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Sustainable cities and communities — Descriptive framework for cities and communities

Développement durable des collectivités — Cadre descriptif pour les villes et les collectivités

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Foreword

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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).

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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[4],[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 foster and are fostered by emergent human behaviour[6]. 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) issued in 2015 resolve this relatively abstract ideal into more tangible objectives. The UNSDG Goal 11[7] 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 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.

ISO 37100 contains a list of relevant terms and definitions which are also useful in understanding the descriptive framework.

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 document (including any amendments) applies.

ISO 37100, *Sustainable cities and communities — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 37100 and the following 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/

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.

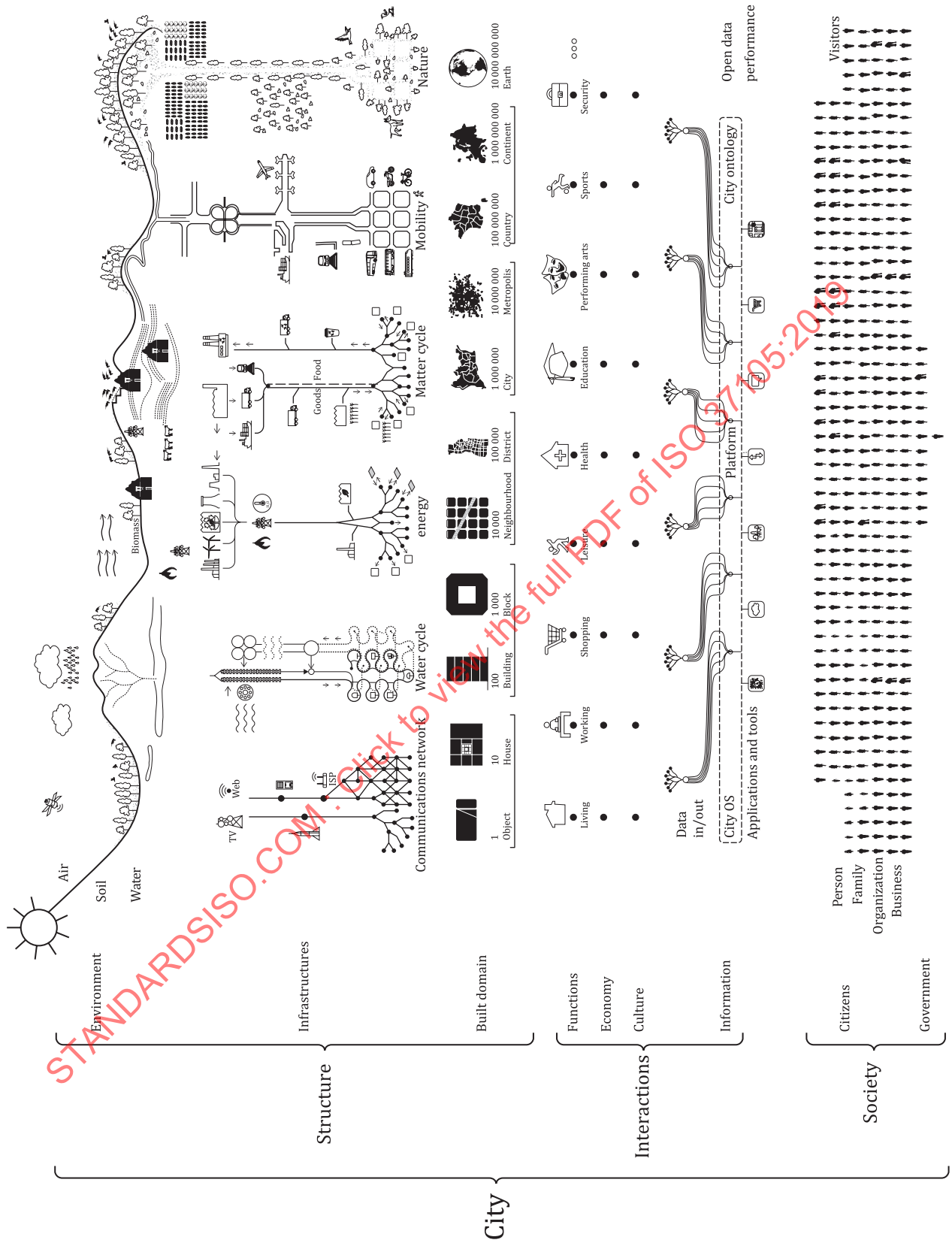


Figure 1 — A timeless, culturally agnostic, scalable, generic descriptive framework for any city or community

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 with:

— a way to describe their aims and objectives, existing or proposed city initiatives, and services in a manner that is consistent across cities, vendors, 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 strength and weakness 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 nature (plant and animals) and by the three basic components – air, earth and water – interacting dynamically in a seasonally variable way, and increasingly subject to the impacts of climate fluctuations linked to anthropogenic greenhouse gas pollution.[1)] The second layer of the structure system element is

1) Anthropogenic sources are those caused or produced by humans, such as the carbon emitted through power generation or transport.

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 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)

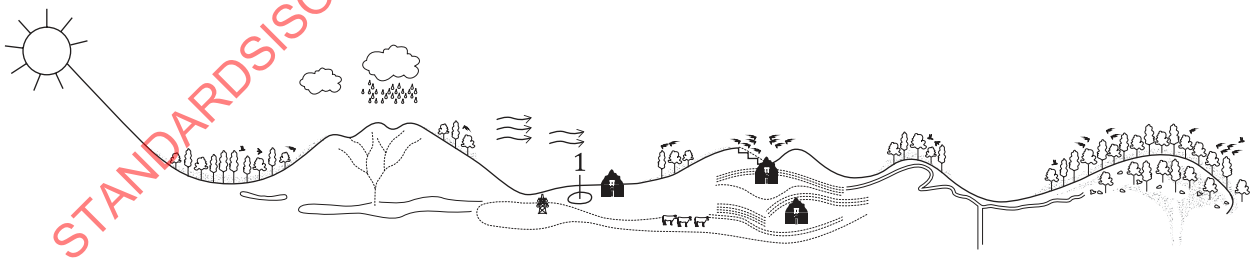
The society system element is composed of the living entities of the city. The first layer is *citizens*, which can be broken down into: *person (the individual), family*, *organizations* and *businesses.* The second layer is *government*, whose head is, typically, the mayor.

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.



Key

1 gas

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 nature (plants and animals) and the three basic components – air, soil and water – which interact 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.

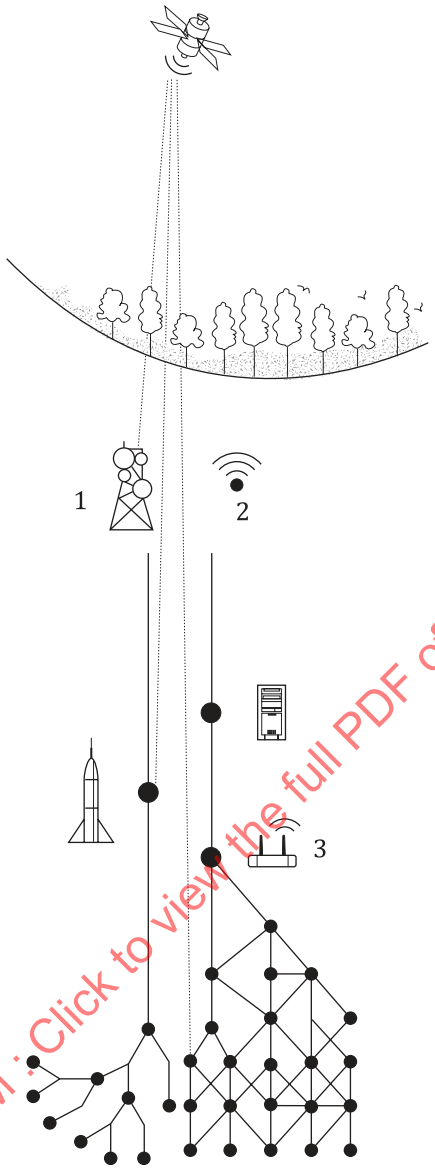
4.5.2 Infrastructures

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.

4.5.2.2 Communications network

The first infrastructure depicted in Figure 1 is the communications network shown in detail in Figure 3. The communications component is composed of all 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 fibre optic cables, as well as through the electromagnetic spectrum, are all examples of communication infrastructure.



Key

1 TV

2 Web

3 Internet service provider

Figure 3 — Communications network

4.5.2.3 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 processes and consume it. Grey water[2)] 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.

2) Grey 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.

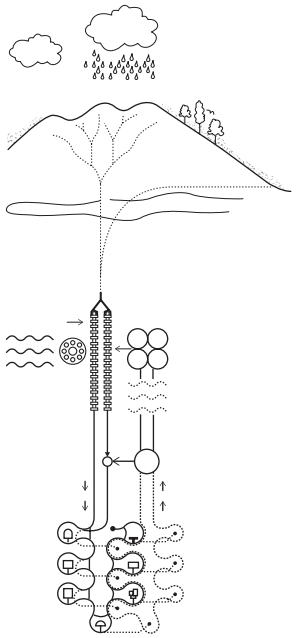
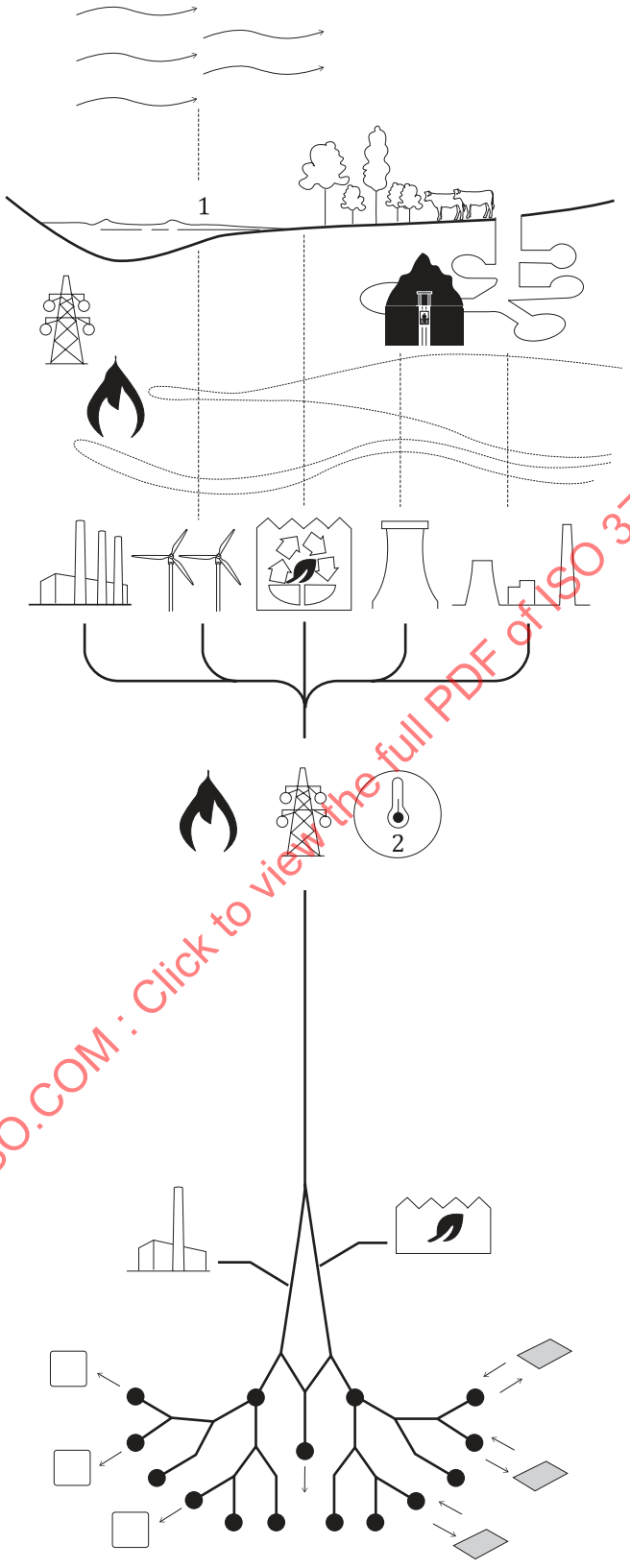


Figure 4 — Water cycle

4.5.2.4 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 do distributed energy nodes, like rooftop solar for thermal energy or electricity.



Key

1 biomass

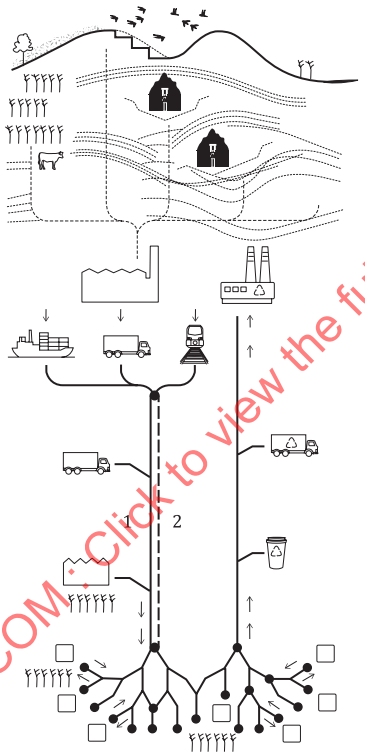
2 H_2O

Figure 5 — Energy

4.5.2.5 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.



Key

1 goods
2 food

Figure 6 — Matter cycle

4.5.2.6 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 and 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 also form an integral part of a city's public space, which is important for many aspects of city life.

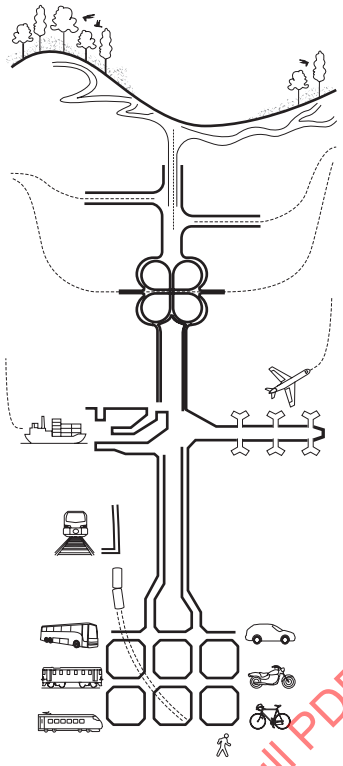


Figure 7 — Mobility

4.5.2.7 Green infrastructure

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[3)], or any other natural element, like trees and open space that has an effect on the quality of city life.

3) Bioswales are landscape elements designed to concentrate or remove silt and pollution from surface runoff water.

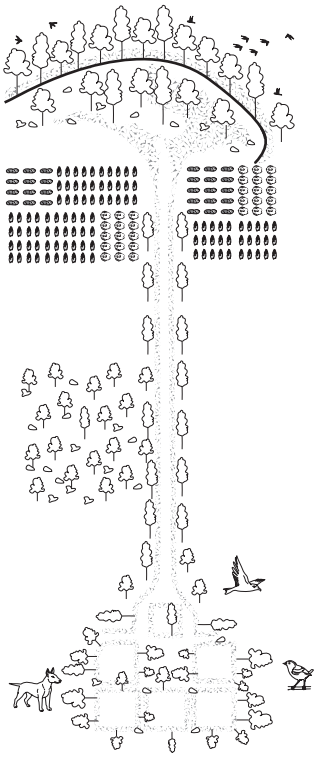


Figure 8 — Green infrastructure

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 in Figure 9, this scale can be represented as: houses, building, blocks, neighbourhoods, districts, the city, the metropolis, the country, the continent and ultimately the whole planet.

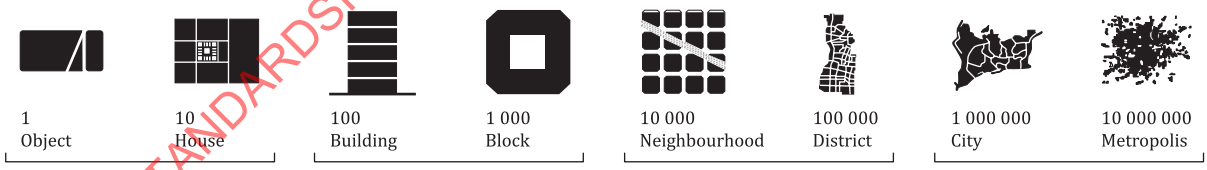


Figure 9 — Built domain

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 Figure 1 and Figure 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; 1 000 block; 10 000 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 rights-of-way 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 these 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.

4.6.2 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.

4.6.3 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.

4.6.4 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.

4.6.5 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 in 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.

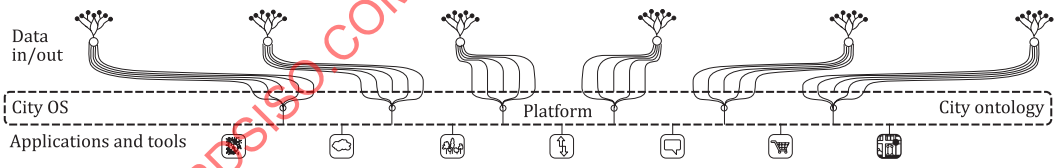


Figure 10 — Information platform

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 is 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 citizens and government.

4.7.2 Citizens

Citizens include the individual (or person), family, organizations and businesses. The term person is applied broadly, and includes individuals who live in, work in and/or visit 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 includes the many ways people organize themselves (e.g. into clubs), 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.

4.7.3 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 (CAO)

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 among 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, i.e. 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 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 concepts' 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, an 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 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 for ontology extensions.

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

5.3.2 Basic competency questions of the descriptive framework foundation 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 does each subsystem *relate/interact* 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.

5.3.3 Strategic design objectives of the descriptive framework 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 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.

5.3.4 The city as a “system of systems”

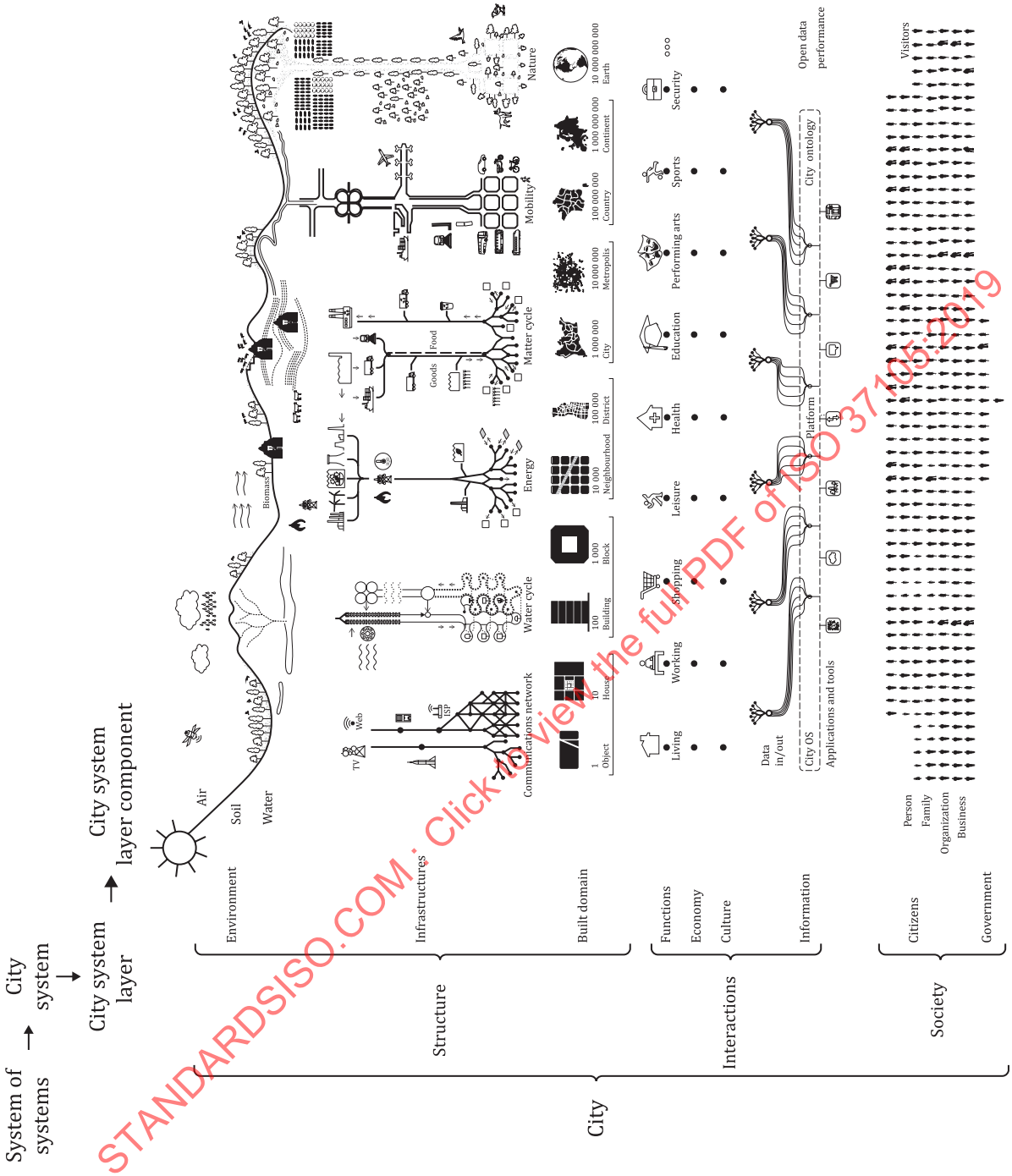


Figure 11 — Schematic representation of the descriptive framework city anatomy

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 one (i.e. some) 'City_system' concept via the interactsWith relation. It is also related to at least one 'City_system_layer' via the isOrganizedAs relation.

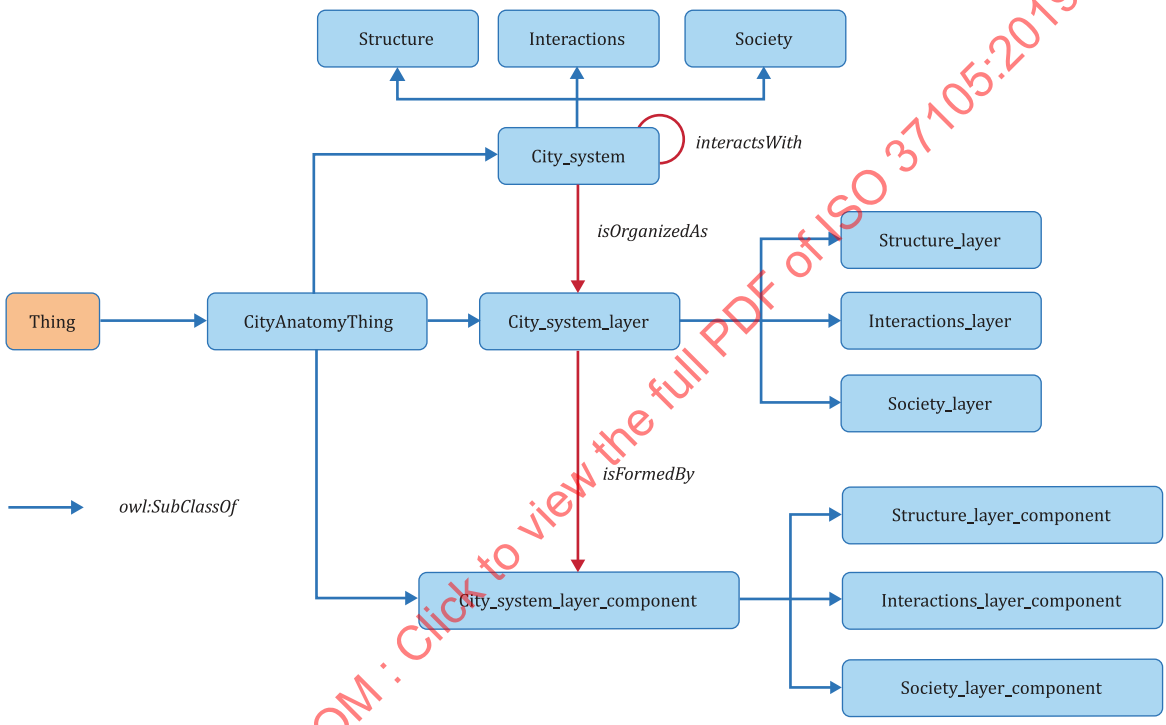


Figure 12 — Main CAO entities and relationships that describe a city from a systems science perspective as a *system of systems*

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*	CityAnatomyThing
	interactsWith	***some*** City_system
	isOrganizedAs	**some** City_system_layer
City_system_layer	*owl:SubClassOf*	CityAnatomyThing
	isConstituent	***some*** City_system
	isFormedBy	**some** City_system_layer_component
City_system_layer_component	*owl:SubClassOf*	CityAnatomyThing
	isConstituent	**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 interrelationships.

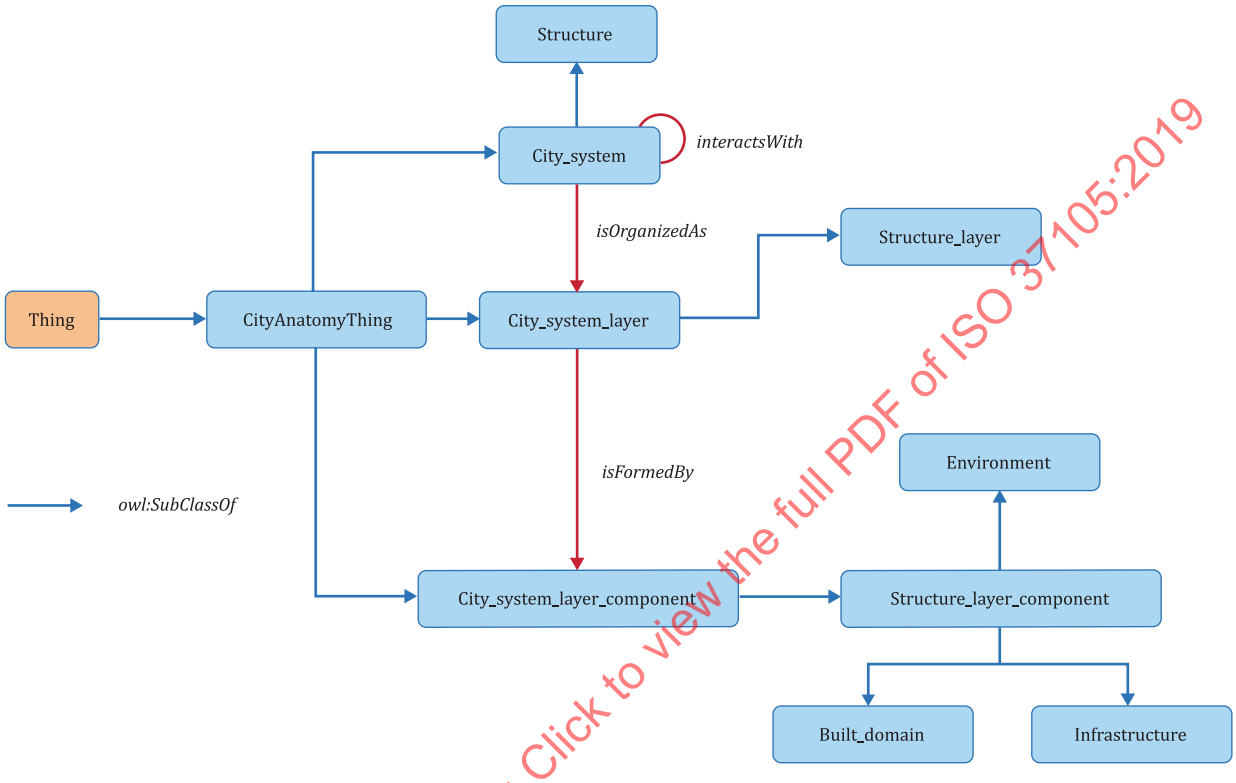


Figure 13 — Structure subsystem of the descriptive framework city anatomy with layers of environment, infrastructures and build domain

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*	City_system
	isOrganizedAs	***only*** Structure_layer
	owl:DisjointWith	Interactions
	owl:DisjointWith	Society
Structure_layer	*owl:SubClassOf*	City_system_layer
	isFormedBy	***only*** Structure_layer_component
	owl:DisjointWith	Interactions_layer
	owl:DisjointWith	Society_layer

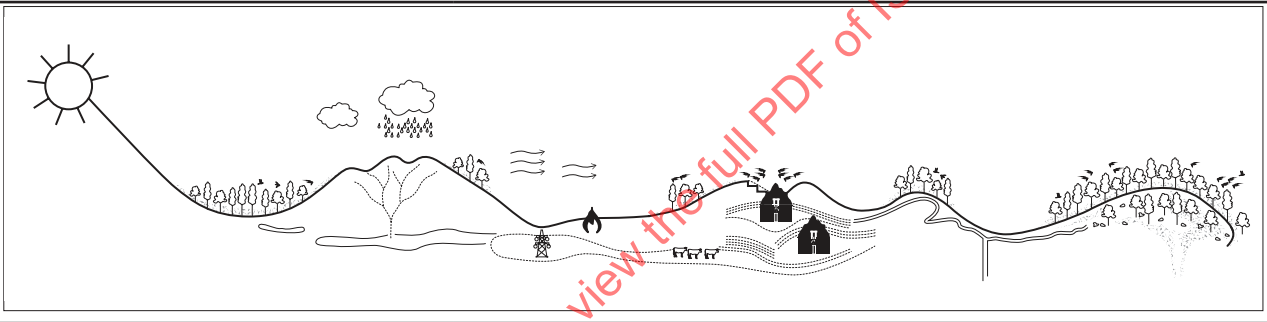
Table 2 *(continued)*

Class	Property	Value restriction
Structure_layer_component	*owl:SubClassOf*	City_system_layer_component
	isConstituent	***only*** Structure_layer
	owl:DisjointWith	Interactions_layer_component
	owl:DisjointWith	Society_layer_component

5.4.2 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

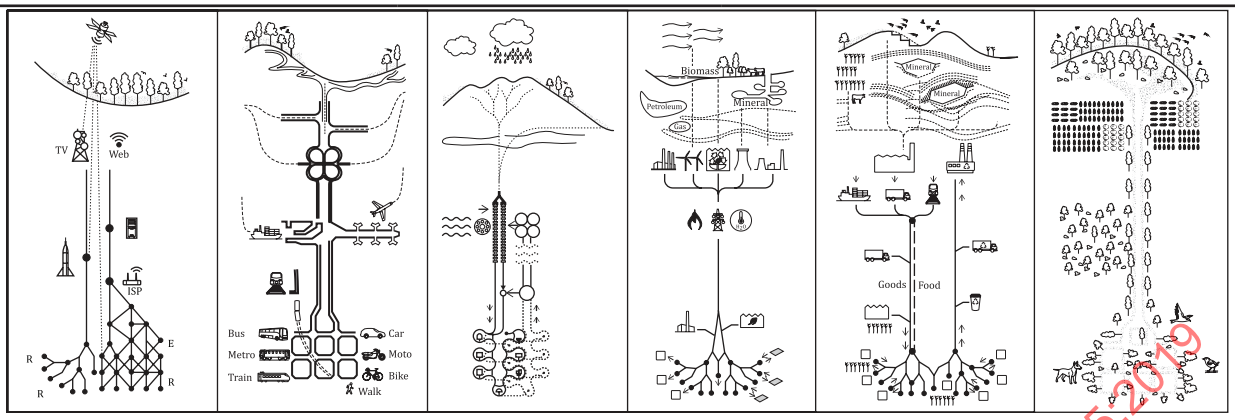


Class	Property	Value restriction
Environment	*owl:SubClassOf*	Structure_layer_component
	isFormedBy	***some*** (Biodiversity **and** Environmental_compartment)
	isRelatedTo	***some*** Settlement
Biodiversity	*owl:SubClassOf*	CityAnatomyThing
Environmental_compartment	*owl:SubClassOf*	CityAnatomyThing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

5.4.3 Infrastructures

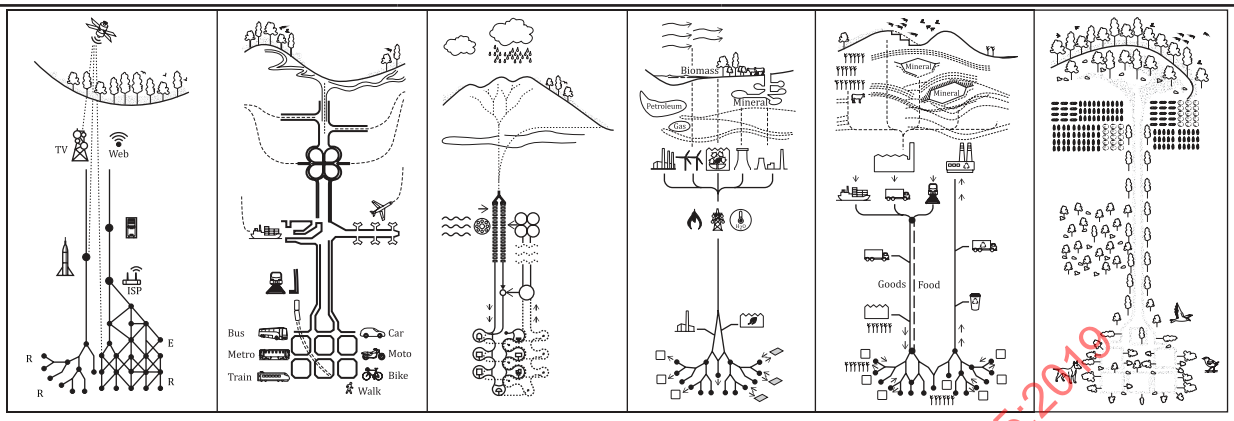
The second subsystem layer within the anatomy structure comprises the infrastructures, i.e. connective structures that enable people to get the resources they need, especially from the environment, and bring them to the city, or that enable the flows or cycles inside the city itself. Two main types of 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*	Structure_layer_component
	enable	***some*** Flow
	transports	***some*** TransportableThing
Network_infrastructure	*owl:SubClassOf*	Infrastructure
	isNodeOf	**some** Network_infrastructure
Data_communication_network	*owl:SubClassOf*	Network_infrastructure
	transports	**some** Data
	owl:NamedIndividual	*Internet*
Metropolitan_area_network	*owl:SubClassOf*	Data_communication_network
Local_area_network	*owl:SubClassOf*	Data_communication_network
Mobility_network	*owl:SubClassOf*	Network_infrastructure
	hasElement	**some** Mobility_network_component
Mobility_network_component	*owl:SubClassOf*	CityAnatomyThing
	isElementOf	**some** Mobility_network
Subway	*owl:SubClassOf*	Mobility_network_component
Bus/Bus Rapid Transit	*owl:SubClassOf*	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*	Network_infrastructure
	isNodeOf	**some** Energy_cycle
	transports	**some** Electricity
Sewer_network	*owl:SubClassOf*	Network_infrastructure
	isNodeOf	**some** Water_cycle
Water_distribution_network	*owl:SubClassOf*	Network_infrastructure
	isNodeOf	**some** Water_cycle
	transports	**some** Water
Cycle_infrastructure	*owl:SubClassOf*	Network_infrastructure

Table 4 *(continued)*



Network infrastructures	Cycle infrastructures	
Class	**Property**	**Value restriction**
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

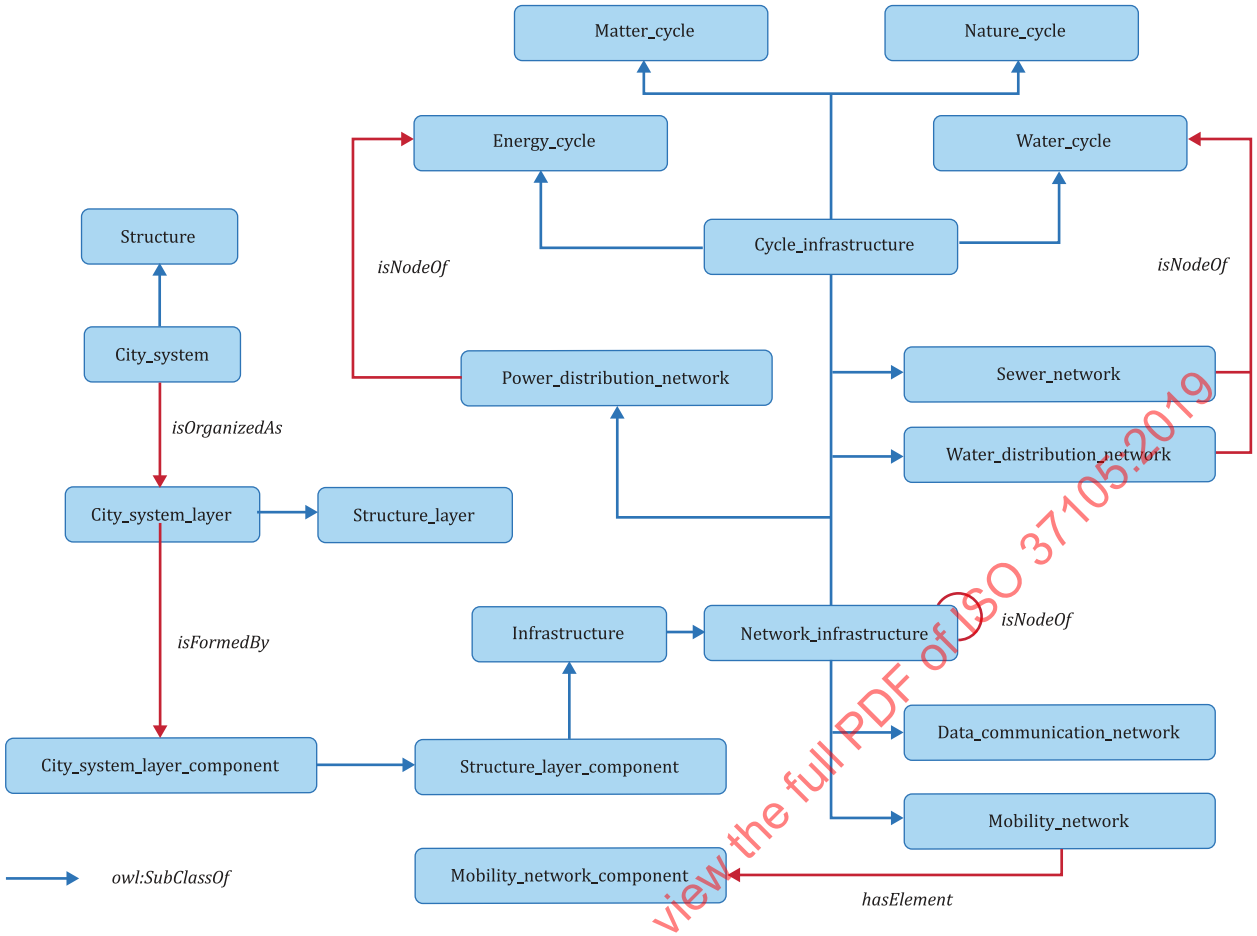


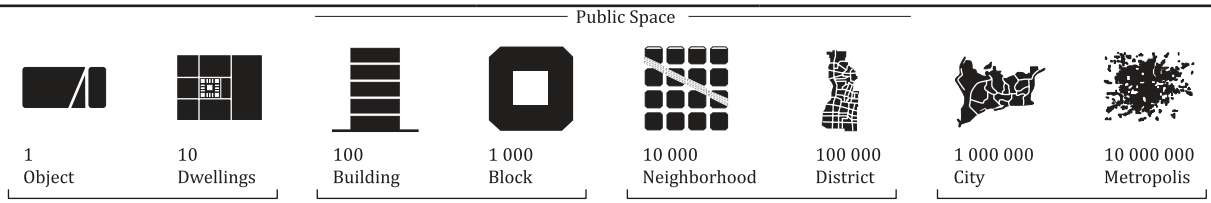
Figure 14 — Main classes and relationships in the infrastructure component of the city anatomy structure layer

5.4.4 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 artefacts 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 5 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.

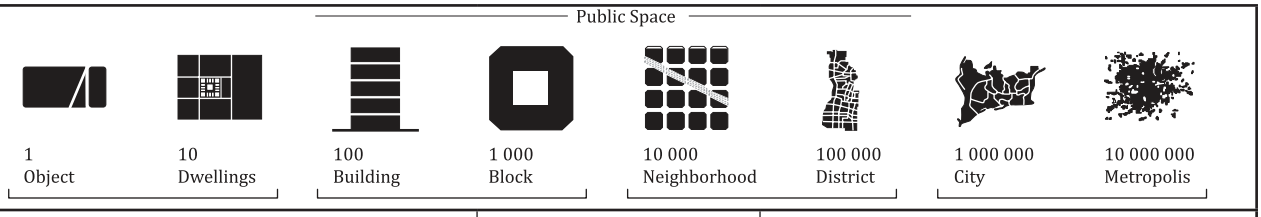
NOTE ISO/IEC 30182 BUILDING concept can be mapped onto the CAO Building class and ISO/IEC 30182 FUNCTION concept can be mapped onto the CAO Urban function class.

Table 5 — CAO classes used to describe the built domain



Class	Property	Value restriction
Built_domain	*owl:SubClassOf*	Structure_layer_component
	hasConstituent	**some** Built_domain_element
	performs	**some** Urban_function
Built_domain_element	*owl:SubClassOf*	CityAnatomyThing
Generic_built_domain_element	*owl:SubClassOf*	Built_domain_element
Specific_built_domain_element	*owl:SubClassOf*	Built_domain_element
	hasCost	**some** Cost
	hasImpact	**some** Impact
	hasOwnership	**some** Ownership
	hasUse	**some** Use
	isLocated	**some** sc:Place
	performs	**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*	sc:AdministrativeArea
	owl:SubClassOf	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*	Specific_built_domain_element
	hasUse	**value** public_use
	hasOwnership	**some** publicly_owned
Use	*owl:SubClassOf*	CityAnatomyThing
	owl:NamedIndividual	*private_use*
	owl:NamedIndividual	*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

Table 5 *(continued)*



Class	Property	Value restriction
org:government_owned	*owl:SubClassOf*	org:Ownership
Cost	*owl:SubClassOf*	CityAnatomyThing
	owl:NamedIndividual	Maintenance_cost
	owl:NamedIndividual	Operation_cost
	owl:NamedIndividual	Production_cost
Urban_function	*owl:SubClassOf*	CityAnatomyThing
Impact	*owl:SubClassOf*	CityAnatomyThing
	owl:NamedIndividual	economic_impact
	owl:NamedIndividual	environmental_impact
	owl:NamedIndividual	social_impact

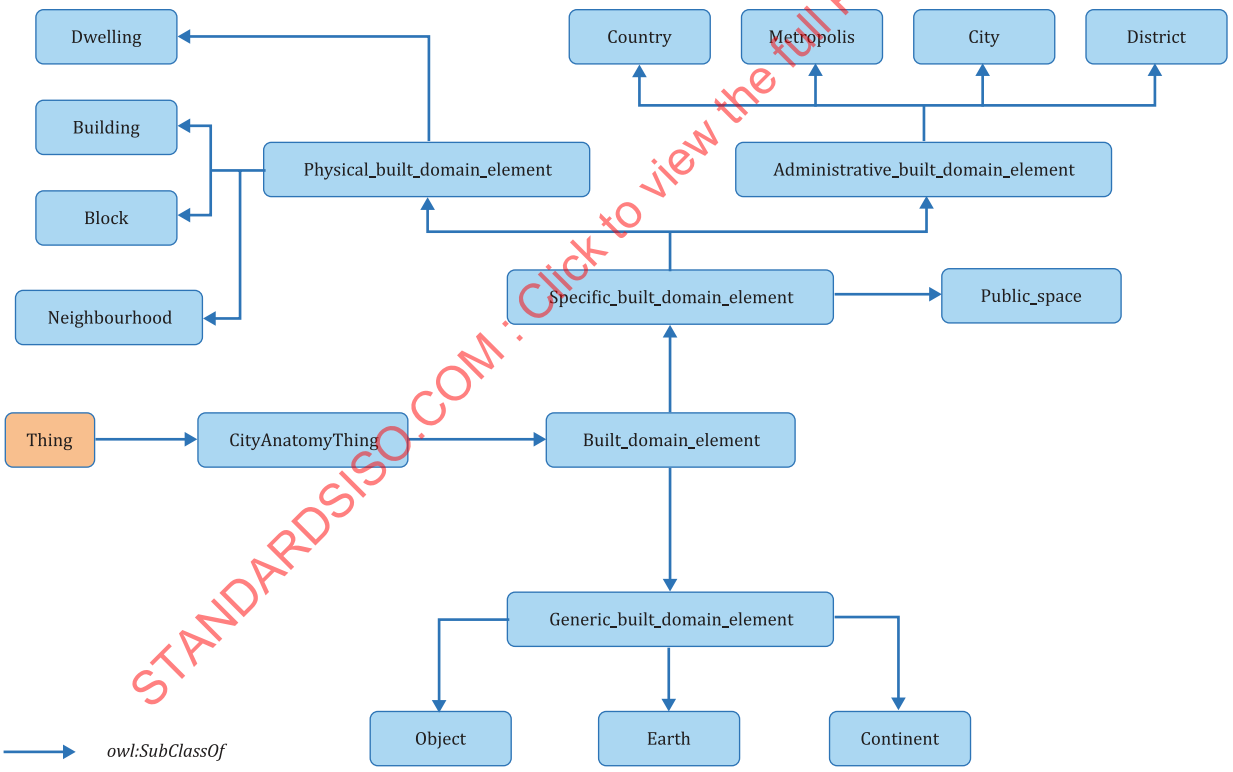


Figure 15 — Representation of the built domain entities and relationships

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, healthcare, 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, 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 show 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 list and depict the CAO classes of the information subsystem.

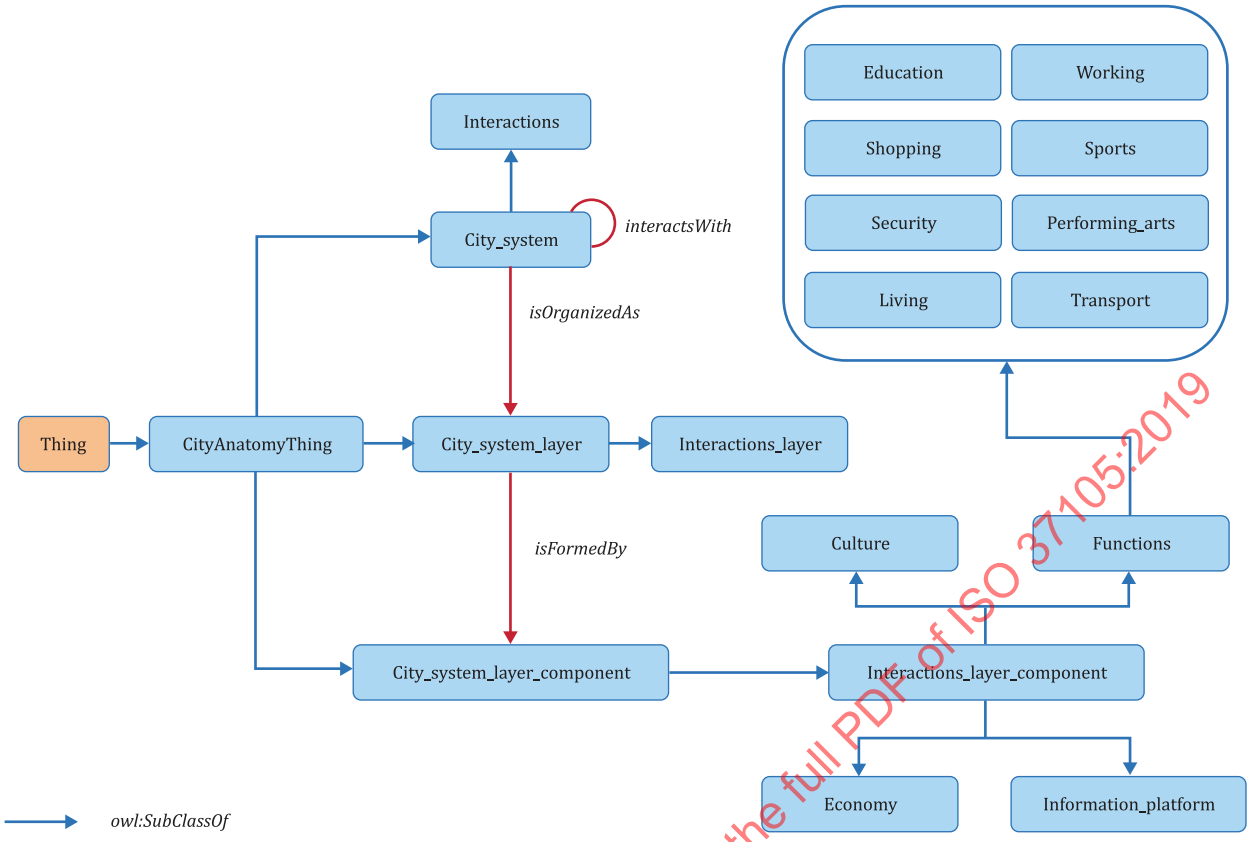


Figure 16 — Components of the interactions system

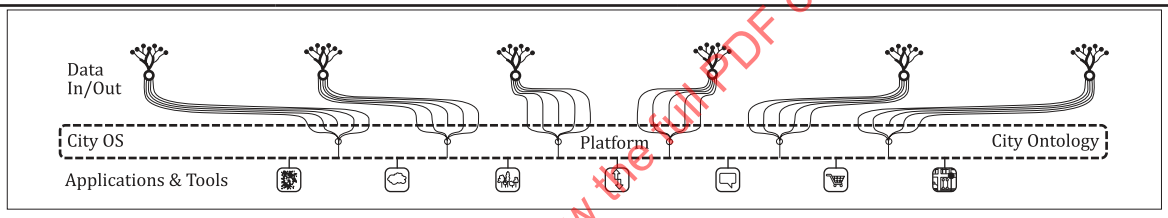
Table 6 — CAO classes used to describe the interactions subsystem

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

Table 6 *(continued)*

Class	Property	Value restriction
Economy	*owl:SubClassOf*	Interactions_layer_component
	owl:NamedIndividual	*Commerce_and_trade*
	owl:NamedIndividual	*Competitiveness*
	owl:NamedIndividual	*Entrepreneurship*
	owl:NamedIndividual	*Finances*
	owl:NamedIndividual	*Wealth_distribution*
	owl:NamedIndividual	*Wealth_production*
Culture	*owl:SubClassOf*	Interactions_layer_component
	owl:NamedIndividual	*Diversity*
	owl:NamedIndividual	*Heritage*
	owl:NamedIndividual	*Social_expression*

Table 7 — Main CAO classes in the information platform



Class	Property	Value restriction
Information_platform	*owl:SubClassOf*	Interactions_layer_component
	hasElement	**some** City_information_portal
	hasElement	**some** City_operating_system
	hasElement	**some** City_indicator
	hasElement	**some** City_application
City_operating_system	*owl:SubClassOf*	CityAnatomyThing
	isElementOf	**some** Information_platform
	owl:EquivalentClass	CityOS
City_information_portal	*owl:SubClassOf*	CityAnatomyThing
	isElementOf	**some** Information_platform
City_application	*owl:SubClassOf*	CityAnatomyThing
	isElementOf	**some** Information_platform
City_indicator[a]	*owl:SubClassOf*	CityIndicatorThing
	isElementOf	**some** Information_platform

[a] City indicators are described in full detail in 5.5.1.

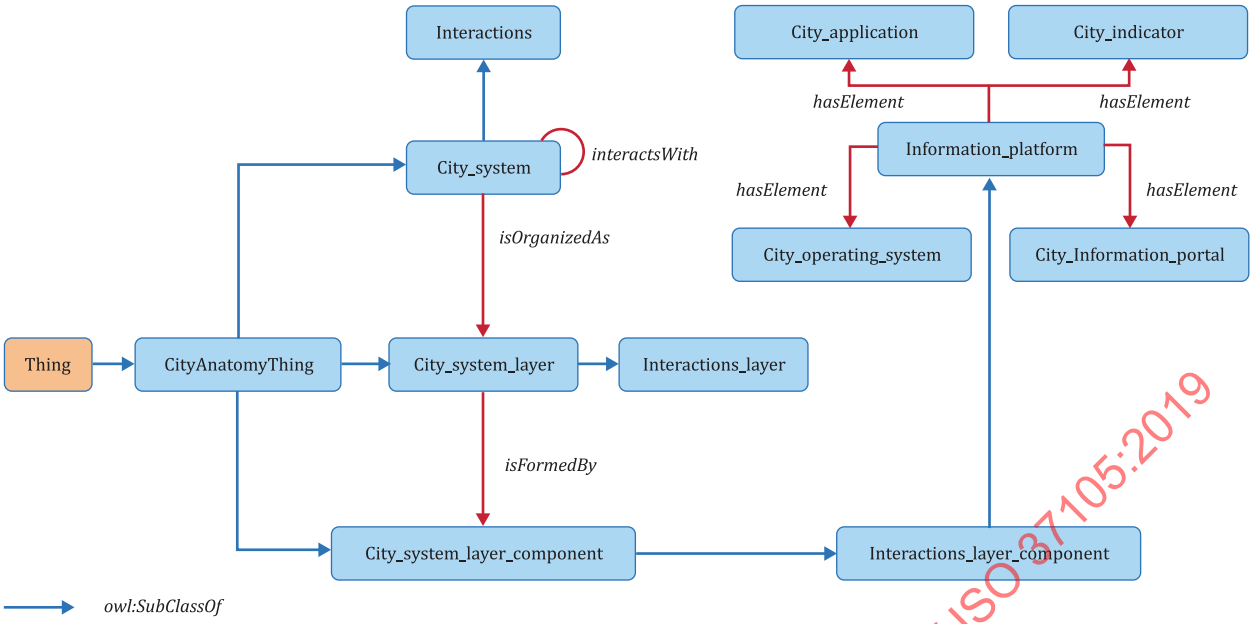


Figure 17 — Components and relationships in the information platform

5.5.2 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 modelled 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.

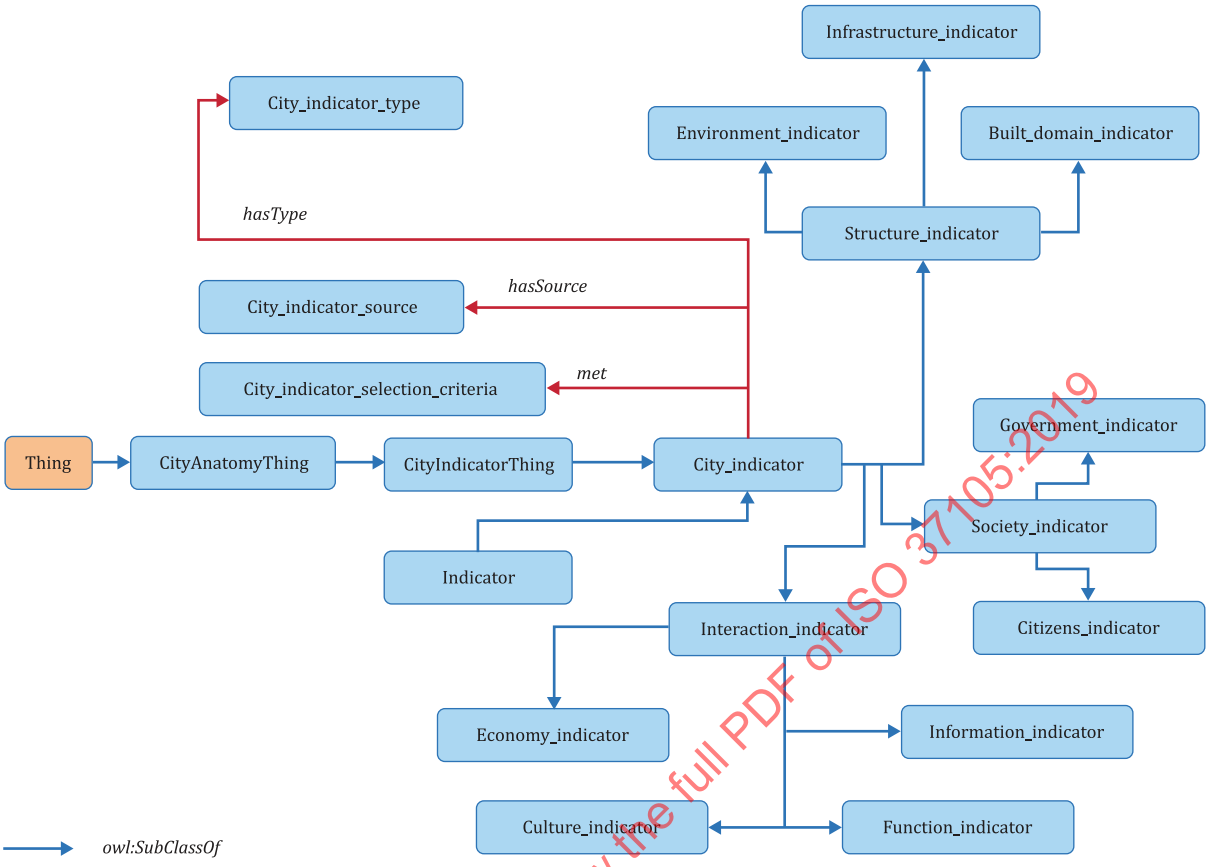


Figure 18 — CAO modelling of city indicators

Table 8 — CAO classes used to describe the city indicators

Class	Property	Value restriction
CityIndicatorThing	*owl:SubClassOf*	CityAnatomyThing
Indicator	*owl:SubClassOf*	iso21972:Indicator
	hasPurpose	**some** Purpose
	isDerivedFrom	**some** Raw_data
	measures	**some** Measurable_thing
	hasType	**some** 'unit of measure'
	hasValue	**some** measure
City_indicator	*owl:SubClassOf*	Indicator
	owl:SubClassOf	CityIndicatorThing
	isElementOf	**some** Information_platform
	isRelatedTo	**some** City_process
	measuresProgressTowards	**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

Table 8 *(continued)*

Class	Property	Value restriction
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 21972[4] defines an upper level ontology for smart city indicators. The ontology extends the 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. The CAO incorporates ISO/IEC 21972 in two ways:

1) CAO Indicator is an owl:subClassOf iso21972:Indicator[5], thereby inheriting the properties of ISO/IEC 21972's Indicator definition.

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

4) Under preparation. Stage at the time of publication: ISO/IEC PRF 21972:2019.

5) iso21972 is the namespace prefix for the owl file that contains the ISO/IEC 21972 ontology.

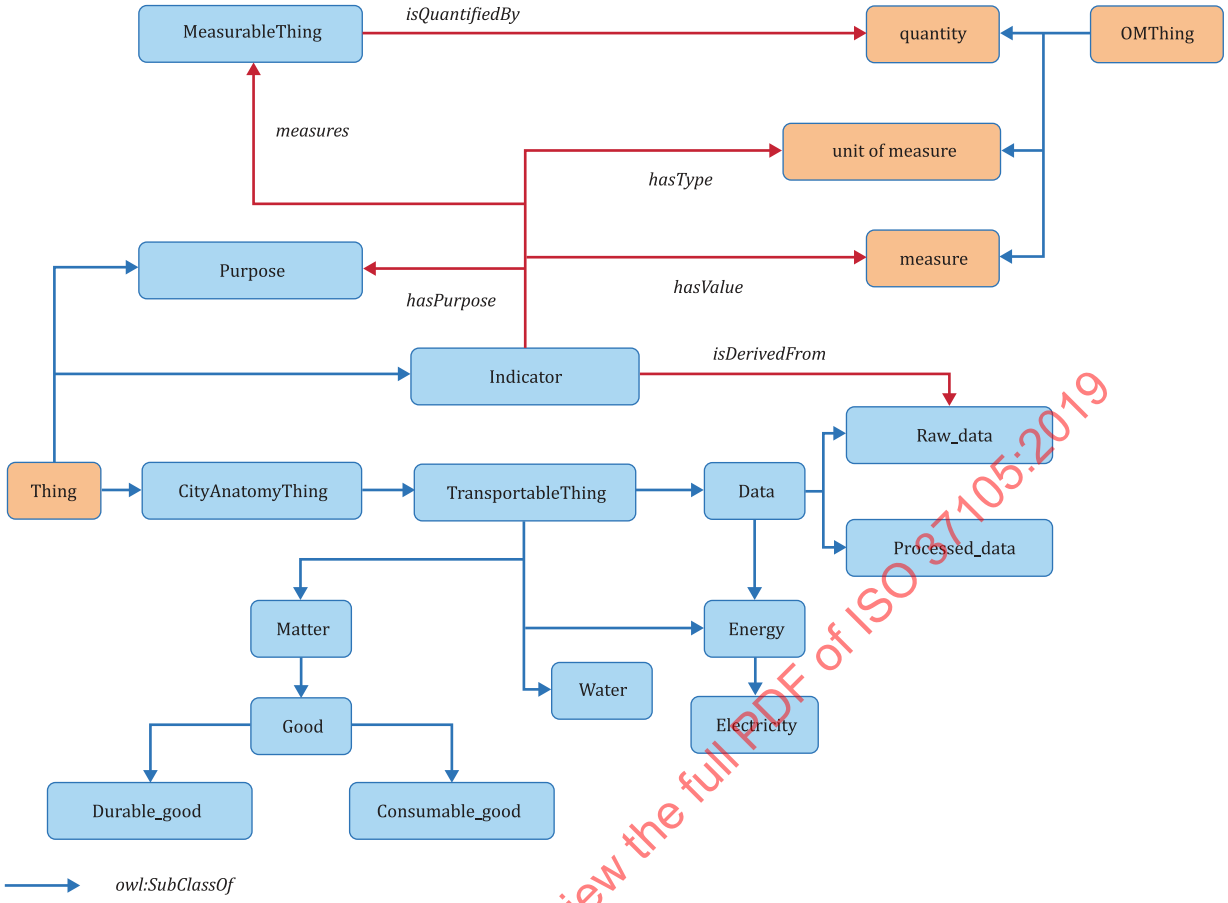


Figure 19 — Indicators, city indicators, data and properties

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

1) *Citizens*, including person (the individual), family, organizations and businesses. The term person is applied broadly, and includes individuals who live in, work in, and/or visit 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).

2) *Government*, 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 5.7.

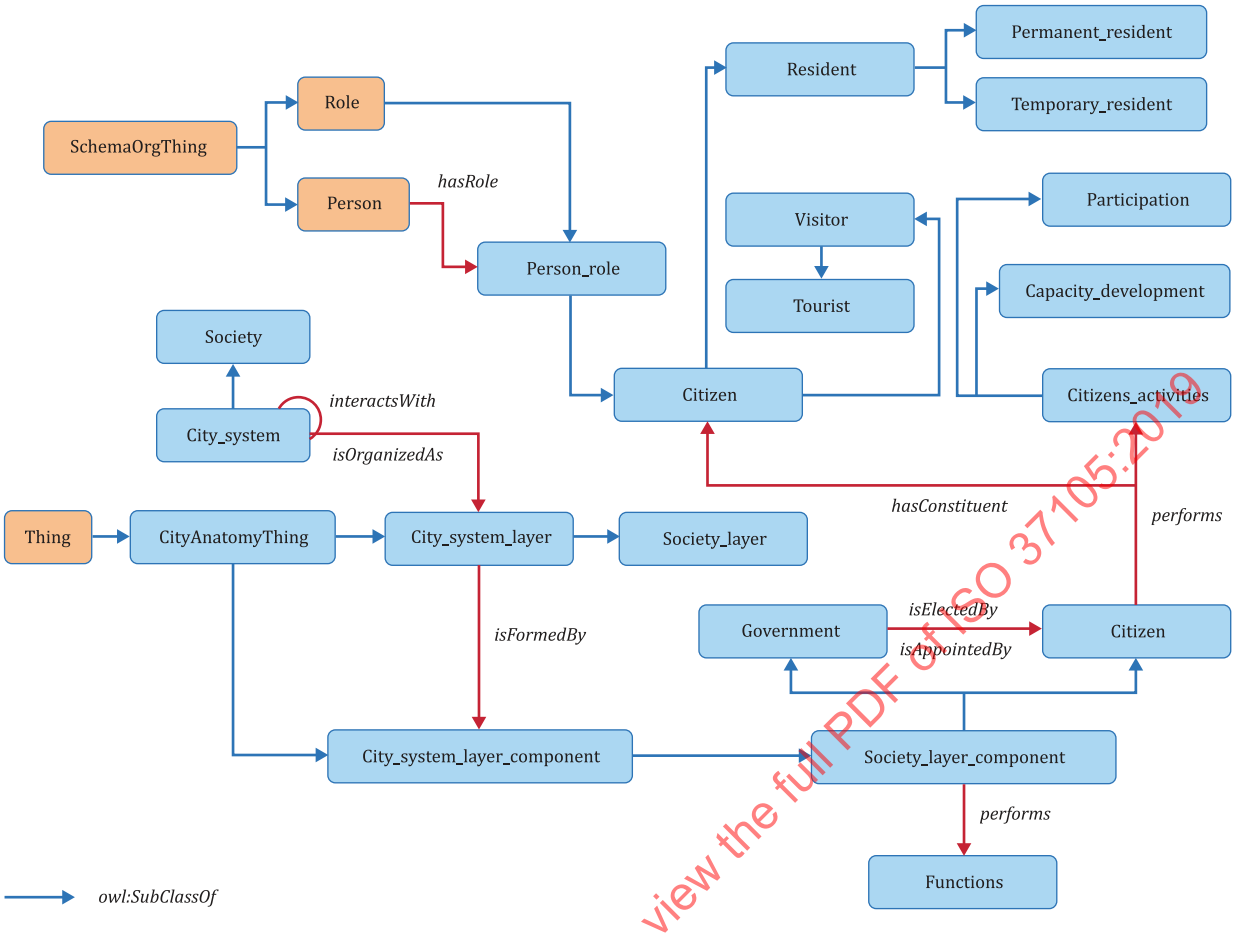


Figure 20 — Components of the society subsystem

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*	City_system_layer
	isFormedBy	**only** Society_layer_component
	owl:DisjointWith	Interactions_layer
	owl:DisjointWith	Structure_layer
Society_layer_component	*owl:SubClassOf*	City_system_layer_component
	owl:DisjointWith	Interactions_layer_component
	owl:DisjointWith	Structure_layer_component
	performs	**some** Functions
Citizens	*owl:SubClassOf*	Society_layer_component
	hasConstituent	**some** Citizen
	performs	**some** Citizens_activities
Citizens_activities	*owl:SubClassOf*	CityAnatomyThing
Capacity_development	*owl:SubClassOf*	Citizens_activities

Table 9 *(continued)*

Class	Property	Value restriction
Participation	*owl:SubClassOf*	Citizens_activities
Government	*owl:SubClassOf*	Society_layer_component
	isElectedBy isAppointedBy	**some** Citizens
	serves	**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*	SchemaOrgThing
	hasRole	**some** schema:Role
	isRelatedTo	**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/IEC 30182 concepts onto the 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 for 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.

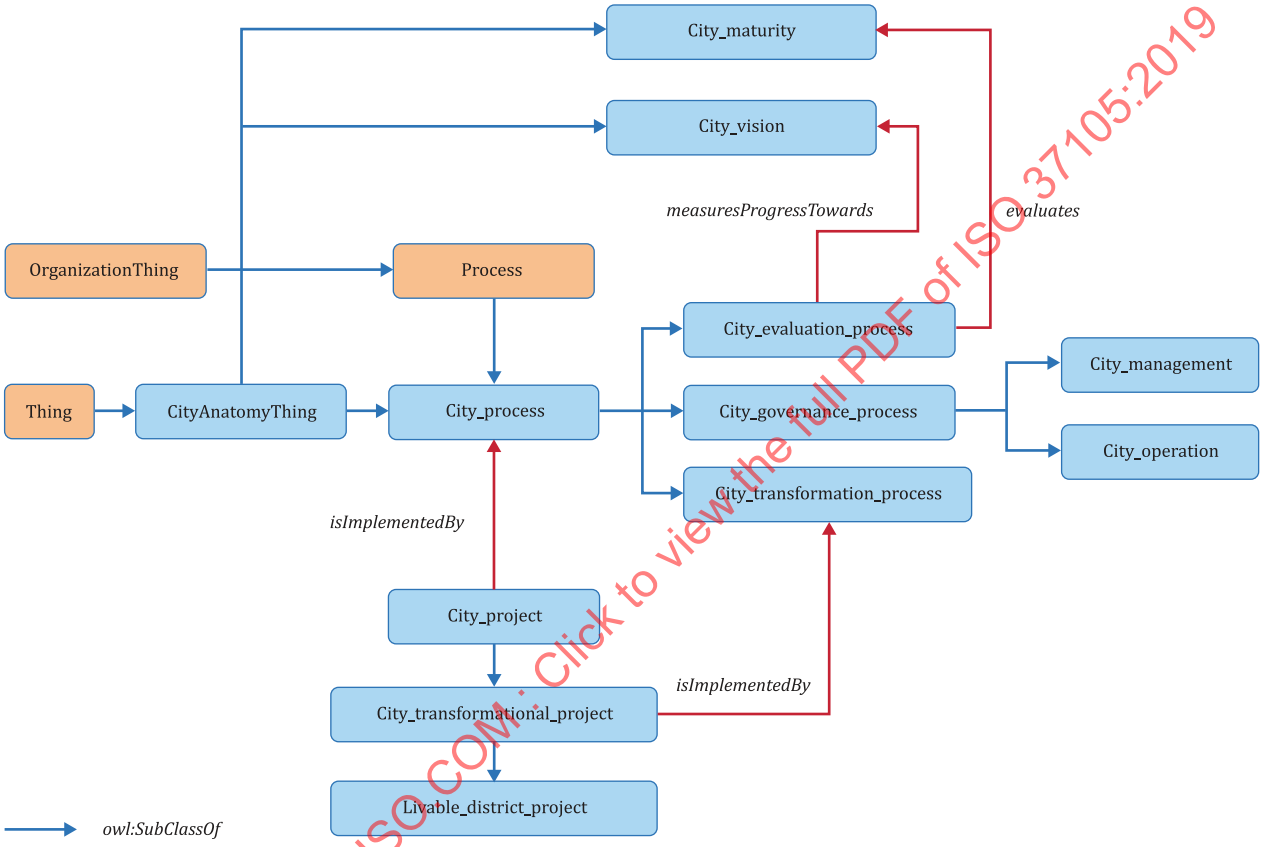


Figure 21 — Entities and relationships in the dynamics of a city

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*	org:Process
	owl:SubClassOf	CityAnatomyThing
City_governance_process	*owl:SubClassOf*	City_process
	governs	**some** City_organization
	isSupportedBy	**some** (Law **or** Policy **or** Regulation)
	requires	**some** Leadership
	serves	**some** City_vision
	sets	**some** City_priority

Table 11 *(continued)*

Class	Property	Value restriction
City_management	*owl:SubClassOf*	City_governance_process
	isRelatedTo	**some** City_objective
City_operation	*owl:SubClassOf*	City_governance_process
City_organization	*owl:SubClassOf*	CityAnatomyThing
	owl:SubClassOf	Org:Organization
City_formal_organization	*owl:SubClassOf*	City_organization
City_informal_organization	*owl:SubClassOf*	City_organization
City_evaluation_process	*owl:SubClassOf*	City_process
	measuresProgressTowards	**some** City_vision
	sets	**some** Transformational_project
	evaluates	**some** City_maturity
	measures	**some** City_performance
City_maturity	*Owl:SubClassOf*	CityAnatomyThing
Transformational_project	*owl:SubClassOf*	City_project
	isRelatedTo	**some** City_evaluation_process
	isImplementedBy	**only** City_transformation_process
City_project	*owl:SubClassOf*	CityAnatomyThing
	isImplementedBy	**some** City_process
City_transformation_process	*owl:SubClassOf*	City_process
	isRelatedTo	**some** Transformational_project
Transformational_objective	*owl:SubClassOf*	City_objective
	isRelatedTo	**some** Transformational_project

ISO/IEC 30182's METHOD concept can be mapped onto the 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 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 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 the list along the vertical axis is not intended to be an exhaustive representation of all 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 reorganize governance to better serve city objectives and priorities.[6)]

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

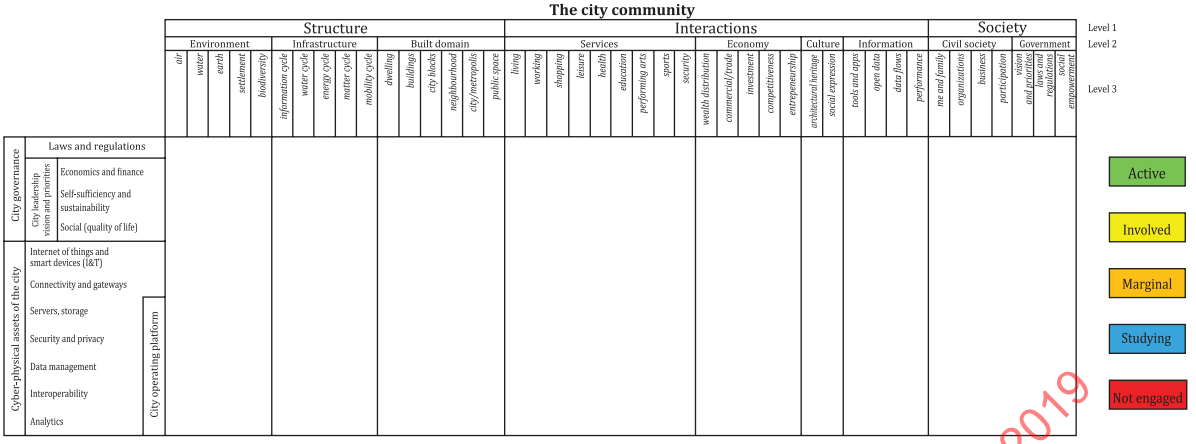


Figure A.1 — Smart city deployment matrix consistent with the architecture in Figure 11

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 A.2. Figure A.2 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.

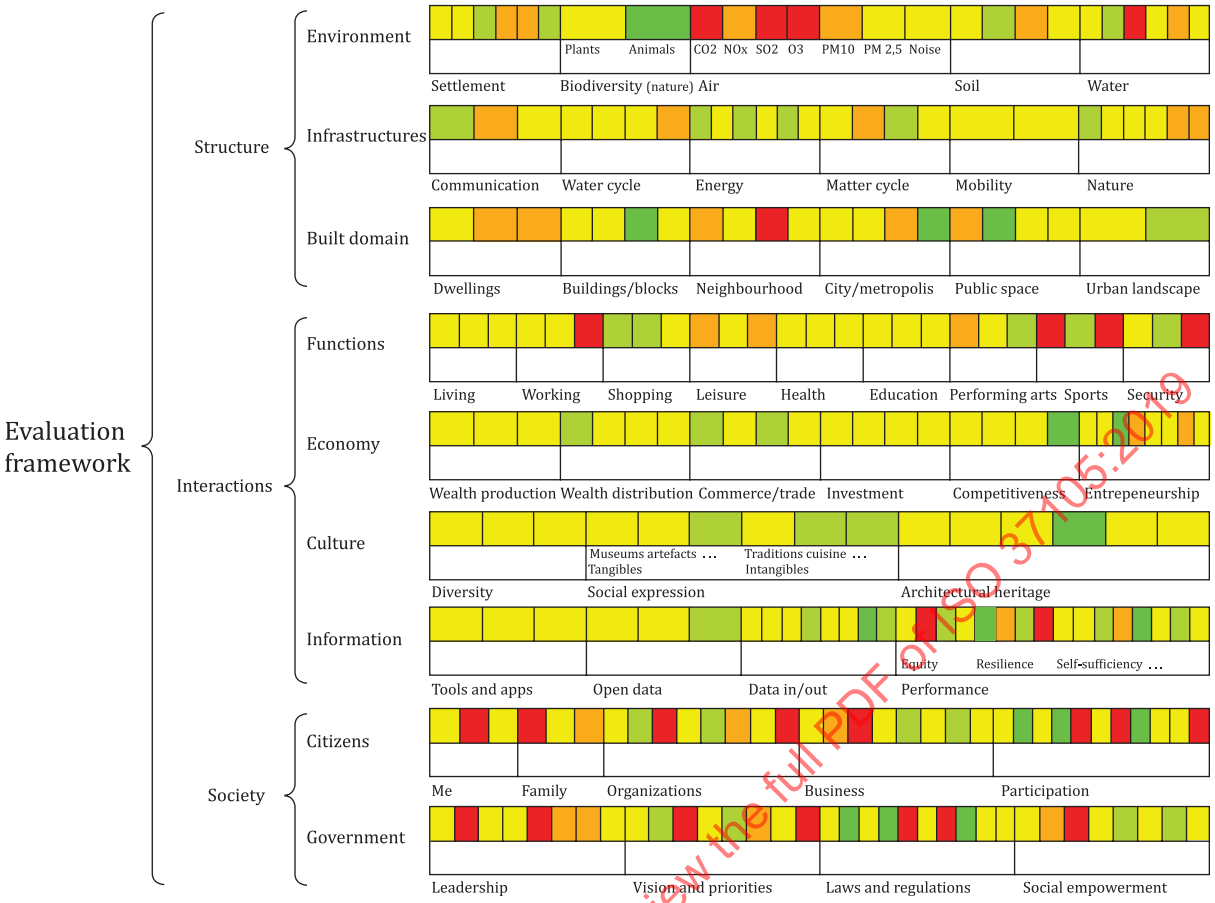


Figure A.2 — Evaluation framework with top-level indicators for city transformational projects

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 analysing 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[7]), 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?

7) http://www.citymayors.com/environment/slow_cities.html

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

Annex B
(informative)

Developing guidelines for multipurpose 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 such as 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 multipurpose 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; and 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. Multipurpose 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. Multipurpose 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.

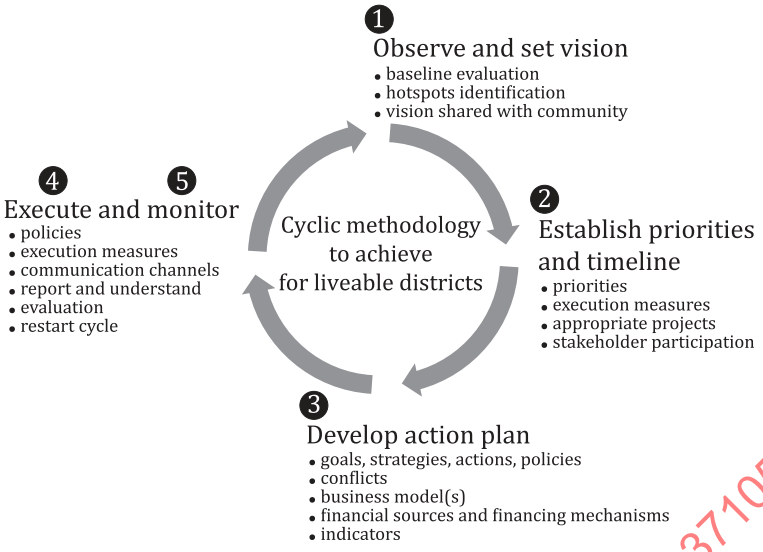


Figure B.1 — Methodology to progressively develop community projects

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 multipurpose 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 multipurpose public spaces):

Public and 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 multipurpose 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[8] to provide access to:

   — street sidewalks accessible to all ages and abilities;

8) https://www.asla.org/uploadedFiles/CMS/Meetings_and_Events/2014_Annual_Meeting_Handouts/FRI-A07_Infrastructure is Public Space.pdf