The Smart City Ontology 2.0:
Assessing the components and interdependencies of city smartness

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Abstract

The paper is a follow-up of a previous investigation and effort to develop the ontology of the smart city (Komninos, N., Bratsas, C., Kakderi, C., and Tsarchopoulos, P. "Smart city ontologies: Improving the effectiveness of smart city applications". *Journal of Smart Cities*, vol. 1(1), 1-17. https://www.komninos.eu/wp-content/uploads/2015/07/2015-Smart-City-Ontologies-Published.pdf). Since the publication of this article in 2015, research and literature on smart cities have evolved significantly, as have the technologies for digital spaces and applications that support city functions. These developments are reflected in the present form of the smart city ontology 2.0 we propose. It depicts the building blocks of the smart city ontology (technologies, structure, function, planning), and the object properties and data properties that connect structural blocks and classes. The aim of the SCO 2.0 is to provide a better understanding and description of the smart/intelligent city landscape; identify the main components and processes, the terms used to describe them, their definition and meaning; clarify key processes related to the integration of the different dimensions of the smart city, mainly the physical, social, and digital dimensions. The paper is accompanied by an owl file, developing the ontology through the editor Protégé.

Key words: intelligent city; smart city; smart ecosystem; ontology; city smartness

1.Introduction

The origin of the present work goes back to 2015 at the first attempt to define the smart city ontology (SCO 1.0) (Komninos et al., 2015). In the framework of that work, the aim of developing an ontology of the smart city was to assess smart city applications and e-services. The underlying hypothesis connected the effectiveness of software applications and e-services to their ontology, and in particular their position in the overall smart city ontology. Thus, the aim of SCO 1.0 was to define how wide and effective was the ontology of a smart city application. Another version (SCO 1.1) was developed in 2018 with minor changes in classes, but it was not released and remained for internal use in our lab.

Since these first attempts for an SCO, many things have changed in the domain of smart cities, both in theory and practice. We may say that currently, we have a better understanding of the smart city landscape, the family of terms proposed and used, their meaning, and their relationships. Also, the work on platforms and frameworks for the development of ontologies has progressed and we now dispose of more elaborated high-level ontologies for the design of domain-specific ontologies, such as BFO, DOLCE, and others.

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The present work and development of SCO continue the efforts that started in 2015, integrates and re-uses many of the initial entities (classes, object properties, data properties) but also has some important differences. The most important differences are about (a) the aim of the SCO development and (b) the use of the Basic Formal Ontology (BFO) as a high-level ontology to develop a domain-specific ontology for the smart city. The motivation for continuing this work has been the interest of the smart city community for an ontology of the smart city, the many demands that we have received for providing the owl file of the SCO 1.0 to be used in various other experiments and assessments, as well as the few works that can be found in the literature on this subject, besides the plethora of publications on smart cities.

The aim of the SCO 2.0 is to provide a better understanding and description of the smart/intelligent city landscape; identify the main components and processes, the terms used to describe them, their definition and meaning; clarify key processes related to integration of the different dimensions of the smart city, mainly the physical, social, and digital dimensions. Also, we have two specific goals. First to help researchers and smart city developers identify areas in which smart technologies and solutions may improve the digital infrastructures and e-services that cities provide. Smart cities evolve by integrating digital and non-digital city elements. Identifying virgin areas of digital transformation may help to develop new smart city solutions for optimization of assets and the design of innovative e-services. Second to provide a framework for more extensive work on the smart city ontology, leading to a full SCO from the community of researchers working in this field.

The smart city is becoming the standard model for the design and development of 21st-century cities, addressing the grand challenges of sustainability, climate change, platform-based growth, safety and security, and the SCO is a fundamental pillar for the informed use and further development of this model, which is shaped by interdisciplinary efforts from the engineering, social sciences, and information technology.

An important contribution of the SCO is to reveal linkages between the digital and non-digital dimensions of the city and improve both: the physical and social space of the city through the deployment of digital services, data, and Internet infrastructure; the digital space of cities and solutions by considering the dynamics of the physical and social space of the city, and revealing fields for further deployment.

2. The Basic Formal Ontology (BFO)

> "In 1993, Gruber originally defined the notion of an ontology as an "explicit specification of a conceptualization" [7]. In 1997, Borst defined an ontology as a "formal specification of a shared conceptualization" [1]. This definition additionally required that the conceptualization should express a shared view between several parties, a consensus rather than an individual view. Also, such conceptualization should be expressed in a (formal) machine readable format. In 1998, Studer et al. [15] merged these two definitions stating that: "An ontology is a formal, explicit specification of a shared conceptualization."
>
> *Guarino, Oberle, and Staab (2009, p.2)*

The Basic Formal Ontology (BFO) that we use as a high-level ontology to guide the design of a domain-specific ontology for the smart city, deviates from the above understanding, considering the term 'concept' as ambiguous and proposing the term 'universal' for the ontology classes. Thus, ontologies deal with 'types' (or 'universals'), what is general in reality, rather than 'particulars' (or 'instances').

For the BFO, ontologies are representations of the reality that is described by science. This is the fundamental principle of ontological realism (Smith and Ceusters, 2010), which is quite consistent with the aim of BFO: "BFO's primary goal is to assist scientists and others in the development of practically useful, accurate, coherent, and interoperable domain ontologies by providing a starting point for downward population through the formulation of Aristotelian definitions" (Spear, Ceusters, and Smith, 2016, p. 111).

The BFO proposes an organization of entities valid for any domain of reality along two dimensions: time and scale. The time dimension classifies entities in 'continuant' and 'occurrent', while the scale dimension classifies entities by their granularity. The architecture of the BFO 2.0 version is presented in figure 1.
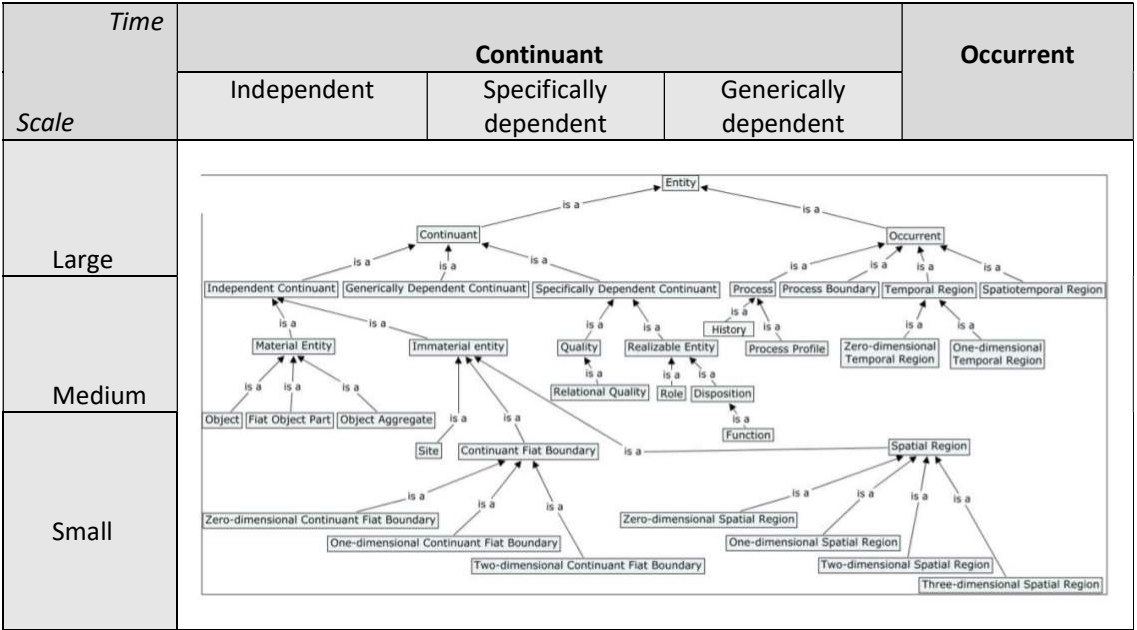

Figure 1: BFO 2.0 architecture
Source: Adapted from BFO 2.0 Specification and User Guide, p. 3

A series of publications inform about the architecture and terms of the BFO (Arp and Smith, 2008; Arp, Smith, and Spear, 2015; Spear, Ceusters, and Smith, 2016) and how it can be used in specific domains of science and technology (Brandão, and Loureiro, 2020; Smith, 2020; Hagedorn et al., 2019; Iliadis, 2019). Information resources are provided on the BFO website (https://basic-formal-ontology.org/), key publications (https://basic-formal-ontology.org/publications.html), as well as video tutorials ranging from introduction to particular topics and applications (https://www.youtube.com/user/hxo3nql/playlists?view=50&sort=dd&shelf_id=2). Extremely useful is the *BFO 2.0 Specification and Guide*, "a guide for those using Basic Formal Ontology (BFO) as an upper-level (formal, domain-neutral) ontology to support the creation of lower-level domain ontologies" (Smith, 2015, p. 1).

Key principles described in the BFO 2.0 Specification and Guide are:
- "An entity is anything that exists" (p.6).
- ''Entities can be divided into instances (your heart, my laptop) and universals or types (heart, laptop)'' (p.6)
- ''All entities are either particular or universal'' (p.11).

- ''The dichotomy between continuant and occurrent ontologies forms the central organizing axis of the BFO ontology. Continuant entities are entities which can be sliced to yield parts only along the spatial dimension'' (p.16). "An occurrent is an entity that unfolds itself in time or it is the instantaneous boundary of such an entity (for example a beginning or an ending) or it is a temporal or spatiotemporal region which such an entity occupies_temporal_region or occupies_spatiotemporal_region'' (p.66).
- ''Universals have instances, which in BFO are in every case particulars (entities located in specific regions of space and time)'' (p.10).
- "Whether an entity is a particular or a universal is not a matter of arbitrary choice or of convenience. It is not up to BFO to decide what universals exist in any given domain; this decision is made by domain experts" (p.10).
- ''Entities are linked together in relations, at the level of both instances and types'' (16).
- "Three groups of relations are distinguished: (I) Instance-level relations. (II) Type-level relations. (III) Instance-type relations (p.7).
- ''Definitions of terms are required to be always of the form: A = Def. B which Ds. where 'A' is the term to be defined, 'B' is its immediate parent in the relevant BFO-conformant ontology hierarchy, and 'D' is the differentiating criterion specifying what it is about certain Bs in virtue of which they are As (p.8)''

Some other important premises of the BFO are:

- The distinction between s-dependent and d-dependent: Specifically dependent (s-dependent) continuant is an entity dependent from a continuant dependent. Generically dependent (g-dependent) continuant is a continuant that depends on one or more other entities. Specifically dependent continuants are subject to the axiom of non-migration – they cannot migrate from one bearer to another. Generically dependent continuants, in contrast, can in a sense migrate, namely through a process of exact copying.
- The distinction between type and collection: "The distinction between collections and types is used by scientists themselves to monitor progress in discovering the structure of reality. Discovering universals is a scientific achievement".
- Terminology: In a domain-specific ontology, all terms are singular nouns because they represent universals, not instances or particulars. Universals are types not collections of instances. The rationale is that science is about types and universals, not specific particulars, objects, or people.
- Also, a domain-specific ontology should have a modular architecture. A hub and spoke architecture might be very appropriate for this goal.

3.The smart city ontology from the BFO perspective

The BFO is the guiding framework for the development of the Smart City Ontology. The domain-specific knowledge necessary for the SCO is provided by our publications in this field over the last 20 years, and mainly the concepts and solutions we have discussed in Komninos (2002, 2008, 2014, 2020) and Komninos and Kakderi (2019). We intend to describe the highest levels of the SCO tree, including classes and properties, rather than the full and exhaustive ontology from top to bottom. We start with the first-level universals and the way these are connected.

We follow the BFO principles and architecture in most parts of our work on the smart city ontology with one exception: the monohierarchy principle, according to which each node in the graph of universals should have at most one asserted parent. This principle adds simplicity, clear structure, and helps to prevent many errors in ontology construction. But it does not correspond to reality as the meaning comes from structures and networks of terms (Greimas, 1970; 2015), and the same term can be found under many different branches of the smart city tree.

3.1. First level universals (Owl: classes)

In the time dimension, we have the three types of continuant entities, the independent continuant, the Generally Dependent Continuant and the Specifically Dependent Continuant (G-dependent continuant and S-dependent continuant) and the occurrent classes. The yellow color is for the independent continuant, the brown for the two types of dependent continuants, and the green for the occurrent. In the scale (or granularity) dimension, we use three scales, the 'city', the 'city component', and the 'city element'.

A key decision in the time and scale dimensions of the SCO is about the first level universals that capture the entire set of the smart city classes.

RELATION TO TIME GRANULARITY	CONTINUANT				OCCURENT
	INDEPENDENT CONTINUANT	**G-DEPENDENT CONTINUANT**		**S-DEPENDENT CONTINUANT**	
CITY	Community	Architecture	Function	Standard	Urbanization
	Environmental context			Document	Environmental process
	Cyber-physical city	Challenge	e-Service innovation	Space representation	Planning
COMPONENT	Subsystem			Plan	Governance
ELEMENT	Element	Output		Data	Social movement
	Boundary			Algorithm	Digital system design

Table 1: The SCO 2.0 organized by the BFO architecture

As it appears in table 1, in the independent continuant class, we propose the universal 'community', 'cyber-physical city' for any type of smart or intelligent city, 'environmental context' for the climate, natural resources, natural ecosystems of the city, 'cyber-physical subsystem' for any type of large-scale component of the 'cyber-physical city', a category in accordance to the understanding of the city as a system of systems (IBM Institute for Business Value, 2009), and 'city element' for any type of elements composing the 'cyber-physical city'. The 'cyber-physical city' is the wider type of any kind of smart, intelligent, digital, cyber, etc., city, and it differentiates all these types from the pro-Internet period in which the cyber and digital dimensions of the city were absent. A connotation, in addition to the explicit meaning of the term 'cyber-physical city', is the association of the smart city with the digital world and the information technology as main drivers of this new type of city. 'Community' is a fundamental independent continuant, covering whatever is related to people and legal persons located in the city.

In the generally dependent continuant class, we organize the 1st-level universals with respect to dichotomies 'challenge' vs 'innovation', 'architecture' vs 'function', and 'e-service' and 'output' for any kind of economic, social and environmental output. All these universals are directly dependent on the type of cyber-physical city, its subsystems, elements, and the natural and legal persons of cities.

In the specifically dependent continuant class, we propose six types of information continuants to classify standards (planning standards, ISO, Web, etc.); documents for any type of document, book, paper, manual, report; any kind of 2D or 3D plan; space representations, such as a map, photo, video,

and other; software; data for any data including personal or related to organizations located in the city; and algorithm.

Finally, in the occurrent class, we propose as 1st-level universals those of 'urbanization process' for any kind grassroots process; 'policy process' for the wider decision making and political representation and engagement determining city planning; 'planning' for any kind of city and regional planning, intra- and inter-city, including also supra-city plans related to the city; 'social movement' for grassroots political movements influencing city planning; 'digital system design' as a separate and distinctive class not covered by planning as it has been shaped over the 20th century.

Thus, the SCO 2.0 includes 23 first-level classes compared to the 10 classes first-level classes of SCO 1.0. This is not however the only difference. Equally important are the changes in the classes of these constituting components, processes, and planning.

3.2. Hubs, spokes, and relationships (Owl: object properties)
The way the 1st level classes are connected defines the high-level architecture of the smart city ontology. In figure 2, the text of a sample of smart city definitions is represented by a Wordle cloud. Three areas can be distinguished.

Figure 2: Wordle cloud of intelligent city and smart city definitions
Source: Komninos (2014, p. 23)

At the left side, a group of entities describing the city and its elements, such as community, activities, citizens, and characteristics. On the right side are entities related to smart systems, urban technology, strategies and planning, sustainable development. In the center are the information, knowledge, and innovation processes that support the intelligence of the smart city.

A quasi-similar architecture we propose in figure 3 as the structure of the 1st level smart city classes. It contains three hubs and a group of spokes per hub, both from the continuant and occurrent classes.

At the left side of the figure is the 'community' hub containing elements of high and low granularity, such as entities, organized in architectures, city subsystems, and types of cyber-physical cities. At the bottom right side of the figure is the 'smart city planning' hub and around it the entities related to planning, such as challenge, governance, social movement, and digital system design, which determine or are determined from city planning. At the center is the hub are dependent continuant

entities that shape the smart city, with 'data' and 'e-service innovation' as core entities, and architecture, function, and output as spokes.

17 out of the 23 1st-level entities, defined in section 3.1, are linked with various relationships in the smart city architecture depicted in Figure 3. Not included are the generally dependent continuant classes (except for data), which gather various types of information related to the main universal of the smart city. However, this does not affect the entire structure as the informational entities are dependent descriptors of independent continuant entities.

The 3-hub landscape of the smart city corresponds to the theory of city formation and development. Any city is shaped by the convergence of bottom-up urbanization processes and top-down planning processes, having the provision of services at the core of the city's added value. This city formation and evolution understanding are also valid for the cyber-physical city, the smart or intelligent city.

In the next section, we take one-by-one these seventeen 1st-level smart city classes and look into their constituting sub-types and organization.
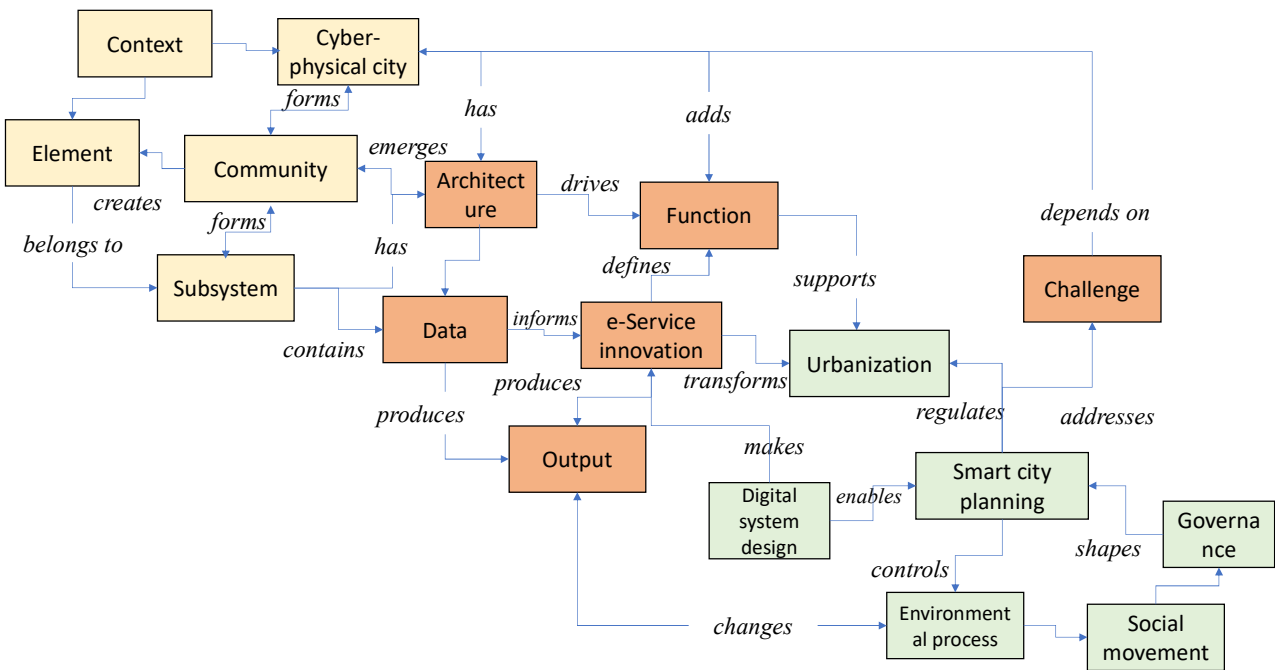

Figure 3: Fundamental relations between SCO 2.0 1st-level classes

4. The 1st-level smart city ontology classes

The SCO evolves from the set of the 1st-level classes, which provide the high-level structure of the SCO. Per class (type or universal) we give some clarifications on the meaning, and we propose some sub-types. However, this downstream classification is not exhaustive and more sub-types of the universals can be added. Above all, we intend to show the forms and subtypes that each class contains and how components are organized.

4.1. Community
A large number of definitions of 'community' led authors to consider it as a non-concept that confuses rather than elucidate the respective reality (Clark, 1973). With the rise of the Internet and the world wide web the interest in communities, and virtual communities, in particular, has risen. In cyberspace,

the community is a structure "in which network nodes are joined together in tightly knit groups, between which there are only looser connections" (Girvan and Newman, 2002, p. 7821).

Frequently we use the term community to refer to a physical concentration of individuals in one place. This meaning also has a connotation about the social organization among the spatial gathering of the population (Minar and Greer, 2017). This ecological understanding is dominant in the city literature, and the spatial concentration of population and activities (urbanization), is the fundamental process of city formation and growth.

Brint (2001) proposed a typology of the community based on identifying structurally distinct subtypes defined by a small number of partitioning variables. These include (a) the context of interaction, (b) the primary motivation for interaction, (c) the rates of interaction and location of members; and (d) the amount of face-to-face as opposed to computer-mediated interaction. These four partitioning variables produce eight major subtypes of community, depicted in Figure 4.
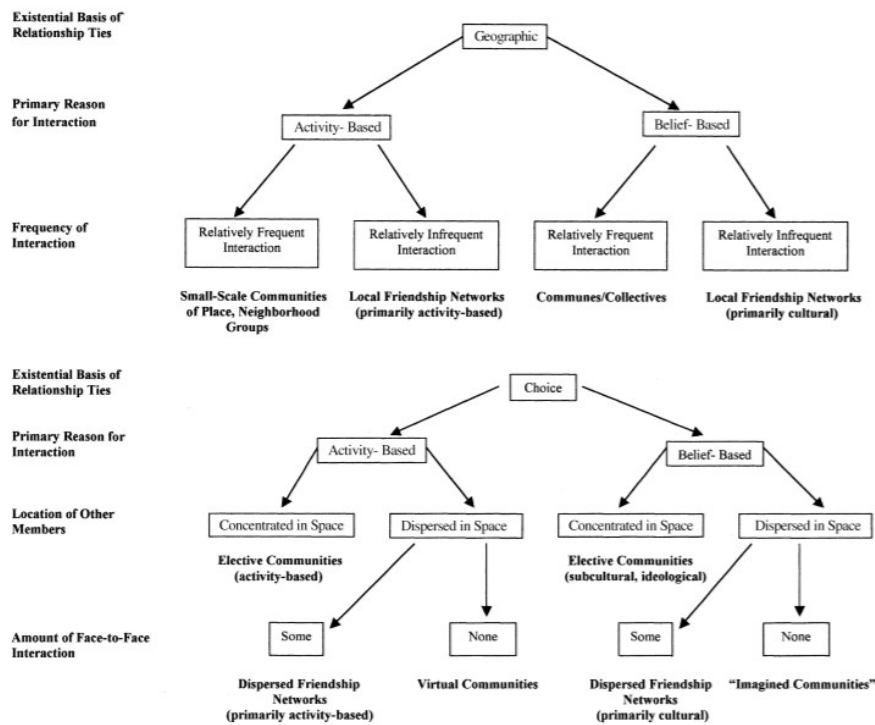

Figure 4: Types of Community
Source: Brint (2001)

Eight types of community derive from the four branching variables, defining major subtypes of community structure: (1) communities of place, (2) communes and collectives, (3) localized friendship networks, (4) dispersed friendship networks, (5) activity-based elective communities, (6) belief-based elective communities, (7) imagined communities, and (8) virtual communities.

Moreover, the *LEED v4.1 Cities and Communities*, a global standard for green cities design, construction, operation and performance, defines communities as following: "Communities are defined as every urbanized location that is not a "city," including sub-city locations (such as districts), and meta-city regions (such as counties). In addition, privately developed or owned urban areas (for example, Songdo District or Rockefeller Center) generally fit within the definition of "Community,"

except where they are self-identified (per definition of "city" above) as cities." (https://rb.gy/rtwxse). This definition is close to our city subsystem or city ecosystem defined by areas, activities, or networks.

In the SCO class 'community' we merge the above two perspectives of community types.

4.2. Environmental context

This 1st-level class includes also the context related to the natural environment and resources on which a city stands, as well as the natural ecosystems within the administrative boundaries of a city. To describe continuant and occurrent entities of this class, we borrow and reuse some classes from the 'Environment Ontology' (ENVO) developed by Buttigieg et al. (2013; 2016). The full ENVO is available at the BFO website (http://obofoundry.org/ontology/envo.html). It is a community ontology to help humans, machines, and semantic web applications understand environmental entities of all kinds and scales. The ENVO is a large ontology, going down to very detailed environmental assets and processes. Linking the SCO to the entire set of ENVO entities would be disproportional to SCO.

From a large catalog of environmental assets, we focus on entities most relevant for the smart city development and planning, such as those related to:

- Renewable energy: geothermal, wind, solar, and rain activity
- Natural ecosystems: animal habitat, aquatic environments, monuments of nature
- Physical resources: agricultural land, mines, forests, water bodies, mountains

LEED v4.1 Cities and Communities defines natural resources as following: "Natural resource areas include but are not limited to critical aquifer recharge areas; deserts and arid lands; fish or wildlife habitat, natural deltas or floodplains, steep slopes, natural parkland, forests, geologically hazardous areas, grasslands and prairies, habitats of endangered and threatened species, shorelines and their buffers, streams and their buffers and wetlands."

4.3. Element

Probably, this is the most important entity of the smart city ontology, defining its low-level ingredients. Following the BFO, these entities can be 'object', 'fiat object part', 'object aggregate', a 'site' or 'fiat boundary' (see Fig. 1).

We distinguish four types of elements:

- elements composing the physical space of the city, such as buildings, roads, bridges, parks and green areas, monuments, mobile city equipment, sites, and areas
- elements composing the social space of the city, such as activities and land uses, which have a material dimension (e.g., land use reflected on the physical space) or immaterial dimension (e.g., institution, legal person, company, organization)
- digital elements composing the digital space of cities, which can be classified into different layers of the smart city digital space, from small components such as sensors and actuators to applications and e-services, urban operating systems, and large-scale broadband networks extending over the entire city
- human elements, people, citizens, and visitors of the city.

In the elements of the physical space and social space of the smart city, we find three core entities that cross many other classes also. These are the 'Area", the 'Activity', and the 'Network'. The classification of types of areas, activities, and networks are used for classifying more complex smart city entities such as ecosystems and e-Services. The owl file at the end of the paper shows the subcategories of areas (also for districts), activities, and networks (also for infrastructure).

In the smart city ontology, we do not apply the classification of the BFO in material and immaterial entities of the independent continuant class (see Figure 1) and we are classifying social elements under the class of 'smart city element', both for material and immaterial entities. It happens for many immaterial entities (e.g., land uses, companies) to be tightly linked to their material part. Land uses and building uses, for instance, are tightly connected to their physical form, which is shaped by activities and functions. But over the long run, the physical form is detached from the usage, and what has been designed and used initially as a house can be now a museum, and what has been initially designed and used as a palace to house a parliament.

Figure 5 provides a good overview of the digital elements in the smart city, organized in four successive layers of sensing, network, data and computing, and applications at the top. Each layer comprises its components. We use this structure to define the digital elements of the smart city in the owl file and classification. Digital elements together with business models (see s-dependent continuant for documents) form e-services, which are at the core of the second hub of the smart city ontology.
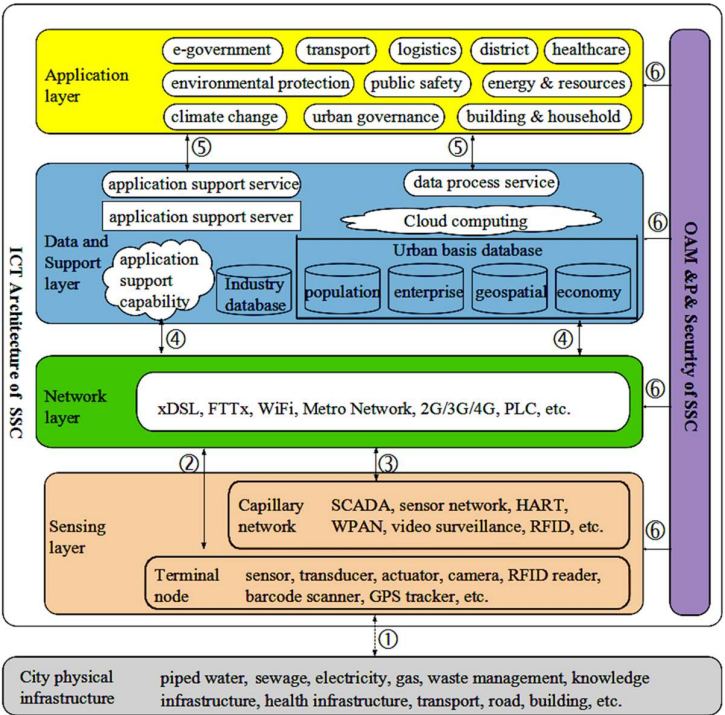

Figure 5: Layers and elements of the digital space of cities
Source: FG-SCC, ITUT (2015

An important classification standard we use in the elements of the social space is the NACE classification of activities. As shown in Table 2, NACE classifies activities into 4 levels (sections, divisions, groups, classes). In the owl file, we have the classification of activities by sections. Most usual however is the classification by divisions.

4.4. Subsystem

The subsystems of a cyber-physical city (smart city included) reflect the idea of the city as a system of systems. Smart city subsystems are integral entities of a city with well-defined functions but depending on other city subsystems. Urban transport is a good example of a city subsystem. It is composed of elements specific to transport (roads, lanes, cross-sections, vehicles, etc.), it has a clear function different from the function of other city subsystems (health, education, etc.), but depends

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on the city and its subsystems, the allocation of activities and land uses and the daily commuting patterns.

In definitions of the smart city usually cited, we find the subsystem perspective:

- "A Smart City is a city well performing in a forward-looking way in these six characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens". These areas include the smart economy, smart people, smart governance, smart mobility, smart environment, smart living. (Giffinger et al., 2007, p. 11).
- Along the same line, Frost & Sullivan (2019) has defined the smart city as one that has an active presence and plan in at least five of the eight areas (smart governance, smart energy, smart building, smart mobility, smart infrastructure, smart technology, smart healthcare, smart citizen) and has demonstrated and implemented projects in place.

Other terms we usually find that denote smart city subsystems are the 'silo' and the 'vertical market'. In the 'silo' perspective, these entities do not communicate with each other, which there are clear benefits from interoperability, information, and knowledge transfer. In the 'vertical market' perspective, the smart city is segmented into markets with different value sizes, which grow independently, with their specific growth rates.

We prefer the term 'ecosystem' to denote these smart city subsystems. The spatial specialization of urban areas in industrial, trade, education, housing, and other districts is an expression of the ecosystem logic: groups of activities form ecosystems, connected by collaboration chains, externalities, and platform-type infrastructures. Ecosystems appear under many different forms, as supply chains of commodities, clusters of co-located activities, city districts, land use zones, activity parks, groupings of activities in interaction with each other, organizations over common platforms, and networks of interrelated entities. Each city ecosystem brings together all the universals of the smart city ontology, presented in Figure 3, in its specific domain.

But how many subsystems, silos, vertical markets, or ecosystems do exist in a smart city? Well, it depends on the level of granularity we chose to define them. The classical NACE classification of economic activities includes 21 Sections, 88 Divisions, 272 Groups, and 615 Classes (Table 2). Each one can be considered as a 'silo', or a 'vertical market', or an 'ecosystem'.

Section	Division	Group	Class	Description of the class
C	25	25.9	25.91	Manufacture of steel drums and similar containers
	28	28.1	28.11	Manufacture of engines and turbines, except aircraft, vehicle ar
		28.2	28.24	Manufacture of power-driven hand tools
		28.9	28.93	Manufacture of machinery for food, beverages and tobacco pro
			28.95	Manufacture of machinery for paper and paperboard producti
G	46	46.1	46.14	Agents involved in the sale of machinery, industrial equipment
		46.6	46.61	Wholesale of agricultural machinery, equipment and supplies
M	71	71.1	71.12	Engineering activities and related technical consultancy

Table 2: NACE industry classification in sections, divisions, groups, classes
Source: NACE, rev.2, p.28

Twenty ecosystems that we usually find in a city, even a small one, are listed in Figure 6. Each one is a potential smart city ecosystem or a smart city subsystem. A more detailed classification is given in the owl file that codifies the entities of the smart city ontology.
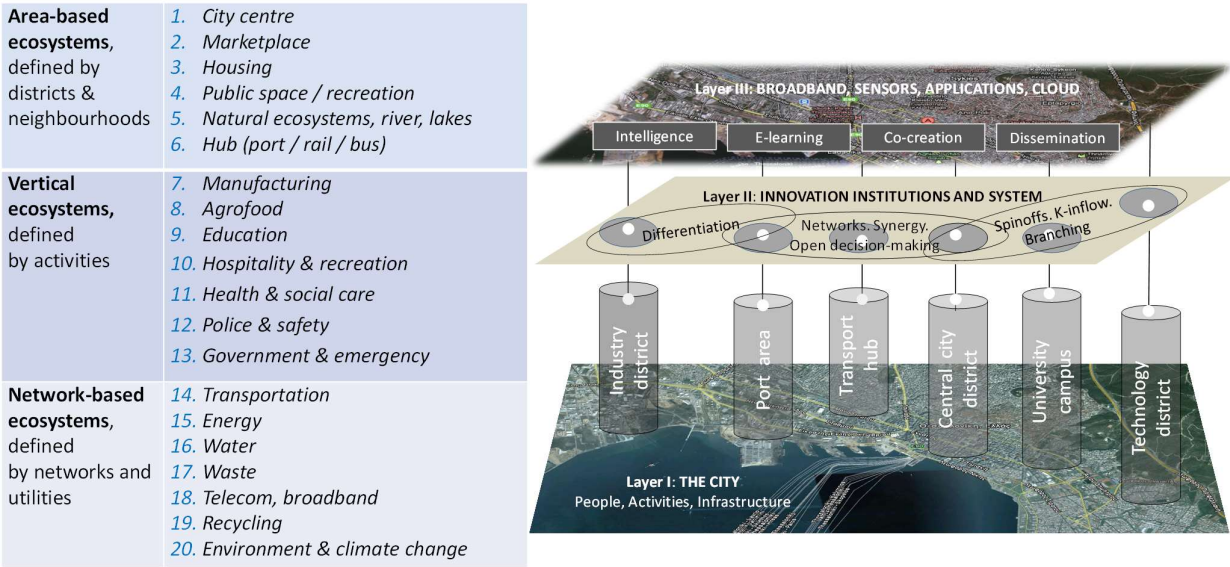
Area-based ecosystems, defined by districts & neighbourhoods	1. *City centre* 2. *Marketplace* 3. *Housing* 4. *Public space / recreation* 5. *Natural ecosystems, river, lakes* 6. *Hub (port / rail / bus)*
Vertical ecosystems, defined by activities	7. *Manufacturing* 8. *Agrofood* 9. *Education* 10. *Hospitality & recreation* 11. *Health & social care* 12. *Police & safety* 13. *Government & emergency*
Network-based ecosystems, defined by networks and utilities	14. *Transportation* 15. *Energy* 16. *Water* 17. *Waste* 18. *Telecom, broadband* 19. *Recycling* 20. *Environment & climate change*

Figure 6: Twenty most usual ecosystems in smart cities

4.5. Cyber-physical city

From a bot-up point of view, smart city elements (physical, social, digital, and human) are organized in smart city subsystems, which in turn make a smart city. The cyber-physical city, as a more general type of city in the Internet era, has all features and qualities of the city plus the information, knowledge, and innovation generated by Information and Communication Technologies, IoT, and smart systems. It is not a reality in cyberspace or the digital space of the computer, but a complex physical, social, and digital reality.

Types of the cyber-physical city are:
- the 'digital city', which is mainly a representation of the city in the digital space
- the 'cyber city', a digital city focused on decision-making, government, and governance
- the 'intelligent city', a cyber-physical city in which e-services and data are improving human capabilities, skills, and decision making
- the 'intelligent community' that covers both district-based, city-based, and region-based intelligent cities or territories
- The 'Smart city', a cyber-physical city in which e-services and data optimize city processes and infrastructures mainly through automation
- The 'Internet city' a synonym of 'smart city', used in a few cases in digital city transformation (e.g., Dubai Internet City), in publications (The Internet City, a book of Edward Elgar Publishing). The term may also denote any kind of digital city, cyber, smart, or intelligent city.

Should we include the digital city or the virtual city or the cyber-city, which exists only in computers as types of smart or intelligent city? Yes, because they do have a social dimension, setting social relations and interactions between humans, and some physical dimension through the broadband infrastructure, cloud, and computer infrastructure needed to their existence.

'City 2.0' is also a relevant term for the cyber-physical city. It is a concept that depicts an essential in urban life. "Its roots are in the idea of Web 2.0, but as a concept, it is much richer and broader in scope. In essence, City 2.0 combines social, technological, democratic, and sustainable aspects of urban life revolving around innovative and democratic urban governance." (Anttiroiko, 2012, p. 17).

4.6. Challenge

The challenges of the cyber-physical city, the smart city included as a sub-type of the former, are the usual challenges of cities plus the challenges related to smart systems and technologies. Thus, apart from the grand challenges of cities in the areas of growth, employment and poverty, sustainability, safety and security (Komninos, 2020), we should add those related to applying and maintaining a high level of digital infrastructure, data, applications, and e-services, such as cyber-crime, high volatility, personal data protection, new social divides around digital assets and skills.

Challenges change with the type and location of cities. For instance, while the wealth of cities in developed counties is linked to the increase of productivity, in developing counties wealth comes with diversification from traditional to higher-value products and services (Hausmann, 2015). The same is true at the sub-national level. National growth is not reflected uniformly at the regional and local levels. The cities and regions of a country do not follow the same development path, nor do they exhibit the same growth rates. However, this variety does not affect the typology and classes of smart city challenges.

Challenges change also over time. The current challenges for environmental sustainability, CO_2 emissions, climate adaptation, energy-saving and transition to renewable energy, recycling of materials, and the circular economy, are rather new. As the world continues to urbanize, these sustainable development challenges are increasingly concentrated in cities, particularly in those cities where urbanization is very rapid.

Table 4 shows the most usual types of challenges in cities, which are inherited to smart cities. They are classified into four main typical domains of cities, (1) challenges related to economy, (2) living conditions, (3) infrastructure and utilities, and (4) government. Two more domains added in the owl file covers challenges related to climate change, and digital infrastructure, e-services, and digital skills. Challenges may relate to independent continuant (object-related) and occurrent (process-related). We should further examine whether they should be presented in one or two classes.

Economy		Infrastructure and Utility	
Growth	- GDP and employment growth - City growth - Suburban growth - Innovation - Extroversion - Attraction of talent and investment	*Mobility*	- Traffic jam - Long commute - Pollution due to traffic - Parking shortage - Traffic accident
Decline	- Decline of industry - Disinvestment / capital flight - Brain-drain - Urban decay / inner-city decline - Poverty - Unemployment / job loss - Social and economic divide	*Utility: energy, water, waste, Internet*	-Renewable energy provision -Shortage of electric power -Energy saving -Clean water provision -Waste disposal -Aging infrastructure -Low broadband
Living conditions – quality of life		Governance	
Housing	-Lack of housing -Homelessness -Slums and squatter areas -Illegal housing -Crowding / high-density area -Gentrification	*Decision-making*	-Non-transparent government -Undemocratic government -Closed government -Non-participatory government -Planning shortage

Crime	-Crime, gang activity -Violence, aggression -Vandalism -Safety and security	System failure	-Corruption -Political clientelism -Red tape -Fiscal crisis -Planning failure
Social care	-Public health -Social care for vulnerable group -Health in low-income neighborhood	Access to services	- A few online services - Disregard of citizen's request - Low-quality services
Climate change		**Digital system**	
Environmental degradation	-Air pollution -Pollution of land -Water pollution -Natural habitat at risk	Infrastructure	-High Speed Broadband
		e-service	-At various domains of services -Data analytics
Greenhouse gas emission	-CO_2 emission -Methane - Other GG (nitrous oxide fluorinated gases)	Digital skill	-Shortage of digital skills

Table 4: Most common smart city challenges

4.7. Data

Back in 2017, *The Economist* published a story titled "The world's most valuable resource is no longer oil, but data." This statement is quite relevant for smart cities with data being their oil to burn and function.

Data are "factual information (such as measurements or statistics) used as a basis for reasoning, discussion, or calculation" (Merriam-Webster); "information, especially facts or numbers, collected to be examined and considered and used to help decision-making, or information in an electronic form that can be stored and used by a computer" (Cambridge Dictionary); "characteristics or information, usually numerical, that are collected through observation. In a more technical sense, data are a set of values of qualitative or quantitative variables about one or more persons or objects, while a datum (singular of data) is a single value of a single variable" (Wikipedia).

Data can be classified from different perspectives, each leading to different datatypes:
- By size and volatility: big data, small data
- By access: open data, restricted data
- By subject: personal data, non-personally identifiable data
- By source: sensor data, social media data, crowdsourcing data.

Different types of data are defined and used in the framework of programming languages:
- In XML, a 'datatype' is a 3-tuple, consisting of (a) a set of distinct values, called its 'value space', (b) a set of lexical representations, called its 'lexical space', and (c) a set of 'facets' that characterize properties of the 'value space', individual values or lexical items. Main datatypes are 'Primitive' (string, boolean, decimal, float, double, duration, dateTime, time, date, gYearMonth, gYear, gMonthDay, gDay, gMonth, hexBinary, base64Binary, anyURI, QName, NOTATION) and 'Derived' (normalizedString, token, language, NMTOKEN, NMTOKENS, Name, NCName, ID, IDREF, IDREFS, ENTITY, ENTITIES, integer, nonPositiveInteger, negativeInteger,

long, short, byte, nonNegativeInteger, unsignedLong, unsignedInt, unsignedShort, unsignedByte, positiveInteger

- Java uses a quasi-similar classification presented in Figure 7-up
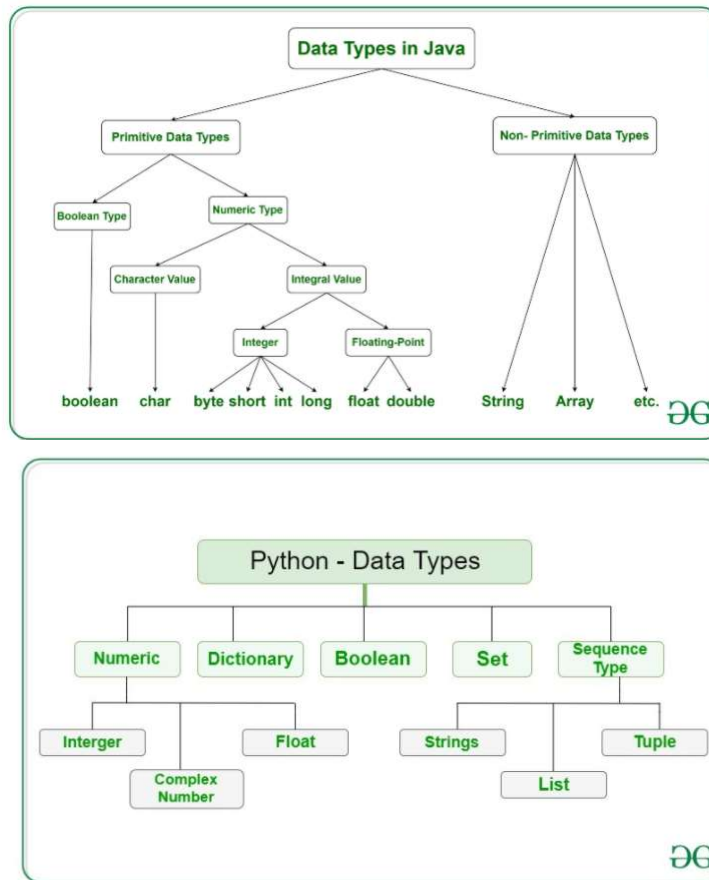- Fewer categories and types are in Python, as shown in Figure 7-down

Figure 7: Datatypes in Java and Python
Source: https://www.geeksforgeeks.org/data-types-in-java/

In occurrent classes, data-related processes are an important dimension of digital systems design. Processes such as data collection, protection, especially of personal data, data anonymization, data modeling, classification, cleansing, compilation, and analytics are critical parts of smart city applications and e-services.
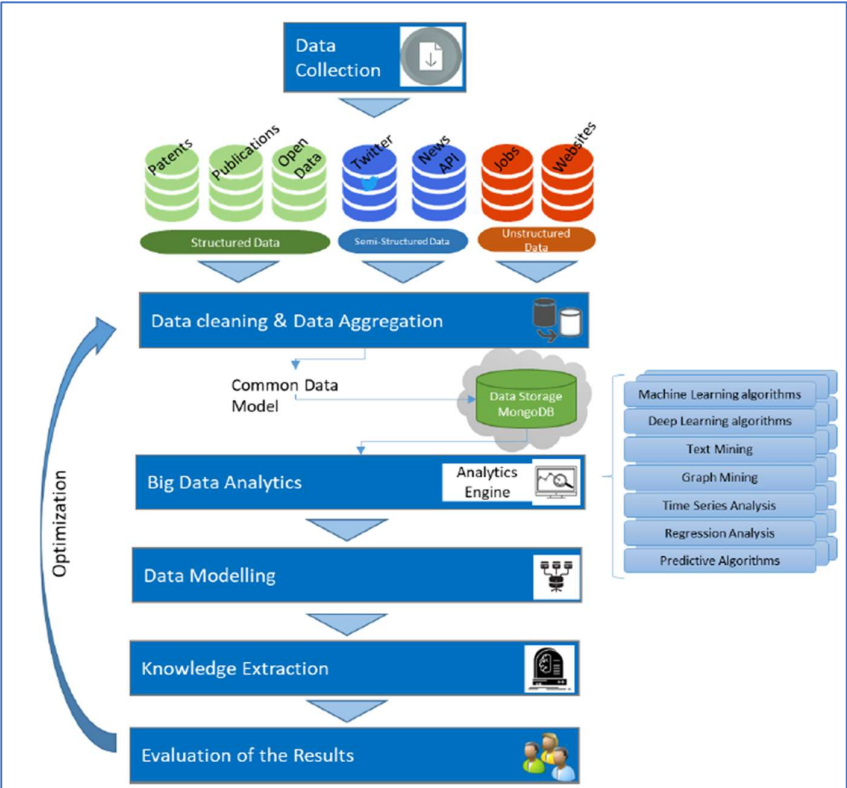
Figure 8: Data processes in smart city applications and e-services

4.8. e-Service innovation

If we continue the metaphor about 'data being the new oil', then 'e-service' is the engine that burns data to produce value. It is probably the most important entity of smart cities, which makes the difference from all previous forms along the evolution of cities.

e-Service is a very complex object, an object of objects, extending in all categories of continuant and occurrent classes. e-Service is a continual dependent class (depending on social and digital elements), but it also is an occurrent class, a process of simultaneous service production and consumption. Some e-Services are classic services, such as smart mobility, for instance, consumed at the time of their production. Others stand as autonomous objects and can be consumed at any time, such as transaction and e-commerce services.

e-Service is also the fundamental innovation in the smart city, a product-innovation that crosses all industry sectors and city ecosystems. We propose the term 'e-Service innovation' to capture both dimensions of 'e-Service' and 'Innovation'.

We started building the hierarchy of e-services with a classification by area, activity, and network, which classes organizing the smart city subsystems, assuming that e-services follow their subsystem of reference. However, we realized that e-services classified by activity and by area fully overlap, as within city areas we find activities too. Thus, e-Service types are partly aligned to smart city subsystems, and two main types can gather all e-services: 'e-service activity-based', and 'e-service network-based'.

Figure 9 presents the main building blocks of e-Service, organized in three layers: the service provider – service user relationship layer, the models enabling a continuous and sustainable operation, and the

technical layer of data and software. Within every e-service, we find these components which sustain the provider-user relationship, the online features, the added value, and sustainability of the e-service.
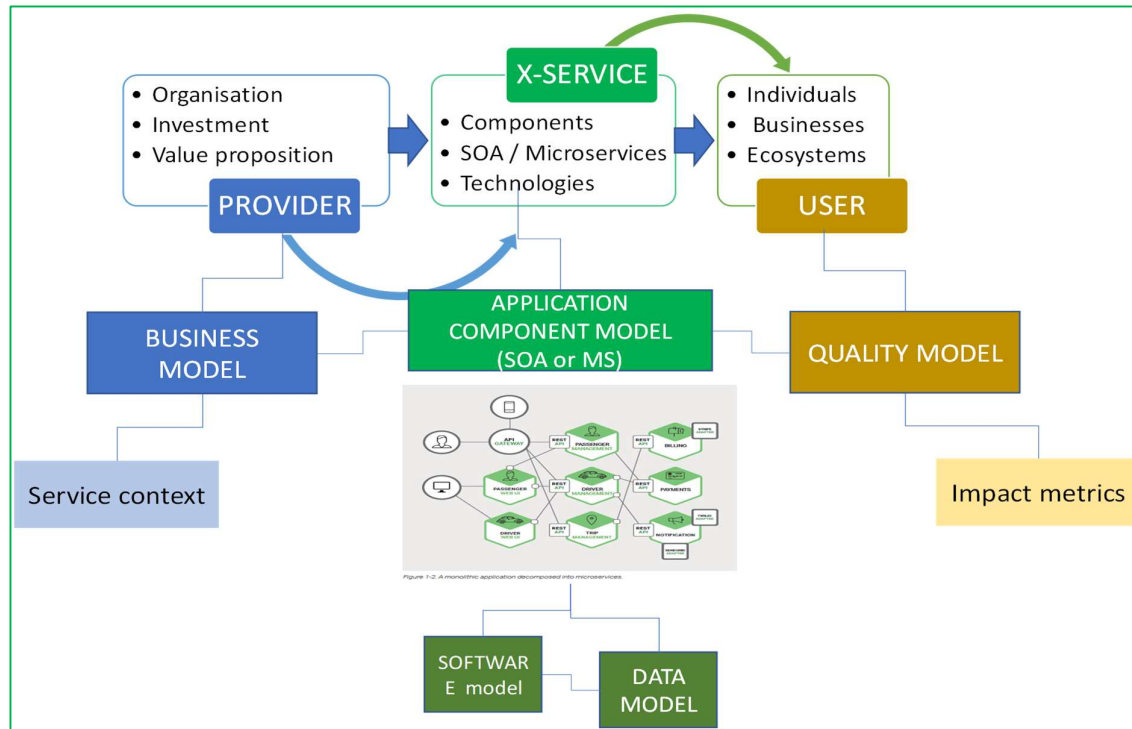

Figure 9: Layers and components of e-Service

4.9. Architecture (=structure)

The architecture (the equivalent term is structure) of the smart city can be described by a combination of layers and components within each layer. The number of layers and component vary according to choices for physical world context, city ecosystems, information processes, digital technology, software, other. *City Protocol*, an initiative of Barcelona Smart City, for instance, proposed a model of the smart city composed of 6 layers (environment, infrastructure, public space, nodes, information, and people) and a large number of components per layer (Figure 10).

Our description of the smart city structure includes three large-scale layers and numerous subsystems and components per layer and subsystem. The three large-scale layers are:

- *The city layer* with the city's population, knowledge-intensive activities, and infrastructure. The population of the city (knowledge workers and innovative companies) and its sectors and clusters are the fundamental elements upon which smart cities are built. A critical factor in this layer is the spatial agglomeration of human capital, human skills, and the intelligence of the city's population.
- *The information and knowledge layer* with institutions for knowledge creation and cooperation in technology and innovation. Institutions trigger and manage knowledge flows, agreements between academia and producers, innovation funding and allocation of resources, organize networks of distributed intelligence and produce collective intelligence. Critical factors in this layer are institutional thickness, social capital for collaboration, trust, and knowledge spillovers within the city.
- *The digital space (or smart environment) layer with* the digital technologies stack, including broadband networks, cloud computing infra and platforms, software applications and e-services, and digital skills that enhance collaboration and the functioning of cities in real-time.

These technologies make the innovation system of cities more open and participatory, and the functioning of cities more efficient thanks to streams of data, real-time information, and automated control. Critical factors on this level are broadband communication and digital networking, data and content management technologies, data collection and information analytics, algorithmic processing, and various forms of machine-to-machine communication and intelligence. (Komninos, 2016).
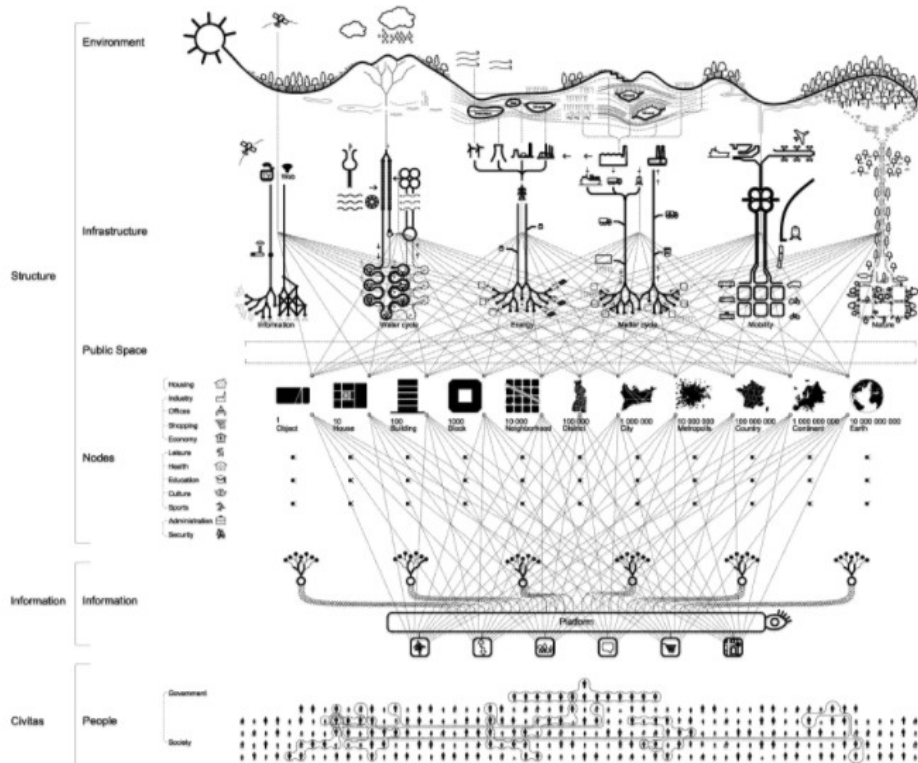

Figure 10: Vertical and horizontal smart city structure
Source: https://issuu.com/cideu/docs/2012_cideu_bcn_city

Other types of smart city architecture include the 'architecture of spatial intelligence' how the different physical, social, and digital elements of the smart city are connected and structured to produce city smartness or city intelligence. We have identified four types of architecture of spatial intelligence (Komninos, 2018)

- '*Agglomeration intelligence*' is based on groups of digital applications and e-services, created by the engagement of the city's population of the city and scales-up with content management systems, co-design tools, collaborative work environments, crowdsourcing platforms, and content mashups.
- '*Orchestration intelligence*' is based on a large-scale division of work and integration of knowledge tasks that are distributed among the population, the institutions, and infrastructure of a smart city (with Bletchley Park as flagship instance)
- '*Empowerment intelligence*' rests on improvements in human skills and know-how realized through a combination of institutional and digital means. It is an individual learning process, but when practiced on a massive scale across the entire city can produce great results.
- '*Instrumentation intelligence*' is about gathering information from sensors, social media, and urban activities, processing this information, and providing real-time information, alerts, forecasts, and wiser decisions.

4.10. Function

The smart city is produced by adding a digital layer over the physical and institutional layers of the city. The digital layer and the resulting digital transformation optimize existing city functions and add also new functions relating to data-based decision-making and e-services. Thus, the smart city inherits all functions of a city (we may call them civic, mobility, transportation, governance functions) and adds new innovation functions related to e-services, system and behavior improvement. Figure 11 outlines three circuits of innovation, creating digital services and data, system improvement, and user behavior optimization.
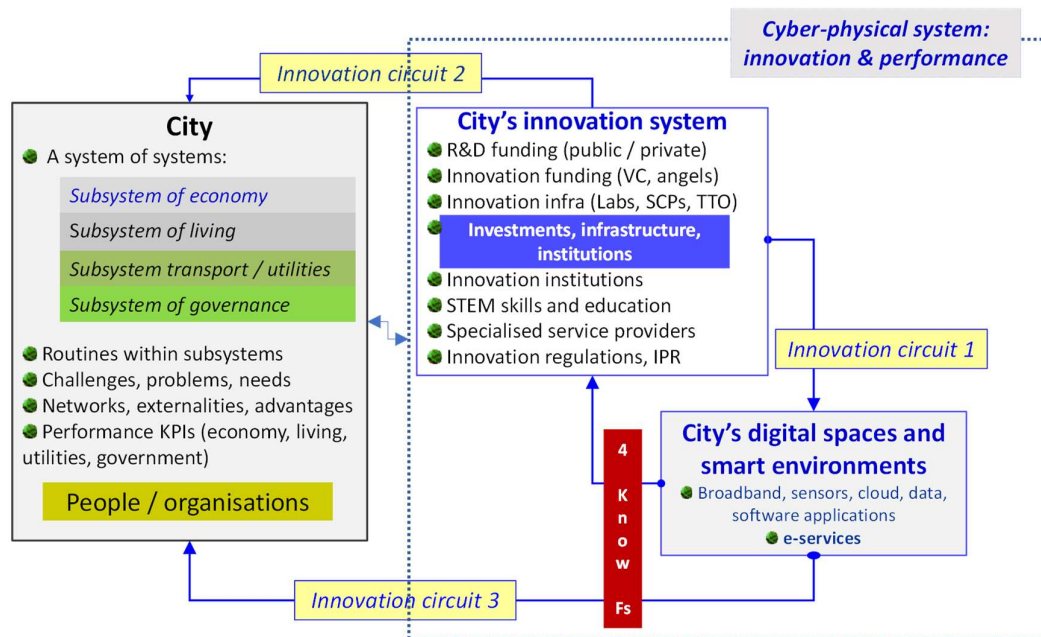

Figure 11: Innovation and optimization functions of a smart city
Source: Komninos (2020, p. 47)

The 1st innovation circuit concerns the creation of digital spaces, smart environments, and e-services over the city. This includes a multilevel edifice composed of broadband networks, smart devices and meters, embedded systems, data repositories and management technologies, cloud-based solutions, platforms, and applications. The innovation function of circuit 1 is about the creation of the urban digital space with the elements of the smart city ontology described in section 4.3 and Figure 5.

The 2nd innovation circuit introduces innovation and optimization in the city's system of innovation. Through the digital space of innovation circuit 1, a hybrid system of innovation is produced enriching existing innovation institutions and mechanisms with data, analytics, forecasting, and e-services of R&D, funding, product design, production, and marketing. Skills and capabilities of a larger population are mobilized, both local and global, which crowdsource resources, creativity, and insights for optimization and innovation. The innovation function of circuit 2 is about innovation and optimization of the city's system of innovation.

The 3rd innovation circuit starts from other types of data and e-services that do not change the city but optimize the way citizens and organizations use the city, the public space, and the urban infrastructure. Intelligent transportation systems and GPS guiding urban mobility, e-parking services, smart energy metering, sensor-based street lighting, sensor-based waste collection and route optimization are examples of solutions for better usage of the city. The innovation function of circuit

3 is about saving resources and transferring practices from the physical to the digital space of cities, and a behavioral change in using urban resources, avoiding waste, and improving sustainability.

4.11. Output

We can describe different types of smart city outcomes in a gradual way, as a succession of effects and impact along with the operation of the smart city and the evolution of innovation circuits stages presented in Figure 11. This description is compatible with the understanding of innovation as the primary function of the smart city, and the smart city as an advanced system of innovation.

The digital space of the city, from broadband to e-Service, is the first type of smart city outcome, a complex entity unique to the smart city produced at the end of the 1st innovation circuit.

Knowledge and intelligence are outcomes at the end of innovation circuit 2, providing advanced decision-making capabilities to organizations select investments, public goods, design infrastructures, and new institutions. The smart city enriches existing forms of intelligence in cities, such as the individual human intelligence and collective intelligence, with new forms such as cyber-intelligence, representation intelligence, and mainly connected intelligence. In the smart city, a variety of connected intelligence forms appear, based on combinations of human, collective, and machine intelligence, some having more human features relying on human cognition and some having more machine-type features relying on automation (Komninos, 2020).

The systemic effect is the outcome of the smart city at the end of innovation circuit 3, providing various types of systemic effects to city users and organizations, due to spatial and digital proximity with other users and organizations, such as externalities, agglomeration economies, public goods, and knowledge spillovers.

An externality is a value from an economic activity freely received by unrelated organizations; It is a value external to market transactions. Well-known types of externalities are 'external economies of scale' and 'external economies of scope'. Economies of scale are recognized when the marginal production cost of a product decreases. They can be internal when the cost decrease depends on the size of the organization or external when the cost decrease comes from the size of the industry or the agglomeration. Economies of scope are realized when the average production cost of many products decreases by increasing the variety of products produced (Chandler et al., 2009). Scott described a set of locational scenarios and urban growth types depending on combinations of transaction costs and external economies (Scott 1996, fig. 3). Now, the Internet is full of externalities and 'free lunch' supplies. The creation of positive externalities by digital means is the core driver of city smartness. The 'digital empowerment' of the smart city is not about propriety but having access to networking, communication, data, and e-services.

Smart ecosystems are the combined outcome of the above types of outcomes. The combined outcome of smart city functions, knowledge, intelligence, and systemic effects can be documented and measured. Figure 11 outlines a measuring process at the level of smart city ecosystems, which evolves along with investments in human skills, innovation at the supply and demand sides, and digital systems. Improvements occur in all dimensions of the city, the economy, living conditions, infrastructure, and decision-making. In the data properties of the SCO owl file (see section 6) we give a set of indicators that can be used to capture the changes in the urban system introduced by digital systems, data, and new s-services.
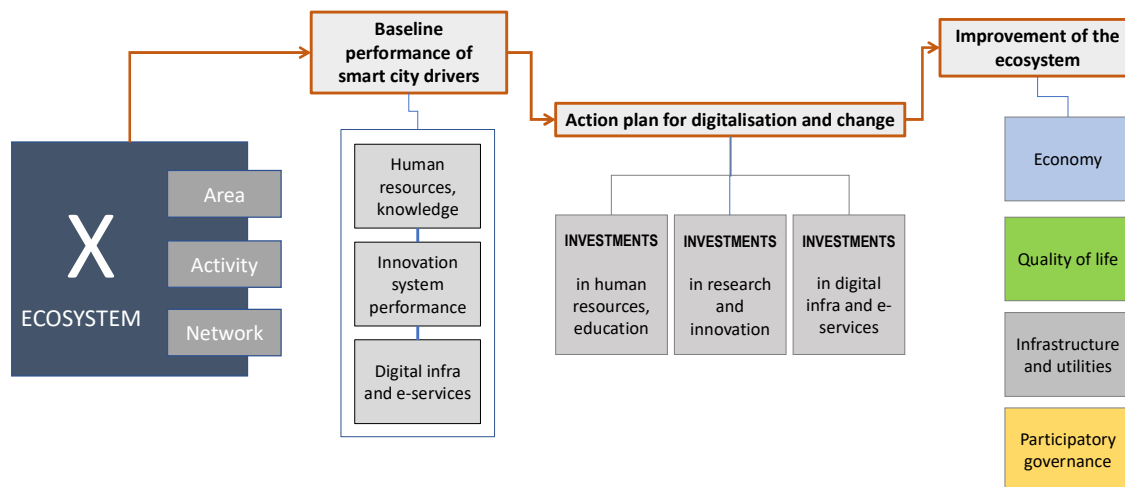
Figure 12: Measuring the outcomes of the smart city

4.12. Urbanization process

Urbanization characterizes the shift of social life, population, and activities from the countryside to the city and consequently the organization of a new form of sociability in the city. It is a much wider process from a narrow understanding of city growth, the population shift from rural to urban areas, the increase in the proportion of people living in cities, and other similar definitions we find in dictionaries and wikis.

In urban theory since the 1970s, urbanization has been explained by social and economic processes, such as the social division of labour and urban-rural dynamics (Castells, 1973; Keeble et al., 1983); industrial location or relocation (Oakey et al., 1980; Walker and Storper, 1981); the geographies of urban restructuring (exopolis, flexcities, cosmopolis) (Soja, 1994); capital accumulation and globalization (Harvey, 1973 and 1978; Lipietz, 1977); uneven development (Garofoli 1983); metropolitan restructuring (Scott A. (1982). The paper of Scott and Storper (2015) on the nature of cities discussed urbanization, moving ahead more forcefully than at any other time in human history, in terms of a theoretical framework that combines two main processes, (a) the dynamics of agglomeration/polarisation and (b) the nexus of locations, land uses and human interactions in the city.

This wide understanding of urbanization leads us to treat the term as an umbrella universal for any kind of bottom-up process shaping the city, including processes of demographic change, migration, capital mobility, urban and industrial location, internationalization of cities, globalization. These are considered as sub-types of urbanization. The complement not included are processes related to policymaking, planning, and state intervention that regulate urbanization. It has become evident in informal settlements and cities that urbanization takes place in a vacuum of such state policy and planning, driven only by dynamics of markets, exchanges, and other human interactions.

The cyber-physical city, the smart city included, is a game-changing factor of urbanization affecting, in the first place, the division of social and economic activities of the city in the digital and physical space, and, in the second place, digitally transforming all processes that shape urbanization. More many of these ongoing interactions between 'smart' and 'urbanization' the language has not yet invented the terms, and we speak with periphrases, using more than one term to express a concept or a fact.

4.13. Planning

Per analogy to city planning as the complement of urbanization in the making of a city, smart city planning is the complement of urbanization in the making of the smart city. It covers all dimensions

and forms of planning at the city level and the city subsystems in which digital solutions are deployed, including the environment, transport, buildings, and urban design. We distinguish three main types of planning (a) city planning, (b) transport planning, and (c) environment planning.

Our paper on "smart city planning from an evolutionary perspective" (Komninos et al. 2019) extends the evolutionary thinking and the emerging dynamics of cities to smart city planning. We argue that smart city planning does not have the usual features of planning. It is a more complex system integrating institutions, technologies, user engagement, and windows of opportunity, which are fuzzy at the start of the planning process. The evolutionary logic of cities, until now ascribed to the working of markets, is now shaping the institutional aspects of planning for smart cities.

The horizon of smart city planning goes far beyond the physical space of cities, addressing all the grand challenges of 21st-century life in cities: (a) the growth, (un)employment, and poverty nexus; (b) sustainability and its aspects, from optimized land use and nature-based solutions, to the management of ecosystems, air quality, CO_2 emissions, climate adaptation, energy savings and the transition to renewable energy, water, waste recycling of materials, green mobility, and the circular economy; (c) the urban safety nexus with man-made or natural threats, such as crime, terrorism, attacks on infrastructure, vandalism, natural catastrophes, urban accidents and other types of emergencies. In sum, it addresses all aspects of the social and economic life of cities, not just the physical space, land uses, and infrastructures, which were mainly addressed in 19th and 20th-century city planning.

Looking into the intelligent/smart city planning cases, we find a variety of planning types. They differ in the area of intervention, the thematic focus of the initiative, the degree of citizens and user involvement, the technology deployed, and the priority given to people vs. infrastructure. Some major types are:

- *Intelligent city planning focused on the entire city* and the major sectors of activity, such as Singapore's Intelligent Nation 2015 Masterplan, which aims to enable innovation among businesses and individuals by a digital platform supporting enterprise and talent.

- *Urban renewal, focused on city districts or clusters*, such as the Plan for Intelligent Thessaloniki, aiming at the renewal of city districts, such and the port area, the historic centre, the university campus, the technology district in the eastern part of the city through wireless broadband networks, digital automation and e-services that improve innovation and entrepreneurship in every district.

- *Planning focused on the renewal of multiple cores and focal points*, such as the plan for Amsterdam Smart City, which continuously introduces new projects and initiatives in the domains of the smart economy, living labs, infrastructure, smart mobility, living, society, smart areas, and open data.

- *Planning focused on smart city infrastructures*, such as the plan for broadband networks and e-services of Stockholm, which was built around the publicly owned entity Stokab that leases fibre optic networks to telecom operators, businesses, local authorities, and organizations to deploy digital applications and e-services.

- *Planning for new intelligent cities or city districts*, where entire new city areas are planned and developed with smart city principles, such as the PlanIT Valley project in Parades, Northern Portugal, which uses the Living PlanIT's Operating System to integrate all city systems, hubs, buildings, and devices.

This diversity of smart city planning types is much greater if we consider that the smart city planning process takes place per vertical market or ecosystem. Thus, the types of universals of the 'smart city subsystem' are also types of the 'smart city process' (see, 4.4. Smart city subsystem).

We should also underline that planning for intelligent/smart cities differs from software applications and e-services design and development in its holistic perspective. City problems of growth, sustainability, inclusion, and government are addressed by projects that integrate physical, institutional, and digital elements and collaborative networks inside and outside the city. Applications and IT solutions are present and an essential component of the planning roadmap, as a means for engaging communities in becoming more efficient and innovative.
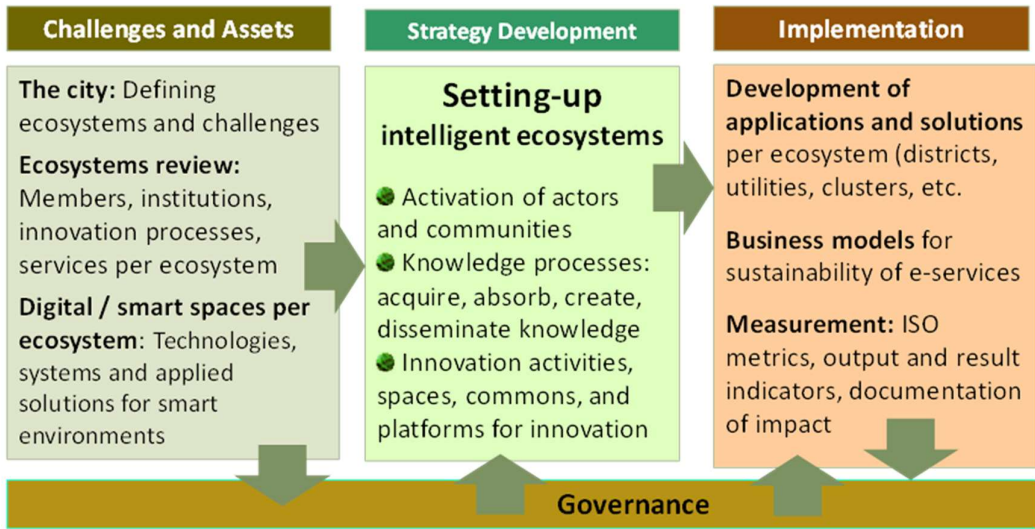

Figure 13: Smart city planning process

Besides the diversity of smart city domains and verticals, there is some standardisation of internal planning processes. This is depicted in Figure 13. Initially is the definition of context and challenges at the level of the smart city layers (city, innovation, digital); then user and stakeholder engagement for setting intelligent ecosystems, based on data, analytics, sharing solutions, crowdsourcing, forms of collaborative actions; and at the end the action plan with the design and development of digital and non-digital projects, old and new infrastructures, e-services, business models, monitoring, and assessment.

Smart city planning is closely related to other forms of urban planning, which we have added in this class. For 'environment planning, we follow the classification of the EU Green Taxonomy and the six sectors of Environmental Contributions (https://rb.gy/swxjrk): climate change mitigation; climate change adaptation; water; circular economy; pollution; and ecosystems. Particularly important is the classification of NACE activities, which we use in the activity class, with those six areas of environmental impact (pp. 56-63).

4.14. Environmental process
The impact of climate change on cities and the wide acceptance of sustainable development as a growth path to follow in the EU and elsewhere have risen strong concerns for the environment and the city. Environmental processes gather a lot of attention, both the level of urban conditions and city planning.

The class 'environmental process' in the SCO describes environmental processes (not environmental monitoring and planning processes) that we can observe in cities and the surrounding natural ecosystems. Understanding the dynamic of these processes is essential to design urban policies and planning for environmental sustainability.

The terms in this class are based on the 'Environment Ontology' (ENVO) developed by Buttigieg et al. (2013; 2016). ENVO, under the term 'process', develops a hierarchy of 426 types of environmental processes at 10 successive levels. Out of these classes, we borrow the first two levels of 'biological process' and 'environmental system process' and their next categories of 3 and 28 classes. Overall, we include 33 types of environmental processes in the SCO, referring to biosynthetic, living, ecosystems, and climate processes (Fig. 13).

Another option is to merge the SCO with the 'process' class of ENVO. We have tried this solution also. But, including all 426 environmental processes of the ELVO at this stage is disproportional to the size and levels of SCO, whose hierarchy goes down 4-5 levels only. It can be done in a future version and more detailed development of the SCO.

Figure 14: A part of the ENVO hierarchy of environmental process
Source: ENVO, http://obofoundry.org/ontology/envo.html

4.15. Governance

Governance is a critical twin of planning and defines the decision-making framework in which smart city planning is placed, strategy development, and action plan, monitoring and assessment, and feedback from the implementation. Governance is a participatory type of government, which defines the level of stakeholder engagement and bottom-up processes. Given the dependence on context, smart city governance is unique, and therefore there is no single solution that can be universally applied to every context.

Ruhlandt (2018) reviewed a large corpus of publications on smart city governance and gives an outline of the process in four blocks that contain both continuant and occurrent entities: (1) contextual factors, (2) components, (3) measurement, and (4) outcomes. Some key processes within each block are presented in Figure 15.

Processes revolve around stakeholder engagement and the allocation of decision-making powers. The selection of stakeholders is the starting point of governance. It may include individuals, groups, agencies, parties, or organizations. The stakeholders' roles and responsibilities are of importance and define stakeholder decision-making power, roles, and responsibilities. These arrangements are usually codified in the working principles of a Steering Committee (SC) and Management Unit (MU) assuring strategy implementation, adaptation, and assessment. In collaboration with the SC and MU, support organizations may include political, administrative, and (private) external organizational formations that facilitate interaction among stakeholders or allow for certain processes.

Monitoring and assessment give feedback to the government. It is a key activity to capture the intangible impact of smart cities, hidden in log files and administration registers. Measurement and assessment of intelligent city performance are about using key performance indicators (KPIs), the creation of scoreboards, gathering of data, using analytics, and identifying factors that shape the performance of cities. Different measurement methodologies can be applied to capture the impact of smart cities. They vary by the perspective and variables that are measured and assessed. The policy-focused measurement uses indicators that capture the effort of policies and planning; city-focused measurement is based on the characteristics and performance of cities; infrastructure-focused measurement relies on sensor data and can capture the usage patterns of urban utilities. A good methodology of assessment should include a clear statement of objectives, indicators that combine a policy-focused and city-focused approach. These may be KPIs from the three building blocks of smart cities: knowledge skills, innovation ecosystem features and digital spaces for drivers of change, and documenting the outcome on typical subsystems of cities, such as the urban economy, quality of life, infrastructure, and government using widely accepted indicators (such as ISO 37120:2014).
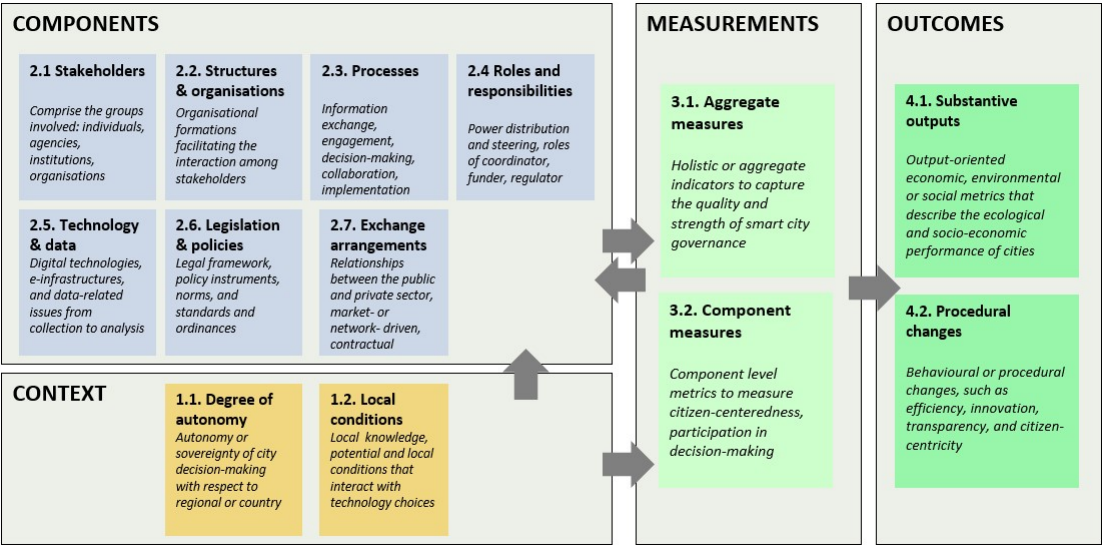

Figure 15: Smart city governance
Adapted from Ruhlandt (2018)

The *Institutional framework* defining the degree of a city's autonomy in decision-making is the most important contextual factor that influences governance through legislation and the autonomy of the governance processes. The legislation provides the legal base, policies, and administrative structures enabling the implementation of a strategy. The degree of autonomy or sovereignty describes decision-making and power distribution for strategy implementation. Usually, the city government has limited

autonomy in managing wider processes of innovation and a digital agenda-based transformation. However, this limited municipal autonomy favours a participatory governance model, based on the alliance of many stakeholders from the public, community, and private sectors.

4.16. Social movement

The concept of 'social movement' englobes the "purposive and collective attempt of a number of people to change individuals or societal institutions and structures" (Zald and Ash, 1996; p.329), or the "collective action by a group of people with a shared or collective identity based on a set of beliefs and opinions that intend to change or maintain some aspect of the social order" (Open Education Sociology Dictionary). A social movement is also "regarded as consisting of more diffuse gathering of individuals within civil society who are linked together by ideology, beliefs, or collective identities" (Rubin, 2001, p.4). The European thinking on social movement, grouped under the term "new social movement theory" suggests that a key to understanding this process is collective identity. The latter is the shared definition of a group the derives from the members' common interests, experiences, solidarity, and culture (Taylor et al., 1992).

There is a long tradition of social movements in urban planning and city governance through which citizens attempt to influence and achieve some control over their urban environment, the built environment of the city, the projects for renewal, the social fabric, and the local decision-making (Pruijt, 2007). Urban movements are quite usual in urban regeneration projects, a form of urban planning to transform existing city neighbourhoods and districts. Probably, the most known case of urban social movement is about the efforts of Jane Jacobs against the construction of a highway throughout Greenwich Village in New York at the height of the urban renewal and slum clearance period.

> "It's the early 1960s in New York City's West Village. Years earlier, master builder Robert Moses, a formidable urban planner and the longtime New York City Parks Commissioner, had proposed a new highway that would run down Broome Street. The Lower Manhattan Expressway was to be a 10-lane elevated highway that would cut through SoHo and Little Italy, destroying Washington Square Park, demolishing numerous buildings, and displacing thousands of families and businesses. The plans had been delayed for several years but were picking up steam again. In response, a coalition of council members, business owners, and local activists joined forces to fight the plan. Among the protestors was Jane Jacobs, a journalist, a mother with young children, and a resident of the West Village. She was vehemently opposed to the expressway and organized protests and rallies in her community. She became the chairman of the Joint Committee to Stop the Lower Manhattan Expressway. She was even arrested in 1968, accused of starting a riot at a public hearing. But she and her fellow protestors were ultimately successful. The plan was scrapped, and the underdog won. David defeated Goliath."
>
> *(National Trust for Historic Preservation, April 14, 2016)*

New forms of social movement in cities come with the World Wide Web and the turn to sustainable urban growth. ICTs' influence on social movements, and political participation more broadly, is clear on how citizens communicate, collaborate, and demonstrate. The literature describes three mechanisms that potentially link technology and participation: reduction of participation costs, promotion of collective identity, and creation of community (Kelly Garrett, 2006). A recent feature of public engagement is the use of the Internet by a wide range of activists and groups engaging in social and political protest. It is not only to facilitate mobilization and participation in traditional forms of protest but to give these protests a more transnational character by effectively and rapidly diffusing communication and mobilization efforts (Van Laer and Van Aelst, 2010).

The concern for the environment, in both the United States and Continental Europe, is another driver of current social movements in cities. People who were otherwise indistinguishable from the general population are engaged in political action by the deterioration of the air and water quality, the degradation of natural ecosystems, and the extinction of wildlife species (Rubin, 2001).

However, the most preeminent social movements in the smart city are about user and stakeholder engagement, and crowdsourcing. These trends are becoming synonymous with smart cities, as new ways of governance, city planning, and participation in decision-making. User engagement is considered as an engine for smart city strategies (Badii et al., 2017), and stakeholder engagement is seen as a generator of opportunities for smart city projects, e-services, and shared data repositories (Komninos et al., 2019).

4.17 Digital system design

This class of processes is central to the overall architecture of the smart city ontology. Most software applications, e-services, and the underlying data processes depend on the design of digital systems, in which their key features are defined. In general, the requirements and processes for e-service design are complex and distributed in networks of providers and users, as the design of the e-service is tightly connected with service use and the feedback from users contributes to the evolution of service-oriented systems.

In a literature review of main approaches in the area of e-service design, Henkel et al., (2011) identify various methods based on business processes, business functions, business models, and goals when designing e-services. These include:
- business processes have been used as a basis for designing service-based systems
- business functions have also been used to drive the development of e-services
- other approaches employ enterprise business models as a foundation to create IT systems
- a goal-oriented analysis is used as a starting point for the design of e-services, and several levels of both goal and context diagrams are combined to analyze the requirements of e-business systems
- high-level business goals, identified by business executives, business owners, and business modellers, which are decomposed into a hierarchy of sub-goals, and e-services provided by existing software components are designed to satisfy these sub-goals.

Following this literature review, Henkel et al., (2011) propose a model containing four sub-processes, (i) value modelling to capture high-level economic resource transfers between actors, (ii) top-level goal identification to further refine transfers in the value model, (iii) goal-driven identification of e-services leading to e-services as means to fulfil sub-goals, and (iv) e-service refinement to select and structure the e-services that result from the goal modelling.

At a lower level of granularity, Bultan et al. (2003) consider e-service design as a conversation process. An e-service (a) provides services through "service sessions" and (b) reacts to "events" during a session. Events form the enabling mechanism in composing e-services. They can take the form of messages between individual e-services. The messages are organized into a collection of classes, each having a name and a set of attributes. A message of a class consists of an identifier of the e-service session, an identifier of the message, the sender, the receiver, and a function giving value to each attribute.

In applications and e-services we designed and developed at URENIO Research, we followed a process in which the e-service design was integrated with application co-design and the business model. It includes three sub-processes and twelve steps, from concept development to the design of user interface, application programming and hosting, and business model and license (Table 5).

1. Concept development	2. Design of user interface and prototype	3. Programming, hosting, and license
1.1. Concept: A problem to resolve. Ontology and data to frame the problem	2.1. Information flow diagrams – Algorithmic processes	3.1. Selection of development platform (WordPress, Joomla, Android, iOS)
1.2. Consider similar solutions / applications / e-services	2.2. Graphic design	3.2. Engage the developer community. Code & data
1.3. Placing the application/e-service into the city structure	2.3. Prototype development	3.3. Cloud: IaaS, PaaS, SaaS
1.4. User co-design and concept development by crowdsourcing	2.4 User feedback in each step: User experience	3.4. License and business model

Table 5: Applications and e-services design: 3 stages and 12 steps
Source: Complexity and Co-design in Smart City Development, ENoLL 2019

In another publication (Anttiroiko and Komninos, 2019) we investigated the design of smart city services from the perspective of service-dominant (S-D) logic. The latter posits that e-services should break free from the traditional industrial or manufacturing-based model and the goods-dominant (G-D) logic. The value of e-services is created when they are used, hence the idea of value-in-use. The co-creation relationship is also a key relation in S-D logic. The client owns or controls some aspects of the social setting that the provider aims to transform guided by its value proposition. Their relationship is formalized in an agreement between the provider and the client. Thus, the S-D logic embraces the concepts of value-in-use and the co-creation of value rather than value-in-exchange associated with traditional G-D logic and related market transactions. S-D logic takes a broad view of the value created by organizations, including the need to work and market with customers and other value-creation partners in the wider value network. This turn comes from the essence of smart city services which revolve around technologically enhanced systemic and collective intelligence that drives innovation through user engagement, big and real-time datasets, digitalization, and more recently datafication and cloudification.

This quick reference to e-services design shows that the design processes depend on the methodology used. Consequently, it is not feasible to define the SCO universal process and sub-process classes, as each methodology has its system of reference. Neither is feasible to cover all methods that can be found in the literature and their sub-processes. Thus, the path we adopt is selective and indicative, as we identify some digital systems design methodologies and their constituting processes.

5.Object properties

In owl, object properties define relationships at the level of both instances and types. These can be relationships at instance-level (instance-to-instance), type-level (universal-to-universal), and instance-type level (instance-to-universal).

In SCO 2.0, we define object properties at the 1st level classes. These are type-level properties defining relationships between universals. Setting properties at a high level of universals, these properties are inherited in the sub-classes of those universals. When a class is a subclass of another, it means that any properties on the individuals of the superclass can be on individuals of the subclass (see, OWL Class and Subclass Property Inheritance, https://rb.gy/zwgaaf).

At the 1st level classes of SCO 2.0, the object properties we propose fall into the following categories:
-define relationships between class and sub-class (is_a)

-define predicates of possession (has, owns)
-define predicates of information (informs, disseminates, diffuses)
-define predicates of digital transformation (digitalize, digitize, cloudify)
-define predicates of inclusion (belongs, contains, is_located)
-define predicates of impact (creates, forms, transforms, produces, innovates, regulates, supports)
-define predicates of interaction (connects, depends_on, defines, enables, drives)
-define predicates of usage (uses, employ operate)
Using these object properties, we can define most relationships of the SCO high-level classes.
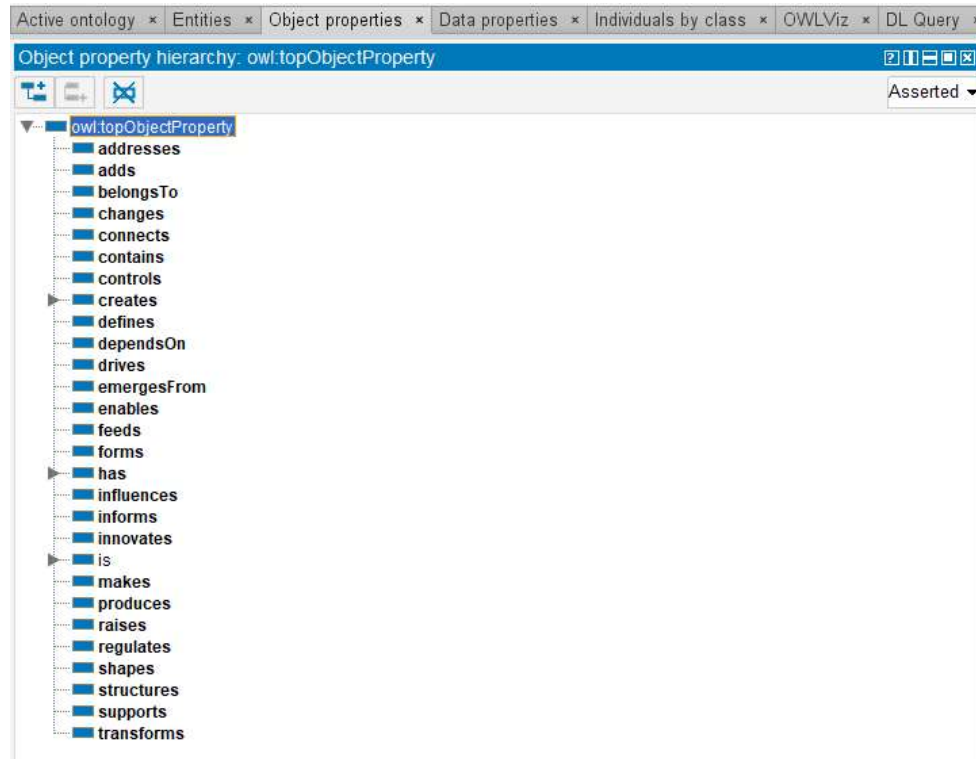
Figure 16: SCO main object properties

6.Data properties

The SCO 2.0 data properties hierarchy is organised according to the structure of the smart city. It contains indicators and measures for the three layers of the smart city (physical space, innovation space, digital space) and three dimensions of the smart city (elements, subsystems, and governance). The indicators and measurement units selected come from different sources as explained below.
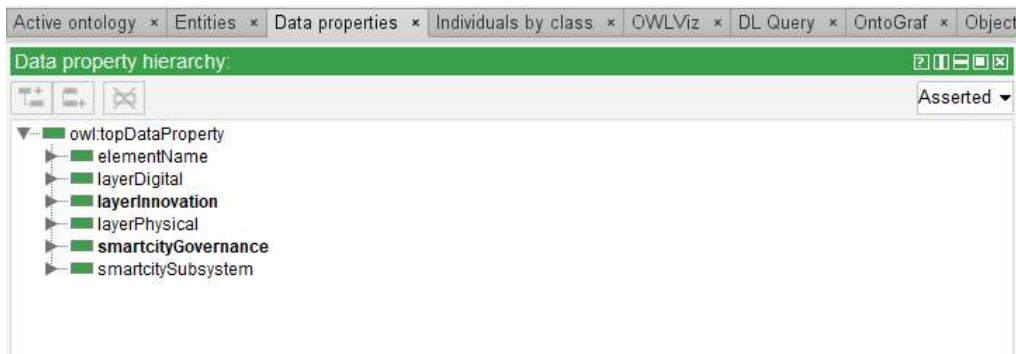

Figure 17: SCO data properties structure

The 'element name' contains names ID for any smart city instance, buildings, building blocks, streets, communities, institutions, applications, e-services, etc.

The 'digital layer' contains indicators that can measure (a) Internet coverage and high broadband coverage and (b) the use of different e-services. These indicators are selected from the Digital Economy and Society Index (DESI) of the EU. DESI is a composite index that summarizes indicators on Europe's digital performance and tracks the evolution of EU Member States, across five main dimensions: Connectivity, Human Capital, Use of the Internet, Integration of Digital Technology, Digital Public Services. The index is available at https://digital-agenda-data.eu/datasets/desi/indicators

The 'innovation layer' contains indicators that can measure innovation enablers, activities, and performance. The indicators selected come from the EU Innovation Scoreboard that monitors innovation performance in the EU over the last 20 years, at national and regional levels.

The 'physical layer' contains indicators that can measure features of the physical space of smart cities, such as dimension, density, and people.

The 'smart city governance' contains indicators taken from the governance category of the ISO 37120: 2014 on sustainable development of communities, dealing with user participation in governance, corruption, voting, and representation.

The 'smart city subsystem' contains indicators for 13 different smart city subsystems and major ecosystems, either area-, or activity- or network-based. These range from education and health to energy and transportation. The selected indicators come from the ISO 37120:2014 "Sustainable Development of Communities" (http://www.iso.org/iso/catalogue_detail?csnumber=62436).

7. The owl file of SCO 2.0

The classes and properties of the SCO, which we briefly outlined in the previous sections, show the logic we follow for a more detailed description of the SCO with the Protégé editor. The discussion paper drives our work with the Protégé in defining the basic structure of classes, their alignment, and relationships. The owl file of SCO is a fundamental complement of this discussion paper. Some parts of the discussion paper appear also as annotations in SCO entities.

The Smart City Ontology (SCO) we propose, describes the smart city as a city enhanced by broadband networks, the world wide web, online communication and interaction, digital tools, applications, data, and e-services. The smart city is a new kind of city. It inherits properties of the 20th century city but adds new ones stemming from digitalization, information sharing, knowledge creation, and innovation. It is created at the intersection between the city system, the information/knowledge system, and the digital system, and their common area is continuously expanding into each system.

The owl file that describes the SCO entities is in continuous change, as universals are added, deleted, or moved from one branch of the ontology to another as corrections are made and second thoughts define a better place into the SCP (e.g., from s-dependent to g-dependent or from g-dependent to occurrent). To make clear these changes, the owl file brings at the end of its name the date of the version (Smart City Ontology 2.0-Final.owl).

Both the latest versions of the discussion paper and the owl file are available at
https://drive.google.com/drive/folders/1i5pkxB310DlnJ7Y3CXxCUsYGHlGlL01g?usp=sharing

SCO 2.0 contains 918 classes, 66 object properties, 197 data properties, and 27 individuals. Compared to SCO 1.0, the main changes are the increase in the number of entities, the layers of the hierarchy, and the 1st-level universals (concepts) that define its structure and relationships (Table 6). Individuals are included only for applications and those already in the SCO 1.0. Even in this class a few individuals are named (just 27) compared to 174 intelligent/smart city applications and solutions we have registered in the ICOS repository (https://icos.urenio.org/). An overall picture of the SCO 2.0 is given in the Figure 19.

SCO entities	SCO 1.0	SCO 2.0
Classes	424	918
1st level classes	10	23
Object properties	62	66
Data properties	190	197
Individuals	27	27
Total	**713**	**1231**

Table 6: Comparison between SCO 1.0 and SCO 2.0

The Protégé v5.5.0 editor to open the SCO owl file is available to download at the address https://protege.stanford.edu/products.php
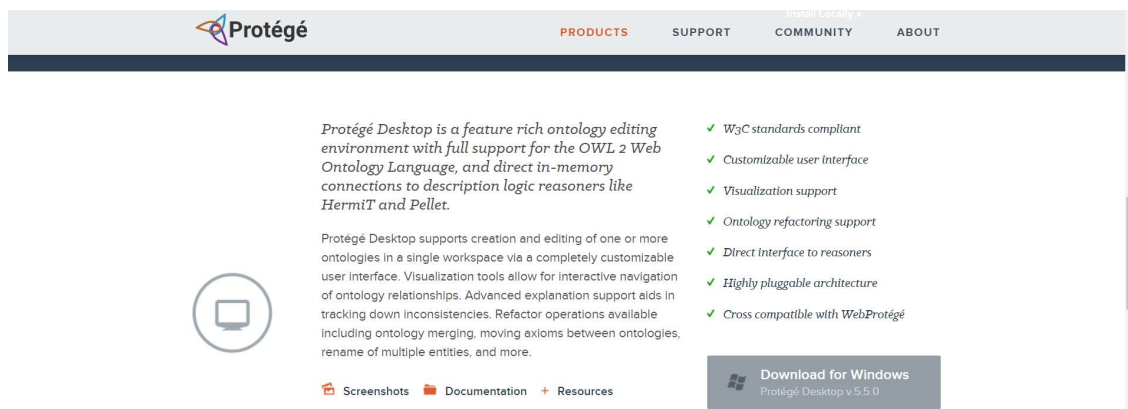

Figure 18: The Protégé editor download page

Comments, suggestions for changes, contributions, or participation to the further development of the Smart City Ontology, please contact any author of this discussion paper at the email below:

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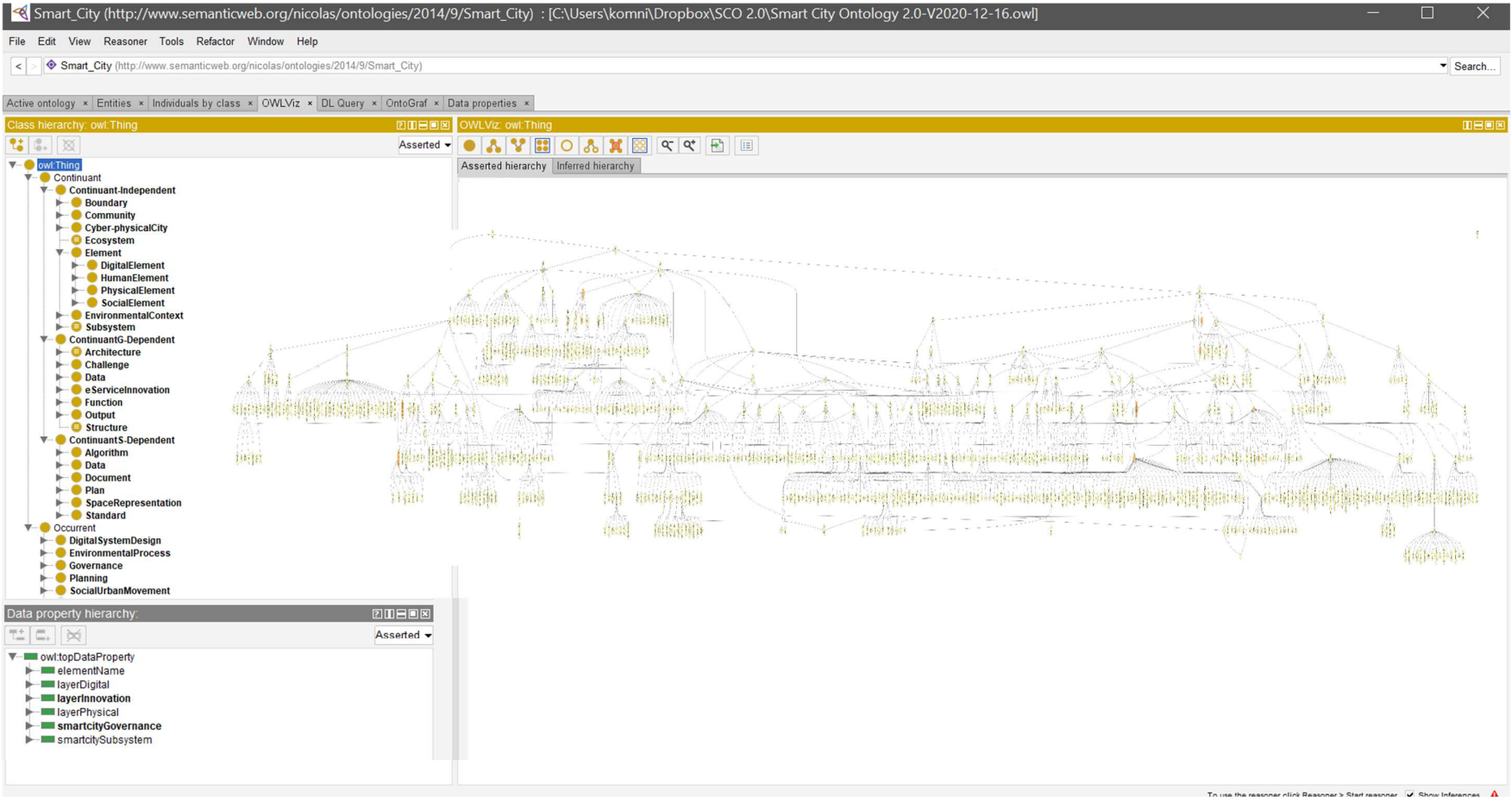
Christina Kakderi: christina@urenio.org

Figure 19: The Smart City Ontology in Protégé

References

Anttiroiko, A. V. (2012). Urban Planning 2.0. *International Journal of E-Planning Research (IJEPR)*, *1*(1), 16-30.

Anttiroiko,A.V. and Komninos, N. (2019). Smart Public Services: Using Smart City and Service Ontologies in Integrative Service Design. In: Rodriguez Bolivar M. (eds) *Setting Foundations for the Creation of Public Value in Smart Cities*. Public Administration and Information Technology, vol 35. Springer, Cham

Arp, R., & Smith, B. (2008). Function, role, and disposition in basic formal ontology. *Nature Precedings*, 1-1.

Arp, R., Smith, B., & Spear, A. D. (2015). *Building Ontologies with Basic Formal Ontology*. MIT Press.

Badii, C., Bellini, P., Cenni, D., Difino, A., Paolucci, M., & Nesi, P. (2017, May). User engagement engine for smart city strategies. In *2017 IEEE International Conference on Smart Computing (SMARTCOMP)* (pp. 1-7). IEEE.

Brandão, A. A., & Loureiro, G. (2020). An Overview of the BFO-Basic Formal Ontology-and Its Applicability for Satellite Systems.

Brint, S. (2001). Gemeinschaft revisited: A critique and reconstruction of the community concept. *Sociological Theory*, *19*(1), 1-23.

Bultan, T., Fu, X., Hull, R., & Su, J. (2003, May). Conversation specification: a new approach to design and analysis of e-service composition. In *Proceedings of the 12th international conference on World Wide Web* (pp. 403-410).

Buttigieg, P. L., Morrison, N., Smith, B., Mungall, C. J., & Lewis, S. E. (2013). The environment ontology: contextualising biological and biomedical entities. *Journal of Biomedical Semantics, 4(1), 43*.

Buttigieg, P. L., Pafilis, E., Lewis, S. E., Schildhauer, M. P., Walls, R. L., & Mungall, C. J. (2016). The environment ontology in 2016: bridging domains with increased scope, semantic density, and interoperation. *Journal of Biomedical Semantics*, 7(1), 57.

Castells M. (1973). *La Question Urbaine*. Editions Maspero.

Chandler, A. D., Hikino, T., and Chandler, A. D. (2009). *Scale and Scope: The Dynamics of Industrial Capitalism*. Harvard University Press.

Clark, D. B. (1973). The concept of community: A re-examination. The Sociological Review, 21(3), 397-416.

Economist (2017). The world's most valuable resource is no longer oil, but data. https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data

FG-SCC, ITUT (2015). Setting the framework of an ICT architecture of the smart sustainable city. Focus Group Technical Specifications, 49

Frost and Sullivan (2019). Smart Cities. https://ww2.frost.com/wp-content/uploads/2019/01/SmartCities.pdf

Garofoli G. (1983). Uneven development and industrial restructuring: the Italian pattern in the '70s. Naxos Seminar Proceedings.

Giffinger, R. (2007). Smart cities: Ranking of European medium-sized cities. Centre of Regional Science, Vienna UT.

Girvan, M., & Newman, M. E. (2002). Community structure in social and biological networks. *Proceedings of the national academy of sciences*, *99*(12), 7821-7826.

Greimas, A. J. (1970). *Du sens: Essais sémiotiques*. Editions du Seuil.

Greimas, A. J. (2015). *Sémantique structurale: recherche de méthode*. Presses Universitaires de France.

Guarino, N., Oberle, D., & Staab, S. (2009). What is an ontology? In *Handbook on ontologies* (pp. 1-17). Springer, Berlin, Heidelberg.

Hagedorn, T. J., Smith, B., Krishnamurty, S., & Grosse, I. (2019). Interoperability of disparate engineering domain ontologies using basic formal ontology. *Journal of Engineering Design*, *30*(10-12), 625-654.

Harvey, D. (1973). *Social Justice and the City*. Edw. Arnold,

Harvey, D. (1978). The urban process under capitalism. *International Journal of Urban and Regional Research*, No 2.

Hausmann, R. (2015). *What are the Challenges of Economic Growth*? Growth Policy.

IBM Institute for Business Value (2009). The vision of smarter cities. https://www-03.ibm.com/press/attachments/IBV_Smarter_Cities_-_Final.pdf

Henkel, M., Johannesson, P., & Perjons, E. (2011). An approach for e-service design using enterprise models. *International Journal of Information System Modeling and Design (IJISMD)*, *2*(1), 1-23.

Iliadis, A. (2019). The Tower of Babel problem: making data make sense with Basic Formal Ontology. *Online Information Review*.

Keeble O., Owens, P.L., Thompson, Ch. (1983). The urban-rural manufacturing shift in the European Community. *Urban Studies*, Vol. 20 (4).

Kelly Garrett, R. (2006). Protest in an information society: A review of literature on social movements and new ICTs. *Information, communication & society*, *9*(02), 202-224.

Komninos, N. (2002*). Intelligent Cities: Innovation, knowledge systems and digital spaces*. Routledge.

Komninos, N. (2008). *Intelligent Cities and Globalisation of Innovation Networks*. Routledge, Regions and Cities series.

Komninos, N. (2014). *The Age of Intelligent Cities: Smart Environments and Innovation-for-All Strategies*. Routledge, Regions and Cities series.

Komninos, N. (2016). Intelligent cities and the evolution towards technology-enhanced, global, and user-driven territorial systems of innovation. In: D. Doloreux, R. Shearmur and C. Carrincazeaux (eds), Handbook on the Geography of Innovation, pp. 187-200, Edward Elgar.

Komninos, N. (2020*). Smart Cities and Connected Intelligence: Platforms, ecosystems and network effects*. Routledge, Regions and Cities series.

Komninos, N. and Kakderi, C. (2019*). Smart Cities in the Post-algorithmic Era: Integrating technologies, platforms and governance*. Edward Elgar, Cities series.

Komninos, N., Bratsas, C., Kakderi, C., and Tsarchopoulos, P. (2015). Smart city ontologies: Improving the effectiveness of smart city applications. *Journal of Smart Cities*, vol. 1(1), 1-17

Komninos, N., Kakderi, C., Panori, A., & Tsarchopoulos, P. (2019). Smart city planning from an evolutionary perspective. *Journal of Urban Technology*, *26*(2), 3-20.

Lipietz A. (1977). *Le Capital et son Espace.* Editions de la Découverte.

Minar, D. W., & Greer, S. A. (Eds.). (2017). *The concept of community: Readings with interpretations*. Transaction Publishers.

N. Komninos. (2018). Architectures of Intelligence in Smart Cities: Pathways to Problem-Solving and Innovation. *ArchiDoct*, 11, Vol. 6 (1), July.

Oakey R.P., A.T. Thwaites, and P.A. Nash (1980). The regional distribution of innovative manufacturing establishments in Britain. *Regional Studies*, Vol, 14.

Planning and Policy, 28(5), 391–412.

Pruijt, H. (2007). Urban movements. *The Blackwell encyclopedia of sociology*, 1-4.

Ruhlandt, R. W. S. (2018). The governance of smart cities: A systematic literature review. *Cities, 81, 1-23.*

Scott A. (1982). Locational patterns and dynamics of industrial activity in the modern metropolis. *Urban Studies*, Vol. 19.

Scott, A. J. (1996). Regional motors of the global economy. Futures-the Journal of Forecasting

Scott, A. J., & Storper, M. (2015). The nature of cities: The scope and limits of urban theory. *International Journal of Urban and Regional Research*, *39*(1), 1-15.

Smith, B. (2015). Basic Formal Ontology 2.0. Specification and user's guide. https://github.com/BFO-ontology/BFO/raw/master/docs/bfo2-reference/BFO2-Reference.pdf

Smith, B. (2020). Ontologies for Space and Ground Systems.

Smith, B. et al. (2015). Basic Formal Ontology 2.0. Specification and user's guide.

Smith, B., & Ceusters, W. (2010). Ontological realism: A methodology for coordinated evolution of scientific ontologies. *Applied ontology*, *5*(3-4), 139-188.

Soja, E. (1994). Los Angeles 1965-1992: Six Geographies of Urban Restructuring.

Spear, A. D., Ceusters, W., & Smith, B. (2016). Functions in basic formal ontology. *Applied Ontology*, *11*(2), 103-128.

Spear, A. D., Ceusters, W., & Smith, B. (2016). Functions in basic formal ontology. *Applied Ontology*, *11*(2), 103-128.

Rubin, E. L. (2001). Passing through the door: Social movement literature and legal scholarship. *University of Pennsylvania Law Review*, *150*(1), 1-83.

Taylor, V., Whittier, N. E., & Morris and Mueller. (1992). Collective Identity in Social Movement.

Van Laer, J., & Van Aelst, P. (2010). Internet and social movement action repertoires: Opportunities and limitations. *Information, Communication & Society*, *13*(8), 1146-1171.

Walker R. and Storper, M. (1981). Capital and industrial location. *Progress in Human Geography*, No 4.

Zald, M. N., & Ash, R. (1966). Social movement organizations: Growth, decay and change. *Social Forces*, 44(3), 327-341.