Sustainable cities and communities **ISO/TC 268**

Date:
2019-02-08

Doc. Number:
N 0428

Assistant:
Patricia SAINT-HERVE
Direct line :
patricia.saintherve@afnor.org

Your contact:
Etienne CAILLEAU
Direct line : 01 41 62 85 71
etienne.cailleau@afnor.org

Draft for ISO FDIS 37105 - Sustainable cities and communities -- Descriptive framework for cities and communities

COMMENTARIES / DECISIONS	Dear member, You will find below the ISO DIS 37105 which includes modifications in accordance with the resolution of comments submitted during the DIS ballot and made by WG 3. This will let the opportunity to each member to see the modifications made into the DIS. This version of the document will be submitted by March 15th 2019 to ISO/CS in order to launch the DIS if there is no comment received.
FOLLOW UP	For information
SOURCE	ISO/TC 268/WG 3

ISO FDIS/37105

ISO TC 268/WG3

Secretariat: NFPA

Sustainable cities and communities — Descriptive framework for cities and communities

FDIS Stage

Warning for WDs and CDs

This document is not an ISO International Standard. It is distributed for review and comment. It is subject to change without notice and may not be referred to as an International Standard.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 268, *Sustainable cities and communities.*

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The descriptive framework for cities and communities detailed in this document helps city and community stakeholders define a common language to describe cities and communities. This framework can facilitate the sharing of ideas, data and solutions within, and also between, cities. The descriptive framework, which can also be referred to as the city anatomy, serves as a basic blueprint to facilitate the integration of operating systems and services within a city or community.[5] Ultimately, the descriptive framework can be the basis of a formal ontology, or knowledge model, which can be useful for helping to plan and implement city operating solutions, particularly those that might require digital machine-readable information.

A city or community is a system of systems and interactions that fosters and are fostered by emergent human behaviour.[1] It can be seen as an arrangement of, and set of relationships between, the multiple layers of a permanent human settlement, with an administrative and legal status supported by laws and generally recognized throughout the world. Rather than being static, discreet entities, cities or communities often have porous and sometimes ambiguous borders (politically, economically, environmentally, and socially) and can thus often be difficult to describe. The structure, interactions, and societal aspects of a city or community are also integral parts of all wider systems extending beyond the city borders. However, more than half the world's population now lives in cities or communities and many of humanity's chronic challenges are faced in cities or communities. A common descriptive framework for cities or communities is a useful tool to assist them in sharing knowledge and finding solutions to issues common to cities or communities all over the world.

Solutions to the issues cities face are intended to improve the quality of life for all city citizens and follow sustainable development principles. These principles dictate that the solutions to city issues implemented today do not compromise the ability of future generations to meet their own needs. The United Nations' Sustainable Development Goals (UNSDG)[2] issued in 2015 resolve this relatively abstract ideal into more tangible objectives. The UNSDG Goal 11 provides these objectives for cities, creating 10 targets for improving the quality of life for citizens and the city's resiliency, while also limiting the impact of human activity on the environment. Tools such as ISO standards, for example ISO 37101 and ISO 37120, help cities plan for, monitor, and reach these objectives. The purpose of this document is to

[1] Emergent Human Behavior: its existence and activities are ad hoc and therefore unique to the event. These are small or large groups that take shape and carry out tasks or activities that institutionalized groups cannot accomplish. Thus the emergent organized response (people sometimes speak of 'emergent groups' too), is related to the idea of non-traditional and new behavior (example of mutual assistance groups that form just after a catastrophe to look for the injured and help evacuate them). While the informal emergent groups are generally organized in the period after the disaster and more rarely during the event, during which period individuals organize their actions more around their families and friends (Quarantelli, 1988), institutionalized groups, whether emergent or not, act both during and after the event.

EMERGENT HUMAN BEHAVIOR DURING A DISASTER: THEMATIC VERSUS COMPLEX SYSTEMS APPROACHES Damienne Provitolo, Edwige Dubos-Paillardy and Jean-Pierre Muller EPNACS- September, 2011

[2] **Sustainable Development Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable: (11.1)** By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums; (**11.2)** By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons**; (11.3)** By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries; **(11.4)** Strengthen efforts to protect and safeguard the world's cultural and natural heritage**; (11.5)** By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations; (**11.6)** By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management; (**11.7)** By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities; (**11.a)** Support positive economic, social and environmental links between urban, per-urban and rural areas by strengthening national and regional development planning**; (11.b)** By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels; (**11.c)** Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials.

provide a common language for the description of cities that will enable those goals and support the sharing of city solutions.

The descriptive framework is based on work by the City Protocol Society. It uses an analogy to human anatomy and its dynamic physiology to describe any city or community, of any size, in a manner that is timeless, culturally agnostic, scalable, and generic. The descriptive framework categorizes the components of the city into three major elemental systems: a set of physical structures (Structure), the living entities that create a city's society (Society), and the flow of interactions between them (Interactions). These elemental systems are further resolved into, or described by, layers that capture all the activities of importance to a city, both within and outside the city boundaries, as well as all the natural and built domain components within a city.

Sustainable cities and communities — Descriptive framework for cities and communities

1 Scope

This document specifies a descriptive framework for a city including an associated foundational ontology of the anatomical structure of a city or community. The descriptive framework is intended to have the following qualities:

— *timeless*, i.e. compatible with any human settlement at any time in history;

— *acultural*, i.e. valid for any culture and any type of city;

— *scalable*, i.e. valid for a metropolis, a city, a small town or a village;

— *generic*, so that everything we could define as a "human settlement", such as a "smart city", has a place in this structure.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced documents (including any amendments) applies.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

ISO 37100, Sustainable cities and communities-Vocabulary, contains a list of relevant terms and definitions which are also useful in understanding the descriptive framework.

3.1
Descriptive framework
logical structure that describes how the key entities within a specific domain can be classified so as to show their relationship with each other

Note 1 to entry: "Entities" refers not only to tangible things, but also to anything important that has a separate and distinct existence, for instance elemental conventions, principles, practices, strategies, policies, decision making structures and accountabilities.

3.2
Ontology
specification of concrete or abstract things, and the relationships among them, in a prescribed domain of knowledge

[SOURCE: ISO/IEC TR 19763-9:2015, 3.1.3, modified — Note removed.]

3.3
Urbanism
urban life and environment

4 Descriptive framework of cities and communities

4.1 General description of a city

Figure 1 shows the three overarching logical elements of a city or community ecosystem as the holistic integration of: the physical structure (structure), the people who live in it and occupy this physical space while carrying out functions (society), and the interactions through which the society engages with the structure.

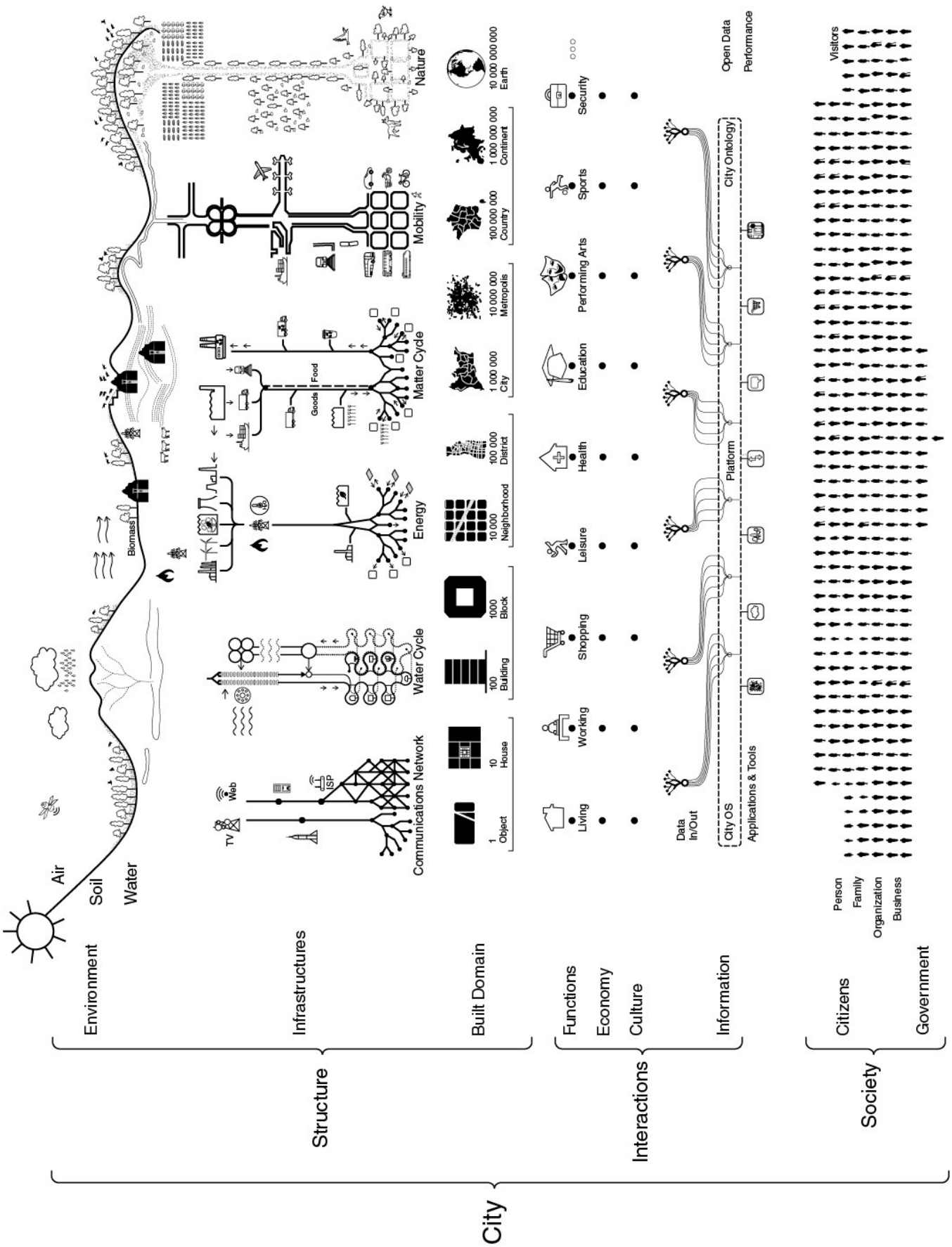


Figure 1 — A timeless, culturally agnostic, scalable, generic descriptive framework for any city or community

4.2 Cities as ecosystems

A city can best be viewed and understood as an ecosystem, broken down into three elements:

1. the *physical structure* of that ecosystem;
2. the *living entities* that it contains;
3. the *flow of interactions and information*.

The descriptive framework offers a common language to describe the city ecosystem as: a set of physical structures, the living entities that make up a city's society, and the flow of interactions between them. In so doing, it suggests an analogy to the human anatomy and its dynamic physiology.

4.3 How the descriptive framework supports governance and transformation

Ultimately, the descriptive framework aims to help enable effective governance, evaluation, and transformation by providing city officials and other stakeholders:

- a way to describe their aims and objectives, existing or proposed city initiatives, and services in a manner that is consistent across cities, vendors, and service providers, and standards developers;
- a comprehensive checklist of key city aspects and domains.

By providing a framework for describing projects and objectives in a way that is consistent with other cities, city solution providers and standards organisations will enable them to more easily:

a) Identify opportunities and potential areas for innovation and collaboration within or between cities;
b) Improve communications between different city service owners and/or operators within the city;
c) Communicate their objectives and priorities clearly to citizens and service providers;
d) Frame and support emerging processes and citizen demands; and
e) Identify the standards that are most relevant to the needs they are seeking to address.

The checklist can help them:

1. Review their city in a comprehensive way to evaluate areas of strengths and weaknesses and set priorities for future action;
2. Review potential projects to understand the areas of city life they are likely to impact and the city stakeholders that need to be consulted or involved; and
3. Develop comprehensive sets of evaluation criteria to judge the success of projects.

See Annex A for a more detailed description of applying the descriptive framework for cities: governance, evaluation, and transformation.

4.4 Basic elements of the descriptive framework for cities and communities

4.4.1 Structure (system)

The first layer within the structure system element is the *Environment*, which is the physical and geographic setting of the city, including the natural environment ("nature"). It is formed by the nature (plant and animals) and by the three basic components— air, earth, and water—interacting dynamically in a seasonally variable wayand increasingly subject to the impacts of climate fluctuations linked to anthropogenic

greenhouse gas pollution.[3] The second layer of the Structure system element is *Infrastructures,* the connective structures that enable resource gathering and extraction from the environment, transporting resources to the city, and the material and energy cycles within the city itself. These infrastructures include those that support *communications*, the *water and energy cycles*, the *matter cycle* that supports the movement of goods and food as well as the resultant waste, the *mobility networks*, and *nature* or green infrastructure of the city. The third layer is the *Built Domain*, which can best be organized according to the approximate number of people that it can accommodate on a physical basis. Thus, within the *Built Domain*, an *object* corresponds to a *single person*, *house*, *building*, *block*, *neighbourhood, district, city,* and *metropolis* or *region,* each increasing the scale by an order of magnitude. Private and public spaces are contained within each level of scale.

4.4.2 Interactions (system)

The first layer within the Interactions system element comprises urban *Functions* including *living*, *working*, *education*, *shopping*, caring for *health*, the *performing arts*, and many more. The second layer is the *Economy*, which influences urban innovation and the everyday operation of the city, as well as the life cycles of services provided by cities. The third layer is *Culture* — the languages, traditions, beliefs, values, and the ways in which people organize their conceptions of the world around them (i.e., the non-material assets of the city). The fourth and final layer is *Information*. It includes the *City Operating System* (City OS), *City Performance Indicators and Indexes*, *Tools and Applications, City Ontology*, and an *Information Portal* for open data and specific learning protocols and related resources.

4.4.3 Society (system)

The Society system element is composed of the living entities of the city. The first layer is *Citizens*, which can be broken down into: *person (the individual), family*, *organizations,* and *businesses.* The second layer is *government*, whose head is, typically, the mayor.

Note: The term *governance* is used when the descriptive framework of a City is used for evaluation purposes. The term governance is the process of running a government and, as such, it focuses on its effectiveness.

4.5 Structure (system)

4.5.1 Environment

The first subsystem layer within the structure system element of the descriptive framework (see Figure 1) is the environment, the setting of the city, as shown in Figure 2.

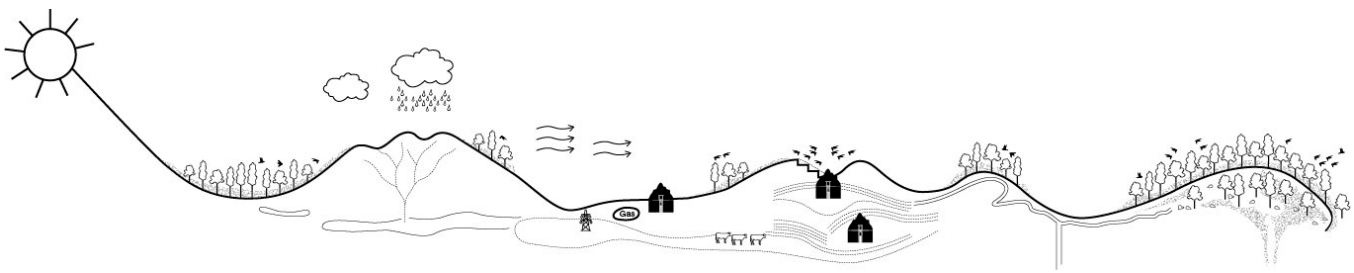


Figure 2 — Environment

The environment existed well before the establishment of the city and includes the topography, morphology, living systems, and natural flows and cycles that form the city's physical setting. The environment is the nature (plants and animals) and the three basic components—air, soil and water—which interact

[3] Anthropogenic sources are those caused or produced by humans, such as the carbon pollution emitted through power generation or transport.

dynamically in seasonally variable ways. Each of these components has its own indicators to assess quality and other characteristics.

Air quality can be assessed by measuring particulate concentration, ozone levels, and other chemistry, as well as CO_2 levels, temperature, and other measures related to global warming. The ground topography (*soil*) is fundamental for siting a city and serves as an important resource, supporting agriculture, plants, and animals. It is also an important source of minerals and energy. *Soil* too has physical and chemical properties, which can be measured. Finally, *water* cycles through the environment—atmosphere to surface water to groundwater to oceans. Both water quality and water quantity can be measured in a number of ways.

These are the components, which interact to form the Environment Layer and are critical in the functioning of a city.

4.5.2 Infrastructures

4.5.2.1 Introduction

The second subsystem layer within the Structure System Element is the **Infrastructures**, the connective structures that enable resource extraction and use, as well as enabling city life. The infrastructure layer includes the networks that support communications and mobility, as well as those that support cycles for water, energy, and matter. It also includes the natural—or green—infrastructure that plays an important role in many communities.

4.5.2.1.1 Communications network The first Infrastructure depicted in Figure 1 above is the communications network shown in detail in Figure 3. The communications component is composed of all of the technologies that carry information, such as Information Communication Technologies (ICT) (wire and cellular telephone technologies, radio, television) and the Internet. Centralized models of communication with one emitter and many receivers (i.e., radio and television) have evolved into a more distributed arrangement of information with many emitters and many receivers of information (i.e., the Internet).

Telecommunications networks transporting information through copper and/or fiber optic cables, as well as through the electromagnetic spectrum, are all examples of Communication Infrastructure.

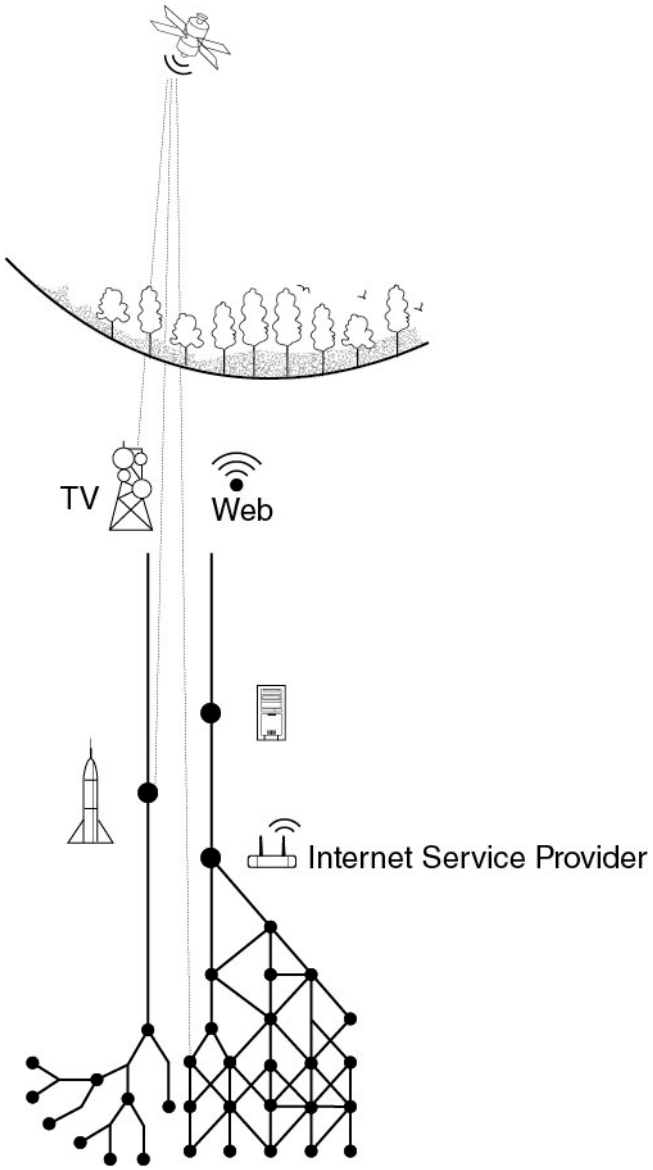


Figure 3 — Communications network

4.5.2.1.2 Water cycle

The second Infrastructure is the water cycle component, which includes water supply, treatment, and management of wastewater, surface water runoff, and floodwaters (see Figure 4). Cities draw water from the environment, perform treatment process, and consume it. Gray water[4] and wastewater is discharged back into receiving bodies, often after treatment, and sometimes recycled directly back into the community's own water supply. Water infrastructure describes all of the physical elements that form the water cycle—from its extraction to its disposal or reuse—and that operate it in a structured way to serve a city or community.

[4] Gray water is wastewater from sinks, baths, washing machines, and other sources that can be used or recycled for other purposes where potable water is not required, like toilet flushing.

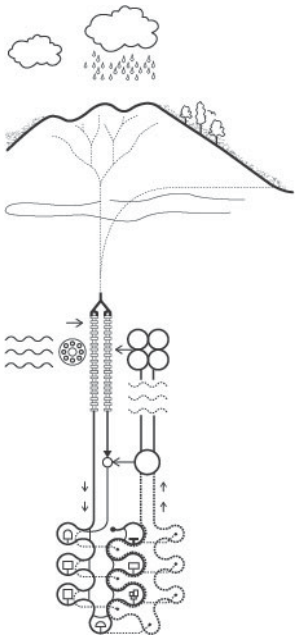


Figure 4 — Water cycle

4.5.2.1.3 Energy The third Infrastructure is the energy cycle component (see Figure 5) composed of the entire power system, including functional nodes producing power (e.g. nuclear and fossil fuel power plants, wind farms, biomass/bioenergy power plants, hydroelectric plants, solar generating plants) often located outside of the city; the networks needed to transmit electricity or convey fuel—like natural gas—into the city; as well as other networks of pipelines, ships, rail, and trucks needed for the transport of fossil fuels and chemicals as raw or refined products. In addition, smaller production nodes, like district-level

generating plants, bio-energy systems, and steam generation often operate in cities, as well as distributed energy nodes, like rooftop solar for thermal energy or electricity.

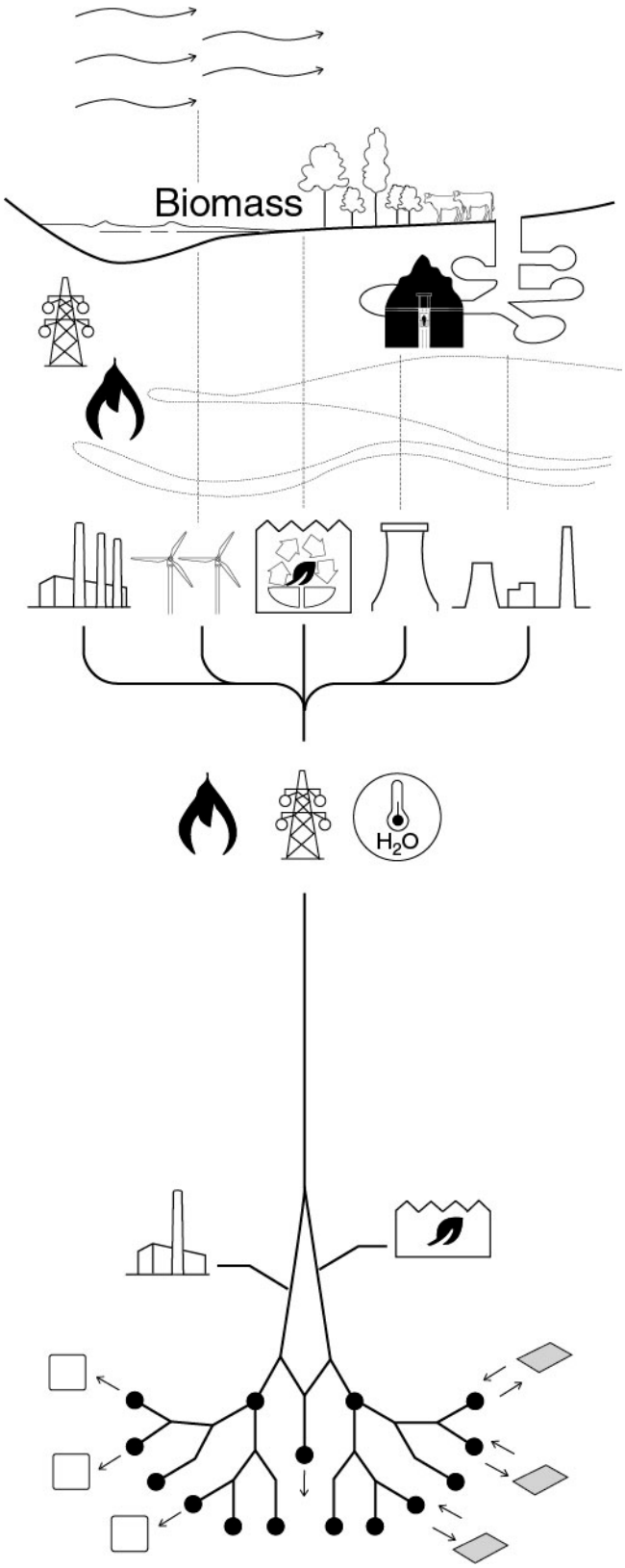


Figure 5 — Energy

4.5.2.1.4 Matter Cycle

The fourth Infrastructure is the materials or matter cycle (see Figure 6). This infrastructure component includes the extraction of material resources from nature (including food), their industrial level or small-scale manipulation to create products, the transportation and logistics infrastructures to reach consumers, and the management of waste materials. Stated another way, the matter cycle includes: (i) everything involved in the extraction of resources from the environment and the transport of those resources to factories or production centres; (ii) the distribution of resources and products around the world enabled by logistics platforms, containers, and other means; (iii) deliveries within cities; (iv) consumption within cities; (v) waste generation; (vi) transport of waste to landfills; and (vii) waste recycling and/or waste-to-energy production.

Figure 6 depicts two main types of materials: (i) the matter incorporated into consumer goods and construction materials within the city, shown as a solid line, and (ii) food—both plant-based and livestock—shown as a dotted line.

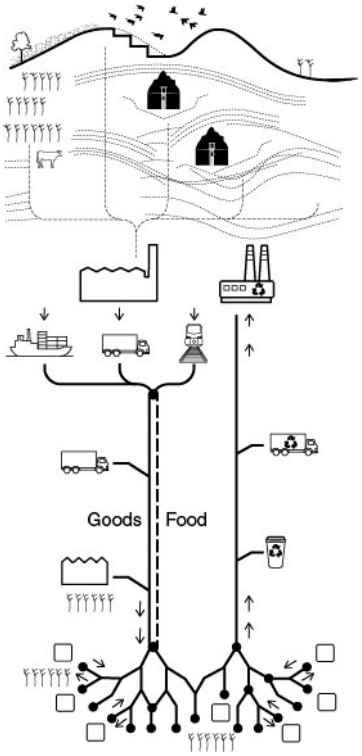


Figure 6 — Matter cycle

4.5.2.1.5 Mobility

The fifth type of Infrastructure is mobility (see Figure 7). Mobility chiefly refers to transportation for people, though often the same facilities, networks, and means of conveyance transport goods as well, like airports and ports, and other facilities devoted to shipping and logistics. Mobility networks include large systems, such as railways, airports, highways, as well as road systems, including city streets. City streets, used by pedestrians, bicyclists, vehicles, and public transportation, are not only important for mobility, but they also form an integral part of a city's public space, which is important for many aspects of city life.

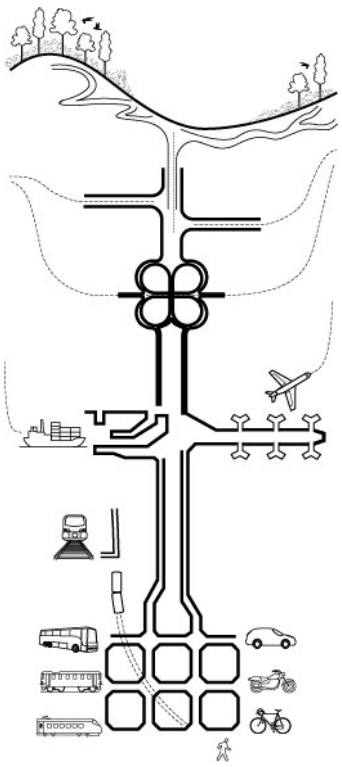


Figure 7 — Mobility

4.5.2.1.6 Green infrastructure/nature

The final Infrastructure is the green infrastructure (see Figure 8)—i.e., the infrastructure provided by the natural environment. It can be composed of natural elements used in a structured way, like rain gardens or bioswale[5], or any other natural element, like trees and open space that has an effect on the quality of city life.

[5]Bioswales are landscape elements designed to concentrate or remove silt and pollution from surface runoff water.

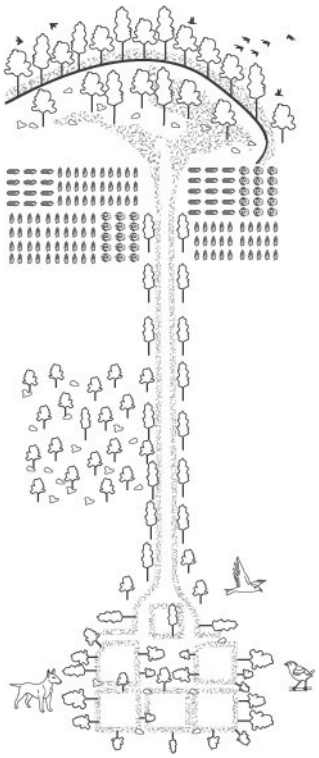


Figure 8 — Nature

4.5.3 Built Domain

The third component of the city structure system element is the built domain, both public and private, and the surrounding public space. The built domain has two distinct and essential characteristics in relation to urbanism: (i) it is the main expression of the material culture of a city, and (ii) it is fundamentally multi-scale in nature (i.e., scale is an intrinsic characteristic of the built environment), as illustrated in Figure 9. At the highest level of resolution, the built environment supporting urban functions can be viewed as objects. Scaling up, the built domain is a collection of objects and the space that contains them. As illustrated below, this scale can be represented as: houses, building, blocks, neighbourhoods, districts, the city, the metropolis, the country, the continent, and ultimately the whole planet.

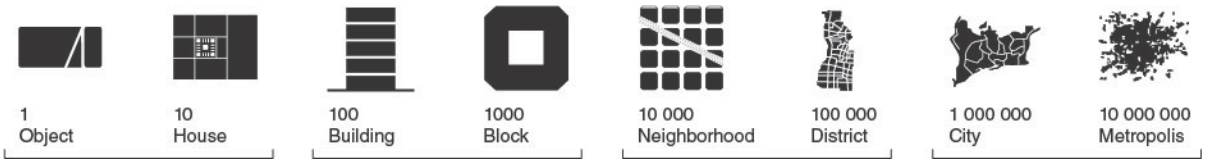


Figure 9 — Built domain

Objects are also those structures at the smallest scale that can ultimately have their own identity in a global network of the Internet of Things (IoT). Most objects belong to a functional category since they support one or more functions for human life in cities. In many cases they become part of a larger scale network made up of other elements and systems (e.g., buildings or the city itself).

The built domain in both Figures 1 and 9 is ordered according to the number of people that each level of scale approximately relates to on a physical basis, for example 1 object; 10 house; 100 building; 1000 block; 10000 neighbourhood; 100 000 district; 1 000 000 city; 10 000 000 metropolis or region.

The built domain determines where the essential functions attached to human life in cities take place, both publicly and privately. Thus, it is typically buildings like apartments/flats, hospitals, offices, and other places of employment, but it can also be the public space of streets and squares. These public spaces are also often the right-of-way's through which infrastructure and vehicles pass, and which host green space. It includes

blocks of flats/apartments, hospitals and places of employment. In addition, the public space can have its own intrinsic value in the city as a space shared by people to meet, relax, and carry out activities, either individually or communally.

Different city models can be identified or defined based upon the scales at which individual needs are met as they, in turn, determine the associated models for mobility, density, and social interaction. Every node in the built domain has a production and an operational cost, with an economic, social, and environmental impact on its setting and, ultimately, on city finances and efficiency.

4.5.4 The three subsystems of the structure

The three subsystems of the *Structure*—the environment, infrastructures, and the built domain—are the physical remnants of a city that would remain if the people disappeared. The three structure layers help explain the city as a system of systems and interactions. As depicted in the diagrams, these networks have connecting lines on which information, energy, or material travel and nodes where such may be processed and/or stored.

The relationship between Structure and Society is characterized herein as Interactions, which is the second system element considered in the anatomy of Figure 1.

4.6 Interactions (system)

4.6.1 Introduction The second system element considered in the descriptive framework is Interactions. The Interactions between the Structure and Society effectively reflect the activities in the city and can be analysed and measured as flows of information.

Interactions includes four subsystem layers: (i) functions, (ii) economy, (iii) culture, and (iv) information.

4.6.1.1 Functions

Functions include living, working, education, shopping, caring for health, the performing arts, tourism (business and personal), and many more. The built domain, including public space, typically hosts most of these functions, though this subsystem layer is concerned with the activities themselves and not the buildings that play host to them. This is an important distinction because some of these Functions, like education and shopping, can be delivered via the Internet and may no longer be confined to specific buildings or facilities. However, Functions, many of which are supported by the city, generally emerge from the interaction between the people in the city and different parts of the built domain.

4.6.1.2 Economy

Wealth production and distribution, commerce and trade, innovation and entrepreneurial ecosystems, competitiveness, tax base, and financing vehicles are among the many dimensions that create the Economy of a city, the second subsystem of the Interactions System Element. The economy plays a critical role in any city, impacting quality of life and the level of support for city services.

The Economy, at both the micro- and macro-economic scales, operates via an increasingly rapid rate of information exchange between people, institutions, companies, and economic and financial agencies. This is particularly true in cities, which today are responsible for generating most of the world's GDP. The Economy influences urban innovation, as well as everyday city operations and life cycles of services provided by cities. It is also a key element in the evolution of cities, determining the feasibility of transformational projects to increase the quality of life for residents.

4.6.1.3 Culture

Culture encompasses the languages, traditions, beliefs, values, and other non-material assets that comprise parts of the city's identity. It also includes the tacit knowledge that builds shared understanding and trust among people in a given community that can become explicit practices, expressions, representations,

knowledge, skills, and organizational behaviours. Culture impacts and reflects all dimensions of human life—emotion, intelligence, spirituality, creativity, and community.

4.6.1.4 Information

The conceptual model of a city as a system of systems and interactions at different scales of time and space implies the inclusion in the Framework of an informational or systems platform, depicted Figure 10. This platform has the following five functional elements:

- City ontology, or knowledge model, which is the lexicon, syntax, and semantics needed to promote the interoperability and proper integration of city models, bringing together all the structural elements of the anatomy, along with the time and spatial reasoning coupled with the information systems that are involved in the formulation, generation, and evaluation of urban planning, design, and transformation;

- City operating system (City OS) that functions as a shared—or trans-disciplinary—set of tools to manage and organize the city as a system of systems for all city activities by defining protocols that standardize methods for improving knowledge acquisition and information transfer (i.e., data flows);

- City performance indicators and indexes that include broad performance categories, such as resilience, self-sufficiency, habitability, welfare and economic empowerment, and that also consider qualitative information in an evaluation framework defined for assessment purposes, for example ISO 37120;

- Tools and applications for system-level data analysis and representation/visualization, decision support, management actions, and data privacy and security actions; and

- Information portal for open data and specific learning protocols and related resources, including information on both hard and soft systems, and on the many different mechanisms by which cities acquire and apply knowledge.

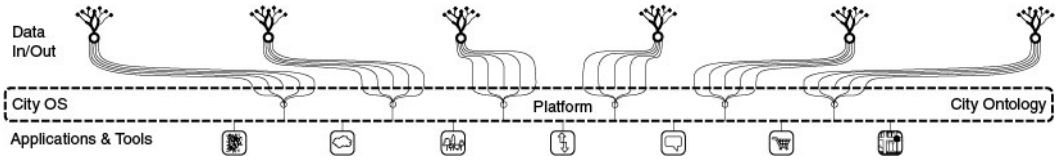


Figure 10 — Information platform

Many cities today are adopting and implementing information platforms to integrate all of the information flows that move data through interconnected and integrated layers of systems and subsystems that form the anatomy in Figure 1. These flows pass through specific domains like mobility, water, energy, or others.

Cities can have multiple information systems. For example, there may be a system to collect different types of data in real time, which may be separate from the data generated by the administration of the city or generated by city residents and businesses. These streams of data can be connected to a platform for integration and processing. This set of basic data collection and processing systems are the basis of what the Framework refers to as the operating system of the city, or the City OS (see Figure 10). As cities collect more information, applications can be designed and implemented to manage systems within the city. Cities can create open data platforms, enabling greater engagement in city life and governance by the public, and potentially accelerating innovation.

The city performance indicators enable evaluation and transformation, sometimes in real time, or through city governance or other processes. The performance indicators (like the ISO 37120 indicators) are key to the larger concepts like resilience, sustainability, attractiveness, well-being, and social equity, enabling evaluation of how well the city works or is meeting the UNSDGs, and other objectives determined through a sustainable development management system like ISO 37101 or other tools. Performance indicators also

facilitate learning from past efforts to promote change within a city as well as efforts made in other cities to address challenges. In both cases, the Framework provides a common frame of reference.

4.7 Society (system)

4.7.1 Introduction The third city system element is Society, including residents and government.

4.7.1.1 Citizens

Citizens include the individual (or person), family, organizations, and businesses. The term person is applied broadly, and includes individuals who live, work, and/or visit within a city, whether or not they are permanent or legal residents. Visitors are identified in Figure 1 as a cluster of individuals that cross city borders as a flow of people. Beyond individuals, citizens include the many ways people organize themselves (e.g., into clubs) and work and do business (e.g., in corporations, small businesses, or other entities).

Note: The term person could also be extended to include pets or domestic animals.

4.7.1.2 Government

Government is the part of Society that is elected or appointed to serve the community. It includes the decision makers, as well as the personnel and apparatus that carry out the will of the decision makers and city operations.

Note: The process of running a government, governance, is used for evaluation purposes in this document.

5 A foundation ontology for the descriptive framework of cities and communities

5.1 The descriptive framework as a basis for the city anatomy ontology

In addition to the uses of the descriptive framework described in 4.3, it can also be used as the basis of an ontology, as described in this clause. The ontology provides a machine-readable representation of the concepts and properties that underlie the City Anatomy framework. It serves several functions:

- It elaborates and clarifies the framework by providing a more precise description of the concepts that appear in the framework, enabling a clearer and more complete interpretation of the framework.
- It provides a data model that cities can use to represent and reason about the anatomy of their city. The data model can be used for planning and operational purposes, and it enhances the interoperability of data amongst city departments.
- It provides the means of operationalizing framework-based design of cities and communities with the information infrastructure that underlies city operations.

5.2 Ontologies taxonomies and controlled vocabularies

An ontology is commonly referred to as "a formal, explicit specification of a shared conceptualization." In this context, the term *conceptualization* refers to the development of an abstract model of some phenomenon in the world by having identified its relevant concepts. *Explicit* means that the type of concepts identified, and the constraints of their use, are explicitly defined. *Formal* refers to the fact that the ontology should be machine-readable. Finally, the term *shared* reflects the notion that ontology captures consensual knowledge, that is, not the personal view of the target phenomenon of some particular individual, but one accepted by a group.

Ontologies are designed to be used in applications that process the content of information, or perform some type of reasoning, rather than simply presenting raw, unprocessed information. Ontologies also permit greater machine interpretability of content than that supported by general technology syntax schema such

as XML, RDF, and RDF Schema (RDF-S). Ontologies provide additional vocabulary along with a formal semantics.

From a structural point of view, an ontology is composed of disjointed sets of concepts (i.e., those having no elements in common), relations, attributes, and data types. Concepts are sets of real world entities with common features. Relations are binary associations between concepts. There exist inter-concept relations, which are common to any domain and domain-dependent associations. Attributes represent quantitative and qualitative features of particular concepts, which take values in a given scale defined by the data type.

Concepts are classes organized in one or several taxonomies, linked by means of transitive *is-a* relationships. Multiple inheritance (i.e., the fact that a concept may have several hierarchical ancestors) is also supported. Binary relations can be defined between concepts. In those cases, the concept in the origin of the relation represents the domain and those in the destination, the range. Those relationships may fulfil properties such as symmetry or transitivity. By default, concepts may represent overlapping sets of real entities (i.e., an individual may be an instance of several concepts simultaneously). If necessary, ontology languages permit specifying that two or more concepts are disjointed (i.e., individuals can only be instances of one of those concepts).

There are formal languages to codify ontologies, and a key feature to implement the descriptive framework's City Anatomy Ontology (CAO) is the use of logical axioms that represent restrictions at a concept level; for example as used with OWL-DL and OWL-Full. Axioms are expressed with a logical language and contribute to define the meaning of the concepts by means of specifying limitations on the concepts involved. Several restriction types can be defined:

- Cardinality: defines that a concept's individual can be related (by means of a concrete relation type) to a minimum, maximum, or exact number of other concept's instances.
- Universality: indicates that a concept has a local range restriction associated with it (i.e., only a given set of concepts can be the range of the relation).
- Existence: indicates that a least one concept shall be the range of a relation.

All those restrictions can be defined as *necessary* (i.e., an individual should fulfil the restriction in order to be an instance of a particular class) or *necessary and sufficient* (i.e., in addition to the previous statement, an individual fulfilling the restriction is, by definition, and instance of that class). This is very useful for implementing reasoning mechanisms when dealing with unknown individuals, for example to represent more complex restrictions by combining several axioms using standard logical operators (e.g. AND, OR, NOT).

5.3 Descriptive framework city anatomy foundation ontology design principles

5.3.1 Introduction The CAO ontology described in this clause was developed according to the following design principles:

- Identification of the competency requirements of the ontology (i.e., the questions that the ontology must be able to answer)
- Identification of relevant terms (vocabulary) from the Descriptive Framework City Anatomy and their properties
- Organization of terms to form a taxonomy
- Extraction of relationships between terms and definition of axioms to provide an unambiguous interpretation of the terms
- Support ontology extensions

In addition, where appropriate concepts defined in ISO/IEC 30182 that can be mapped onto concepts within CAO should be identified.

5.3.1.1 Basic competency questions of the descriptive framework city anatomy foundation ontology (CAO)

The ontology must be able to answer a set of competency questions, which are related to the concepts and relationships described by the Descriptive Framework City Anatomy. The basic competency questions for CAO are:

- Which are the *systems* of a city?
- What is the *structure* of each system?
- How each subsystem *relates/interacts* with other systems?

The identification of the core entities needed to answer the above questions has been organized along two dimensions to facilitate the design of the ontology. The first dimension deals with the representation of the city from a systems science perspective whereas the second relates to the representation of the dynamic processes that occur in the day-to-day operation of a city. This is the same organizing principle as the descriptive framework, which, through the subsystems and layers, represents the city as a system of systems and the interactions that occur within and between these systems.

5.3.1.2 Strategic design objectives of the descriptive framework city anatomy ontology (CAO)

Examples of key questions related to the main strategic objectives of a city are:

- How self-sufficient is a city and how can it become a zero emissions city?
- How can we decrease the number of cars in a city to improve mobility?
- How resilient is a city?
- How can a city attract investments?
- How can a city achieve the goal of greater equity in available opportunities?
- How can a city foster entrepreneurship?
- How can the quality of life be improved in a city?

The Descriptive Framework City Anatomy Ontology (CAO) is a foundation ontology that provides the necessary building blocks to frame the above questions in the context of the descriptive framework in a formal and unambiguous way.

5.3.1.3 The city as a "system of systems"

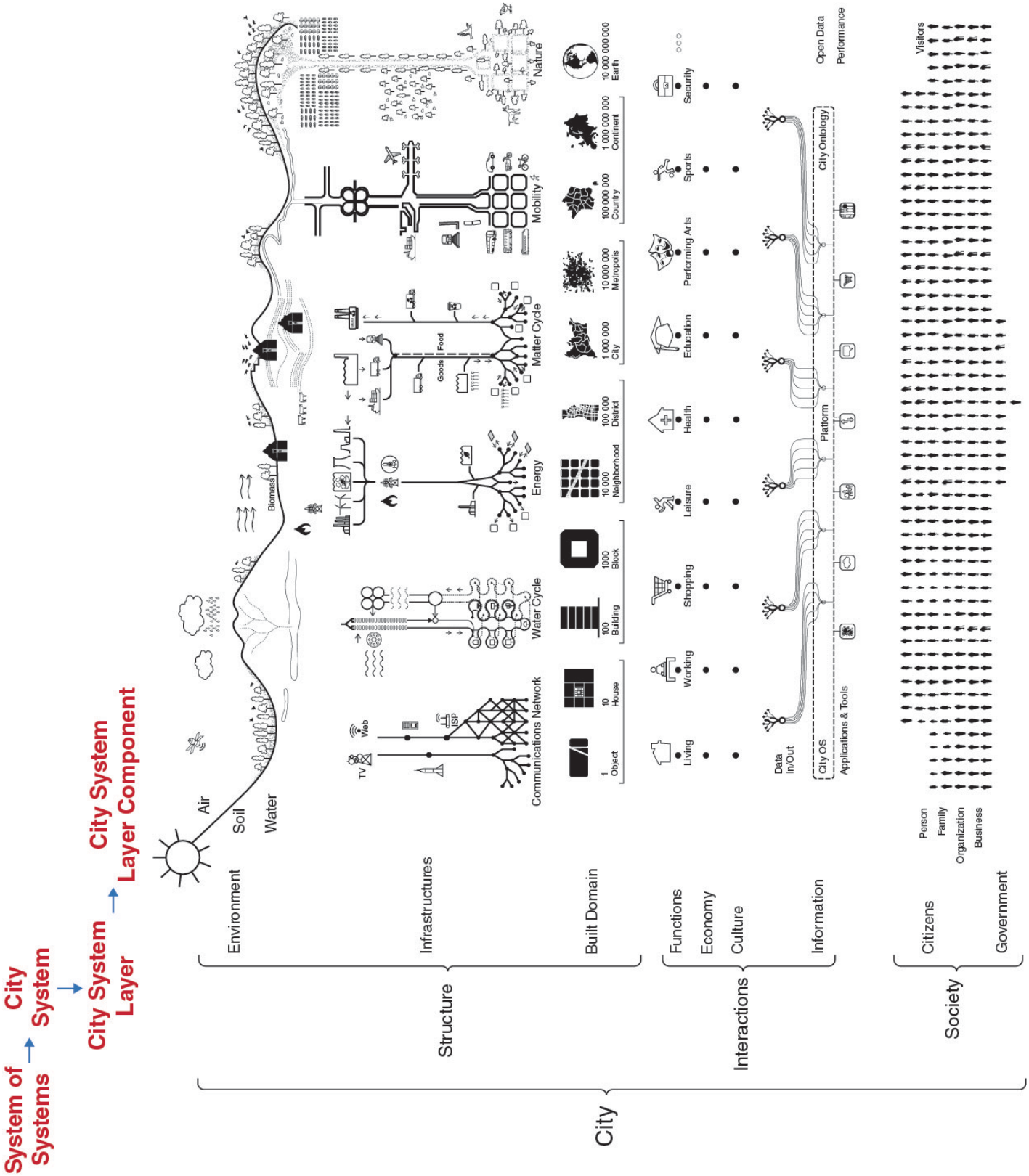


Figure 11 — Schematic representation of the descriptive framework city anatomy

A city is a system of systems and interactions that fosters and are fostered by emergent human behaviour+. See Figure 11 for a representation of this interaction. Cities can also be regarded as an arrangement of, and set of relationships between, multiple layers of a relatively large and permanent human settlement, with an administrative and legal status supported by local laws, and one that is generally recognized as such worldwide. The core entities of the CAO are designed to model the city and its internal processes from a systems science perspective.

Figure 12 shows the relationships among the basic entities that form the core of the ontology. The root of the graph is the concept 'Thing'. It represents the universal concept that subsumes all other concepts. 'CityAnatomyThing' is a SubClassOf 'Thing' and subsumes all concepts in the CAO. For example, 'Built_domain_element' is one of many concepts that are a SubClassOf 'CityAnatomyThing'. In addition to depicting the concept taxonomy, other relations between concepts are depicted. The SubClassOf relation denotes subsumption and defines the taxonomy of concepts. Secondly, other binary relations are introduced, such as isInformedBy, isOrganizedAs, and interactsWith. (Common practice is that concepts begin with a capital letter and relations with a small letter.) The specific structure of the classes and their relationships is based on the descriptive framework introduced in Clause 4.

Table 1 provides a formal description of a subset of the concepts in the diagram. The formalization used is Description Logic and specified using the Manchester syntax. For example, 'City_system' is defined to be a SubClassOf 'CityAnatomyThing' and related to at least 1 (i.e., some) 'City_system' concept via the interactsWith relation. It is also related to at least 1 'City_system_layer' via the isOrganizedAs relation.

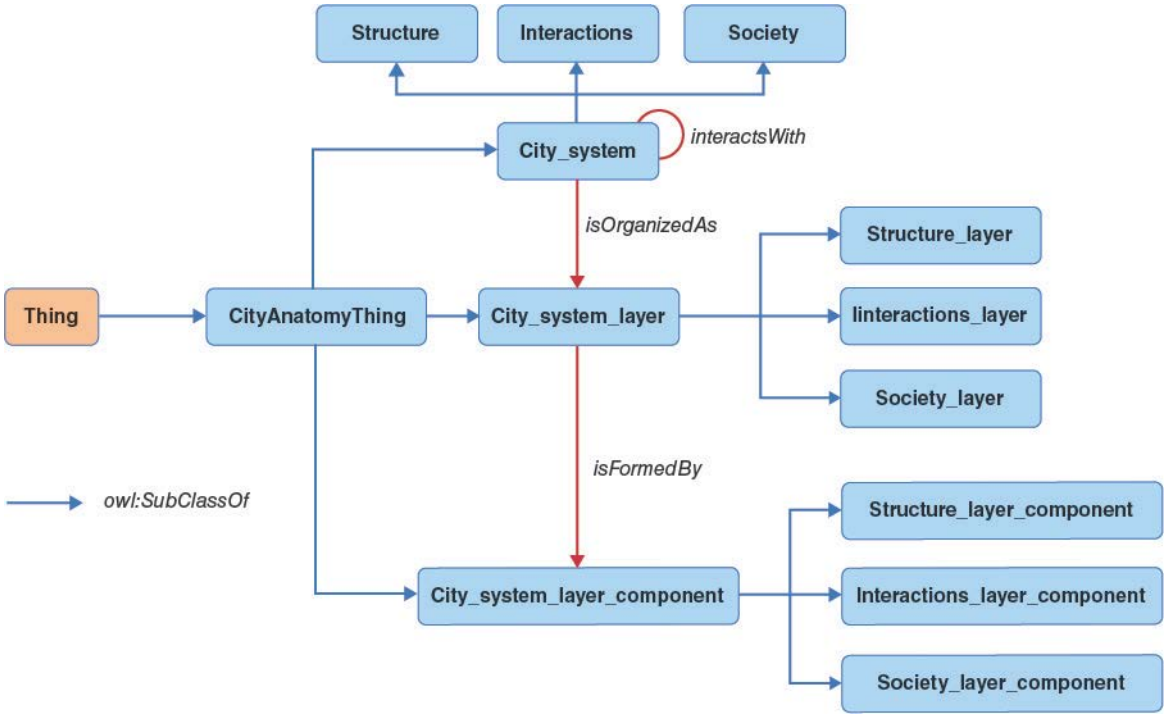


Figure 12 — Main CAO entities and relationships that describe a city from a systems science perspective as a *system of systems*

A detailed description of the most relevant entities is provided in Table 2.

Table 1 — Core CAO classes used to describe the city from a systems science perspective

Class	Property	Value Restriction
CityAnatomyThing	*Convenience class that groups all the city anatomy elements*	
City_system	*owl:SubClassOf* *interactsWith* *isOrganizedAs*	CityAnatomyThing *some* City_system some City_system_layer
City_system_layer	*owl:SubClassOf* *isConstituent* *isFormedBy*	CityAnatomyThing *some* City_system some City_system_layer_component
City_system_layer_component	*owl:SubClassOf* *isConstituent*	CityAnatomyThing exactly 1 City_system_layer

5.4 Structure system

5.4.1 Introduction Three layers that correspond to the environment, infrastructures, and built domain compose the structure of the city anatomy.

Figure 13 depicts the main entities and their inter-relationships.

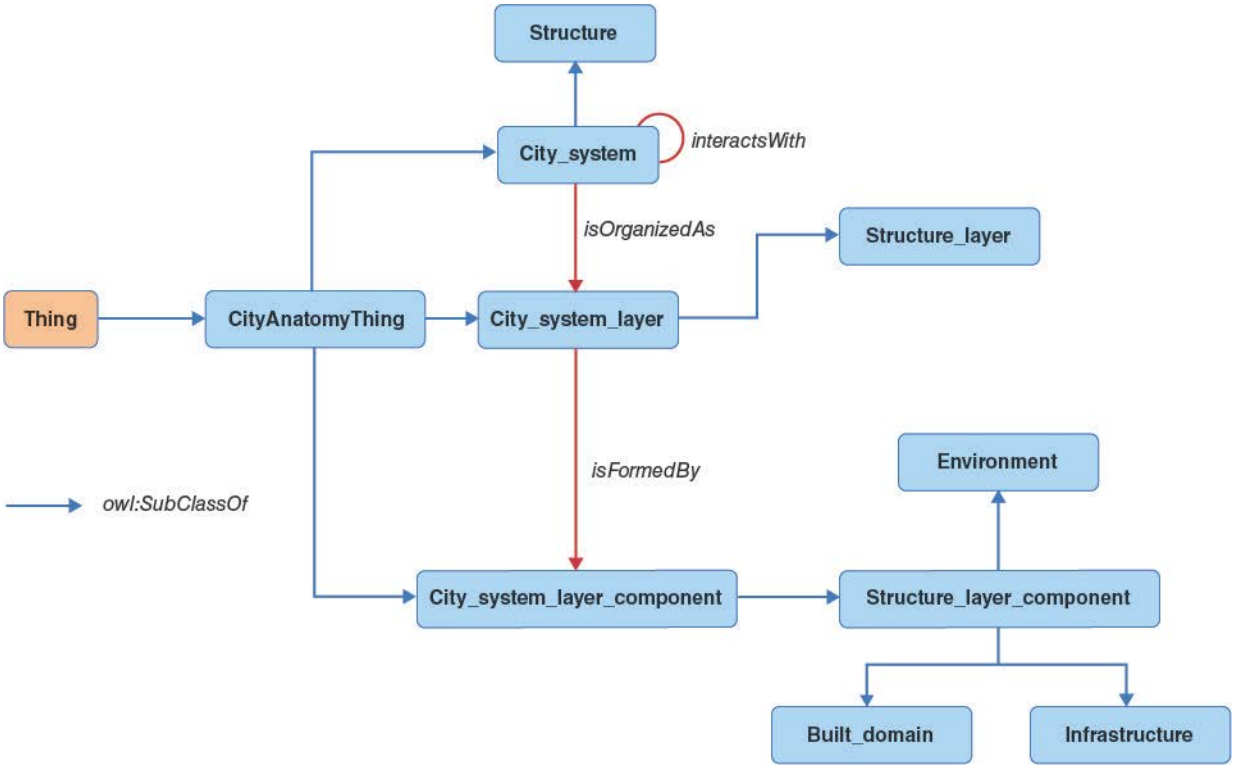


Figure 13 — Structure subsystem of the descriptive framework city anatomy with layers of environment, infrastructures, and build domain.

Annex B provides an elaboration of the CAO ontology classes, with a detailed description of the most relevant entities provided in Table 2.

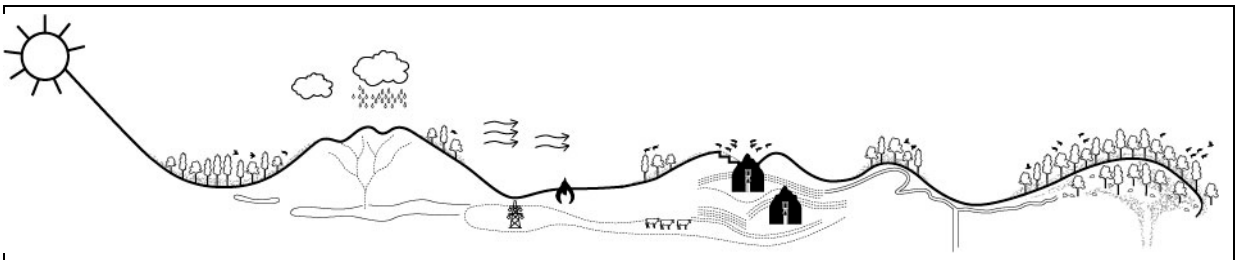
Table 2 — CAO classes used to describe the structure system

Class	Property	Value Restriction
Structure	*owl:SubClassOf* *isOrganizedAs* *owl:DisjointWith* *owl:DisjointWith*	City_system *only* Structure_layer Interactions Society
Structure_layer	*owl:SubClassOf* *isFormedBy* *owl:DisjointWith* *owl:DisjointWith*	City_system_layer *only* Structure_layer_component Interactions_layer Society_layer
Structure_layer_component	*owl:SubClassOf* *isConstituent* *owl:DisjointWith* *owl:DisjointWith*	City_system_layer_component *only* Structure_layer Interactions_layer_component Society_layer_component

5.4.1.1 Environment

The first component of the structure layer is the environment. The environment is the setting of the city. The environment is formed by nature (plants and animals, may be referred to as biodiversity) and by the three basic environmental compartments, air, soil, and water, interacting dynamically in a seasonally variable way as described in Table 3. Each of these compartments has its own quality indicators.

Table 3 — CAO classes used to describe the environment layer

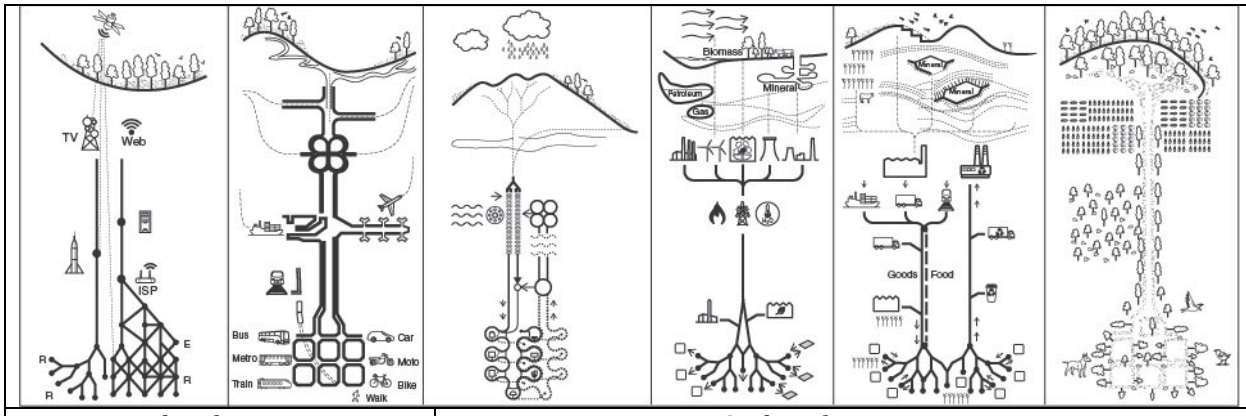


Class	Property	Value Restriction
Environment	*owl:SubClassOf* *isFormedBy* *isRelatedTo*	Structure_layer_component *some* (Biodiversity and Environmental_compartment) *some* Settlement
Biodiversity	*owl:SubClassOf*	CityAnatomyThing
Environmental_compartment	*owl:SubClassOf* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual*	CityAnatomyThing *Air* *Soil* *Water* *Sediment* *Biota*
Settlement	*owl:SubClassOf*	CityAnatomyThing

5.4.1.2 Infrastructures

The second subsystem layer within the anatomy structure comprises the infrastructures, i.e., connective structures that enable people to get the resources they need, especially from the environment, and bring them to the city or that enable the flows or cycles inside the city itself. Two main types of infrastructures are considered: **networks** and **cycles**, where a cycle can have a network as one of its interconnected nodes. Tables 4 and 5 along with Figure 14 describe and depict the main entities and relationships in the infrastructure component.

Table 4 — CAO classes used to describe the infrastructure layer



Network infrastructures	Cycle infrastructures	
Class	**Property**	**Value Restriction**
Infrastructure	*owl:SubClassOf* *enable* *transports*	Structure_layer_component *some* Flow *some* TransportableThing
Network_infrastructure	*owl:SubClassOf* *isNodeOf*	Infrastructure some Network_infrastructure
Data_communication_network	*owl:SubClassOf* *transports* *owl:NamedIndividual*	Network_infrastructure some Data *Internet*
Metropolitan_area_network	*owl:SubClassOf*	Data_communication_network
Local_area_network	*owl:SubClassOf*	Data_communication_network
Mobility_network	*owl:SubClassOf* *hasElement*	Network_infrastructure some Mobility_network_component
Mobility_network_component	*owl:SubClassOf* *isElementOf*	CityAnatomyThing some Mobility_network
Subway Bus/Bus Rapid Transit	*owl:SubClassOf* *owl:SubClassOf*	Mobility_network_component Mobility_network_component
Road	*owl:SubClassOf*	Mobility_network_component
Railway	*owl:SubClassOf*	Mobility_network_component
Pedestrian_way	*owl:SubClassOf*	Mobility_network_component
Highway	*owl:SubClassOf*	Mobility_network_component
Bicycle_way	*owl:SubClassOf*	Mobility_network_component
Airports	*owl:SubClassOf*	Mobility_network_component
Power_network	*owl:SubClassOf* *isNodeOf* *transports*	Network_infrastructure some Energy_cycle some Electricity
Sewer_network	*owl:SubClassOf* *isNodeOf*	Network_infrastructure some Water_cycle
Water_distribution_network	*owl:SubClassOf* *isNodeOf* *transports*	Network_infrastructure some Water_cycle some Water
Cycle_infrastructure	*owl:SubClassOf*	Network_infrastructure
Energy_cycle	*owl:SubClassOf*	Cycle_infrastructure
Matter_cycle	*owl:SubClassOf*	Cycle_infrastructure
Nature_cycle	*owl:SubClassOf*	Cycle_infrastructure
Water_cycle	*owl:SubClassOf*	Cycle_infrastructure
Green_infrastructure	*owl:EquivalentClass*	Nature_cycle
Flow	*owl:SubclassOf* *transports*	CityAnatomyThing some TransportableThing
TransportableThing	*owl:SubClassOf*	CityAnatomyThing
Data	*owl:SubClassOf*	TransportableThing

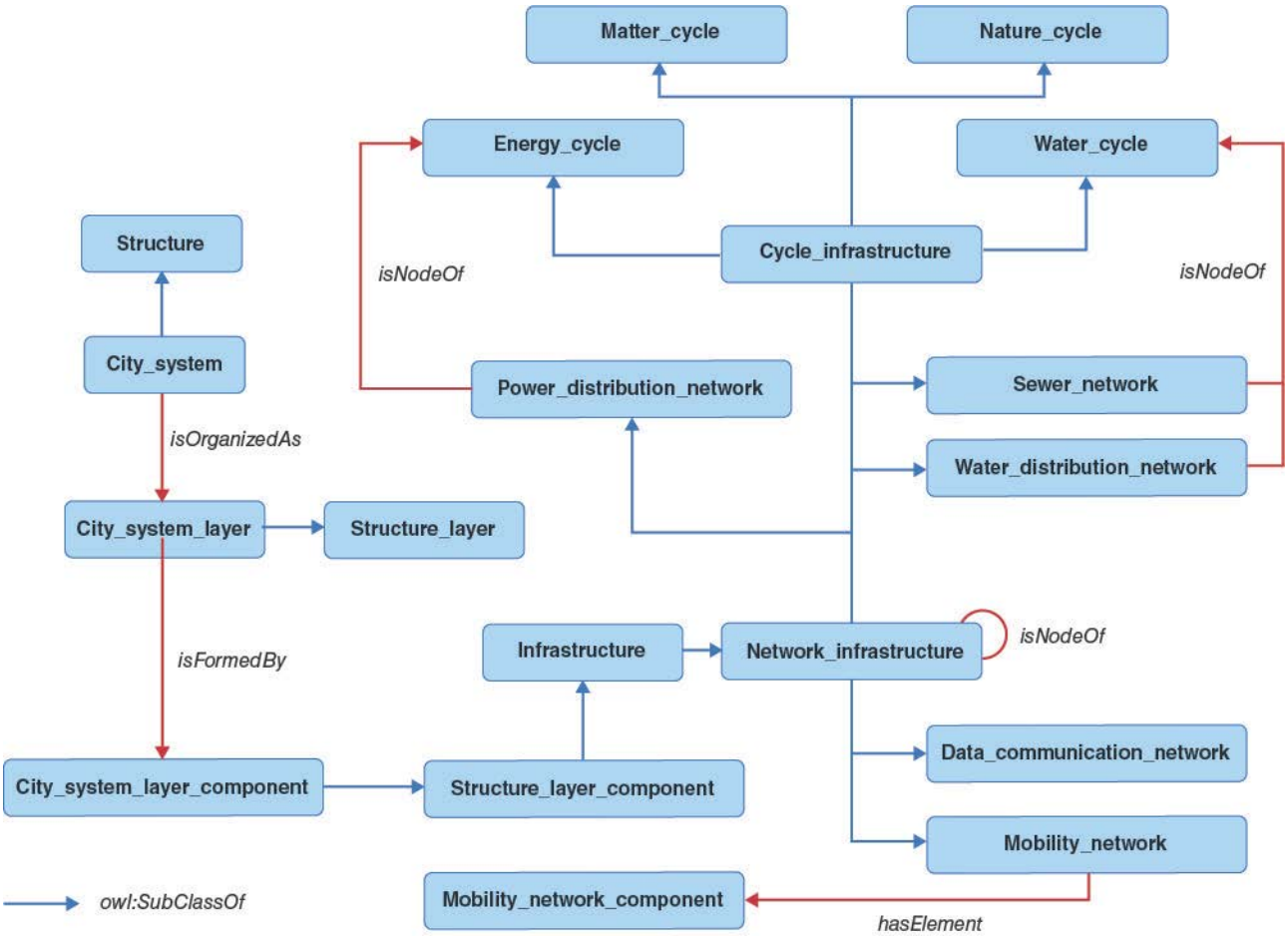


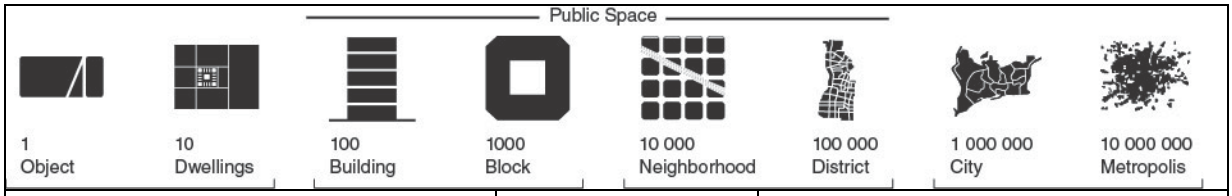
Figure 14 — Main classes and relationships in the infrastructure component of the city anatomy structure layer

5.4.1.3 Built domain

The third component of the structure layer is the built domain, public and private, which includes the surrounding public space. The built domain has two distinct and essential characteristics in relation to urbanism (i.e., urban life and organization): (i) it is the main expression of the material culture of a city (i.e., it contains most physical artifacts created by people), and (ii) it is fundamentally multi-scale in nature (i.e., scale is an intrinsic characteristic of the built environment). Every node in the built domain has a production and an operational cost, with an economic, social, and environmental impact on its setting and, ultimately, on city finances, efficiency, and quality of life. The built domain, with its public spaces, hosts the more systematic, formal, and regulated human functions (services) in the city (i.e., the activities that people engage in or perform). Table 6 lists the CAO classes used to describe the built domain and Figure 15 provides a representation of the entities and relationships of the built domain.

Note that ISO/IEC 30182 BUILDING concept can be mapped onto CAO Building class and that ISO/IEC 30182 FUNCTION concept can be mapped onto the CAO Urban function class.

Table 5 — CAO classes used to describe the built domain



Class	Property	Value Restriction
Built_domain	*owl:SubClassOf* *hasConstituent* *performs*	Structure_layer_component some Built_domain_element some Urban_function
Built_domain_element	*owl:SubClassOf*	CityAnatomyThing
Generic_built_domain_element	*owl:SubClassOf*	Built_domain_element
Specific_built_domain_element	*owl:SubClassOf* *hasCost* *hasImpact* *hasOwnership* *hasUse* *isLocated* *performs*	Built_domain_element some Cost some Impact some Ownership some Use some sc:Place some Urban_function
Object	*owl:SubClassOf*	Generic_built_domain_element
Continent	*owl:SubClassOf*	Generic_built_domain_element
Earth	*owl:SubClassOf*	Generic_built_domain_element
Administrative_built_domain_element	*owl:SubClassOf* *owl:SubClassOf*	sc:AdministrativeArea Specific_built_domain_element
City	*owl:SubClassOf*	Administrative_built_domain_element
District	*owl:SubClassOf*	Administrative_built_domain_element
Metropolis	*owl:SubClassOf*	Administrative_built_domain_element
Country	*owl:SubClassOf*	Administrative_built_domain_element
Physical_built_domain_element	*owl:SubClassOf*	Specific_built_domain_element
Property	*owl:SubClassOf*	Physical_built_domain_element
Dwelling	*owl:SubClassOf*	Physical_built_domain_element
Building	*owl:SubClassOf*	Physical_built_domain_element
Block	*owl:SubClassOf*	Physical_built_domain_element
Neighbourhood	*owl:SubClassOf*	Physical_built_domain_element
Public_space	*owl:SubClassOf* *hasUse* *hasOwnership*	Specific_built_domain_element value public_use some publicly_owned
Use	*owl:SubClassOf* *owl:NamedIndividual* *owl:NamedIndividual*	CityAnatomyThing *private_use* *public_use*
org:Ownership	*owl:SubClassOf*	OrganizationThing
org:privately_ owned	*owl:SubClassOf*	org:Ownership
org:publicly_owned	*owl:SubClassOf*	org:Ownership
org:charitable_owned	*owl:SubClassOf*	org:Ownership
org:government_owned	*owl:SubClassOf*	org:Ownership
Cost	*owl:SubClassOf* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual*	CityAnatomyThing Maintenance_cost Operation_cost Production_cost
Urban_function	*owl:SubClassOf*	CityAnatomyThing
Impact	*owl:SubClassOf* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual*	CityAnatomyThing economic_impact environmental_impact social_impact

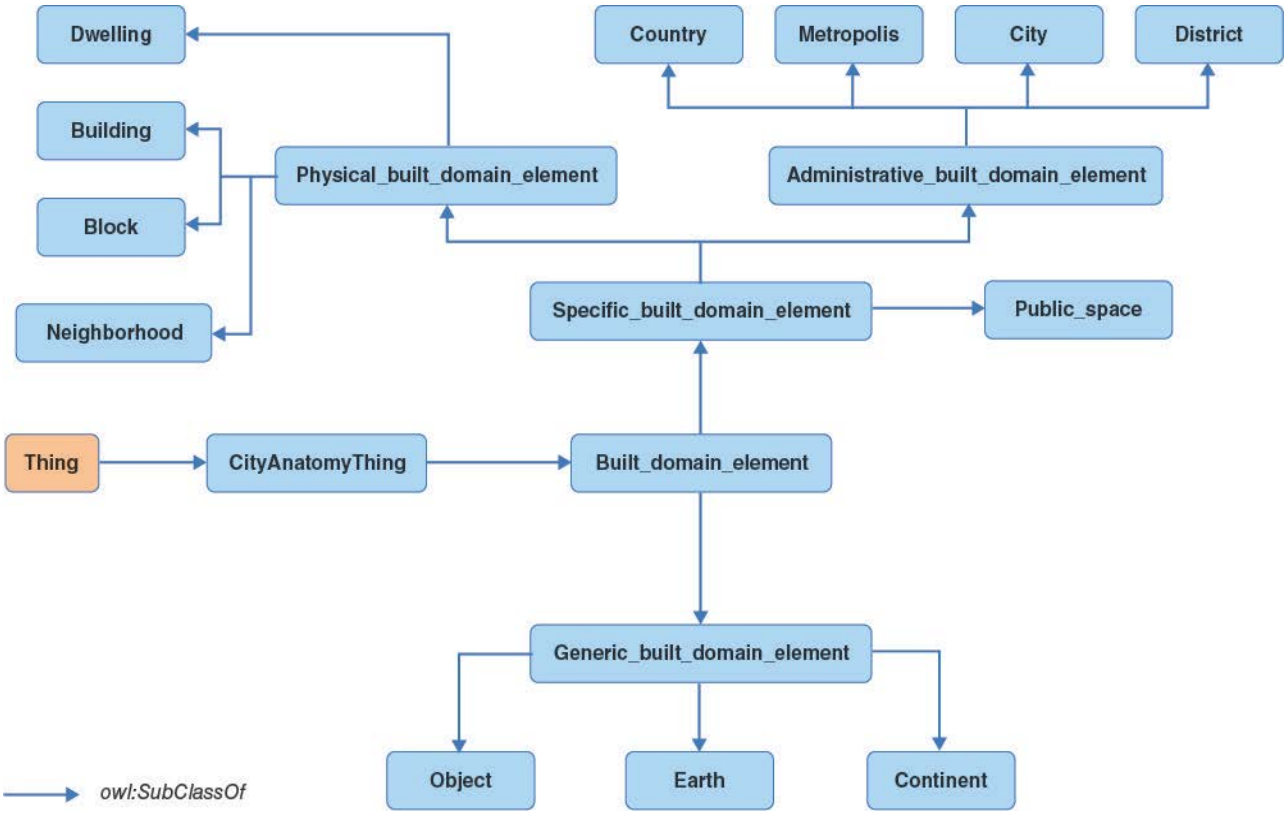


Figure 15 — Representation of the built domain entities and relationships

5.5 Interactions system

5.5.1 Introduction. The Interactions system describes the relationship between Structure and Society, with the nodes where functions take place. The Interactions layer is formed by the following components:

- **Functions,** which are the activities such as living, working, education, shopping, health care, arts, and tourism but not the buildings that host these activities.

- **Economy**, the wealth production and distribution, commerce and trade, and a key element in the evolution of cities determining not only the feasibility of transformational projects for increasing the quality of urban life, but also the fate of cities themselves. Economy also influences urban innovation and the everyday city operation and the life cycles of services provided by cities.

- **Culture** refers to the assets in the city anatomy that are not part of the material world or built domain such as language, traditions, beliefs, values, and the ways in which people organize their conceptions of the world.

- **Information platform**, which integrates all of the information flows that move data through the different interconnected and integrated layers of systems and subsystems that form the city anatomy. The platform has four functional elements:

    - City Operating System (City OS)
    - City Performance Indicators and Indices
    - Information Portal
    - City Applications

Table 6 and Figure 16 shows the components of the Interactions system and their relationships. Table 7 lists the CAO classes used to describe the Interactions subsystems. Table 8 and Figure 17 lists and depicts the CAO classes of the Information substem.

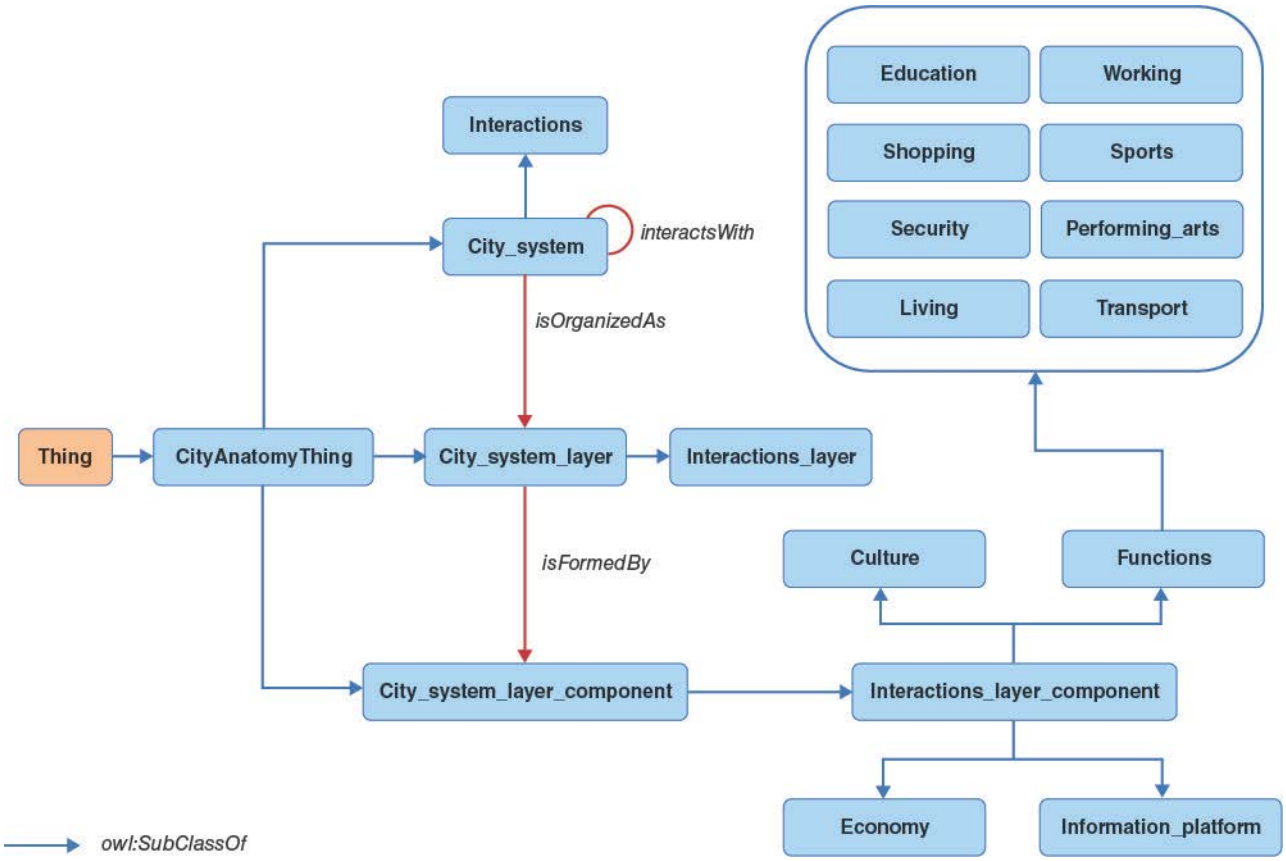
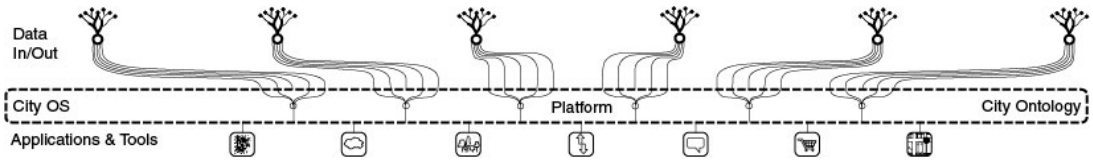


Figure 16 — Components of the interactions system

Table 6 — CAO classes used to describe the interactions subsystem

Class	Property	Value Restriction
Interactions_layer	*owl:SubClassOf* *isFormedBy* *owl:DisjointWith* *owl:DisjointWith*	City_system_layer only Interactions_layer_component Society_layer Structure_layer
Interactions_layer_component	*owl:SubClassOf* *owl:DisjointWith* *owl:DisjointWith*	City_anatomy_layer_component Structure_layer_component Society_layer_component
Functions	*owl:SubClassOf*	Interactions_layer_component
Education	*owl:SubClassOf*	Functions
Health	*owl:SubClassOf*	Functions
Transport	*owl:SubClassOf*	Functions
Tourism	*owl:SubClassOf*	Functions
Urban_planning_and_administration	*owl:SubClassOf*	Functions
Living	*owl:SubClassOf*	Functions
Performing_arts	*owl:SubClassOf*	Functions
Security	*owl:SubClassOf*	Functions
Shopping	*owl:SubClassOf*	Functions
Sports	*owl:SubClassOf*	Functions
Working	*owl:SubClassOf*	Functions
Economy	*owl:SubClassOf* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual*	Interactions_layer_component *Commerce_and_trade* *Competitiveness* *Entrepreneurship* *Finances* *Wealth_distribution* *Wealth_production*
Culture	*owl:SubClassOf* *owl:NamedIndividual* *owl:NamedIndividual* *owl:NamedIndividual*	Interactions_layer_component *Diversity* *Heritage* *Social_expression*

Table 7 — Main CAO classes in the information platform



Class	Property	Value Restriction
Information_platform	*owl:SubClassOf* *hasElement* *hasElement* *hasElement* *hasElement*	Interactions_layer_component some City_information_portal some City_operating_system some City_indicator some City_application
City_operating_system	*owl:SubClassOf* *isElementOf* *owl:EquivalentClass*	CityAnatomyThing some Information_platform CityOS
City_information_portal	*owl:SubClassOf* *isElementOf*	CityAnatomyThing some Information_platform
City_application	*owl:SubClassOf* *isElementOf*	CityAnatomyThing some Information_platform
City_indicator	*owl:SubClassOf* *isElementOf*	CityIndicatorThing some Information_platform
[a] City indicators are described in full detail in 5.5.1.		

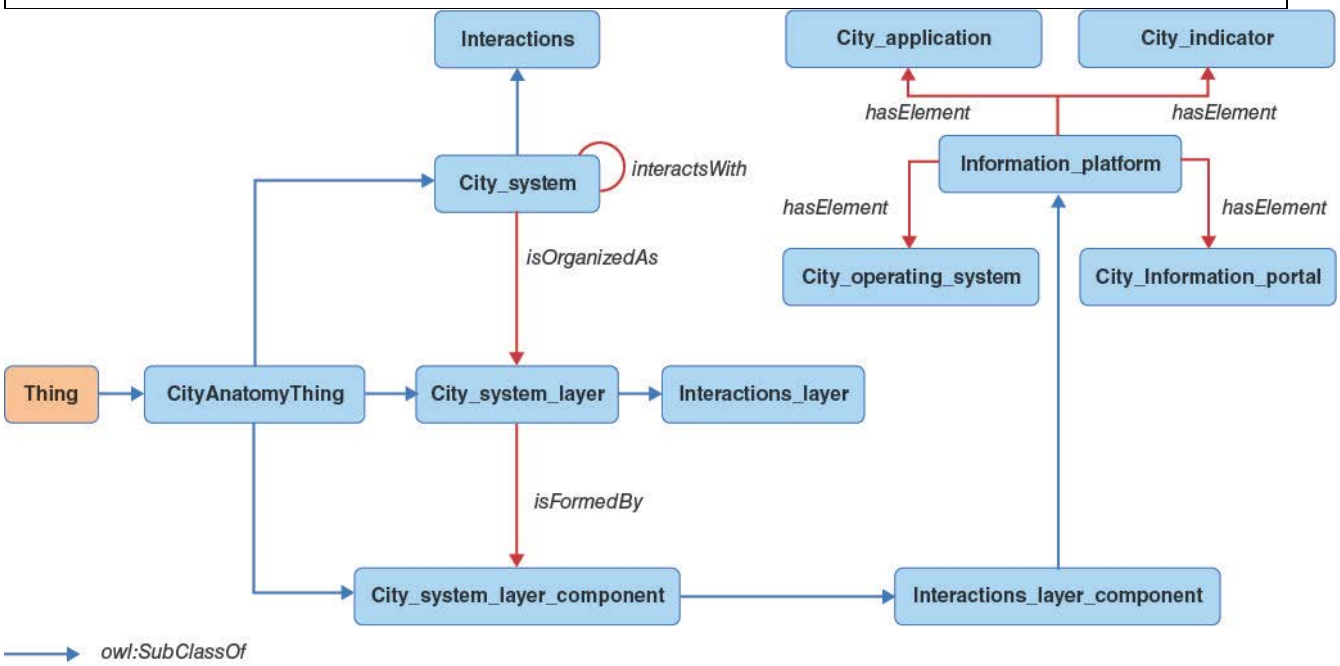


Figure 17 — Components and relationships in the information platform

5.5.1.1 City Indicators

The city performance language in the platform enables both city evaluation and transformation, either in real time or through the more complex and slower processes, such as urban growth and development. City indicators are the explicit elements that measure performance in the city anatomy framework. Performance is measured in terms of progress towards the achievement of specific "city objectives" like self-sufficiency,

mobility, resilience, investments, equity, entrepreneurship, and quality of life. Figure 18 depicts the way in which city indicators have been modeled in the ontology. At the ontology level, all the classes related to city indicators are grouped under the convenience *CityIndicatorThing* class. Table 9 lists the CAO classes used to describe the city indicators.

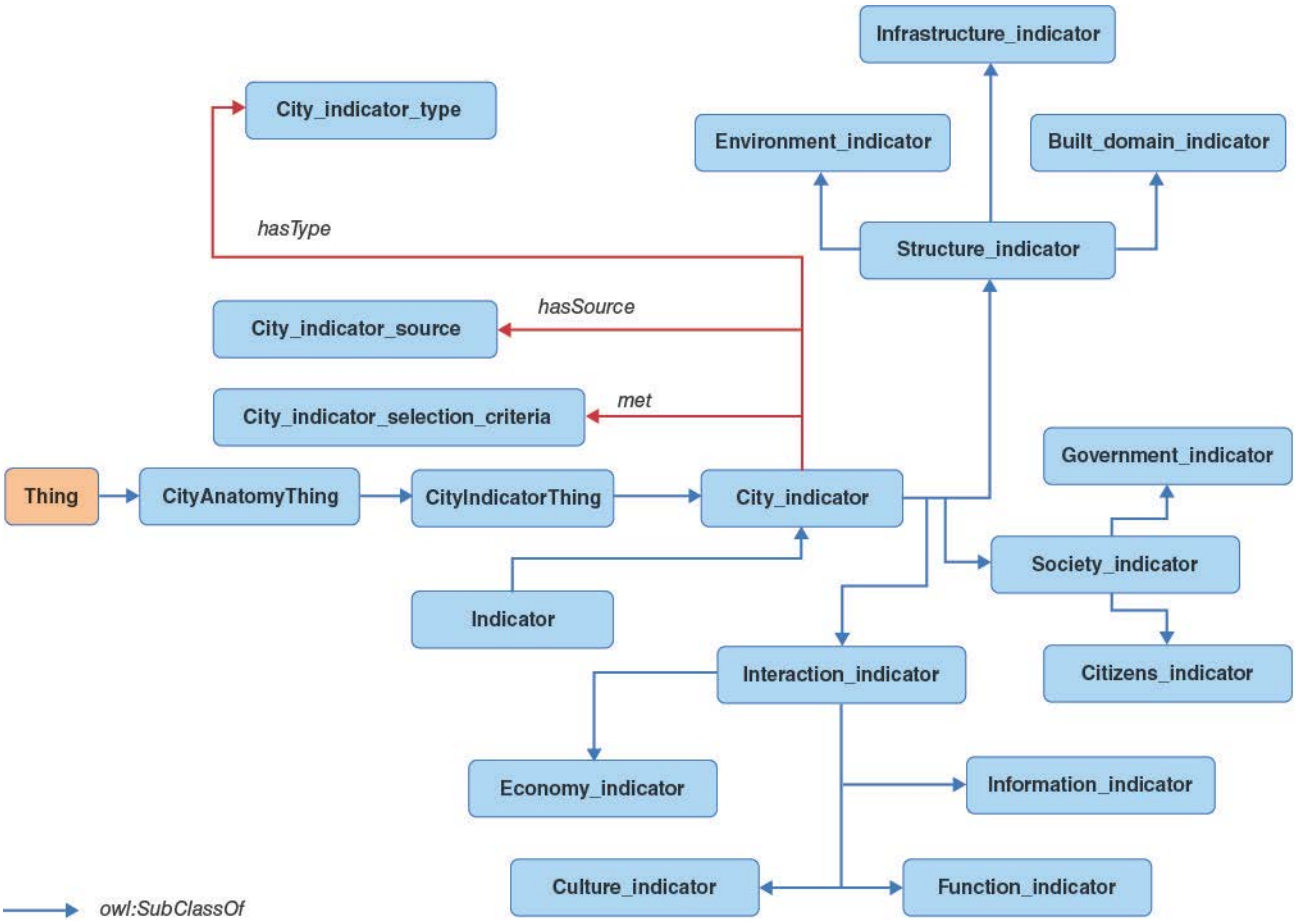


Figure 18 — CAO modelling of city indicators

Table 8 — CAO classes used to describe the city indicators

Class	Property	Value Restriction
CityIndicatorThing	*owl:SubClassOf*	CityAnatomyThing
Indicator	*owl:SubClassOf* *hasPurpose* *isDerivedFrom* *measures* *hasType* *hasValue*	iso21972:Indicator some Purpose some Raw_data some Measurable_thing some 'unit of measure' some measure
City_indicator	*owl:SubClassOf* *owl:SubClassOf* *isElementOf* *isRelatedTo* *measuresProgressTowards*	Indicator CityIndicatorThing some Information_platform some City_process some City_objective
Structure_indicator	*owl:SubClassOf*	City_indicator
Environment_indicator	*owl:SubClassOf*	Structure_indicator
Infrastructure_indicator	*owl:SubClassOf*	Structure_indicator
Built_domain_indicator	*owl:SubClassOf*	Structure_indicator
Interaction_indicator	*owl:SubClassOf*	City_indicator
Culture_indicator	*owl:SubClassOf*	Interaction_indicator
Economy_indicator	*owl:SubClassOf*	Interaction_indicator
Function_indicator	*owl:SubClassOf*	Interaction_indicator
Information_platform_indicator	*owl:SubClassOf*	Interaction_indicator
Society_indicator	*owl:SubClassOf*	City_indicator
Citizen_indicator	*owl:SubClassOf*	Society_indicator
Government_indicator	*owl:SubClassOf*	Society_indicator
City_process	*owl:SubClassOf* *owl:SubClassOf*	CityAnatomyThing org:Process
City_objective	*owl:SubClassOf* *owl:SubClassOf* *isRelatedTo*	CityAnatomyThing org:Goal some City_vision
City_vision	*owl:SubClassOf* *isFormedBy*	CityAnatomyThing some (City_objective and City_priority)
City_priority	*owl:SubClassOf* *isRelatedTo* *ranks*	CityAnatomyThing some City_vision some City_objective

Additional details of the interrelationships between indicators and the data used to develop indicators are shown in Figure 19.

ISO/IEC AWI 21972 defines an upper level ontology for smart city indicators. The ontology extends CAO's Indicator class by providing a machine-readable, precise semantics for the representation of the definition of an indicator and the data used to derive an indicator's value. CAO incorporates ISO/IEC AWI 21972 in two ways:

1. CAO Indicator is an owl:subClassOf iso21972:Indicator[6], thereby inheriting the properties of ISO/IEC AWI 21972's Indicator definition, and

[6] iso21972 is the namespace prefix for the owl file that contains the ISO/IEC AWI 21972 ontology.

2. Importing the ISO/IEC AWI 21972 ontology (available as an OWL file) directly into CAO OWL ontology file, thereby making the classes and properties of ISO/IEC AWI 21972 accessible to users of the CAO.

The consequence of this integration is that precise definitions of a city's indicators can be represented directly by an application, making them available for smart applications.

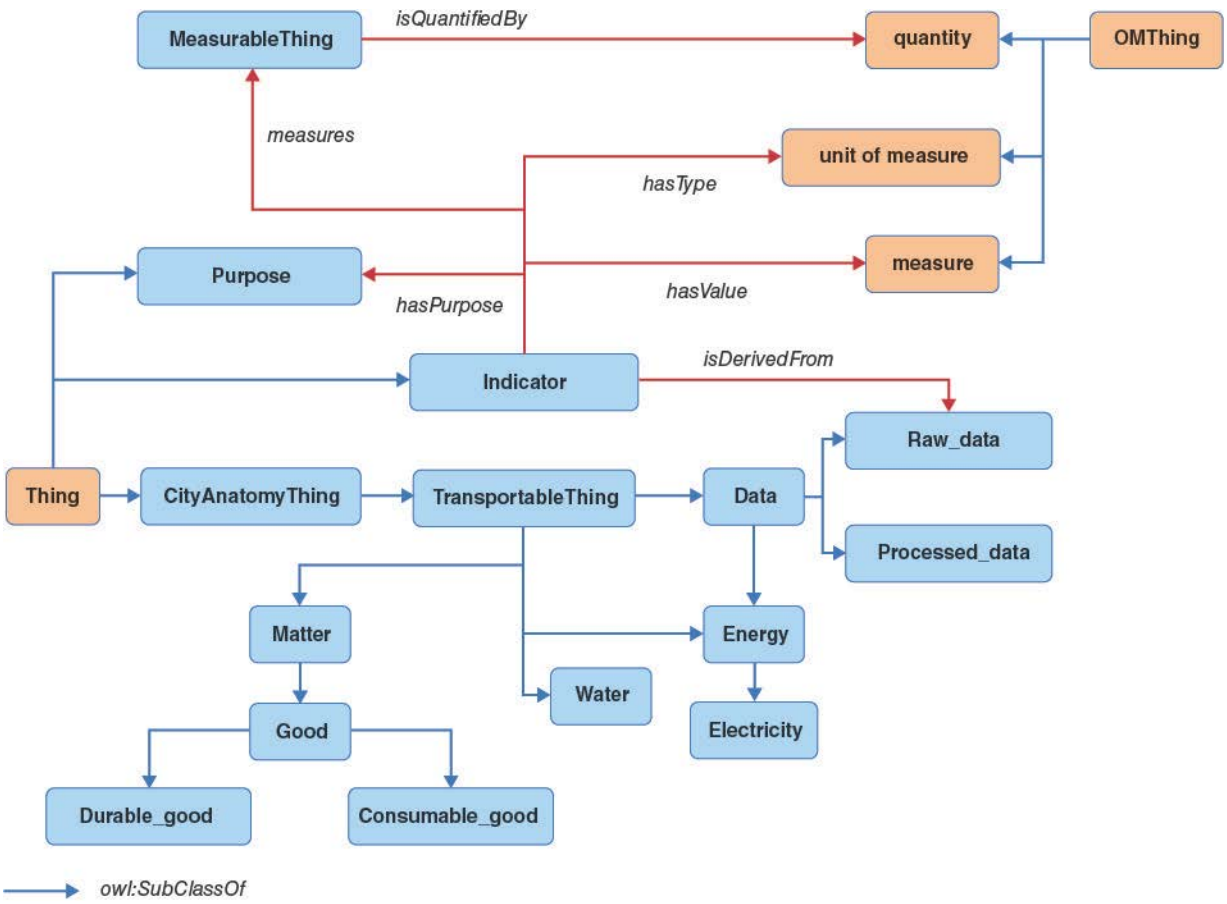


Figure 19 — Indicators, city indicators, data, and properties

Finally, the following mappings can be made from ISO/IEC 30182's concepts onto CAO's classes:

- METRIC onto Indicator
- OBJECTIVE onto City_objective

5.6 Society subsystem

The Society subsystem comprises the living entities of the city. It includes all the people who live in and occupy the physical space of the city while carrying out functions. The structure of the Society system is depicted in Figure 20 and described in detail in Table 10.

The main components of the society system are:

Citizens. Citizens include person (the individual), family, organizations, and businesses. The term person is applied broadly, and includes individuals who live, work, and/or visit within a city, whether or not they are

permanent or legal residents. Beyond individuals, Citizens include the different ways in which people organize themselves (e.g., into clubs), work, and do business (e.g., in corporations and small businesses).

Government. Government is the part of Society that at some point is either elected or appointed to serve the community. The process of running a government, governance, is used for evaluation purposes and discussed in the next clause.

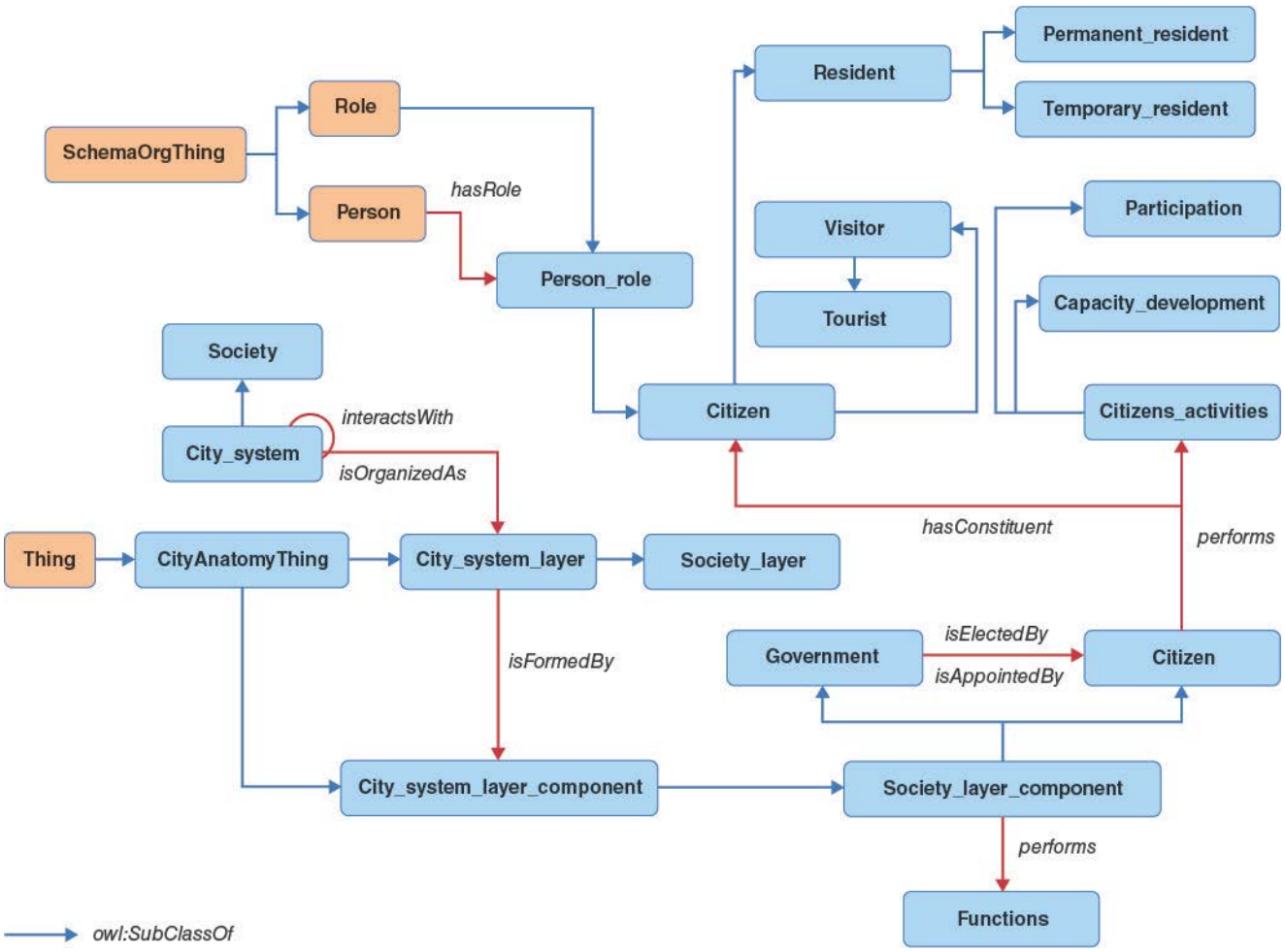


Figure 20 — Components of the society subsystem

In the ontology, society is organized according to the structure shown in Figure 20. The ontology distinguishes between public, private, and social organizations. Governmental organizations are defined as a subclass of public organizations managed by the Government. Examples of social organizations include: family, clubs (e.g., sports club), communities, and non-governmental organizations.

Table 9 — CAO classes used to describe the society subsystem

Class	Property	Value Restriction
Society_layer	*owl:SubClassOf* *isFormedBy* *owl:DisjointWith* *owl:DisjointWith*	City_system_layer only Society_layer_component Interactions_layer Structure_layer
Society_layer_component	*owl:SubClassOf* *owl:DisjointWith* *owl:DisjointWith* *performs*	City_system_layer_component Interactions_layer_component Structure_layer_component some Functions
Citizens	*owl:SubClassOf* *hasConstituent* *performs*	Society_layer_component some Citizen some Citizens_activities
Citizens_activities	*owl:SubClassOf*	CityAnatomyThing
Capacity_development	*owl:SubClassOf*	Citizens_activities
Participation	*owl:SubClassOf*	Citizens_activities
Government	*owl:SubClassOf* *isElectedBy* *isAppointedBy* *serves*	Society_layer_component some Citizens some Citizens some Community

Table 10 — CAO classes used to describe the organizations and citizens within the Society subsystem

Class	Property	Value Restriction
Organization	*owl:SubClassOf*	OrganizationThing
For_profit_organization	*owl:SubClassOf*	org:Organization
Government_organization	*owl:SubClassOf*	org:Organization
Non_government_organization	*owl:SubClassOf*	org:Organization
Social_organization	*owl:SubClassOf*	org:Non_government_organization
Corporation	*owl:SubClassOf*	org:For_profit_organization
Club	*owl:SubClassOf*	org:Social_organization
Community	*owl:SubClassOf*	org:Social_organization
Family	*owl:SubClassOf*	org:Social_organization
schema:Person	*owl:SubClassOf* *hasRole* *isRelatedTo*	SchemaOrgThing some schema:Role some schema:Person
schema:Role	*Owl:SubClassOf*	SchemaOrgThing
Person_role	*owl:SubClassOf*	schema:Role
Citizen	*owl:SubClassOf*	Person_role
Resident	*owl:SubClassOf*	Citizen
Permanent_resident	*owl:SubClassOf*	Resident
Temporary_resident	*owl:SubClassOf*	Resident
Visitor	*owl:SubClassOf*	Citizen
Tourist	*owl:SubClassOf*	Visitor

The following mappings from ISO 30182/IEC concepts onto CAO's classes can be made:

- PERSON onto Person
- ORGANIZATION onto Organization

5.7 City Dynamics as city processes

The descriptive framework of the city anatomy can be applied to facilitate the core organizing activities for cities. Activities in the city are considered as processes that take place in a dynamic way along a certain period of time. The anatomy model defines three different types of city processes: governance, evaluation, and transformation (see Figure 21 and Table 11).

Governance includes the set of all processes of governing the formal and informal city organization together with concrete activities and actions. It requires leadership to guide and influence city organization, by setting the objectives and priorities needed to achieve the city vision within a political, administrative, and legal framework — both within the election cycle and over the long term.

Evaluation measures and evaluates the city to identify and prioritize the actions needed to help the city progress according to its vision. As a result of such assessment, a city could start a transformational process by first evaluating, together with other stakeholders, its current and specific anatomy by means of city indicators. City maturity models or city dashboards constitute examples of the outcome of an evaluation process.

Transformation processes manage the implementation of transformational projects. Cities can achieve their strategic objectives by establishing appropriate policies and by applying well assessed and commonly accepted methodologies for city transformation stemming from a reliable city model and framework (i.e., the city protocol), along with indicators and indexes, tools, processes, shared projects, documents of reference, and guidelines or "de facto" standards.

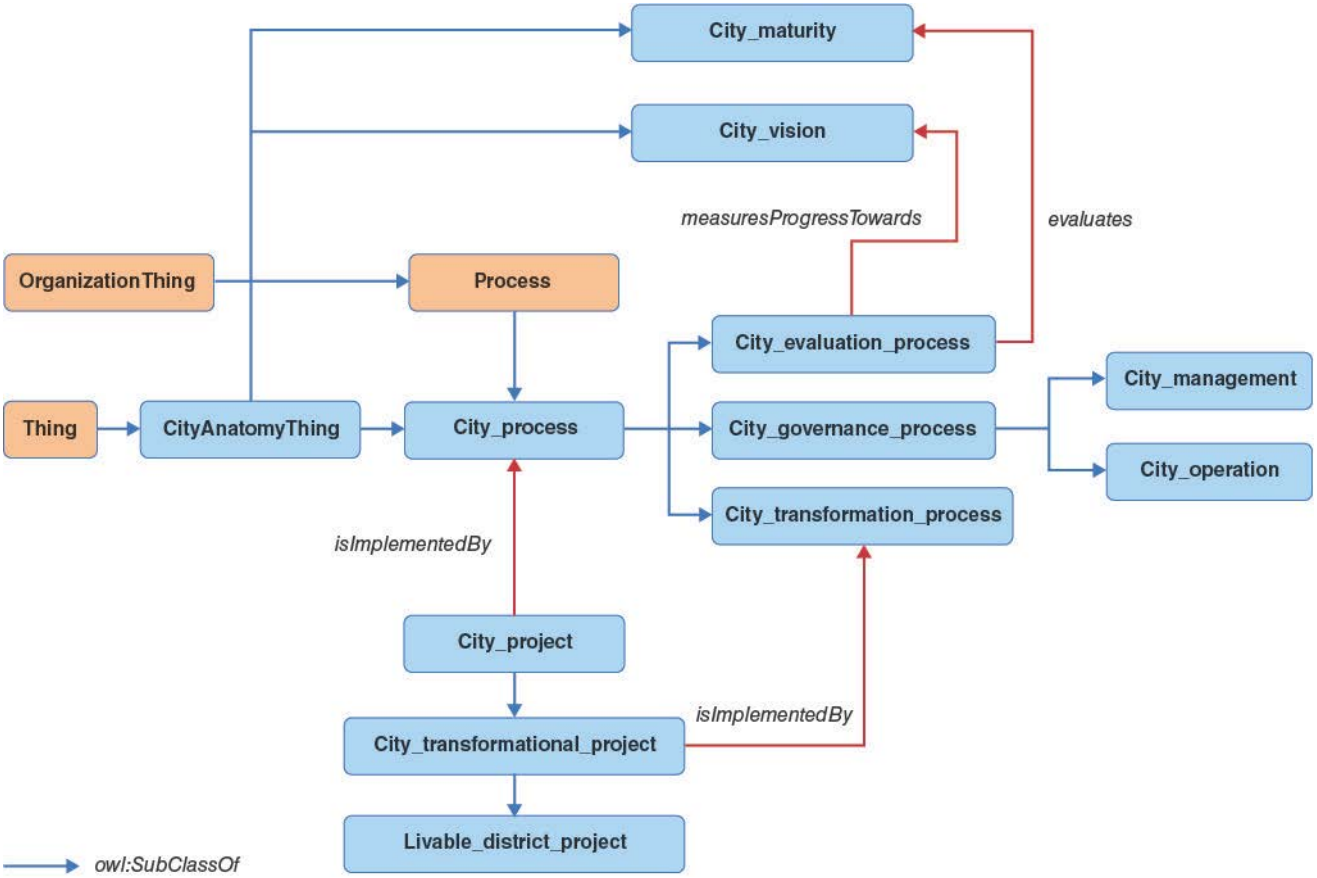


Figure 21 — Entities and relationships in the dynamics of a city

Table 11 — CAO classes used to describe city dynamics and city processes

Class	Property	Value Restriction
org:Process	*owl:SubClassOf*	OrganizationThing
City_process	*owl:SubClassOf* *owl:SubClassOf*	org:Process CityAnatomyThing
City_governance_process	*owl:SubClassOf* *governs* *isSupportedBy* *requires* *serves* *sets*	City_process some City_organization some (Law or Policy or Regulation) some Leadership some City_vision some City_priority
City_management	*owl:SubClassOf* *isRelatedTo*	City_governance_process some City_objective
City_operation	*owl:SubClassOf*	City_governance_process
City_organization	*owl:SubClassOf* *owl:SubClassOf*	CityAnatomyThing Org:Organization
City_formal_organization	*owl:SubClassOf*	City_organization
City_informal_organization	*owl:SubClassOf*	City_organization
City_evaluation_process	*owl:SubClassOf* *measuresProgressTowards* *sets* *evaluates* *measures*	City_process some City_vision some Transformational_project some City_maturity some City_performance
City_maturity	*Owl:SubClassOf*	CityAnatomyThing
Transformational_project	*owl:SubClassOf* *isRelatedTo* *isImplementedBy*	City_project some City_evaluation_process only City_transformation_process
City_project	*owl:SubClassOf* *isImplementedBy*	CityAnatomyThing some City_process
City_transformation_process	*owl:SubClassOf* *isRelatedTo*	City_process some Transformational_project
Transformational_objective	*owl:SubClassOf* *isRelatedTo*	City_objective some Transformational_project

ISO/IEC 30182's METHOD concept can be mapped onto CAO's Process class.

Annex A (informative) Applying the descriptive framework to core organizing activities for cities: Governance, evaluation, and transformation

A.1 Introduction. This Annex describes how the descriptive framework can be applied to the core organizing activities of cities: governance, evaluation, and transformation.

Understanding networks (i.e., the relationships and flows between the objects and entities that comprise the three system elements of a city—structure, interactions, and society) is key to developing a systems-knowledge view that can guide governance, facilitate evaluation, and direct the leadership needed for successful city transformation. The descriptive framework helps build this systems-knowledge view, allowing for the observation of the city at both the macroscopic and microscopic scales. As shown below, this viewpoint can be helpful in framing the core organizing activities of cities.

A.2 Governance

As viewed here, governance is the set of all processes that constitute the structure and function of city organization, including both formal and informal processes. Generally, and as assumed here, it requires leadership. Leadership guides and influences city organization and sets the objectives and priorities needed to achieve the city vision. It must operate within location-specific political, administrative, and legal frameworks, on both near- (electoral cycles) and long-term timelines.

The systems approach of the descriptive framework frames how governance relates to all of the facets of a city and in turn, how the city inhabitants interact with the city structure (i.e., the environment, infrastructure, and built domain) via societal functions, economy, and culture. These interactions generate and are empowered by information—enabled by information communication technology (ICT) or otherwise, and they often extend beyond the boundaries of the city itself. The matrix in Figure A.1 lists the descriptive framework's system elements, with their associated layers and sub-layers along the horizontal axis. The vertical axis identifies "enablers" of governance, such as laws and regulations, as well as examples of overarching priorities, like "self-sufficiency" (i.e., sustainability). In addition, the axis also identifies components or elements of ICT, like "instrumentation and control" or "security and privacy." While list along the vertical axis is not intended to be an exhaustive representation of all of the elements that form either city governance or ICT systems, the matrix helps build a holistic, high-level view of how the relevant city governance elements (like new economic models or ICT projects and initiatives) relate to the elements, layers, and sub-layers that form the city. Enabling this holistic view helps ensure the systems and subsystems can work and be managed together, and may reveal common needs across multiple city responsibilities (i.e., the components of the Framework), or it could reveal the need to re-organize governance to better serve city objectives and priorities. [7]

[7]The elements on the vertical axis of this matrix are inspired by the *Smart City Readiness Guide* (http://smartcitiescouncil.com/smart-cities-information-center/the-scc-readiness-guide).

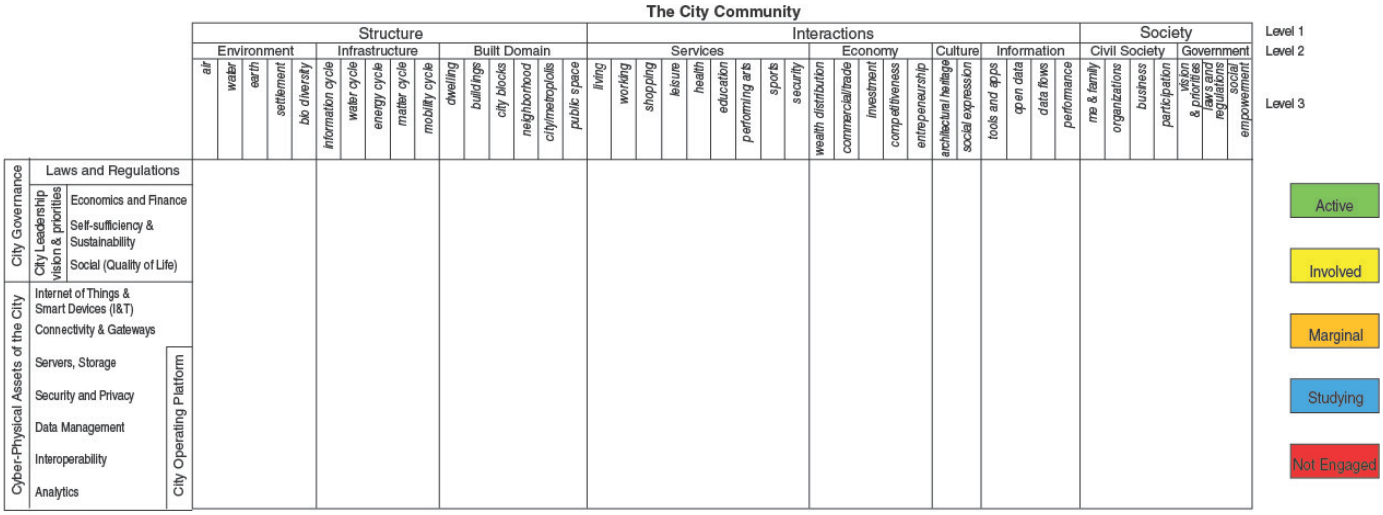


Figure A.1 — Smart City Deployment matrix consistent with the architecture in Figure 11

A.3 Evaluation

The descriptive framework can also be useful in city evaluation activities. Baseline review activities and continuous evaluations are central to the implementation of management systems, like ISO 37101. They are also generally needed to gauge progress towards meeting city goals and objectives. However, central to any evaluation is determining its scope or asking, "What should be measured and evaluated in order to identify and prioritize objectives and priorities to ensure the city progresses according to its vision?"

Using the descriptive framework, stakeholders can create a high-level dashboard based on a common systems understanding, as pictured in Figure A2. Figure A2 shows a dashboard monitoring performance in a hypothetical city. The green, yellow, and red represent evaluative indicators (or measures) for the components of the Framework, showing the degree to which each is meeting a specific goal or objective. This information, together with more detailed analysis of success stories, failures, incomplete goals, and cultural and management barriers, can help focus problem-solving efforts.

This type of holistic dashboard view helps cities, either individually or in collaboration with other cities, define and implement well-scoped projects, evaluating them via a common scheme, which allows for more reliable tracking and assessments over time.

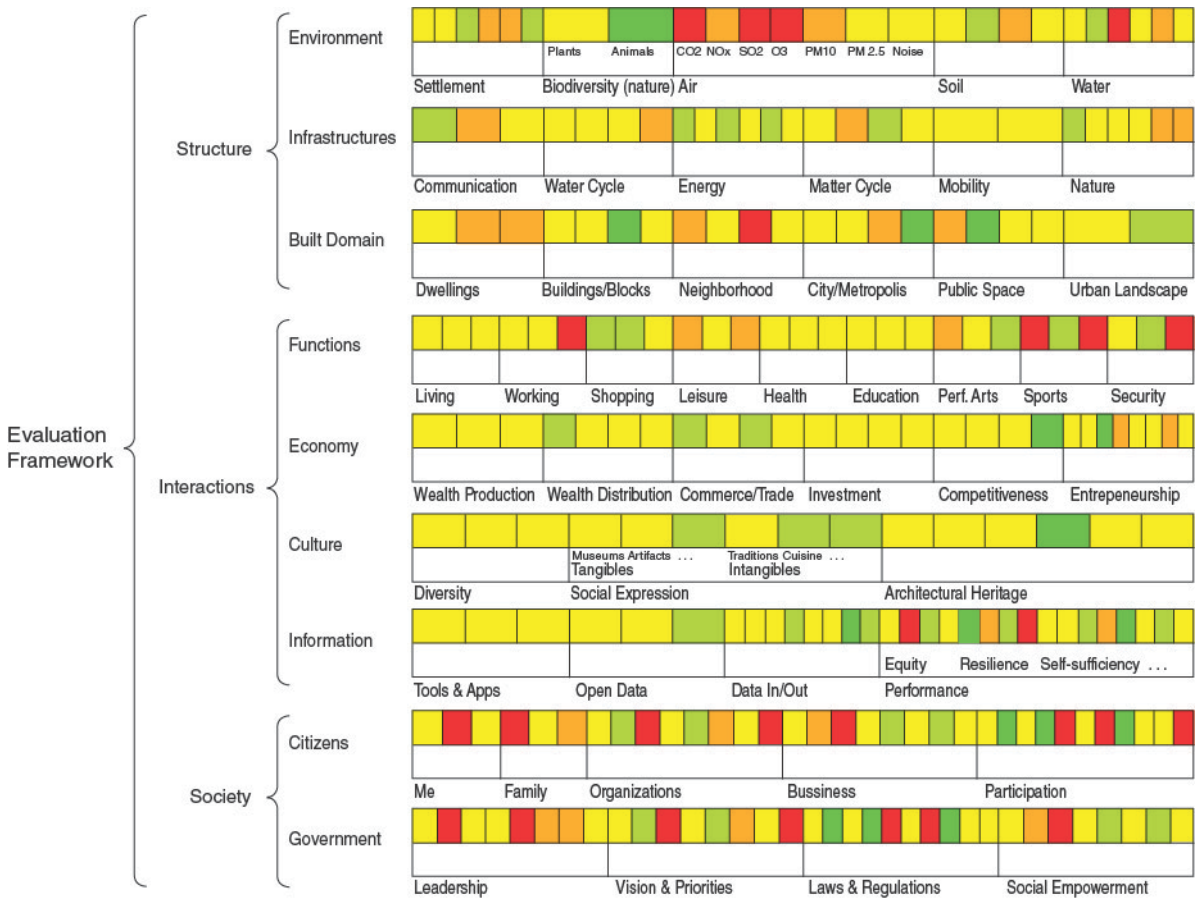


Figure A.2 — Evaluation Framework with top level indicators for city transformational projects

A.4 City Transformation and knowledge sharing

The descriptive framework can also be used as a means of developing a maturity model for a city. Cities are the result of events and changes taking place over the course of their histories. The descriptive framework provides cities with a common means of analyzing their progress over time, which enables the sharing of ideas and strategies across cities. While cities may be bound by constraints unique to each, they might be inspired by common models or initiatives (e.g., the Slow City[8]), and thus able to learn from each other enabled by a common Framework.

The following questions serve to guide cities with transformational objectives. The descriptive framework provides stakeholders with a common, sharable method of identifying answers to these questions, enabling both advancement toward the transformation and solution sharing across cities.

(i) What are the most feasible projects that could be undertaken to cover the agreed needs and whom do they benefit?

(ii) What infrastructures, buildings, scales, functions, information/data, and context (e.g. environment, legal and regulatory, economic) do the agreed initiatives impact?

(iii) What examples of good practice and/or of reference projects exist that are relevant to the proposed transformational project?

(iv) On what basis would the effectiveness of different approaches be compared?

The taxonomy of city elements and concepts present in the descriptive framework shown in Figure 1, including the principles underlying such classification, enables cities to develop and share transformational projects

[8] http://www.citymayors.com/environment/slow_cities.html

together and to systematically identify services and modeling tools that could be adopted across multiple cities and a variety of community contexts.

Annex B (informative) Developing guidelines for multi-purpose public spaces with physiological performance described by the descriptive framework

B.1 Introduction. The purpose of this Annex is to provide an illustrative example of the manner in which the descriptive framework could be used to help plan and assess a city objective. In this case, the descriptive framework assists in the development of indicators to judge the performance of multi-use public space in a community.

Squares, plazas, public recreational areas, parks, and playgrounds are some of the most commonly thought of public spaces (i.e., open and universally accessible urban spaces). However, in some cities, pedestrian-friendly streetscapes can serve this function as well. Even streetscapes occupied by cars are open public spaces. High performing, or high quality, open public spaces encourage community development as places people go to meet, socialize, relax, and carry out community activities and events, such as sports, leisure, performing arts and open markets. While public spaces can be positive forces in a community, poorly designed public spaces may fail to facilitate these aspects of a community, or in fact, help breed negative outcomes, like crime, social isolation, or general community decline. Thus, the physical and social quality of the space are key to whether they support the overall goals of the community.

The performance of multi-purpose open public spaces depends on the physical and social qualities of the space. Among other criteria, physical quality can be assessed by: visual and physical connectivity with the surrounding areas; easy accessibility; social and green dimensions; acoustics; lighting; thermal comfort; as well as air and soil quality. Social quality can be gauged by the ability to attract people and encourage interaction, contact, and coexistence.

In this example, the users' goal is to ensure the community has adequate high performing open public space, and that it is well distributed throughout the community. Multi-purpose public space is integral to a well-functioning, liveable community. It facilitates connectivity—both to the natural and built environment—as well as successful urbanism and civic life by fostering the interactions that help build and strengthen a community, making a city an attractive place to live and visit. Multi-purpose public space can also help improve the environmental performance and resilience of the city. To support these benefits, the public space must be of a certain quality (i.e., high performing).

In addition to designing open public spaces that perform well in terms of the physiological characteristics described above, the process of planning for such places should follow the methodology used to achieve any target action within the community. This process should be conducted in a transparent manner that engenders trust and stakeholder participation. The example shown in Figure B.1 relies on the four step Deming Cycle (Plan-Do-Check-Act) described below. However, a community could also make use of the more robust process established by ISO 37101 to plan and manage community sustainable development.

Figure B.1 — Methodology to progressively develop community projects

As shown in Table B.1, the descriptive framework can be helpful in identifying the characteristics of each element that plays a role in the quality and performance of multi-purpose public space. Identifying these characteristics can help target planning and evaluation activities and enable stakeholders to implement their vision.

Keywords derived from the descriptive framework (focus for multi-purpose public spaces):
Public & common space actions

- Ensure an adequate amount of high performing public space in terms of total surface area and distribution to ensure maximum utility to the community.
- Facilitate connectivity between the constructed public spaces in the community, as well as with the natural spaces.

Specific targets for public common spaces

(1) Develop guidelines for the design of liveable and multi-purpose built public spaces with acceptable performance for the relevant physiological characteristics:

- Air and soil quality
- Acoustic and thermal comfort
- Public space ergonomics
- Visual and physical connectivity with mobility infrastructure
- Spatial proportions
- Visual spatial perception of green infrastructure and social dimensions

(2) Ensure equitable access to all public common spaces.

(3) Restore, reclaim, remake, and redesign mobility infrastructures into built public spaces[9] to provide access to:

- street sidewalks accessible to all ages and abilities
- pedestrian network of pathways
- any other transformed infrastructure (e.g., bridges and elevated rail lines)

[9] https://www.asla.org/uploadedFiles/CMS/Meetings_and_Events/2014_Annual_Meeting_Handouts/FRI-07_Infrastructure%20is%20Public%20Space.pdf

(4) Quality people flow experience

Table B.1 Element-system-component relationship

Element	System	Component
Structure	Environnement	air quality, soil quality, green infrastructure, thermal comfort, sunlight, acoustic comfort
	Infrastructure	air quality, soil quality, green infrastructure, thermal comfort, sunlight, acoustic comfort
	Built Domain	public space, multi-functional, accessibility, square, plaza, community space, playground, park, recreational area, recreation facilities, streetscapes, complete streets, spatial connectivity, human dimension, green perception, insulation, restore, reclaim, remake, multi-purpose, ergonomics
Interactions	Functions	open space, functions, leisure
	Culture	contact, coexistence, street life
	Information	performance
Society	Citizens	perception, people flow experience
	Government	regulations, planning, policies, guidelines

B.2 Elaboration of the CAO classes (in the descriptive framework)

B.2.1 The city as a system of systems Table B.2 describes the city as a part of the system.

Table B.2 City system

Class	Definition

CityAnatomyThing	Convenience class that acts as a placeholder for all the elements of the City Anatomy Ontology (CAO). This document uses an analogy to the human anatomy and its dynamic physiology and is an organizing framework for the City. It creates a foundation upon which to build a collaborative platform and tools to support effective city governance, evaluation, and transformation. It offers a common language describing the city ecosystem as three key system elements: a set of physical structures (Structure), the living entities that make up a city's society (Society), and the flow of interactions between and among them (Interactions).
City_system	A city is a system of systems and interactions, an arrangement of, and set of, relationships between multiple layers of a relatively large and permanent human settlement, with an administrative and legal status supported by local laws, and one that is recognized worldwide. The constituents of the City System are Structure, Interactions, and Society.
City_system_layer	Each of the individual components of a City system. Each layer is formed by a number of layer components.
Layer_component	Each of the constituent elements of a city system layer.

B.2.2 The structure system Table B.3 describes the structure as a part of the system.

Table B.3 Structure system

Class	**Definition**
Structure	The set of physical structures found in a City.
Structure_layer	Container for the individual components of the Structure_system. The structure layer is formed by a number of Structure_layer_components.
Structure_layer_component	Each of the three constituent elements of the structure layer (i.e., Environment, Infrastructure, and Built Domain).
Environment	The first layer in the anatomy structure subsystem. Represents the physical and geographic setting of the city, including the natural environment ("nature"). It is formed by the three basic elements — air, earth, and water — interacting dynamically in a seasonally specific way.
Biodiversity	Biodiversity, a contraction of "biological diversity," generally refers to the variety and variability of life on

Class	Definition
	Earth. One of the most widely used definitions defines it in terms of the variability within species, between species, and between ecosystems. It is a measure of the variety of organisms present in different ecosystems.
Environemental_compartment	The environment is usually modelled as a group of five interacting "compartments" (air, soil, water, sediment, and biota). Each environmental compartment can be characterized by a set of properties.
Air	Refers to the environmental compartment formed by the air.
Soil	Refers to the environmental compartment formed by the soil.
Water	Refers to the environmental compartment formed by the water.
Sediment	Compartment at the interface of water and soil. Refers to the matter that settles to the bottom of a liquid.
Biota	Refers to the animal and plant life in a particular compartment.
Infrastructure	The second layer in the anatomy structure system. Comprises the connective structures that provide people access to the resources they need, especially from the environment, bringing those resources to the city and enabling the flows or cycles inside the city itself. Infrastructures have the responsibility of moving (transporting) things from one place to another.
Cycle_infrastructure	Connective infrastructure formed by nodes and vertices connecting them in a closed chain.
Energy_cycle	This is formed by the whole energy system: functional nodes (nuclear and power plants, wind farms, biomass/bioenergy power plants, hydroelectric plants, and solar fields) located outside cities and where most of the energy is produced; energy networks to transport mainly electricity or natural gas into the city; and pipelines and ships to transport oil to produce fuels and chemicals that are finally consumed in cities as raw or refined products.
Matter_cycle	The matter cycle involves the extraction of material resources from nature (including food), their industrial or small-scale manipulation to transform them into products, the transportation and logistics infrastructures to reach consumers, and also the management of waste materials. The matter cycle includes: (i) everything that extracts goods from nature and transports them to factories or production centres, (ii) distribution around the world via logistic platforms, containers, and other

Class	Definition
	means, (iii) deliveries within cities, (iv) consumption in cities, (v) waste generation, (vi) transporting waste to dumps, and (vii) in some cases, recycling or producing energy or new products from that waste.
Nature_cycle or Green_infrastructure	The "green" infrastructure is formed by the natural elements we bring into the city in a structured way. Includes all flows related to nature (flora and fauna) in the city. It encompasses information about all living non-human entities at all scales, from seeds to trees, animals, and so on. It is the infrastructure that is involved in the reincorporation of nature in, for example, city streets and squares (i.e. of nature in the public space), which has an effect on the quality of life.
Water_cycle	Includes supply, sanitation, and the management of clean, waste, and surface waters, the latter with its drainage/collection systems to avoid rainfall causing flash flooding. We can use the term water infrastructure to describe all the physical elements forming part of the water cycle (clean and waste water) as it operates in a structured way in a city.
Network_infrastructure	This infrastructure is an interconnected system of things or people. The system represents a physical realization of the abstract graph concept. A network can be a node of the network infrastructure (e.g., the Internet is a network of networks).
Data_communication_network	Infrastructure responsible for transporting information using different physical media. Twenty-first century communication networks are mostly digital and follow a distributed organization. Instances of the data communication network are for example, the *Internet* and *Metropolitan Area Networks*.
Mobility_network	This infrastructure mostly relates to human transportation, though sometimes to also transporting goods. Everything that enables people to move throughout the city, or cross the city boundaries, falls within the mobility network. Constitutive elements of this infrastructure include: railways, airports, highways, roads, bicycle paths, subways, bus ways (including bus rapid transit), and the pedestrian streetscape.
Power_distribution_network	An electric power distribution system is one of the elements of the energy cycle and the final stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers.
Sewer_network	The principal element of a sewerage system is one of the elements of the water cycle and formed by an aggregate of underground pipelines and sewers receiving and

Class	Definition
	draining waste waters away from population centres and industrial enterprises and toward the appropriate treatment facilities.
Water_distribution_network.	System of engineered hydrologic and hydraulic components that provide water supply.
TransportableThing	Thing that can be transported by some infrastructure (i.e., cycle or mobility network).
Data	Data as an abstract concept can be viewed as the lowest level of abstraction, from which information and then knowledge are derived.
Built_domain	The third layer in the anatomy structure system. The Built Domain, public and private, includes the surrounding public space. The Built Domain has two distinct and essential characteristics in relation to urbanism (i.e., urban life and organization): (i) It is the main expression of the material culture of a city (i.e., it contains most physical artifacts created by people), and (ii) it fundamentally is multiscale in nature (i.e., scale is an intrinsic characteristic of the built environment).
Built_domain_element	Each of the physical or administrative elements that form the Built Domain. Each of these elements is located in a specific Place. A Place, according to the schema.org ontology, is an entity with some physical extension. Examples of generic built domain elements are: object, continent, and earth.
Administrative_built_domain_element	A specific type of Administrative Area in a city. The more general term Administrative Area is defined by the schema.org ontology as a geographical region under the jurisdiction of a particular government.
City	An Administrative_built_domain_element. Represents a large and densely populated urban area and may include several independent administrative districts. In the anatomy model the scale of the city is in the order of 10^6 people.
District	An Administrative_built_domain_element. Represents a region within a city marked off for administrative or other purposes. In the anatomy model, the scale of the district is in the order of 10^5 people.
Metropolis	An Administrative_built_domain_element. Represents a large and densely populated urban area and may include several independent administrative districts. In the anatomy model, the scale of the metropolis is in the order of 10^7 people.

Class	Definition
Physical_built_domain_element	A specific geographical location within a city. Physical built domain elements are not the result of an administrative division of the city.
Dwelling	A place that serves as living quarters for one or more people or families. In the anatomy model, the scale of the house is in the order of 10^1 people.
Building	A structure that has a roof and walls and multiple stories. In the anatomy model, the scale of the building is in the order of 10^2 people.
Block	Denotes a rectangular area in a city surrounded by streets and usually containing several buildings. In the anatomy model, the scale of the block is in the order of 10^3 people.
Neighbourhood	An area within a city that has some distinctive features and forms a community. In the anatomy model, the scale of the block is in the order of 10^4 people.
Public_space	One of the elements of the Built Domain. The public space has intrinsic qualitative values and a physiological function since this public built space is where infrastructure intersects with the built domain (e.g. buildings, neighbourhoods) and provides the space shared by people to meet, relax, and/or to carry out activities individually or in community.
Use	Refers to the act of using something.
Ownership	Refers to the act, state, or right of possessing a something. In the context of the Built Domain element, ownership is regulated by Property Laws.
privately_owned	The owner is a specific person or group of persons.
publicly_owned	The owner is the community.
government_owned	The owner is the government.
charitable_owned	The owner is a charitable organization.
Cost	Refers to the amount of economic resources that have to be spent to obtain something. Every node in the Built Domain has a production and an operational cost, with an economic, social, and environmental impact on its setting and, ultimately, on city finances and efficiency. Specific instances of cost are: **Operation cost**: Refers to expenses that are related to the operation of a built_domain_element. These costs are necessary just to

Class	Definition
	maintain its existence. **Production cost**: Refers to the costs incurred when manufacturing a built_domain_element. Production costs combine the costs of raw materials and labor.
	Maintenance cost: Refers to the costs incurred to keep a built_domain_element in good condition and/or good working order.
Urban_function	The function of an area is its reason or purpose for being. In urban areas, this relates to the purpose of a land use for residential areas, recreation and industry. Functions can change over time.
Impact	Refers to the effect or influence of one person, thing, or action on another.

B.2.3 The interactions system

Table B.4 describes the interactions as a part of the system.

Table B.4. Interactions system

Class	Definition
Interactions	The Interactions between the Structure and Society reflect the activities in the city. These can be analyzed and measured as flows of information. In the context of the City Anatomy, interactions refer to the urban physiology, including its metabolism or cycles, its nervous system, its circulatory system, and more.
Interactions_layer	Container for the individual components of the Interactions system. The Interactions layer is formed by a number of Interactions_layer_components.
Interactions_layer_component	The Interactions layer is formed by four components: Functions, Economy, Culture, and the Information Platform.
Functions	Refers to the activities that people undertake or perform in the city. The Built Domain, with its public space, hosts the more systematic, formal, and regulated people's functions (services) in the city. This layer component is concerned with the activities themselves and not with the built_domain_elements that host them. Specific subclasses of functions include: • Education: Education is the process of facilitating learning. Knowledge, skills, values, beliefs, and habits of a group of people are transferred to other people. Education can be delivered electronically at

Class	Definition
	home or anywhere with Internet connectivity (as remote education through the Internet) and, thus, no longer needs to take place in a school. • Health: Health refers to the level of functional or metabolic efficiency of a living organism. In humans, it is the ability of individuals or communities to adapt and self-manage when facing physical, mental, or social challenges. Health services are provided through specific health care systems, which are organizations of people, institutions, and resources that deliver health care services to meet the specific health needs of target populations. • Transport: Refers to the movement of people, animals, and goods from one location to another.
	• Living: Refers to the way of life. The act of living is the course and conduct of an individual's life, especially when viewed as the sum of personal choices (or lack of choices) contributing to one's personal identity. • Performing_arts: Refers to art forms in which artists use their voices and/or the movements of their bodies, often in relation to other objects, to convey artistic expression—as opposed to, for example, purely visual arts, in which artists use paint/canvas or various materials to create physical or static art objects. Performing arts include a variety of disciplines but all are intended to be performed in front of a live or broadcast (TV/Internet-streaming) audience. • Security: Security is the degree of resistance to, or protection from, harm. It applies to any vulnerable and valuable asset, such as a person, dwelling, community, nation, or organization. • Shopping: Shopping is an activity in which a customer browses the available goods or services presented by one or more retailers with the intent to purchase a suitable selection of them. In some contexts, it may be considered a leisure activity as well as an economic one. • Sports: Refers to all forms of usually competitive physical activity which, through casual or organized participation, aim to use, maintain, or improve physical ability and skills while providing entertainment to participants, and in some cases, spectators. • Working: Refers to all the activities related to paid employment.

Class	Definition
Economy	An Economy or economic system consists of the production, distribution, or trade, and consumption of limited goods and services by different agents in a given geographical location. The economic agents can be individuals, businesses, organizations, or governments. Wealth production and distribution, commerce and trade, innovation and entrepreneurial ecosystems, competitiveness, tax base, and financing vehicles —these are among the many dimensions that make up the Economy of a city. Economy influences urban innovation and the everyday city operation and the life cycles of services provided by cities, with the emphasis on improving their management and quality. It is also a key element in the evolution of cities since it determines not only the feasibility of transformational projects aimed at increasing the quality of life of citizens, but also the fate of cities themselves. Specific instances of the economy component are: • Commerce and trade • Competitiveness • Entrepreneurship
	• Finances • Wealth distribution • Wealth production
Culture	Refers to the way of life, especially the general customs and beliefs, of a particular group of people at a particular time and in a specific geographic location. Includes all assets in the City Anatomy that are not part of the material world or Built Domain (and, therefore, distinguished from tangible "cultural" objects such as museums, monuments, works of art, archaeological sites and city landmarks). Culture impacts and reflects all dimensions of human life — emotion, intelligence, spirituality, creativity, and community — and may influence personal choices (*see* Functions/Living). Specific instances of culture include: • Diversity • Heritage • Social expression
Information_platform	Element of the interactions layer used to integrate all information flows that move data through the different interconnected and integrated layers of systems and subsystems that form the City Anatomy.
City_operating_system	Component of the information platform. Provides a shared, or trans-disciplinary, set of tools to manage and organize the city as a system of systems for all city activities by defining protocols that standardize methods

Class	Definition
	for improving knowledge acquisition and information transfer (i.e., data flows).
City_information_portal	Component of the information platform that facilitates the access to (open) data and specific learning protocols and related resources, including information on both hard and soft systems, and on the many different mechanisms by which cities acquire and apply knowledge.
City_indicator	Component of the information platform suitable to measure city functions and city performance that provides the city performance language and allows us to look at the city with evaluative or transformational eyes, either in real time or through much more complex and slower processes. City_indicators developed specifically according to the structure of the City Anatomy are divided into core and supporting indicators.
City_application	Component of the information platform that includes Tools and Applications needed for system-level data analysis and representation, decision support, and management actions.
Indicator	Measure of performance of a system or component of a system.
Structure_indicator	City_indicator that measures the performance of specific components of the Structure system. Subclasses of structure indicators include: • Environment indicators • Infrastructure indicators • Built Domain indicators
Interactions_indicator	City_indicator that measures the performance of specific components of the Interactions system. Subclasses of interaction indicators include: • Function indicators • Economy indicators • Culture indicators • Information platform indicators
Society_indicator	City_indicator that measures the performance of specific components of the Society system. Subclasses of society indicators include:

Class	Definition
	• Citizen indicators • Government indicators
City_vision	Refers to the set of objectives and priorities of a city.
City_priority	Priorities allow the ranking of city objectives. The ranking allows the prioritization of transformational initiatives consistently with citizen's needs, available resources, and the city vision.
City_objective	Objectives related to a specific city vision. Cities can achieve their strategic objectives by establishing appropriate policies and by applying well assessed and commonly accepted methodologies for city transformation stemming from a reliable city model and framework (i.e., the city protocol), along with indicators and indexes, tools, shared projects, documents of reference, and guidelines or "de facto" standards.

B.2.4 The Society system Table B.5 describes the society as a part of the system.

Table B.5 Society system

Class	Definition
Society	System that includes the people who live, work, visit, or stay in a city.
Society_layer	Container for each of the individual components of the Society system. The Society_layer is formed by a number of Society_layer_components.
Society_layer_component	The society layer is formed by two components: citizens and government.
Citizens	Citizens include person (me), family, organizations, and businesses. The term in the context refers to all persons regardless of official national citizenship status. The term person is applied broadly, and includes individuals who live, work, and/or visit within a city, whether or not they are permanent or legal residents. Beyond individuals, Citizens includes the different ways in which people organize themselves (e.g., into clubs) and work and do business (e.g., in corporations and small businesses).
Government	Government is the part of Society that at some point is elected or appointed to serve the community.
Organization	An organization is a set of constraints on the activities performed by agents. An organization consists of a set of divisions and subdivisions (recursive definition), a set of organization-agents (said to be members of a division of the organization), a set of roles that the members play in the organization, and an organization-goal tree that specifies the goals (and their decomposition into subgoals)

Class	Definition
	the members try to achieve. Includes the following three subclasses: For profit organization, Government organization, Non-government organization *[Defined in the Organization Ontology, http://ontology.eil.utoronto.ca]*
Social_organization	Is a subclass of 'Non Government Organization' that refers to a social entity comprising multiple people that has a collective goal and is linked to an external environment. Specific instances of this class are: Club, Family, and Community.
sc:Person	Entity in schema.org that represents a person who can be alive, dead, undead, or fictional.
sc:Role	Entity in schema.org that represents additional information about a relationship or property. For example a Role can be used to explain that a 'member' role linking some Sports Team to a player occurred during a particular time period, or that a Person's 'actor' role in a Movie was for some particular character Name. Such properties can be attached to a Role entity, which is then associated with the main entities using ordinary properties like 'member' or 'actor'.
Person_role	Represents the role of a Person in a City.
Citizen	Specific Person_role that corresponds to a person who lives in, works in, or visits a city.
Resident	Specific Person_role that refers to a person who maintains residency (domicile) in a given place. Subclasses of Resident include: • Permanent resident • Temporary resident
Visitor	Specific Person_role that refers to a person visiting another person or a place in a city. Subclasses of Visitor include: Tourist: refers to a person who is visiting a city or a place for pleasure.

B.2.5 City dynamics and city processes

Table B.6 describes the relationship between city dynamics and city process.

Table B.6. City dynamics/city process

Class	Definition
Process	General term that corresponds to a series of actions or steps taken in order to achieve a particular end.
City_process	A process that occurs in the context of a city.
City_governance_process	Refers to the set of all processes of governing the formal and informal city organization, along with concrete activities and actions. It requires leadership to guide and influence city organization, by setting the objectives and priorities needed to achieve the city vision within a political, administrative and legal framework — both within the election cycle and over the long term.
City_management	A specific type of governance process.
City_operation	A specific type of governance process.
City_organization	Refers to the way in which a city is organized. There are two types of city organization: informal and formal.
City_formal_organization	Refers to the deliberately planned structure of a city. A formal organization has a specific purpose and aims at the efficient accomplishment of city objectives.
City_informal_organization	Refers to the unplanned and many times more "organic" city structure that results from informality in urban areas. In a world marked by globalization processes and deep socioeconomic restructuring, the value of informality seems to be central and increasingly important in the structuring of urban processes, as these reflect the actual organization of life, society and economies.
City_evaluation_process	The process of city evaluation defines the methodologies and actions needed to answer the following question: *"What should be measured and evaluated in the city to help identify and prioritize needs to make the city achieve progress according to its vision?"*
City_maturity	Score model to measure the performance of a city.
City_performance	Performance is the set of qualitative or quantitative information that guides the assessment of city operations. It also facilitates learning from past transformations undergone by a city and also learning from the transformational experiences of other cites under a sound comparative basis and common frame of reference.
Transformational_project	Individual or collaborative enterprise that is carefully planned and designed to achieve a particular transformational objective. A transformational project ties to a process that leads to specific, identifiable, and/or measurable change.
City_transformation_process	The core process through which a city changes and evolves. The transformational process has some transformational objectives that are achieved by implementing some transformational project.

Class	Definition
Transformational_objective	Specific goal that aims at transforming some specific aspect in the city.

Bibliography

[1]. ISO 37100:2016, Sustainable cities and communities – Vocabulary

[2]. ISO 37101:2016, Sustainable development in communities -- Management system for sustainable development -- Requirements with guidance for use

[3]. ISO 37120:2014, Sustainable development of communities -- Indicators for city services and quality of life

[4]. ISO/TR 37121:2017, Sustainable development in communities -- Inventory of existing guidelines and approaches on sustainable development and resilience in cities

[5]. "City Anatomy: A Framework to support City Governance, Evaluation and Transformation" by the City Protocol Society, available at https://cpsociety.sharepoint.com/sites/cptf/CPTSC/_layouts/15/guestaccess.aspx?docid=1ce2637bcd0bd44b58b8fcf0803f14bf0&authkey=AeUUezm1_7axXN68TAT7sZ8 "City Anatomy Ontology" by the City Protocol Society, available at https://cpsociety.sharepoint.com/sites/cptf/CPTSC/_layouts/15/guestaccess.aspx?docid=1fb857335cde34ccd80a621b61d284761&authkey=AYQkidv4pvxVMEm_YQVJp1o

[6].

