures, its facilities and buildings, its core services, the city environment and its external interfaces and dependencies.

Another relevant resource for this step is the ITU Y.4904 Smart and Sustainable Cities Maturity Model, which provides a way of assessing how well your city or community is using ICT and data to support the three key dimensions:[17]

- Dimension 1 – Economic: The ability to generate income and employment for the livelihood of the citizens.

- Dimension 2 – Environmental: The ability to protect the existing, as well as the future, quality and reproducibility of natural resources.
- Dimension 3 – Social: The ability to ensure that the welfare (e.g., safety, health, education) of the citizens can be delivered equitably despite differences such as background, race or gender.

These dimensions are aligned with what in the European Union Urban Agenda's "New Leipzig Charter" (EU, 2021) is called productive, green and just – complemented by a new cross-cutting perspective: digital.

A further good resource can be found in Appendix I of Recommendation ITU-T Y.4472 (08/2020), which provides instructions for open API implementation using a four level (from level 0 to level 3) maturity model with instructions on how to move from one level to the next (ITU-T 2020).

Once the goals have been agreed upon, a roadmap has to be developed on how to achieve them. The key is to develop a clear blueprint for what your city or community needs to have in place, and then leverage specific projects that address defined and urgent needs to help put in place the building blocks needed.

3.2 Focus on data

This step focusses on the following aspects:

What: Make a plan for your data, from its creation until its deletion. This is called data life cycle management. Data are not just data: they may, for example, be open, closed or personal; and special consideration should be given to each type. Keep a strong focus on rights and obligations – no data and algorithms (which are code and, therefore, also data) should exist without a clearly applicable set of rules or a specific licence for use and sharing. Particularly in the context of public service, there is a considerable need for transparency, accessibility and independence from specific suppliers. Therefore, it is preferable to ensure a high degree of openness regarding data and algorithms. Access and use are not necessarily free of charge, but should be offered on fair, reasonable and non-discriminatory conditions. Start with data that can create value for you, but be aware that data can add value to other (people's) data without you being aware of it.

Why: Data are the basis for information, which provides us with knowledge, which enables us to act and experience. Digital systems collect and process data that allows us to make good and timely decisions as individuals, organizations and communities. Increasingly, certain decisions are being made automatically by digital systems. Therefore, data and algorithms form an important basis. We are witnessing a significant increase in the amount of data, particularly in data from sensors.

This has created the need to manage these data flows in such a way as to support the provision of services "in real time" with a high degree of automation and without compromising established principles of governance and security.

How: Find out what data you and others need in order to create value. Then identify the individuals in the organization who can establish and monitor your data life cycle. This requires a mandate and a follow-up from management, as well as from technical and legal specialists with links to "the business". In addition, resources for project management, and a forum for exchange and clarification when the system is operating, should be provided. If your organization cannot provide this in house, you will need to seek help from networks, innovation hubs, clusters and the authorities. You can also find courses and consultancy services on the market.

3.3 Build with interfaces

This step addresses the following for the "what", "how" and the "why":

What: Select systems that consist of components with clear functionality and interfaces (APIs) between the components. Choose components that have a broad user base across suppliers and developer tools. Use established metadata models to describe specific information models in their context to make it possible, but not necessary, to express the relationship between more domain-specific data models.

Why: Interfaces (or APIs) make it cheaper and easier to make changes. They also ensure your access to data even if you change supplier or technology. In addition, building with interfaces results in a higher degree of innovation and enables the development of a market based on transparent catalogues of digital components, services and solutions. Metadata models make it possible to translate between more specific data models that are widely used in, for example, a particular sector or geographic area.

How: Follow commonly accepted technical principles for the sound development of software, as laid out by International Standards Development Organizations (SDOs), for example, ITU-T and ISO.

3.4 Secure a minimum but sufficient level of interoperability

This step encapsulates the following:

What: Be sure to always allow for at least a minimum level of semantic interoperability with other systems, particularly when it comes to metadata (Context Information Management), data models and conditions for using and sharing data. Do this by implementing widely used mechanisms to allow for systems and components to be coupled in ways that do not hamper robust and transparent data management.

Why: Minimum interoperability ensures a balance between efficiency and flexibility, and provides benefits to the customer (requisitioner), the supplier, the authorities and to society: Customers are less bound to individual suppliers because they can move their data or have multiple suppliers. Suppliers can address many customers with the same system because the basic requirements are the same, and the design and development costs are lower. Authorities can provide guidance more consistently and have better statistics on the maturity and security of the digital landscape. Society will benefit from a well-functioning, low-risk market that can be used for implementing selected political priorities, e.g., green energy and circular economy. In addition, it promotes innovation, transparency and investment so that core services can be provided cheaply and efficiently, while new opportunities can be tested and exploited quickly. Control of individual systems and data flows is kept at the appropriate level but is subject to normal rules and management principles.

How: Follow the recommendations described in the sections of this paper for the MIMs as a minimum but sufficient level of interoperability when exchanging data. There are metadata models and specific data models, as well as so-called data brokers that simplify the control of data exchange between components, systems and organizations. Preparing a dynamic data exchange on relevant conditions increases the likelihood that, for example, pilot projects will provide value in the short and long term.

3.5 Keep an open mind when choosing technology

This involves the important step of choosing the relevant technologies for a specific smart and sustainable city.

What: Specify requirements that focus on functionality, not on specific implementations. However, it is obvious that functionality should be viewed broadly and includes a perspective that is longer than the time of delivery, i.e., the total cost not only during the life of the system but also during the life of your data, which is potentially very long. Make sure that contracts are reasonably balanced in terms of controllability and flexibility. Pay particular attention to ownership and the right to (re-)use data and algorithms (code) and to letting others build on the system. Formulate a digital strategy that ensures that the various investments and systems are optimally combined, also in the long term. Use relevant standards if they exist. Also consider, in particular, the technology neutral standards that may, for example, be used to ensure the service life and robustness of all parts of the solution.

Why: It has been common to consider a system as a single investment related to, for example, a particular grant or organizational unit. However, data often challenge established economic and organizational logics because new and smarter ways of service provision and management emerge. Limitations resulting from an investment in a particular technology are referred to as technology liabilities and must be taken into consideration when investing.

How: Establish a management perspective on the expectations in relation to a system's contribution to the activities of the organization, in the short and long term. Through contracts, make sure that you have the necessary rights to change suppliers. Make sure to have a technological architecture that allows you to make changes.

3.6 Prioritize partnerships and ecosystems

All smart and sustainable city ventures are predicated on and driven by public and private partnerships. Accordingly, this step will be dedicated to prioritizing partnerships, keeping the following in mind:

What: Make an analysis of the stakeholders related to data and systems you depend on and who does what best. Involve stakeholders in the preparation of metrics for functional characteristics, i.e., how to measure if the system does what it should do. Validate the maturity of the deliverables by means of tests and analyses, preferably integrated into so-called living labs. Make sure to have clear specifications of tasks, responsibilities and rights. Establish partnerships rooted in ecosystems and include both sides of the market (requisitioners and suppliers). Be aware of the options for models of collaboration and control.

Why: Over- and underinvestment in equipment and personnel should be avoided, new projects and continuous development should be weighed against operating costs and depreciation/ obsolescence at all times, and short- and long-term perspectives should be weighed against one another. There are pros and cons, regardless of whether you do all development yourself inside the organization, buy everything from the outside, or have separate responsibility for development and operation. Partnerships are the best way to get beyond the risks involved in committing strongly to a single or a few suppliers (or customers). Building partnerships and living labs takes time and is a significant investment in itself; hence, it requires the organization to have a strategy for how it is done. It is impossible to know everything yourself, so standards, networks and ecosystems are good ways of ensuring access to local, national and international best practices.

How: Acquire an overview of what advice and recommendations you lean on when buying, developing, operating and managing. Within the individual sectors, industry networks and standards are well established, but special attention needs to be given to the areas falling between or outside of industries. This applies to new technologies that are not linked to a single application, e.g., sensors for data collection, artificial intelligence for data processing, and platforms for data sharing. Be aware of your own competencies and involve partners and external resources in the innovation and realization phases of the project, where there is a need to add knowledge and competencies. Learn from others' errors, but make sure to also build a learning culture, where smaller projects can also have a skills development objective.

3.7 Take maturity and complexity into consideration

This step involves keeping the following “what”, “how” and “why” in mind:

What: A good understanding of the maturity of your own organization, the maturity of the technology, the complexity of the task, and the complexity of your collaboration with other actors are critical to obtaining a good result. Assess the need for technical, legal and organizational support based on the organization's experience and resources, and the complexity of the task. Use standards and templates for data, algorithms, quality assurance processes, performance, lifetime estimates and security.

Why: One of the biggest challenges is that competencies are dispersed across different actors, internally in the organization and elsewhere. It may not be possible to find guidance in one single place and in a format that can be used readily, and sometimes it may be contradictory. If you just build in the short term, you risk accumulating technology liabilities in the long term. There are simple ways to minimize this risk, e.g., by making contracts and formulating pilot projects.

How: Place a management responsibility in advance. Maturity models and complexity analyses for organizations and systems help to clearly identify step-by-step development opportunities and to ensure that challenges are accepted that can be solved and that provide an added value. Guidance and courses can empower the organization to make decisions that are optimal in the short and long term.

3.8 Start small, think big

This step entails the following:

What: Plan projects in smaller chunks that can be evaluated continuously and scaled up or down as needed. Focus on learning while developing organizationally and technically. And do not forget to share your knowledge of what is not working well. This knowledge is at least as important to the organization as the successes. In all situations, solutions can be created that have an immediate potential gain and are relatively easy to implement, because there are mature solutions available on the market that can be used. These measures should not be slowed down by the absence of an overall strategy but should instead be used to create learning within the organization and to provide inputs when developing the strategy. The important thing is to keep the other seven recommendations in mind in the planning and execution of projects and actions in order to ensure that the solutions can be included in an overall strategy in the end.

Why: Projects may be so large that it takes too long before the results become visible and can serve as aims. This is a sort of "strategy sickness". Projects may also be too small and contribute too little to the organization's objectives and activities in the long run. This is called "pilot sickness", or costly learning, where projects never come into real operation, either because the solution already existed or because the pilot study conditions do not scale to a more rational operating situation. For large as well as small projects, this increases costs and risks over time.

How: Start out with simple and mature solutions and find out where the potential is greatest. Establish reasonable minimum requirements for all initiatives – see recommendations 2 to 7 above – so that the experiences from one project can feed into other projects. Use a simple but systematic approach to creation, follow-up, experimentation, testing, unforeseen events, scaling, operation, integration, and shutdown. Develop skills for testing new ideas quickly and safely. Make sure that budgeting matches the learning nature of the development process, with changes along the way.

While these eight recommendations are general in nature, they apply directly to the data platforms that every local administration has or is in the process of establishing. And these data platforms are the basis for sustainable, digital service delivery in cities and communities in the 21st century.

4 Blueprint: architectures and platforms

What sort of digital capabilities does a city need to put in place to enable it to manage and share increasing amounts of useful data and use it to support city management and the delivery of city services?

With reference to this question, the two key issues to address are to identify and build the capabilities to handle the data effectively, and the need to ensure interoperability.

There are many different requirements that need to be implemented for a city to be confident that it has a scalable and effective infrastructure to handle the collection, management and use of data, and these are best dealt with by developing an architectural blueprint for the city that is line with city reference architectures built on best practices and with a smart city platform at the centre.

4.1 Architectures

For cities and communities to be managed in a synergistic way, it is important for stakeholders to understand and describe how their city functions now and how it plans to change things to improve the way it works and to adjust to any changes.

"..an architecture defines a framework within which a system can be accurately specified and built at a specific time frame. Its functionally defines what the elements of the system do and how the data and information is exchanged between them. An architecture is functionally oriented and not technology specific, which allows the architecture to remain effective over time. It defines 'what' must be done, not 'how' it will be implemented."[18] (ITU, 2016)

A good example of a typical smart city architecture can be seen in Figure 2.

Figure 2: Smart city architecture – City of Valencia, Spain – based on Recommendation ITU-T Y.4201

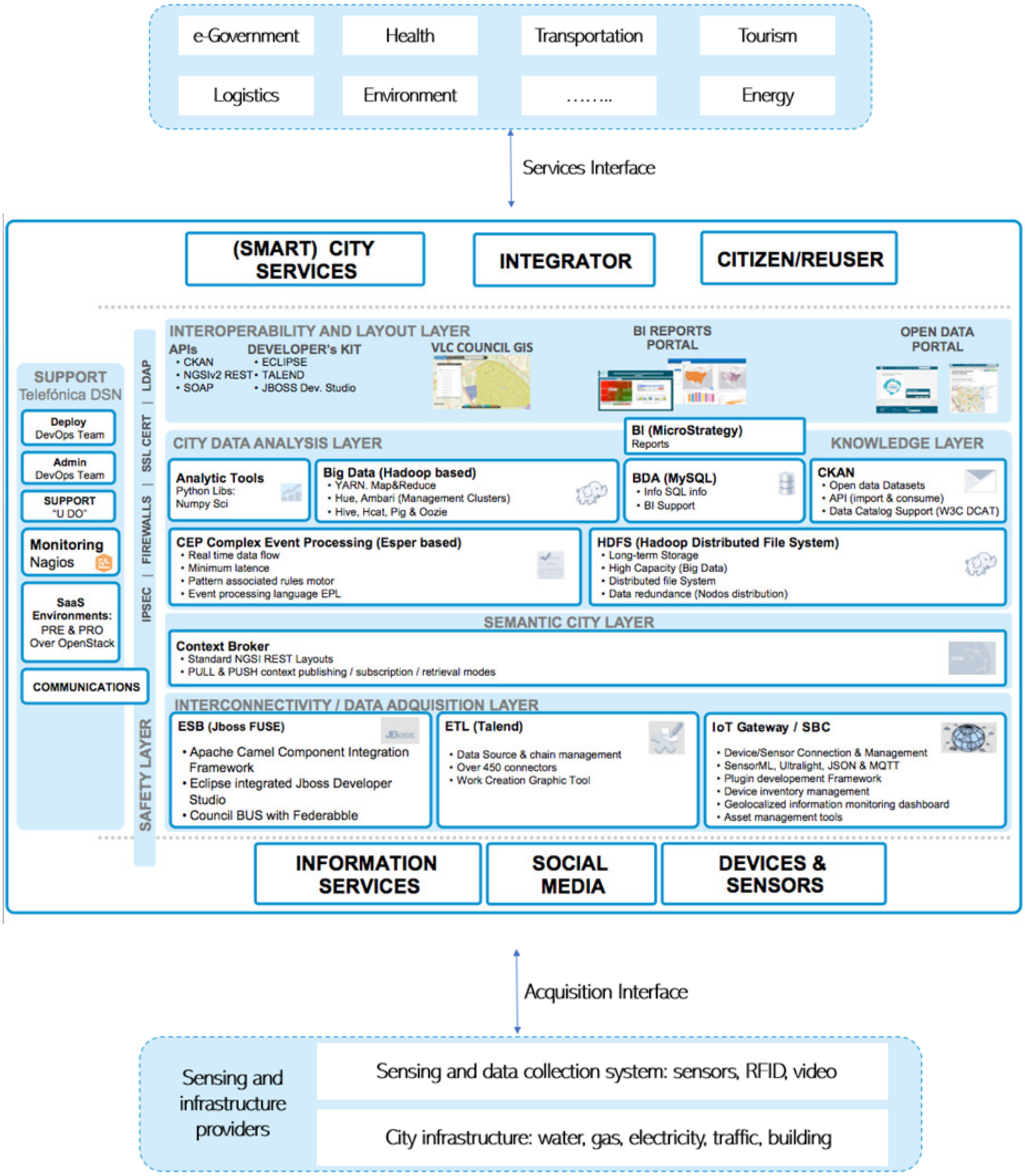


Figure 3: General architecture for smart cities[19]

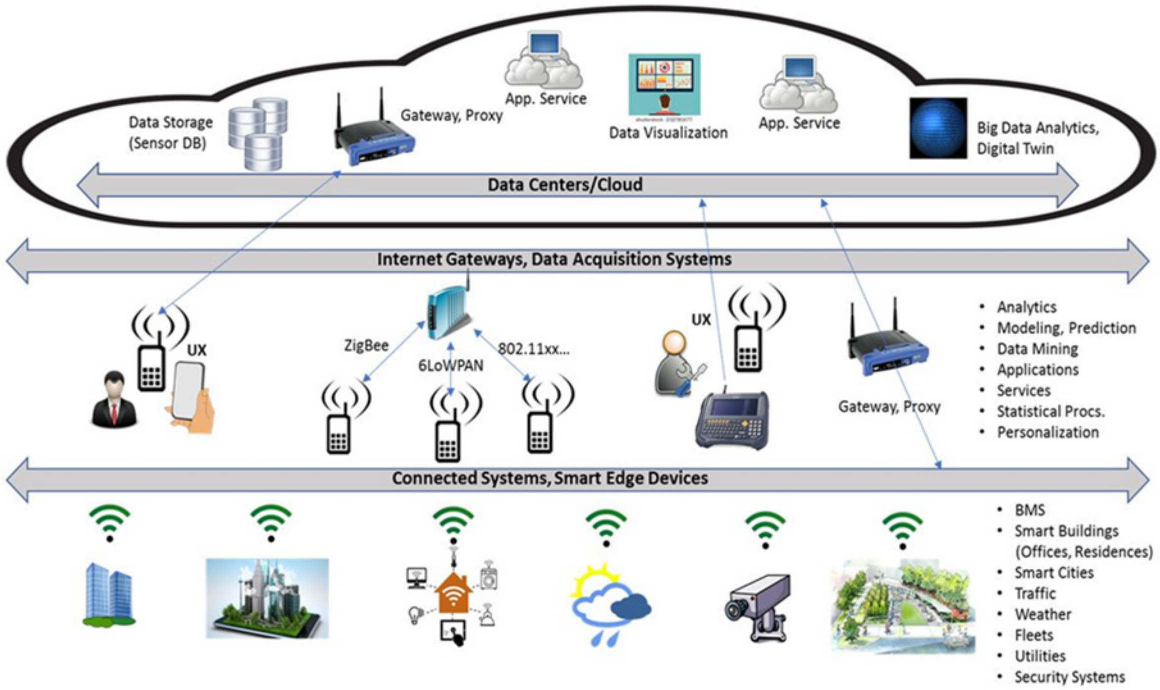
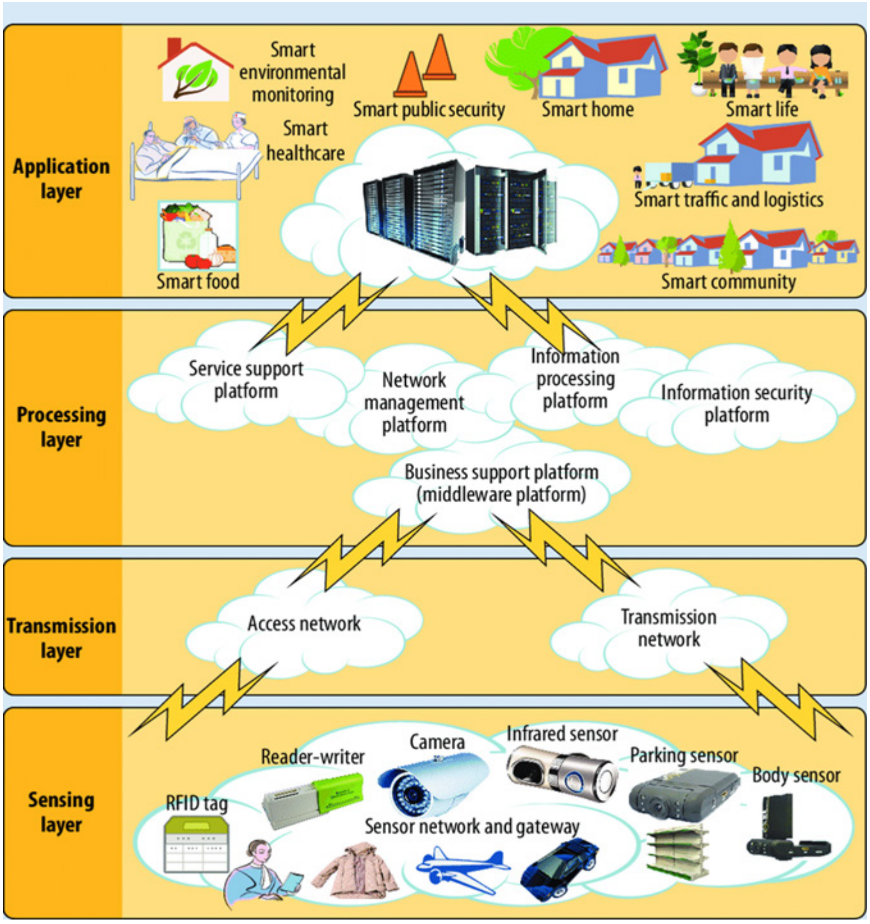


Figure 4: General architecture of smart cities in China[20]



These reference architectures show the different layers and also the key components that could be included in a typical smart city architecture.

4.2 Architectural principles

The following architectural principles are used to guide architectural decisions. These principles are aligned with other leading national guidance documents regarding smart cities initiatives and are synergistic with the overarching global sustainable development goals. The first four principles are technical by nature, while the next three are more organizational:

Focus on data: The goal of this architecture is to open up and make data available with full context to all parties, avoiding locked-in data.

Build with interface (APIs): Since we want to open up access to data, but also allow easy ways of providing data to different solutions, applications, platforms.

Ensure a minimum of interoperability: Interoperability is foundational for smart city and community platforms, enabling scaling of solutions, components and algorithms across platforms (see Box 1).

Adopt an open-by default approach: Platforms and components will evolve over time and new technologies will be developed. We aim to have best of breed/open-source platforms, which avoid vendor lock-ins that are harmful to innovation (See Box 2).

Prioritize partnerships and ecosystems: City and community platforms are seldom concentrated around one solution or solution provider. They are a complex integration of systems of systems built by an ecosystem, so fostering these ecosystems and partnerships is a key element in a smart city and community platform.

Govern maturity and complexity: The platforms are heterogeneous by nature and the variety of the maturity of the components will be very high. This results in systems that are complex to build and maintain. Consequently, it is important to govern this accordingly.

Start small, think big: Don't boil the ocean. Have a big picture of what you want to achieve but start with small chunks that are achievable. Detail those parts, rather than starting with big designs. These platforms will need to evolve and adapt, over time, to changing needs.

Box 1: Interoperability is one of the main challenges – and opportunities – in the development of smart sustainable cities and communities, using digital technologies to become more resilient, liveable and attractive for inhabitants and businesses. The goal is to develop platforms that can allow key stakeholders, including governments, businesses, knowledge institutions and inhabitants, to communicate and work together across domains. Key in achieving this goal is defining modular and scalable, multi-layered ICT solutions to enable cross-domain interoperability, moving beyond existing siloed solutions which address specific challenges such as the improvement of traffic flows, surveillance, smart lighting, among others.

Box 2: Open By Default: Along with interoperability, cities and communities are increasingly adopting an "Open by default" approach, embracing not only open standards, formats and protocols but also open-source software and open data in order to enable non-discriminatory access and avoid vendor lock-in in the provision of digital services.

Such an approach provides cities and communities with a solid foundation to achieve better levels of efficiency, stability and interoperability required for cities and communities' ICT platforms, through source code ownership, collaborative development, re-using and sharing. All of these enable participation in digital services' security, validation and improvement.

An "open approach" not only refers to technology options, but also to a culture that helps individuals and communities to protect their digital rights, to be innovative and to reach goals that are beneficial for society in a collaborative manner. Municipal investment and participation in open-source software projects are also about promoting the development of local skills and reinforcing inhabitants' digital rights, while bringing benefits to the local economy by offering value in terms of long-term sustainability and local economic development.[21]

Moreover, by publishing the components of their ICT service infrastructures and sharing them with others, cities and communities enable wider participation in improving these shared components, individually or collectively, thereby promoting a more sustainable and trusted way of developing smart city platforms.

4.3 Reference architectures for smart cities and communities

Smart City Reference Architectures attempt to provide a systematic methodology and framework for cities and communities to develop their own architecture. The scope of these Reference Architectures can vary. Some of these may attempt to cover every single aspect of the functioning of the city, including all the different service areas and management functions. However, in this document we focus on Reference Architectures related to the collection and use of data in the city.

A smart city data Reference Architecture is an attempt to provide a clear description of all the capabilities that need to be in place, and the stages that are needed for a city to be able to collect and analyse the data it needs and then use it to support all the many city services it delivers. Cities and communities can then use the Reference Architecture as a guide to develop their own blueprint for the design of their own technology solutions to enable them to do this.

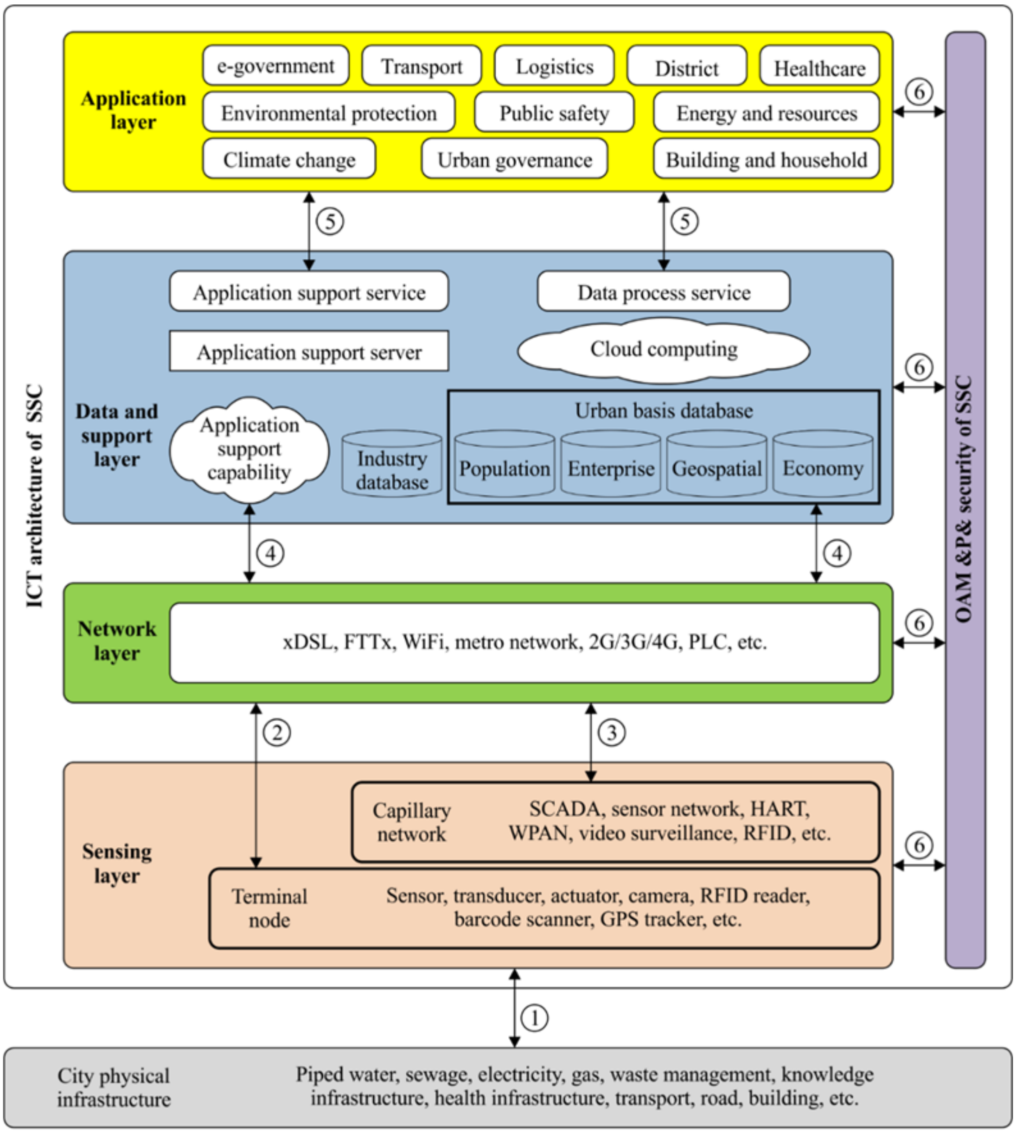
Such Reference Architectures need to be as technology neutral as possible. They must aim to provide a description of the key capabilities required in a way that allows flexibility in how each city implements it, depending on the legacy infrastructure, the size and type of city, the resources available to it, and the particular challenges and opportunities facing it. The core of any Reference Architecture is a diagram that displays those capabilities.

There are many different Smart City Reference Architectures that have been developed by many different organizations. The differences related to which aspects of the process the organization developing it consider most important.

For instance, the diagram providing an overview of the reference architecture developed by ITU Study Group 20 on IoT, Smart Cities and Communities, is highlighted in Figure 5. It showcases the following layers:

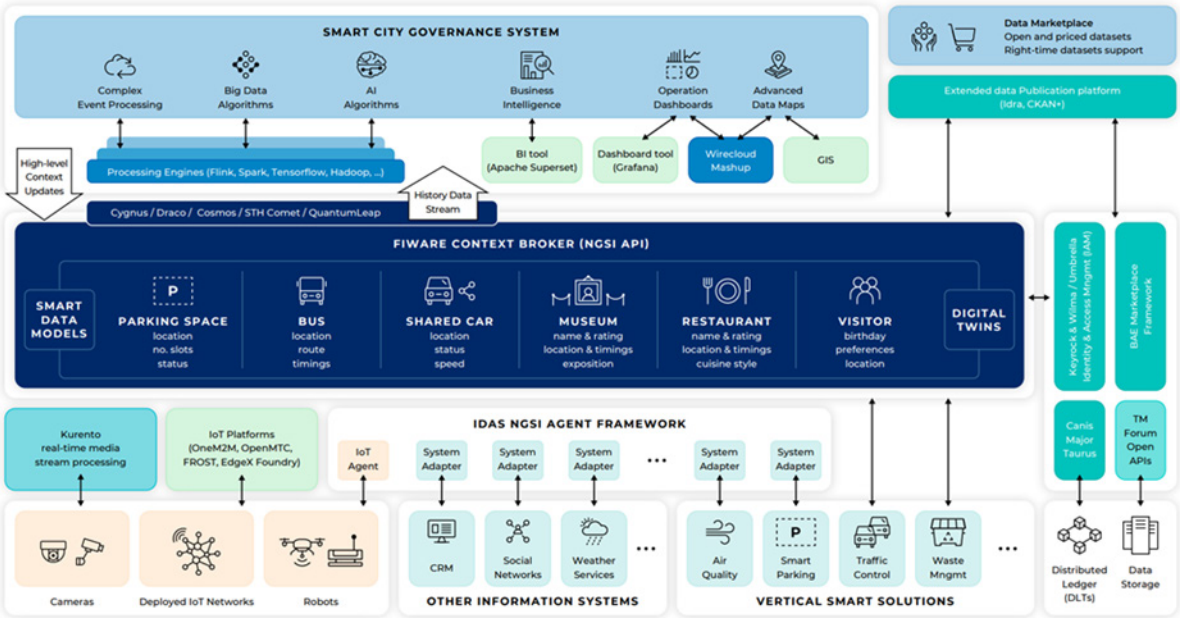
- Sensing layer: It consists of terminal nodes and capillary networks. In this context, terminals include sensors, transducers, actuators, cameras, RFID tags, etc – all of which are capable of sensing the physical world.
- Network layer: This layer includes the telecommunication networks for data processing and application support.
- Data and support layer: This layer includes servers to support the processing of data by applying different statistical models.
- Application layer: The application layer comprises the applications and services that deliver the smart city-based services.

Figure 5: Smart city reference architecture (ITU-T Y-series Recommendations - Supplement 27, ITU-T Y.4400 series)



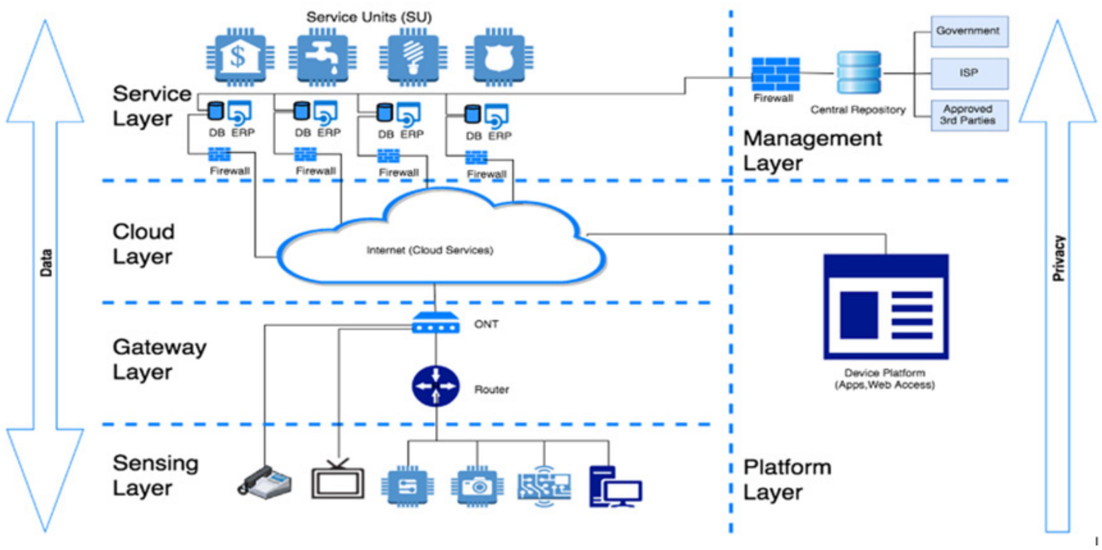
The overall diagram of a Reference Architecture developed by the FIWARE Foundation is given in Figure 6.[22]

Figure 6: FIWARE reference architecture



Another reference architecture referred to as Aura Minora has been provided in Figure 7.

Figure 7: User-centric IoT-based architecture – Aura Minora[23]



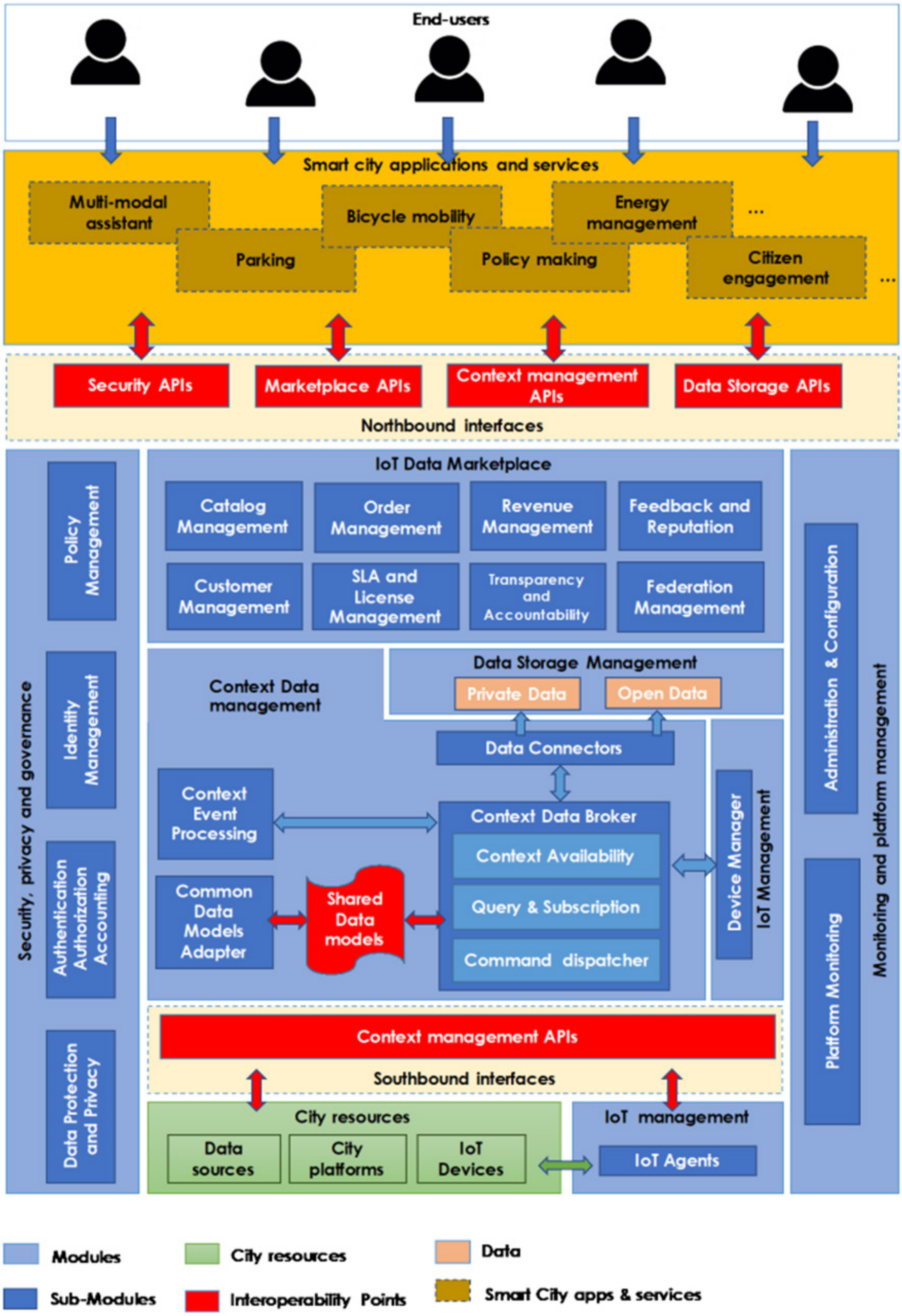
These examples aim to show all the steps and capabilities needed to take data from a range of different sources and transform them into enabling components of various smart city services.

Based on existing solutions, it is essential to identify a minimum set of characteristics that are true of all the main reference architectures in use, and then use this to enable the digital marketplace for cities.

The SynchroniCity Project[24] studied many models and approaches to smart city platforms with the aim of maximizing interoperability and fostering integration with existing local solutions and technical infrastructures in any city.[25] It developed an architecture framework that collects the most common capabilities and technologies needed by cities and is easily extendable for cities that want to extend their existing framework.

To do this, 12 different reference architectures developed by international standards organizations including: ITU-T FG-SCC, ITU-T Y.2060, ISO/IEC JTC 1, oneM2M, AIOT and a number of programmes and projects were reviewed to identify the core characteristics in common. This was to ensure that the reference architecture reflected best practice from around the world. The reference architectures used by eight reference cities were also reviewed in detail to compare the technical requirements those cities had identified as important. From this work, the project developed a generic architecture that can be implemented with different technologies by cities and communities characterized by different levels of "maturity" in terms of IoT infrastructure.[26]

Figure 8: SynchroniCity project reference architecture

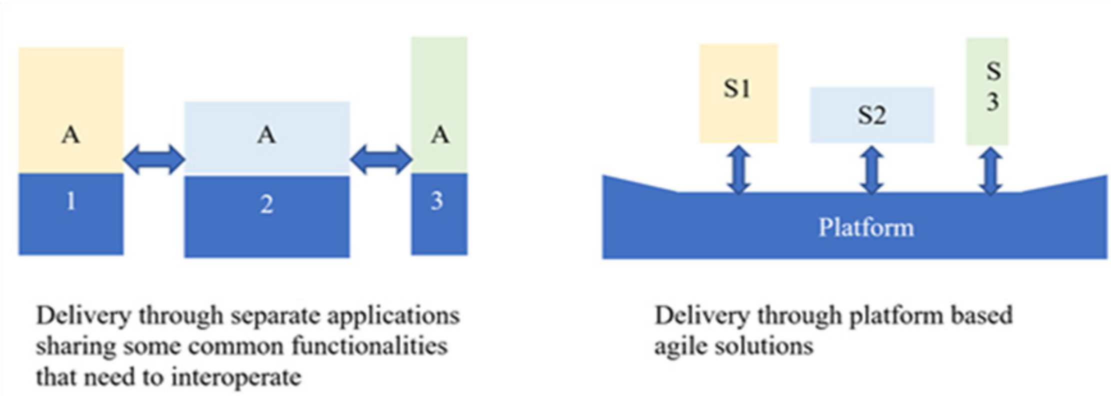


4.4 Integrated City Platforms

City Platforms are a key part of any city architecture, and cities and communities will each have a variety of different platforms at different layers of their overall city platform.

The logic behind the use of platforms is straightforward – instead of using many separate applications containing duplicating functionally, all common functionalities can be collected into a platform and solutions which are built on top of that platform then only need to possess unique functionality.

Figure 9: Platform-based agile solutions[27]



The platform simplifies the use of its platform components and ensures interaction between them. Thus, the platform frees up resources to focus on solving unique problems.

The planning of new solutions can be coordinated within the scope of the platform to minimize duplication of efforts in solving the same problems.

New solutions can be included in the platform gradually for widespread use.

All interactions between the platform and applications can use standardized interfaces (API methodology).

Any city will have many, many existing platforms used by different organizations or departments and with various types of functions. They may be horizontal platforms such as IoT platforms, data platforms, AI platforms, or they may be platforms focused on delivering a specific set of services such as smart mobility platforms, energy management platforms and so on.

The key challenge is that these platforms are often built within silos, and it can be very difficult to share and manage data between them.

ITU defines a *smart city platform* as: A city platform that offers direct integration of city platforms and systems, or through open interfaces between city platforms and third parties, in order to offer urban operation and services supporting the functioning of city services, as well as efficiency, performance, security and scalability.[28]

Hence, a smart city platform is not a massively complex set of software and hardware but rather a federation of many city platforms that work together seamlessly to help manage the city services in a holistic and effective way.

Cities and communities will not need to develop such a platform all at once but rather can use the opportunity of new smart initiatives to develop the relevant parts of that platform in a modular fashion.

What is important is that each platform that is developed to meet the needs of a specific initiative is also designed to fit within an overall common framework so that it can become an integral part of the developing smart city platform.

In short, in order to build a smart city platform, the city needs to:

- Integrate existing platforms so that they can work well together.
- Make sure that new platforms developed to meet some specific priorities are built in a modular way to enable these new platforms to build towards the overall comprehensive smart city platform.
- Refer to relevant international standards related to smart city platforms including Recommendation ITU-T Y.4200 on "Requirements for the interoperability of smart city platforms" and Recommendation ITU-T Y.4201 on "High-level requirements and reference framework of smart city platforms"

To do this, they need to put in place an architectural framework that can act as a blueprint for the work of integration.

5 The requirements needed by the platform enabled ecosystem

There are two key questions cities need to address to ensure that its smart city platform is fit for enabling a data sharing ecosystem:

- What are the sets of capabilities needed to enable an effective data-sharing ecosystem in a city?
- What are the sets of specifications needed to address each of those sets of capabilities:
    - That will ensure that those capabilities are delivered?
    - That will allow sufficient flexibility to allow different ways of delivering them – to give freedom for innovation and competition?
    - While, at the same time, ensuring that all possible compliant solutions will be interoperable, or be easily made interoperable?

The ensuing sub-section will delve into the required sets of capabilities in more detail.

5.1 Architectural requirements

A useful way to consider the key set of architectural requirements needed to ensure the development of practical and effective smart city architectures was developed by the SynchroniCity Project.[29] As mentioned in section 4.3, the project analysed 12 reference models and architectures from a range of relevant international standards organizations. While the solutions proposed by these initiatives had clear differences, it was clear that there are large areas in common relating to basic concepts and functionalities. Specifically, the main logical layers are relatively similar in many architectures, which provides confidence that there is a basic consensus on what these should be. The reference architecture of eight cities was also reviewed to ensure that the reality of city was fully taken into consideration.

This section uses the learning gained from this extensive research based on international standards work to review the system requirements, data management and service requirements and the requirements for security and privacy management of a smart city platform architecture.

5.2 System requirements

5.2.1 Loosely coupled and distributed components

The increasing investment in IoT technology results in a fast and dynamic advancement of solutions available in the market. Current IoT technologies can quickly become old and be replaced by better candidates. For this reason, the system should support deployment through a modular and flexible approach, thus every component can be replaced easily and with a very limited impact on other components and infrastructure. In turn, this will increase the chances of services being adopted by cities and communities by reducing the risk associated with deployment of monolithic or turn-key systems, while also improving the development life cycle. Moreover, designing distributed components ensures that they can run on multiple machines thus easily scaling up the running environment of a component.

Figure 10: Core components of a generic architecture for processing and management for smart cities and communities

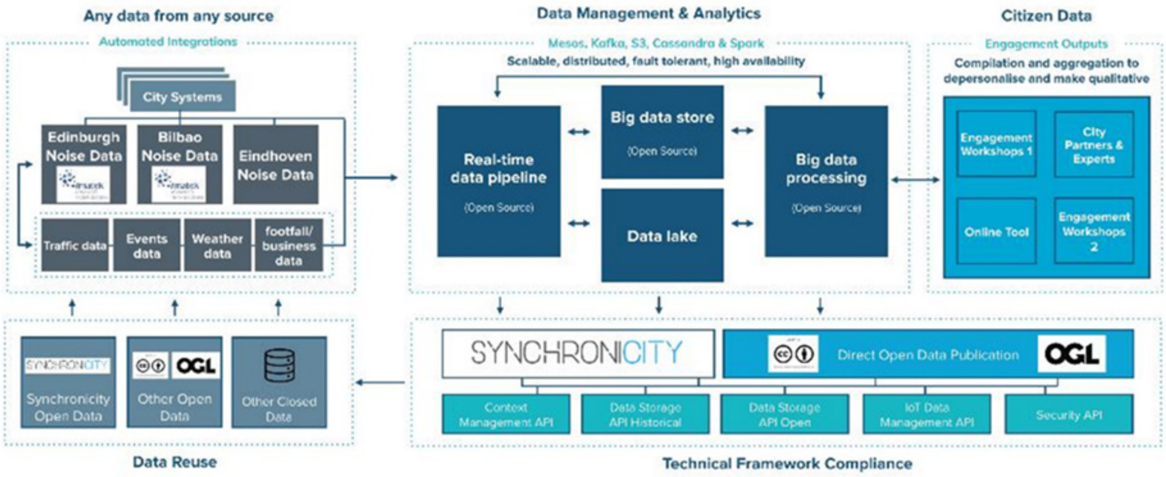
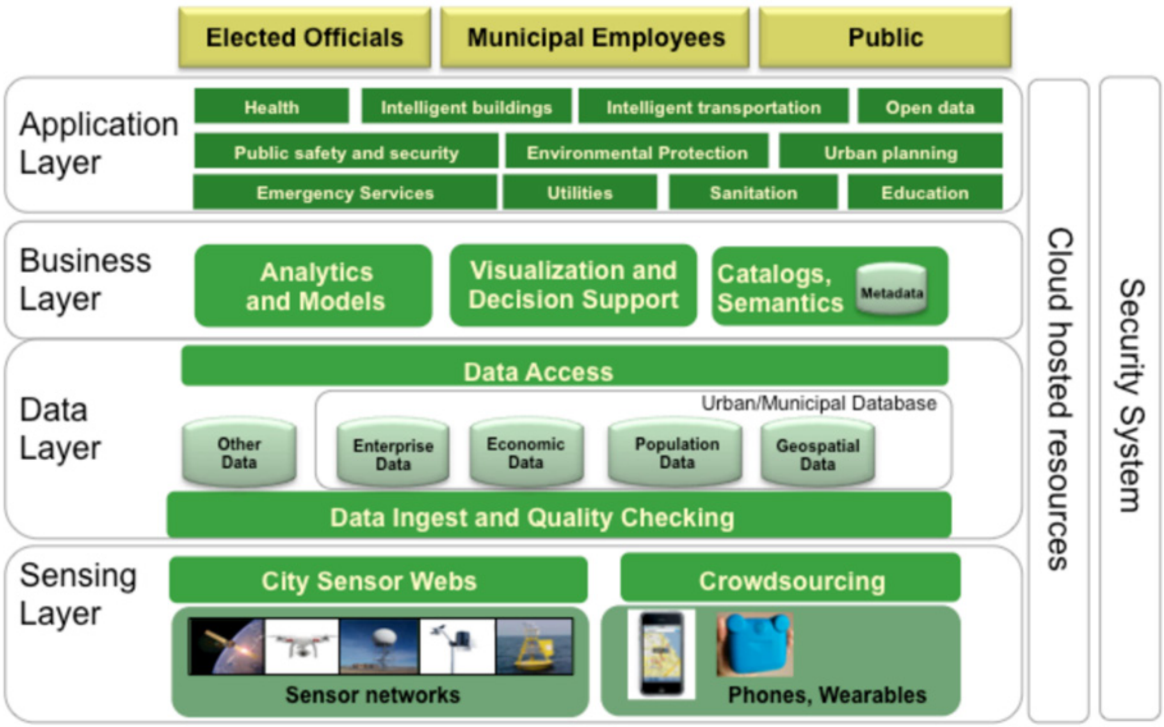


Figure 11: Smart city components and data sources[30]



5.2.2 Interoperability, transparency and usability

To facilitate interoperability, the system must use as many publicly accepted standards as possible for communication and exchanging data; for example, gateways and APIs might act as a glue between those architectural components. The data and information in the platform must be provided and consumed by open protocols, standard technologies and clear agreements, so new components can easily access information already available. This also means that the APIs should be discovered and understood so that new application integrators can use them easily. In addition, the usability seen from the software engineer or developer's perspective should be high – having relevant specifications in theory is not enough, they should also be felt by the developers as appropriate, interoperable and conforming to best practice.

5.2.3 Scalability

The system can be expanded when we foresee more users of "things" and/or streams of data scaling horizontally and vertically. In horizontal scaling, other nodes could be added, where copies of the software will run on, ideally in a dynamic fashion so that nodes are added automatically when the need arises. In vertical scaling, the system can store more data or have more memory to perform advanced computing. In addition, core components should be as lean as possible, meaning that even communities or organizations with limited technical, human and/or financial resource should have access to provision basic functionalities.

5.2.4 Legacy compatibility and heterogeneous landscape

In order to cope with the dynamic technological change, the architecture must be able to support new and legacy components, while handling different versions of the components. Cities and communities need to maximize the use of legacy wired/wireless infrastructures; thus, the system has to support IoT-based services by efficiently (re-)using already available assets. Clearly, understanding the protocols used by the different RZs is a necessity, and the impact of adding new protocols needs to be minimized. The system needs to facilitate accessing and managing heterogeneous devices through a single common framework. It must offer a uniform and extensible way to access the different devices accessible on the marketplace in order to overcome interoperability problems and reduce the friction in dealing with heterogeneous technologies.

5.2.5 Resilience

The architecture must be resilient to failure. Considering that components could fail and communications could be affected, it should provide a self-healing system, including redundant links that cover breakdowns. We should consider that most of the IoT technologies have not yet reached a maturity level free from issues. Moreover, the interaction among many different types of components (e.g., sensors, network, wireless technology, data store, servers) from different actors could generate problems.

5.2.6 Performance

The system should guarantee a real-time user experience. Users should be able to interact responsively with the system, discovering new available assets at runtime. The system should support the availability and execution of the assets in compliance with their SLA. Moreover, a continuous integration and delivery possible for each element in the architecture, automated testing to reduce regression and guarantee quality should support the system to be operational 24/7, and has a close to zero maintenance windows (software upgrades, firmware upgrades).

5.2.7 Communication

Communication in IoT can happen between the sensor/actuator and the gateway or between the gateway towards the platform or, in some cases (e.g., NB-IoT, LTE), directly from sensor/actuator to the platform. Communication with the sensor to the gateway (when wireless) is possible in numerous ways. At this moment, a variety of standards are available; thus, the platform should be able to handle different protocols (e.g., LoRa, 802.15.4, NB-IoT, Wi-Fi, LTE, GPRS) and be flexible in order to incorporate future changes. When new components are selected, they should comply with communication patterns such as:

- Telemetry, where communication flow is one-way from IoT device to gateway.
- Inquiries, where requests from devices looking to gather required information or asking to initiate activities; for example, devices having their own business logic need input from a central server.
- Commands, where the system provides execution commands to a device, or a set of devices, to perform specific activities.
- Notifications where information flows from other systems to a device, or a group of devices, by sending a broadcast message such as a time-sync message.

5.3 Data management and service requirements

5.3.1 Data management APIs

Access and consumption of data and services through standard and open APIs facilitate the re-use of solutions, thus avoiding vendor lock-in. Moreover, by providing data publish/subscribe functionality, sending and receiving data in the system can be simplified and improved. The system should provide a set of standard and open APIs to track changes and version updates, along with notification and asset search functions among other capabilities. As a result, the system will be able to avoid problems and inconsistencies in accessing the resources, while simplifying the access to the APIs in the marketplace.

5.3.2 Data storage management

The architecture should address the storage of data from platform and usage perspectives. From a platform point of view, data could be stored in an on-premise system, in a cloud service or in a hybrid system. Several factors can drive the decision on where to store data. For instance, data embedding sensitive information may call for on-premise systems in order to be compliant with data protection and privacy regulations. On the other hand, whenever there are no restrictions on the physical data storage location, and depending on the expected amount of data, cloud service can be considered a flexible and viable solution. In this latter case, the system should take into account the latency of the network. A hybrid between both solutions, where some data will be saved in locally owned systems and some data in cloud services, would be also possible. From a usage perspective, applications and services may require processing data in various formats. For instance, structured data carries specific information that may fulfil the immediate needs of an application or a service, whereas raw data can embed information that may be used in the near future. Thus, the architecture should consider different data formats, providing storage support for unstructured (e.g., raw data) and structured data and API to access historical data in a uniform manner. In order to guarantee that data access is performed in accordance with their licence, policies of distribution and/or charging, the system should support different data categories based on restriction on their usage such as public or open data, private data and commercial data.

5.3.3 Data models

The adoption of standard and open data models facilitates the re-use of assets and solutions, avoiding vendor lock-in. The system has to support open and standard data models and metadata by providing pre-built taxonomies to describe assets (e.g., data, services, applications, devices), to simplify the definition of the assets description and to allow re-use of existing data models.

5.3.4 Dynamic data exchange

The architecture includes mechanisms to manage terms and conditions for data exchange, whether or not there is a monetization aspect. Many local governments see the benefit in having a local data ecosystem, or even a concrete IoT data marketplace in which data can be exchanged among users. The best-known examples are in the energy sector, where commodities like renewable energy are traded based on operational data. IoT Data Marketplace providers can define different governance policies which, for example, allow different political approaches on the conditions imposed on data collected in public space. The system should thus support fine grain management in terms of validation procedures to be followed. Cities and communities should be able to decide how to regulate the access to their data – either by vetting registration requests from data providers and data consumers, or by allowing an open access – how to be federated with other cities and communities, what type of data should be accessible (e.g., personal data, anonymized data). Quality of published resources and providers (e.g., in terms of documentation, availability, completeness and reputation), as well as easy asset discovery, should be supported to facilitate better interaction between consumers and providers. Ultimately, as cities and communities consider inhabitants' trust as a key success factor, the system should provide tools that foster transparency on data usage and sharing by tracking SLA agreements and by providing tools for auditing.

5.3.5 Licences

When sharing data with external parties, either by selling it or by offering it free of charge, it is fundamental to ensure that the data provider will keep control over their data. To support a dynamic ecosystem in which providers can establish various business models the system should provide several licence models for their data, including commercial and open licences. Furthermore, to better match the expectations of the stakeholders, the platform should offer data-license templates with variable content, configurable based on the terms decided by the data provider. This will make it possible to define:

- the exclusivity of the data licence;
- the business sectors for which the data may be used;
- the geographical restrictions for the usage of data;
- the period of validity of the authorization/right to access data;
- the intended purpose for which the data are used;
- the authorization to resell data.

5.3.6 Service level agreements

Many different stakeholders are part of the digital single market and different levels of service may be required. The system should provide functionalities to define and manage extensible SLA for data access, as well as providing common metadata to define SLA so that the management and the comprehension of the SLA descriptions can be simplified.

5.3.7 Feedback and monitoring

Feedback, rating and reputation mechanisms are useful in order to provide a source of suggestions to improve data, services and applications deployed within the city, to facilitate asset selection by the end users, and to build a reputation for the providers that can be exploited among different city marketplaces. Thus, the system has to provide a user feedback management for the different assets published on the marketplace, be able to describe improvements and/or use experience and rate their quality. Moreover, the system has to provide advanced usage monitoring functions necessary in order to enable other services (e.g., usage statistics, revenue models, technical management).

5.4 Security and privacy requirements

5.4.1 Platform security

Data and services can have different security requirements based on their scope. The platform that is going to support the services of the city should provide flexible security capabilities in order to accommodate the different needs of specific target scenarios by providing support for confidentiality, integrity, authentication, authorization, immutability, trust and non-repudiation when needed.

5.4.2 Data protection and privacy

Data protection and privacy issues should be addressed at several levels, from the low-level platforms to specific end-user applications.[31]

The system should use encryption and technology to authenticate and secure data in transit, as well as mitigate the risk of data theft by encrypting physical storage/media to protect data at rest. It is necessary to provide systems for monitoring against any attacks, and if a breach occurs (e.g., data are accessed by unauthorized entities) the system should be able to properly react with defined procedures.

As data providers have the need to restrict the access of data source(s) to third parties, the system has to allow defining and managing policies for data and service access control. The data provider and the data consumer must comply with the privacy and data protection policy; thus, the system should provide procedures and guidelines in order to ensure compliance with respect to data protection rules. In addition, the system should provide data anonymization and aggregation functions in order to delete personal or restricted information.

5.4.3 IoT and edge computing security

The huge heterogeneity in the IoT devices' capability (in terms of memory, computational, or energy requirements) makes it impossible to identify a "unique" or "common" security solution set, whereas they call for a large spectrum of security level versus resource consumption trade-offs. In order to support new and legacy IoT devices, the system should provide end-to-end security at the API level rather than supporting and coping with how different solutions (e.g., LoRa, 802.15.4, NB-IoT, Wi-Fi, LTE, GPRS) handle security measures such as key management, authentication, integrity and confidentiality. More specifically, the system should define adaptation policies of these mechanisms in the boundary points while assuring that security remains independent from low level IoT components.

6 Interoperability that is minimal yet sufficient

Having a well-designed architecture based on platforms is not enough. Cities and communities traditionally collect data in silos, and different city departments are likely to use different data models and processes. Consequently, within the city it is vital to address the need of interoperability. Just as importantly, for a city to benefit from tried and tested, and cost-effective, smart city products and services, it needs to ensure that it follows widespread city practice and standards.

However, given the range of requirements, as covered in the previous section, it is important to identify approaches and mechanisms that will enable minimal but sufficient interoperability to allow a good foundation to be laid for the smart city platform.

6.1 Interoperability points

A fundamental principle when designing system architectures is to establish which parts are tightly coupled and which ones are more loosely coupled. If everything is tightly coupled, data sharing is easier and more predictable, but it also makes the entire system more vulnerable to failures and more difficult to change. One way to balance the needs for easy data interoperability between smart city platforms and the integrity of the same is to identify common interoperability points (also known as Pivotal Points of Interoperability) and then to use Minimal Interoperability Mechanisms (MIMs) to enable effective, robust and future-proof integration of the platforms.

Interoperability points represent the main technical interfaces between smart city platforms and external systems. Interoperability points are also a way to access basic smart city IoT functionalities (sensor networks and actuators such as intelligent traffic management systems, building information management, utility infrastructure related to water and waste flows) and in particular to consume and provide data between and around those systems. Such points and mechanisms assure not only the replicability of solutions (i.e., services, applications) on different smart cities and communities that are compliant with them, but also the interchangeability of components and providers. They are partially or completely decoupled from the specific technological implementation and deployment of the architectural components. Interoperability points are the logical and conceptual representation of a set of open APIs that can be instantiated concretely to provide a technologically specific implementation.

In general, there are two interoperability points in a generic smart city platform:[32]

- **Southbound interfaces**: Represent the main way for interacting with IoT devices/middleware and managing relevant IoT data. They include a set of interfaces used to connect a smart city platform to heterogeneous IoT devices and middleware. The southbound interfaces are intended to be exchanging IoT data with a smart city platform, hiding the complexity of the IoT protocols and communication issues, which are not covered by this Recommendation.
- **Northbound interfaces:** Include a set of interfaces that provide IoT data and its elaboration to the external system and application interacting with the smart city platform. Not all the

northbound interfaces described in this Recommendation can be provided by a generic smart city platform, only the basic ones, which constitute an interoperability layer for IoT data provision.

More specifically, a generic architecture for a local government would contain a set of standardized components with more interoperability points.

6.2 Minimal Interoperability Mechanisms

The concept of Minimal Interoperability Mechanisms (MIMs) is based on what is needed to provide simple, straightforward ways for a city to implement the essential aspects of well-established standards quickly. The aim of defining these is to enable the digital capabilities of a city to be based on a firm foundation. By embedding them within the smart city architecture, the city can be sure it has the data-handling capabilities and the interoperability needed.

Minimal Interoperability Mechanisms (MIMs) are the minimal but sufficient capabilities needed to achieve interoperability of data, systems, and services between buyers, suppliers, and regulators across governance levels around the world. By basing the mechanisms on an inclusive list of baselines and references, they can take account of the different backgrounds of cities and communities and allow cities to achieve interoperability based on a minimal common ground.

Implementation can be different, as long as crucial interoperability points in any given technical architecture use the same interoperability mechanisms. The MIMs need to be vendor neutral and technology agnostic, enabling anybody to use them and integrate them in existing systems and offerings, complementing existing standards and technologies.

MIMs need to be simple and transparent mechanisms, ready to use in any city, regardless of size or capacity. The interoperability points assure the replicability of the solutions built on top of an open city platform, as these are decoupled from the specific technological implementation and deployment of the architectural components.[33]

Below is a list of the relevant MIMs.

Figure 12: OASC MIMs

MIM	Subject	Name
MIM1	Context	Context Information Management
MIM2	Data Models	Shared Data Models
MIM3	Contracts	Ecosystem Transactions Management
MIM4	Trust	Personal Data Management
MIM5	Transparency	Fair Artificial Intelligence
MIM6	Security	Security management
MIM7	Places	Geospatial information management
MIM8	Indicators	Ecosystem indicator management
MIM9	Analytics	Data Analytics Management
MIM10	Resources	Resource Impact Assessment

7 Architectural framework supporting minimal but sufficient interoperability

7.1 Goals

The goals of an architecture framework model for a digital ecosystem for cities and communities is to ensure that the capabilities of interoperable data platforms consider the functional and non-functional requirements needed to implement the minimal interoperability that cities and communities need to deliver a prosperous, sustainable, and inclusive future for their inhabitants.

The fundamental perspective of this framework is that of the technical capabilities required for minimal data interoperability. This framework also encapsulates implementation aspects, e.g., those related to specific software and hardware stacks, and it allows great flexibility when it comes to adapting concrete deployment and integration to a local context. It is also based on a realization from current experiences that establishing data spaces on a minimal but sufficient common ground can be a catalyst to deliver mainstream trusted services for cities and communities in a connected world.

The requirements for interoperable city data platforms should lead to specifications that ensure that the platforms are reliable, durable, future-proof and efficient so that the city can build on the platforms and foster further innovations and evolution. These specifications should also ensure that the platforms can:

- extend to a "system of systems" with all relevant digital means of a community;
- scale to the needs of the cities and communities; and
- guarantee privacy and security by design, making the platforms trustworthy.

Open-source development and the involvement of communities are powerful methods to guarantee transparency, and consequently trust, in the platforms for public operators. This particular aspect will be particularly relevant when injecting algorithms based on AI mechanisms into the platforms.

The implementation of minimal interoperability provides the common technical ground that cities and communities need to enable choice, flexibility, value for money and independence, through avoiding vendor lock-in. The platforms should support formal, *de facto* and emerging standards, in order to ensure they are future-proof and stable.

The trustworthiness and the interoperability of the platforms addresses the triple baseline of social, environmental, and economic benefits, and supports strategic aims such as the United Nations Sustainable Development Goals.

The platform architectures proposed in the recommended specifications and frameworks have been validated in large-scale pilots by a large variety of companies in close and direct partnerships with the cities and communities, as well as networks of cities.

7.2 Architectural capabilities

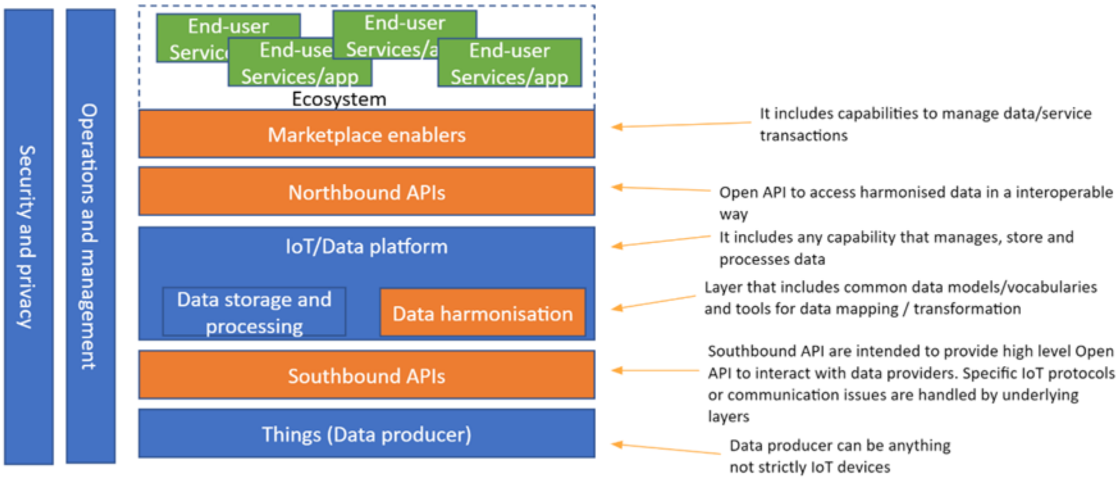
The framework shown in figure 13 provides a description of, and guidelines for, a common architecture/framework, including a layered overview positioning of all the components and interfaces, as well as the associated requirements and specifications. They include a description of reference implementations, including conformance testing and/or feedback from market use validation.

To go more into detail, we consider the following topics as common architectural design principles:

- A layered and capability-based approach to follow a common architectural model in different cities/domains.
- Based on open international standards (where available): we do not want to reinvent the wheel, and this will also ensure stable and widely used technological approaches.
- Compliant with existing technical solutions (e.g., already present in the cities with many legacy systems) focusing on interoperable interfaces rather than component implementation.
- Modular and scalable solutions for small and big cities to support different deployment scenarios and performance requirements.

- Security and privacy by design.
- Availability of reference implementations to foster and simplify the adoption in the cities and communities.
- Architecture modularity that provides the possibility to implement any component with different/proprietary technologies.
- Based on global, standard-based open APIs to enable southbound/northbound interoperability.
- Data harmonization and global standards-based semantic interoperability through the adoption of common, linked data models.
- In this document the following parts are further discussed:
  - Data models and Context information management: Context information management realizes the Northbound open APIs and the Southbound APIs as a high-level open API. The Data models provide the harmonized models.
  - Marketplace: discusses the different marketplace API and transaction management (commercial as well as non-commercial).
  - Data harmonization makes sure that data models can be harmonized to shared data models and between different standards.

Figure 13: High-level architecture framework model



7.3 Recommended specifications and frameworks

The following is the list of specifications that are recommended when developing a smart city architecture:

- Recommendation ITU-T Y.4472: Open data application programming interface (APIs) for IoT data in smart cities and communities (ITU-T, 2020).

- oneM2M Release 2 and Release 3 set of specifications. oneM2M Release 2 has been formally approved as a series of ITU-T Recommendations under the Y.4500 series. oneM2M is a partnership project that specifies a common service layer for IoT. oneM2M is applicable to many verticals, including smart cities. oneM2M specifications cover requirements, architecture, APIs, security, interworking and data models. Although not chartered to produce open source, there are several open-source implementations supporting oneM2M, including Eclipse OM2M and S. Korea OCEAN.[34, 35]
- DIN SPEC 91357 Reference Architecture Model Open Urban Platform (OUP) (DIN, 2017).
- SynchroniCity: Delivering an IoT enabled Digital Single Market for Europe and Beyond – Guideline for SynchroniCity Architecture (Gluhak *et al.*, 2018).
- SynchroniCity: Delivering an IoT enabled Digital Single Market for Europe and Beyond - Synchronicity Reference Architecture for IoT Enabled Smart Cities, Update (Maggio *et al.*, 2018).
- The European Interoperability Reference Architecture (EIRA) Library of Interoperability Specifications (ELIS) repository of technical specifications based on open standards defining the interoperability requirements of the architectural building blocks (ABBs) (European Commission, n.d.).
- SALAR Ten Proposed Principles for IoT-systems – best practices for purchasing / achieving IoT-systems or IoT capabilities.[36]
- ITU-T Recommendations Series Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities.[37] [38]
- ISO/IEC JTC1 Study Group on Smart Cities report.[39]
- SystEmic Standardization apPRoach to Empower Smart citieS and cOmmunities "ESPRESSO Project" Definition of Smart City Reference Architecture (Cox *et al.*, 2016)
- ETSI GS CIM 009 V1.1.1 Context Information Management (CIM); NGSI-LD API.

8 Useful results from the work on MIMs

The MIMs elaborated on in this report are based on the following principles:

- The set of Minimal Interoperability Mechanisms is designed to answer the questions: "What are all the basic building blocks needed to enable a city to set up an effective data-sharing ecosystem?"[40]
- They are Minimal to ensure no unnecessary complexity or time-to-implement, with the aim that the cost to implement (staff time, software, hardware) will be affordable by small and medium-sized cities.

- They need to provide sufficient Interoperability to allow "good enough" integration of systems, as well as the development of a viable market – cutting costs, minimising risk and preventing vendor lock-in.
- They need to be Mechanisms that are clearly enough defined to make it easy to determine if a product or service is compliant and to make it easy to determine the steps to implement.
- They need to be built on existing standards to provide cities with a clear path forward.
  - Where there are existing authoritative standards, the MIMs need to reflect the core requirements of those standards that a city could put in place as a first step to see immediate benefits in developing the local data ecosystem.
  - Where there are several standards initiatives that cover the same ground, the aim will be to identify the lowest common denominator (or the Pivotal Point of Interoperability) that will make it easy to link products and services that comply with those different sets of standards.

8.1 MIM 1: Context information management

8.1.1 Goals

Context information management ensures comprehensive and integrated access, use, sharing, and management of data across different solutions and purposes. It manages the context information coming from IoT devices and other public and private data sources providing cross cutting context data and access through a uniform interface.

8.1.2 Capabilities

Context information contains comprehensive status information about real-world entities defined in a structured way with formal definitions, and provides functionalities to enable access to different data sources and analyse the context information, e.g., for detecting events.

The information that cities, regions and communities possess or gather should be available and easily accessible to applications across different domains. To make the information usable, context information is key.

This will enable applications to discover the information relevant to them; for example, by specifying what is needed and retrieving or subscribing to this requested information. To share and re-use this information, an agreement needs to be in place regarding the definition of the concepts; this can be provided by data information models. This enables the discovery and querying of information, current and historical, and the inclusion of geospatial information. Applications can subscribe to changes of information, so that they are always aware of the current status.

The implementation across (and even within) the city, or any application ecosystem, can be very diverse and heterogeneous. An agreement on the interfaces is necessary in order to be able to access the information. This is enabled by the context management API and the data models. The common data and data models are available in a catalogue and guidelines are available so that different verticals are integrated in a holistic/integrated city data lake to enable interoperability for applications and systems among different cities and communities. The catalogue supports structural interoperability, behavioural interoperability (representation, data mappings) and governance interoperability.

8.1.3 Recommended specifications

- NGSI-LD, as specified by the ETSI Industry Specification Group on Context Information Management (ETSI ISG CIM), provides an API for managing and requesting context information and an underlying meta model based on entities – the core information elements, often the digital counterparts of real-world objects – and their properties and relationships to other entities.[41]
- Even though the NGSI-LD specification has been published relatively recently, there are already three Open-Source implementations (Scorpio, djane and Orion-LD). Orion-LD is the NGSI-LD version of the Connecting Europe Facility (CEF) building block Context Broker.
- In addition, data models are needed that are, or can be made to be, compliant with NGSI-LD.
- NGSI-LD compliant data models for aspects of the smart city have been defined by organizations and projects, including OASC, FIWARE, GSMA and the SynchroniCity project and there is an ongoing joint activity of TM Forum and FIWARE to specify more.
- Existing data models and ontologies, e.g., the SAREF (Smart Applications REFerence ontology) standard by ETSI/oneM2M, can be mapped for use with NGSI-LD by identifying the entities, properties and relationships that can be managed and requested by the NGSI-LD API.
- oneM2M base ontology (that is compatible with SAREF). Additionally, oneM2M provides the means to instantiate ontologies to provide semantic descriptions of the data exchanged (through the use of metadata).

8.1.4 Verification

ETSI set up a Testing Task Force (TTF) to create a Testing toolkit to validate context brokers towards the NGSI-LD specification. The result was a set of clearly defined test descriptions, test purposes and executable robot scripts. All this information can be found on the ETSI CIM Website (ETSI, n.d.).

8.2 MIM 2: Shared Data Models

8.2.1 Goals

To provide:

- Guidelines and catalogue of minimum common data models in different verticals to enable interoperability for applications and systems among different cities and communities.
- Harmonized representation formats and semantics that will be used by applications to consume and publish data.
- Data Models for interoperable and replicable smart solutions in multiple sectors, starting with smart cities and communities but also for smart agri-food, smart utilities, smart industry, among others.

8.2.2 Capabilities

Data models serve as a language in which systems can talk to each other. Clear, defined data models help cities and communities in choosing and opening up data across solutions.

Data models should capture as much as possible of the complete context they are representing. This enables other applications to define what they need for their context and to request the specific attributes in which they are interested.

Harmonization across data models helps in supporting different data models again to support the different applications out there. Clear definitions of the data models help in transforming these data models between the different standards.

8.2.3 Recommended specifications

- NGSI-LD-compliant data models for aspects of the smart city have been defined by organizations and projects, including OASC, FIWARE, GSMA and the SynchroniCity project, and there is an ongoing joint activity of TM Forum and FIWARE to specify more. This led to a joint effort which resulted in the smart data models.[42]
- Existing data models and ontologies, e.g., the SAREF (Smart Applications REFerence ontology) standard by ETSI/oneM2M, can be mapped for use with NGSI-LD by identifying the entities, properties and relationships that can be managed and requested by the NGSI-LD API.
- oneM2M base ontology (that is compatible with SAREF). Additionally, oneM2M provides the means to instantiate ontologies as a means to provide semantic descriptions of the data exchanged (through the use of metadata).

- DTDL is the Digital twin Definition Language developed by Microsoft. This language is based on top of json-ld and the existing Fiware data models are converted in this format.

8.3 MIM 3: Ecosystem transaction management

8.3.1 Goals

Scaling of IoT- and AI-enabled services across many cities and communities requires easy and low-risk access to suitable urban data sources that are already deployed in cities and communities today – on terms that are reasonable and set by the inhabitants and their representatives. This is the aim of the MIM.

Europe is already developing a digital single market for the region and is looking at extending it to other areas with free-trading agreements such as Japan. Other countries and global regions are doing the same and the ultimate aim would be to have such a digital market extending worldwide. This would allow easy and low-risk access to relevant and available local data, solutions and other resources so that services, and solutions already deployed in other places can easily be scaled to reach mainstream deployment. The use and re-use of the data would lead to new revenue streams, incentivising the infrastructure owners to share data, analytics, services and/or solutions in infrastructure partnerships based on key technology enablers – always on the terms and conditions of the people who live in those territories where the virtual service provisioning is taking place.

With a set of such marketplaces established, all parties would be able to co-create applications, solutions, services, and guidelines on top of the common data models and standardized APIs. Facilitating this ecosystem of providers and consumers would lead to sustainable business models and fair mechanisms for sharing and the provision of fair compensation and to reduce the risk in investments.

8.3.2 Capabilities

Such a digital marketplace would realize standardized exposure of data and data sets guaranteeing security and privacy by design. The marketplace would also realize access to services that build on these data and transfer it to knowledge, intelligence and information for the consumers.

The marketplace would need to provide the following six capabilities:

- catalogue management;
- ordering management;
- revenue (sharing) management;
- SLA management;
- quality management; and

- data licence management.

A crucial aspect of enabling such a marketplace is ecosystem transaction management. This would need to include functionalities to enable effective matchmaking of urban IoT data sources from providers with respective data consumers, to facilitate trusted exploitation of such data based on enforceable data usage agreements and to secure value flow between these stakeholders.

There are various ways of realising such Ecosystem Transaction Management. A standardized way of doing so is provided by the TM Forum, which has created an API suite of specifications for digital marketplaces, named the Business API Ecosystem.

8.3.3 Recommended specifications

- TM Forum Open APIs and component suites provide a service and technology neutral suite of APIs that provide the minimum building blocks for interoperability across all operational management areas. Each API and component suite provide the specification, reference implementations and in most cases conformance test kits. Reference Implementations are available under the Apache2.0 license. These APIs have gained global adoption in the Telecommunications industry and are proven to maximize re-use. They are designed to be extendable as required for specific services. The respective data models have been harmonized with FIWARE and GSMA data models.
- UDX (Urban Data Exchange) Catalogue, coordinated by Urban Data Collective.
- SynchroniCity: Delivering an IoT enabled Digital Single Market for Europe and Beyond - Basic Data Marketplace Enablers.
- SynchroniCity: Delivering an IoT enabled Digital Single Market for Europe and Beyond - Guidelines for the integration of IoT devices in OASC compliant platforms.

8.4 MIM 4: Personal data management

8.4.1 Goals

Personal Data Management (PDM) means providing clear and easily usable means for inhabitants/ users to control which sets/attributes they want to share with solution, application or service providers under transparent circumstances, enabling trust between the different parties. Inhabitants should be able to identify themselves with an ID of their choosing and be able to transparently (dis)allow the service providers to access their data and control the granularity of the access (full, anonymously).

The following goals need to be achieved:

- The right to have insight into what personal data are available, stored and shared by the providers of the applications and/or services in use.
- The right to change and/or delete part of, or all, personal data available, stored and shared by the provider of the applications and/or services in use.
- The setting up of a "permission arrangement" indicating the circumstances in which personal data are available to which parties.
- The requesting and maintenance of consent from the users by the providers of the applications and/or services, be it governmental or businesses, that attribute-based, decentralized storage and "revealing" of personal data attributes provides full service and access to these applications and/or services.
- The creation of a centralized authentication service that aggregates public and private identity providers and creates a keychain of identifiers to be used by applications.
- The ability to initiate or revoke the consent by the users given to the party.
- The right to be forgotten by services.
- The ability to know in full transparency what data are tracked and stored from a user.
- The ability to port personal data between services in different cities and communities.

8.4.2 Capabilities

Personal data management systems need to be able to authenticate users based on a self-provided identity, linking their data in full transparency and making sure that a user can manage the data that is collected and allow service and solution providers to access the data on the terms and conditions that the users decide. In some cases, these systems need to be aligned with government initiatives like, for example, GDPR in Europe. Users also need the ability to determine the location and portability of the stored data, being able to choose where to store their health, insurance, or mobility data.

These PDMs need to offer a machine-readable audit function for persons (and their representatives) to be able to see personal data sets and activities relating to these data sets, e.g., operations involving aggregate data, like a search or analysis based on address/position/pseudo-ID).

8.4.3 Recommended specifications

- The MyData.org initiative that allows users to select the data operator for their data.[43, 44]
- IHAN as a testbed for fair Data economy.[45]

- Streamlining Governmental Processes by Putting Citizens in Control of Their Personal Data (Buyle *et al.*, 2019).
- When working on project architecture and use cases, re-use the "I Reveal My Attributes" (IRMA) architecture and apps.[46]
- Solid specification that allows people store their data securely in decentralized data stores (Solid, n.d.).

8.5 MIM 5: Transparent AI

8.5.1 Goals

Governments, including local governments, are increasingly seeking to capture the opportunities offered by automated decision-making using algorithmic systems, to improve their services. However, government agencies and the general public have justified concerns over bias, privacy, accountability and transparency of such automated decision-making processes. New examples continue to emerge of potential negative consequences from the inappropriate use of ("black box") algorithms.

Here, "Algorithmic System" is defined as: "software that automatically makes predictions, makes decisions and/or gives advice by using data analysis, statistics and/or self-learning logic."

An automated decision-making algorithmic system does not necessarily require any form of self-learning logic (such as machine learning). In actual practice, software is often used that does not contain any self-learning logic, but the application of which may have great and sometimes unknown or unintended impact on inhabitants.

To provide inhabitants and governments at all levels with a proper process to mitigate risk, Amsterdam city council, along with some other cities, proposed the Fair AI MIM 5 as part of their work to develop a European norm for procurement rules for government agencies to use when procuring algorithmic systems to support automated decision-making.[47] Alongside this, guidance is being developed in different global regions regarding the actions that government agencies themselves need to take to assess the level of impact and to make sure that automated decision making is trusted, fair and transparent. This will include providing channels for inhabitants to query the decision-making process and involving inhabitants in co-designing the algorithmic systems. Most importantly, there is the need to ensure that the data used by those systems is accurate and appropriate e.g., through publicly available algorithmic registries.

8.5.2 Capabilities

In order to match the procurement norm being developed, the following is the set of six minimal requirements for suppliers of algorithmic systems to ensure that they are fair, trustworthy and transparent.

Procedural Transparency

Full disclosure of the type of choices made, parties involved, risks and mitigation actions in the process of creating an algorithmic model.

Technical Transparency

- Full disclosure to allow the buyer of the source code and model to enable them to explain the model to inhabitants or other stakeholders.
- Access to the learnings of the model, ideally structured using MIM2, to prevent vendor lock-ins.
- Clarity about the process by which an algorithmic system makes decisions in an overall system, i.e., the optimization goals and outcomes of an algorithm.

Technical Explainability

- Ability to explain on an individual level how a model creates certain outcomes.
- Ability to address any restrictions as to whom the information will be classified: e.g., public servants and other experts.

Fairness

Ensuring that the algorithmic systems do not systematically disadvantage, show bias against, or even discriminate against different social groups and demographics.

Context

However, the assessment of fairness depends on facts, events, and goals and, therefore, has to be understood as situation or task-specific and necessarily addressed within the scope of practice. For instance, there may be an explicit goal to address a historic imbalance, where positive discrimination is considered appropriate. Here the aspect of "fairness" needs to be seen in the wider context.

Accountability

- Accountability for the supplier to create algorithms respecting human digital rights, and which are compliant with federal, state and local anti-discrimination laws.
- Agencies should not procure algorithms that are shielded from an independent validation and public review because of trade-secret or confidentiality claims.
- It must be noted that these capabilities should be applied differently to different systems depending on the nature, context and goals of the algorithmic system.
- Technically, these capabilities can be translated into a metadata API that every vendor would provide, when supplying high impact algorithms to cities and communities, and the buyers could put in their requirements when procuring.

8.5.3 Recommended Specifications

- Recommendation ITU-T Y.4470 Reference architecture of artificial intelligence service exposure for smart sustainable cities (ITU-T, 2020);
- ITU-T Y. Supplement 63 Unlocking Internet of Things with artificial intelligence (ITU-T, 2020);
- Danish Standards PAS DS/PAS 2500-1: 2020, Artificial Intelligence – Part 1: Transparency;[48]
- Danish Standards S/PAS 2500-2: 2020, Artificial Intelligence – Part 2: Decision-support usage in public administration.[49]

8.5.4 References

- Standard Clauses For Procurement Of Trustworthy Algorithmic Systems (City of Amsterdam, 2021);
- White Paper on Public AI Registers: Realising AI transparency and civic participation in government use of AI (Haataja et. al, 2020).

8.6 MIM 7: Geospatial information management

8.6.1 Goals

Specify how to share spatial (and spatio-temporal) data, and make them interoperable with, within, and between systems and territories. This goes from static data about assets such as streetlights, buildings and streets to spatio-temporal data from sensors. The purpose of this Minimal Interoperable Mechanism (MIM) is to make these data and the way they are shared interoperable across cities and communities, but also among stakeholders within the same city. This MIM will also provide input to MIM2 Data models, in particular regarding data that have an explicit geospatial dimension.

8.6.2 Capabilities

Geospatial information contains comprehensive bi-dimensional, tri-dimensional and (when time is also involved) four-dimensional representation of real-world entities defined in a structured way. Different datasets can be combined easily based on location. In addition, powerful spatial analyses and sophisticated visualization can be performed that provide important insights to different stakeholders in the city. It is, therefore, essential to include the geospatial data dimension into smart city information systems.

The discovery, querying, retrieval, visualization and editing of geospatial information based on location and temporal criteria can be achieved through open standard formats, protocols and preferably through the use of standardized API interfaces. Integrating context information with geospatial information can be enabled by the context management API and geospatial management API through common data information models defined in the MIM2 Data models.

8.6.3 Specifications

The specifications that are subject to adoption are focussing on:

i) web interfaces for discovery and access to data; and

ii) data encoding formats.

Web Interfaces

Specifications by the Open Geospatial Consortium (OGC).

OWS-based family of standards

Those OGC Web Services standards follow the same conceptual model. They are mature, well-known by the geospatial community and supported by a wide number of client and server implementations.[50]

- Catalogue Service for the Web (CSW)
- Web Map Service (WMS)
- Web Map Tile Service (WMTS)
- Web Feature Service (WFS)
- Web Coverage Service (WCS)
- Sensor Observation Service (SOS)
- API-based family of standards

The new OGC Web API family of standards are built upon the legacy of the OGC Web Service standards to define resource-centric APIs that take advantage of modern web development practices. These new standards are web-friendly and are being constructed as "building blocks" that can be used to assemble novel APIs for web access to geospatial content. (The following OGC APIs are at a different stage of development: Features, Common, Maps, Records, Processes, Coverages, Tiles, Environmental Data Retrieval).

- The OGC SensorThings API standard provides an open source and uniform API to connect IoT devices, data and applications on the Web; it provides a standard way to manage and retrieve observations and metadata from IoT sensors built on the legacy of the OGC SOS and SPS. The SensorThings API standard supports request-response and asynchronous transactions.
- The OGC API – Features standard provides a modular, encoding-agnostic and web-friendly means for the exposure of geospatial features on the web.

Data encoding

This section specifies data encodings for geospatial data that are also relevant for the provision of MIM2 Data models.

Semantic 3-D city models or digital twin standards for representing the entities of cities and landscapes.

- CityGML, an OGC open data model and XML-based format for the storage and exchange of virtual 3-D city models.
- CityJSON, a community standard, JSON-based encoding for storing 3-D city models, also called digital maquettes or digital twins.
- Industry Foundation Classes (IFC), a building Smart open, international standard (ISO 16739-1:2018), for a standardized, digital description of the built environment, including buildings and civil infrastructure.
- ISO Observations & Measurements, providing a conceptual model for representing spatio-temporal observation data. JSON and XML-based implementations of the conceptual model are available. This data encoding is the default for the OGC Sensor Observation Service (xml-based), and the Sensing profile of the OGC SensorThings API.
- GeoPackage provides an open, compact and efficient format for sharing geospatial data. It is based on an SQLite database, and is very well supported by proprietary and open-source software tools.

9 Conclusion

This Report has undertaken an important journey of acquiring a better understanding of smart city platforms. While the importance of data in enabling cities to become smarter and more sustainable was well acknowledged, urban stakeholders are now increasingly exploring new pathways for enhancing the existing urban architecture oriented towards sustainable digital development, keeping interoperability as the basis for all operations and leveraging existing data streams.

By reviewing existing smart city architectures to support the move to a platform-based approach to data management along with the list of key requirements for a city platform-enabled ecosystem, it was feasible to extrapolate the minimal interoperability mechanism for deploying the upgraded urban architecture for sustainable digital development.

The area of data platforms for cities and communities to support sustainable development is an evolving one, with leading cities pushing forward the boundaries of technology to enable them to provide better services and quality of life for their inhabitants.

However, the foundations for the new architecture covered in this report will remain the same, and the advice provided in this report will continue to be relevant and helpful for many years to come to cities and communities as they set out on this important journey.

One key recommendation is that further guidance should be developed to help cities and communities at whatever stage they are with their procurement of data platforms.

U4SSC will keep in touch with ongoing developments, capturing best practice and learning and making it available to help support cities and communities to become smarter and more sustainable.

To get engaged and to take the next steps, the reader is encouraged to follow the activities of ITU-T Study Group 20 on IoT and Smart Cities and Communities, and to participate in different fora where contributions to global standards and policy are being discussed and formed based on the needs of cities and communities.

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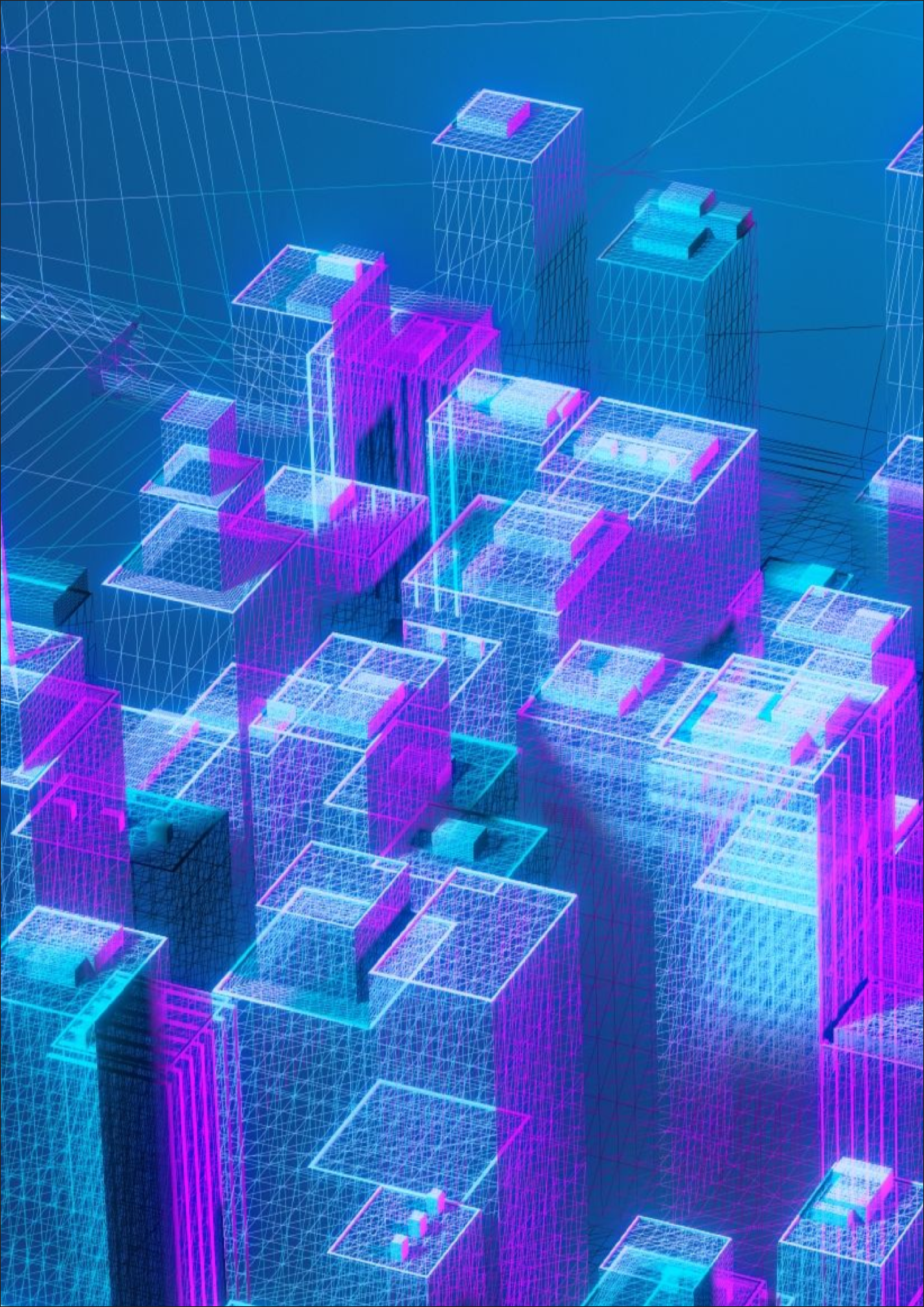

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