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SYSTEMS REFERENCE DELIVERABLE

Smart city system ontology –
Part 1: Gap analysis

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SMART CITY SYSTEM ONTOLOGY –

Part 1: Gap analysis

FOREWORD

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The text of this Systems Reference Deliverable is based on the following documents:

Draft	Report on voting
SyCSmartCities/322/DTS	SyCSmartCities/334/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Systems Reference Deliverable is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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- withdrawn, or
- revised.

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INRODUCTION

Ontology is becoming a key subject in the world of big data, AI, IoT, and smart city system standards. The following benefits of ontology are recognized as important with respect to interoperability, connectivity, traceability of digital content, particularly machine readability, executability and interpretability of digital content for decision making and actions.

– Increase interoperability across domains.
– Enable machine-readable code for computational reasoning and decision making.
– Create semantic linkages between data, information and knowledge systems.
– Build accessible APIs and semantic linkages between web-based data objects.
– Link data domains with shared concepts or canonical data models.
– Connect shared data concepts and definitions between domains.

However, ontology has a variety of definitions in different international standards. How to understand different meanings of ontology and select the right definition for the right stakeholders' concerns for the right purposes is a big challenge for effective integration of business, data, information, knowledge and decision making, across disciplines, domains, systems, platforms and applications in smart cites. Moreover, how to deal with the grand challenges of interoperability of many and various ontologies to satisfy the demands from artificial intelligence and big data analytics are gaps to be filled in the area of smart city systems. How to develop digital content that is machine readable, executable and interpretable, working in the system without human effort for a smart city system are emerging needs to be studied. There are significant demands for better communication, coordination, cooperation, collaboration and connectivity of existing ontology standards to smart cities practical sectors. This document aims:

- to identify existing ontology standards from different Standards Development Organizations (SDOs) and to provide best practice examples and considerations of ontology standards development and maintenance for smart city systems;
- to identify gaps in existing ontology standards for smart city systems and the opportunities and challenges in ontology standards development taking into account multi-dimensional and muti-domain stakeholders' concerns city wide, and to provide recommendations for ontology standards development and maintenance to enable integration, interoperability, efficiency and effectiveness of smart city systems.

SMART CITY SYSTEM ONTOLOGY –

Part 1: Gap analysis

1 Scope

This document provides a gap analysis on ontology relevant standards for smart city systems to be used as a base document for mapping, developing and maintaining a set of ontology standards for smart city systems.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
characteristic
abstraction of a *property* (3.8)

Note 1 to entry: Characteristics are used to describe concepts.

[SOURCE: ISO 1087:2019, 3.2.1, modified – The EXAMPLE has been deleted.]

3.2
concept
unit of knowledge created by a unique combination of *characteristics* (3.1)

[SOURCE: ISO 1087:2019, 3.2.7, modified – The Notes to entry have been deleted.]

3.3
definition
representation of a concept by an expression that describes it and differentiates it from related *concepts* (3.2)

[SOURCE: ISO 1087:2019, 3.3.1]

3.4
digital system
system consisting of hardware, software, and possibly network components, used to generate and/or use data to fulfil one or more specific functions

EXAMPLE 1: A digital traffic system that uses sensors to measure real time traffic movement digitally and sends that data to where it can be collected, analysed and used both to control digital traffic signals and to provide information to support decision making by staff in traffic management roles and by travellers.

EXAMPLE 2: A digital health record system that transforms information related to patients into digital form and enables it to be shared and analysed to support treatment.

EXAMPLE 3: A digital payment system that uses smart cards, readers, and secure data transmission, and sends queries and enables the alteration of data within financial institutions, to allow goods and services to be paid for without the need of cash.

EXAMPLE 4: A digital assembly line system in a factory that collects and monitors data coming from a variety of sources and uses that to coordinate robotic assembly processes and make any adjustments necessary to support quality and efficiency goals.

[SOURCE: IEC 60050-831:–, 831-02-03]

3.5
domain
subject field
field of special knowledge

[SOURCE: ISO 1087:2019, 3.1.4]

3.6
object
anything perceivable or conceivable

Note 1 to entry: Objects can be material (e.g. 'engine', 'sheet of paper', 'diamond'), immaterial (e.g. 'conversion ratio', 'project plan') or imagined (e.g. 'unicorn', 'scientific hypothesis').

[SOURCE: ISO 1087:2019, 3.1.1]

3.7
physical system
set of physical objects and processes that work together to fulfil one or more specific functions

EXAMPLE Electrical power distribution systems, logistics systems, metro systems.

[SOURCE: IEC 60050-831:–, 831-03-03]

3.8
property
feature of an *object* (3.6)

Note 1 to entry: One or more objects can have the same property.

[SOURCE: ISO 1087:2019, 3.1.3, modified – The EXAMPLES have been deleted.]

3.9
smart city
city where improvements in quality of life, services, sustainability and resilience are facilitated by the effective integration of many and various types of physical, digital and social systems and the transformative use of data and technology

Note 1 to entry: This is a general definition of a smart city. The IEC looks at these aspects from the perspective of electrotechnology.

Note 2 to entry: The effective integration of physical, digital and social systems can be facilitated by integration of digital twins of all these systems.

[SOURCE: IEC 60050-831:–, 831-01-19]

3.10
system
combination of interacting elements organized to achieve one or more stated purposes

Note 1 to entry: In the context of smart cities, the system as a whole exhibits (as the result of interactions between its elements) some emergent characteristics indispensable to achieve one or more of its stated purposes.

Note 2 to entry: In the city transport system the interactions between traffic management and emergency management, sharing information related to resource allocations, road network conditions, video surveillance imaging and control, enable the emergent characteristic of improvement in traffic congestion.

[SOURCE: ISO/IEC/IEEE 21840:2019, 3.1.8, modified – The Notes to entry have been added.]

3.11
social system
patterned series of interrelationships existing between individuals, groups, and institutions and forming a coherent whole

EXAMPLE Nuclear family units, communities, cities, nations, college campuses, corporations, and industries.

Note 1 to entry: An individual can belong to multiple social systems at once.

Note 2 to entry: The organization and definition of groups within a social system depend on various shared properties such as location, socioeconomic status, race, religion, societal function, or other distinguishable features.

[SOURCE: IEC 60050-831:–, 831-04-03]

3.12
system of systems
SOS
<systems> set of operationally and managerially independent *systems* (3.10) that are coordinated together to achieve one or more commonly stated purposes

Note 1 to entry: Each constituent system is a useful system by itself, having its own management, goals, and resources, and coordinates within the SOS to provide the unique capability of the SOS.

[SOURCE: IEC 60050-871:2018, 871-05-03, modified – The domain <systems> has been added. In the definition, "operated" has been replaced by "coordinated", "commonly" has been added, and "for a period of time" has been deleted. Note 1 to entry has been replaced by new Note 1 to entry from ISO/IEC/IEEE 24748-1:2018, 3.56, in which "but coordinates" has been replaced by "and coordinates".]

3.13
term
designation that represents a general *concept* (3.2) by linguistic means

[SOURCE: ISO 1087:2019, 3.4.2, modified – The EXAMPLE and Note 1 to entry have been deleted.]

3.14
terminology
set of designations and *concepts* (3.2) belonging to one domain or subject

[SOURCE: ISO 1087:2019, 3.1.11]

4 Foundations of concept system building for smart city systems

4.1 Methods of ISO 704:2022

An analysis of key terms relevant to ‘unit of knowledge’ and ‘characteristics’ in definitions of smart city is conducted based on understandings about ‘concept’ and ‘characteristic’ in ISO 704:2022 and ISO 1087:2019.

The relations between the ‘object’, ‘property’, and ‘characteristic’ are well described in ISO 704:2022, 5.4.1, which provides a way to identify object and its characteristics that helps define concept.

4.2 Core concepts and the characteristics of smart city by different SDOs

Based on six collected definitions of smart city, a survey was conducted to identify and investigate core concepts and their characteristics in the definitions of smart city from different SDOs during online meetings from 29 April to 14 May 2021. Eight questions, comprising seven closed questions and one open question, were designed in a questionnaire (see Annex A). The questionnaire was sent to experts from IEC SyC Smart Cities through the IEC collaboration platform and to experts of ISO/TC 268/SC 1/WG 4, ISO/IEC JTC 1/WG 11 and ITU-T SG 20 by email. 14 responses to the survey were collected and validated for the analysis.

Table 1 and Figure 1 show core concepts in definitions of smart city from different SDOs and their relationships and common characteristics.

At the high level, characteristics on smart city involves responding to stakeholder concerns and domain-specific concerns. People’s issues and concerns were represented by over 80 % to 100 % agreement from different stakeholders of different SDOs in stakeholders’ concerns. Therefore, placing a citizen-centric focus on smart city development is recommended or might focus on present generation and future generations for its citizens. Stakeholder concerns also include supplying side services to citizens from government and business agencies, especially customers.

In addition, domain concerns refer to diverse city system feature issues of city which can be divided into digital, environmental, economic, cultural and social aspects. Specifically, the digital aspect can involve information technology, digital transformation, electrotechnical systems, data and information. The environmental aspect includes two elements such as the built environment and natural environment, and social aspect refers to international standards and coordinated and reflexive system.

Means and approaches for smart city could be intermediate level to connect high level and low level. Smart city can select from a wide range of policy, leadership and technical use methods which refer to collaborative leadership, disciplines and city system, recognized metrics at society level and ICT, electrotechnical systems, use of data and information from modern technologies.

Smart object, smart status and visions and goals can be identified from definitions of smart cities. In smart object, integration of physical, digital and social systems is possibly the most important feature of smart city which could provide better understanding and benefits for decision makers, development of sustainability and community. Moreover, effective integration is also essential for smart status. Effective integration enables digitally coordinated systems as self-organizing system that accelerate improvement of services, increase pace of learning and reflexing and innovation. Finally, in terms of visions and goals of smart city, what smart city is intending to achieve is defined by improvements of targeted goals. Hence, smart city is not only intended to achieve competitiveness, stability, liveability and resilience, and repeatability and scalability, but also to enhance fundamental improvements on efficiency, concerns addressing quality of life and better city services.

Table 1 – Core concepts and the characteristics of smart city from different SDOs

Characteristics	Concepts		
	ISO	**IEC**	**ITU-T**
Characteristics in terms of stakeholder's concern about smart city	• citizen (D1, D3)	• citizen (D4, D5)	• present and future generation (D2)
Characteristics in terms of domain's concern about smart city	• built environment (D1) • natural environment (D3)	• city (D4, D5, D6) • international standards and digital transformation (D5) • electrotechnical systems and information technology (D6)	• economic, social, environmental as well as cultural aspect (D2)
Characteristics in terms of smart object of smart city	• integration of physical, digital and human systems (D1) • city (D3)	• city (D4, D5, D6)	• city (D2)
Characteristics in terms of smart status of smart city	• effective integration (D1) • increasing the pace (D3)	• improvements accelerated (D4) • self-organizing system (D5) • digital transformation as digitally coordinated systems with its own pace (D5) • improvements for services (D6)	• innovative (D2)

Characteristics	Concepts		
	ISO	IEC	ITU-T
Characteristics in terms of visions and goals of smart city (improvement of targeted goals)	• a sustainable, prosperous and inclusive future (D1) • fundamentally improving (D3) • provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability, to deliver better services and quality of life (D3)	• improvements in quality of life, services, sustainability and resilience (D4) • repeatability and scalability of digital solutions (D5) • systematically addressing concerns (D5) • city services (D6)	• improve quality of life, efficiency of urban operation and services, and competitiveness (D2)
Characteristics in terms of approaches to and means of smart city	• effective integration of physical, digital and human systems (D1) • engage society applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies (D3)	• by the effective integration of many and various types of physical, digital and social systems and the transformative use of data and technology (D4) • internationally recognized metrics (D5) • electrotechnical systems and information technology (D6)	• information and communication technologies (ICTs) and other means (D2)
NOTE D refers to definition. D1, D2, D3, etc. refer to codes of definitions of ontology in Annex B.			

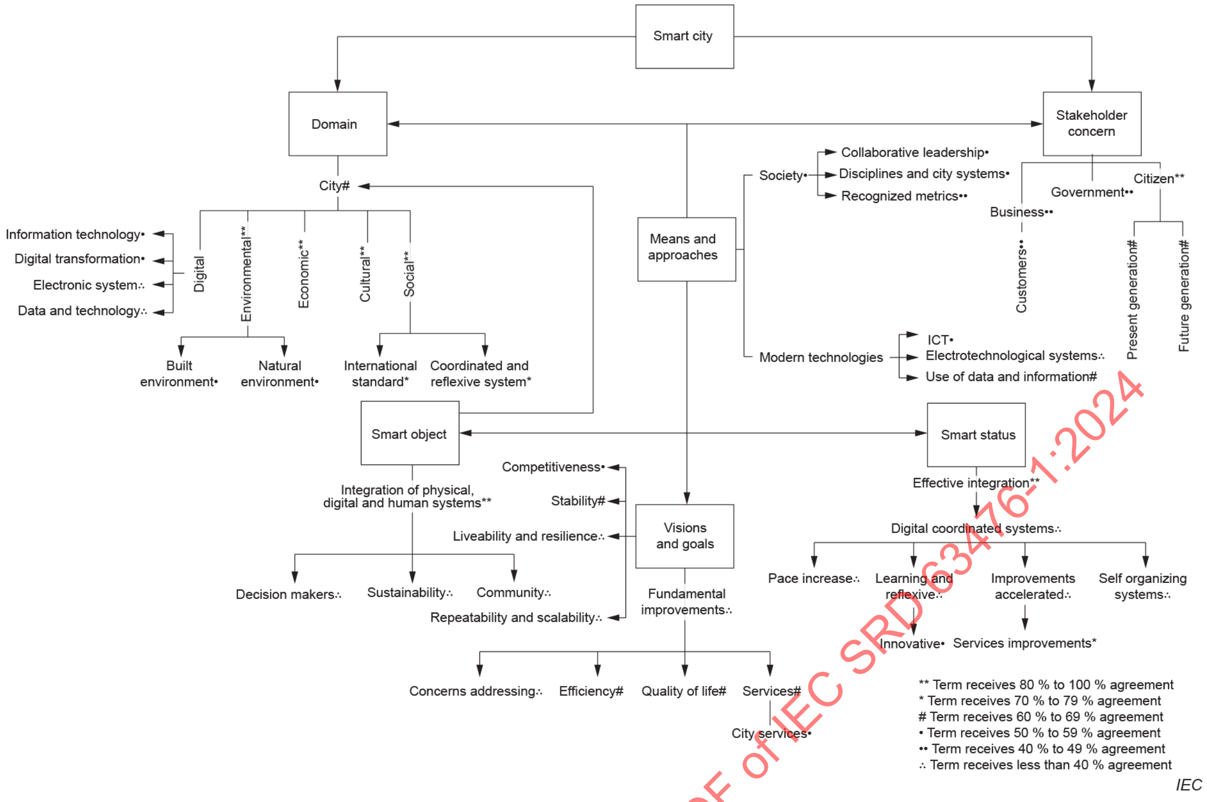


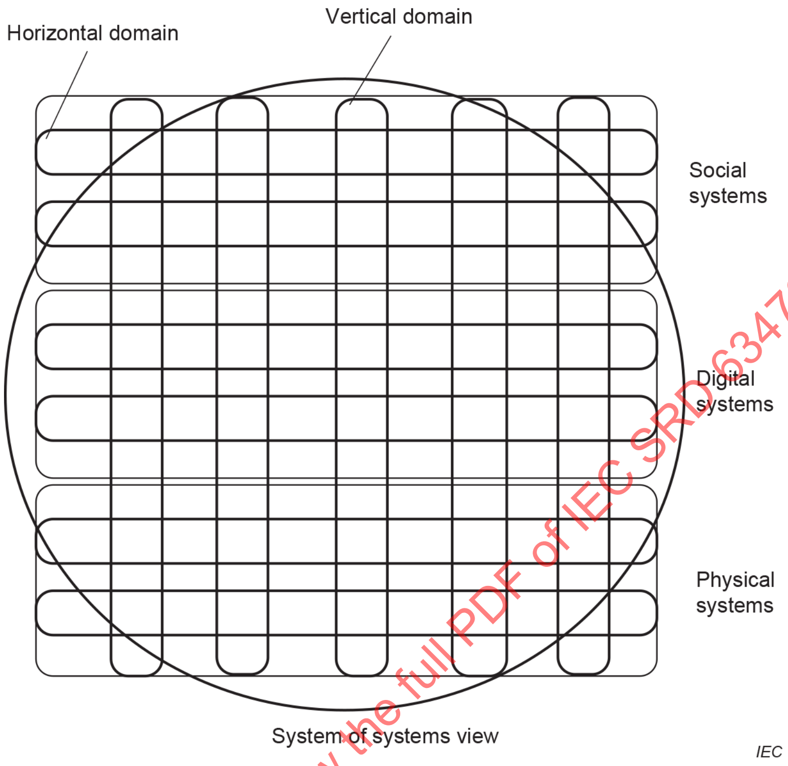
Figure 1 – An integrated concept system on smart city

4.3 System of systems view on smart city system in IEC SRD 63235:2021

Figure 2 shows a system of systems view for smart cities and smart city systems according to IEC SRD 63235:2021:

- A system of systems view (see Figure 2) considers the smart city as a complex system made up of many vertical domains such as transport, health, education, employment and so on. Each of these vertical domains is interconnected by three cross-cutting overarching and horizontal systems that include views aspects of a city centric social system, digital system and physical system of a city and system approach, which work together as a complementary whole in response to the concerns and representing the interests of different stakeholders (ISO/IEC 30182:2017, 2.14). Each of these, in turn, can be subdivided to describe in greater detail other horizontal, cross-cutting domains.
- Taking this system of systems view enables the total capability of a city-wide view to be understood from both a technical domain and a societal perspective to be enhanced to an extent that none of the constituent systems can accomplish on its own. Each constituent system is a useful system by itself with its own management, goals and resources, but when coordinated within the smart city systems (SCSs) contributes to providing a unique broader capability as a member of the SCSs.
- The social system provides a multi-dimensional governance framework (ISO/IEC TR 38502:2017, 3.1) for coordinating arrangements of strategies, policies, decision-making structures and accountabilities to manage multiple stakeholders' concerns in social space and convergence.
- A digital system provides a multi-domain architectural framework (ISO/IEC/IEEE 24748-1:2018, 3.7) for cooperating activities of conventions, principles and practices for individual domain architecture and to enable, operate and support digital transformation.
- A physical system provides a multi-layer application framework (ISO/IEC/IEEE 24765:2017, 3.177) to connect, identify and sustainably manage artefacts in each subsystem, and enable interfaces between systems in physical spaces to support all necessary interactions.

- An integration of the social, digital and physical systems with technical domains supports the convergence of multi-dimensional, multi-domain and multi-layer concerns and interests, can aid the mapping and coordination of digital systems development, design and operations, to support smart city of multiple stakeholders as well as enhancing the adaptive capacity of a city as an ecosystem to deliver a sustainable, prosperous and inclusive future for its citizens.



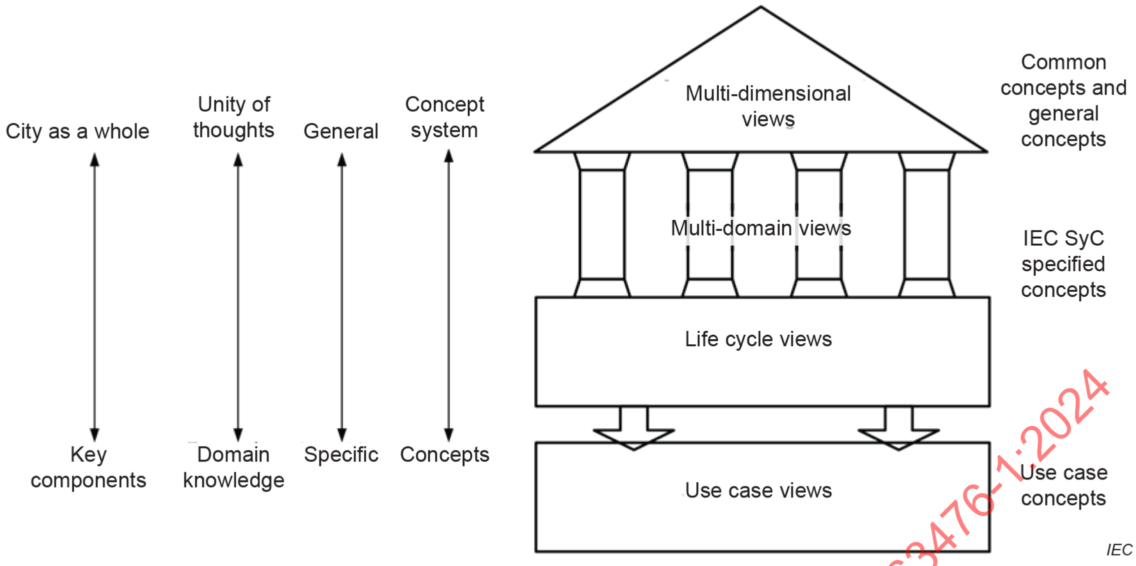
SOURCE: IEC SRD 63235:2021, Figure 1.

Figure 2 – Concept views of smart city systems

4.4 Methodology framework for smart city system concept in IEC SRD 63235:2021

Figure 3 shows a methodology framework for smart cities and smart city systems according to IEC SRD 63235:2021.

- A methodology framework refers to a way, or structure, that supports a number of different methods and languages to be used together effectively when developing a complex multi-domain level system.
- The methodology framework for a smart city system concept system refers to a system of systems way of thinking that supports multi-dimensional, multi-domain and multi-layer, life-cycle and use case analysis approaches to be used together as a complementary whole in developing a smart city system.



SOURCE: IEC SRD 63235:2021, Figure 2.

Figure 3 – A methodology framework for building smart city system concept

4.5 Descriptive framework of city in ISO 37105:2019

ISO 37105:2019 presents a descriptive framework for cities and communities. The descriptive framework categorizes the components of city into three major elemental systems that is physical structures (structure), living entities (society) and the flow of interactions between them (interactions). These elemental systems are further described by layers that capture all the activities of importance to a city. The descriptive framework can be the basis of formal ontology, or knowledge model, which can be useful for helping to plan and implement city operation solutions.

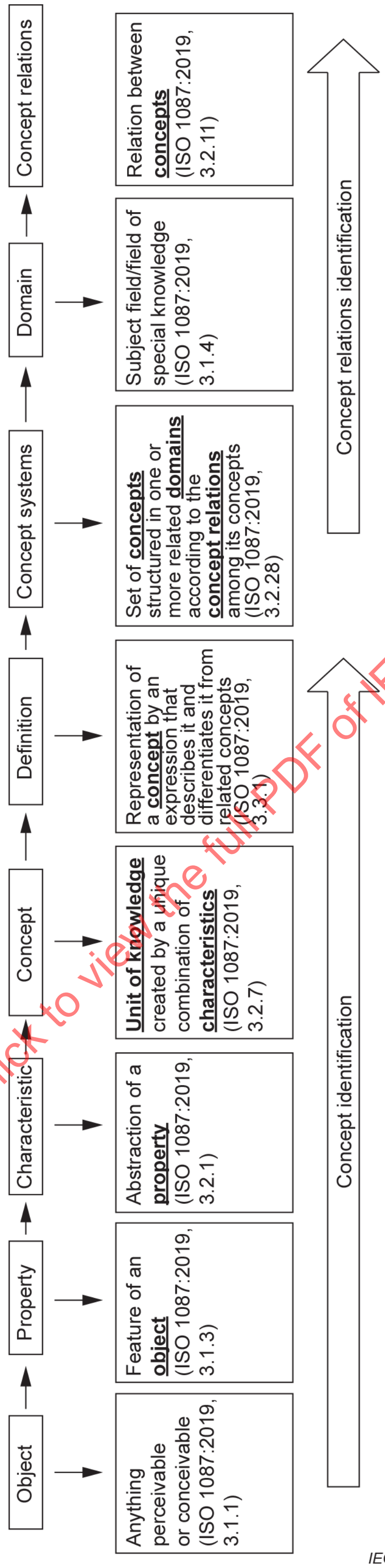
5 Existing ontology definitions from different SDOs

5.1 Existing ontology definitions from different sources

15 definitions existing in different SDOs were collected and analysed at the *Ontology for Smart Cities and Smart City Systems & Standards Workshop* held by IEC SyC Smart Cities, on 30 September 2020. Furthermore, eight additional definitions from different authoritative sources are added from this ontology workshop. In total, there are 23 definitions of ontology collected as samples for analysis (see Annex B).

5.2 Methodology for identification of concepts and concept relations

Methodology for identification of concepts is in conformity with ISO 704:2022 and the basic process for identification of concepts and its relations is shown in Figure 4.



NOTE Based on ISO 704:2022 and ISO 1087:2019.

Figure 4 – Basic process for identification of concepts and their relations

First, concepts are described to distinguish them from others and relationships are also described between them based on past domain-specific knowledge. In order to describe the concept and distinguish it from other related concepts, the definition can be used to represent the concept. After that, in order to identify the concept relation, the concept system is structured by a set of concepts which are related to domain and knowledge.

In addition, ISO 704:2022, 5.5.3 presents three types of concept relation: generic relation, partitive relation and associative relation (see Table 2).

Table 2 – Three types of concept relation

No.	Type of concept relation	Definition
1	generic relation	concept relation between a generic concept and a specific concept where the intension of the specific concept includes the intension of the generic concept plus at least one additional delimiting characteristic. Note 1 to entry: Outside the terminology community, 'type of relation' and 'is a relation' are also used instead of "generic relation". Note 2 to entry: In a generic relation, the subordinate concept is a specific concept and the superordinate concept is a generic concept. [SOURCE: ISO 1087:2019, 3.2.13]
2	partitive relation	concept relation between a comprehensive concept and a partitive concept. [SOURCE: ISO 1087:2019, 3.2.14]
3	associative relation	concept relation that exists when a thematic connection can be established between concepts by virtue of experience Note 1 to entry: Associative relations are non-hierarchical.

5.3 Concept and concept relations about ontology

Ontology concept refers to three key components: Terminology, Subclass of, and Logic (TSL).

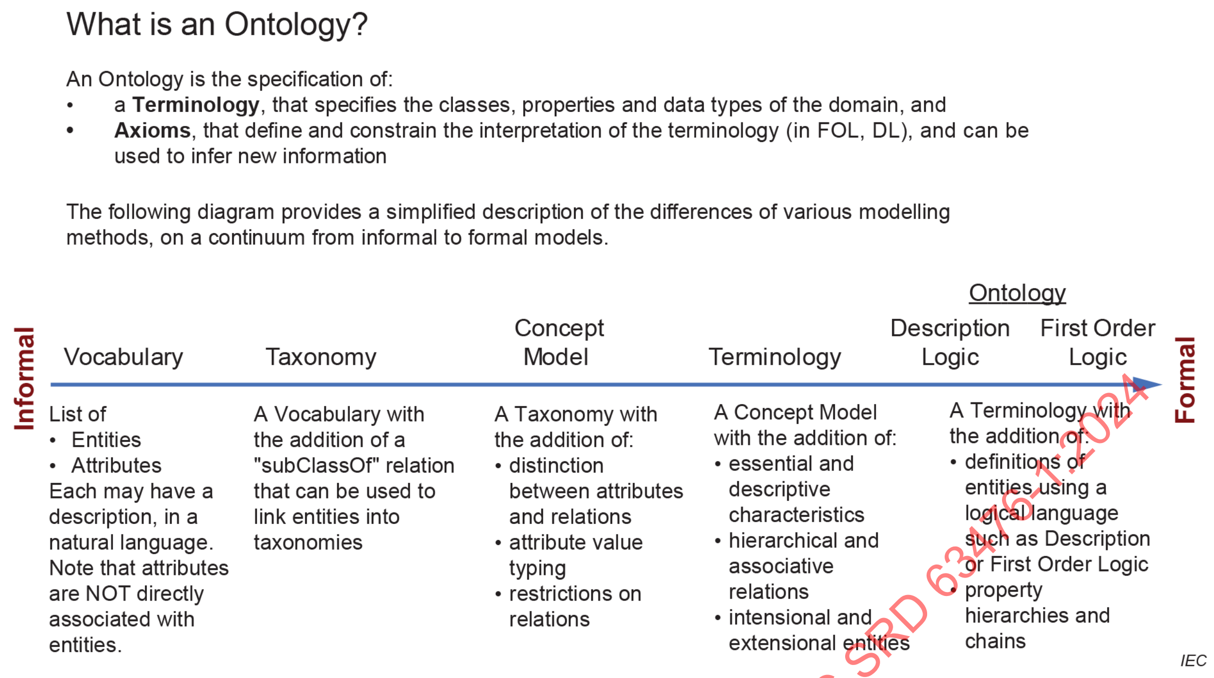
1) Terminology refers to entities with attributes and relations with optional domain and range specifications.
2) Subclass of refers to addition of taxonomic relations.
3) Logic refers to addition of definitions using a formal language; this level involves description logic that has restriction.

Therefore, six types of concept relation in existing definitions of ontology are identified, shown in Table 3 as mapping with TSL viewpoint.

Table 3 – Types of ontology concept relation

No.	Type of ontology concept relation	TSL analysis	Description of concept relation	Source (see Annex B)
1	Conceptualization of domain/rigorous conceptual schema/model	Terminology Subclass	conceptualization of a domain/rigorous conceptual schema representing the subject domain/model that represents a domain and is used to reason about the objects in that domain and the relations between them	D1_D6_D11_D16
2	A lexicon of specialized terminology	Terminology	a lexicon of specialized terminology along with some specification of the meaning of terms in the lexicon	D13_D17_D24
3	Logical structure of concepts or terms	Terminology Subclass of	Organization or logic structure of concepts for which a rational argument can be made/logical structure of the terms used to describe a domain of knowledge	D2_D5_D21
4	Formal, explicit and consensual specification of conceptualization	Terminology Subclass of	explicit and consensual specification of concept/specification of concrete or abstract things, and the relationships among them, informal, explicit specification of a shared conceptualization/formal specification of a conceptualization/an explicit specification of a conceptualization	D3_D4_D10_D14 D15_D18_D22
5	Formal representation of a set of concepts and relationships	Logic	formal representation of phenomena/formal statement of an understanding of the world/formal representation of a set of concepts within a domain and the relationships between those concepts	D7_D8_D9_D12 D19
6	Rule and knowledge with semantic connections	Terminology Subclass of	a set of knowledge terms constructed by rules with semantic connections into particular topic	D20_D23

Therefore, according to the ontology concepts and concept relations, ontology can be defined as the specification of a terminology – which specifies the classes, properties and data types of the domain – and axioms, which define and constrain the interpretation of the terminology (in first order logic or description logic) and can be used to infer new information (see Figure 5).



SOURCE: Mark Fox, 2022, 03, 23 IEC SyC Smart Cities/WG1 and ISO/IEC JTC 1/WG 11/AHG 16 Meeting.

Figure 5 – A continuum thinking about ontology standards development

Furthermore, there is a survey conducted to investigate common understandings about ontology concepts for smart cities and smart city systems in international standardization and also to find out the significance of continuum thinking for ontology standards development (see Annex C). With ontology continuum thinking:

1) There are 24 definitions of ontology in existing standards from different viewpoints, a harmonized concept system to connect and coordinate different concept relations and concerns is needed.

2) The ontology continuum thinking from informal to formal combining with human understandable and machine readable, executable and interpretable contents is needed for ontology building.

3) The survey results show the priorities of the demands for ontology standards development in the following order: terminology-ontology; use case of ontology, roadmap of ontology, ontology taxonomy and interoperability; ontology continuum framework and ontology registration.

4) The survey results indicate that given the great number of ontology standards already in existence, there is a need of gap analysis process in future ontology standards development for smart cities and smart city systems, in order to avoid overlaps and to build collaboration frameworks with generic and specific ontology in existence and build interoperability relationships with existing ontology standards. In addition, whether the existing ontology standards can be adaptable to cross-domain city-wide use or not remains to be established.

6 Existing ontology standards deliverables and activities in different SDOs

6.1 General

Currently, several SDOs have standardization activities on ontology and have published deliverables and under development deliverables about ontology. For example, ISO has seven committees and working groups that are involved in ontology standardization, including ISO/TC 46/SC 4, ISO/TC 211, ISO/IEC JTC 1/WG 11, ISO/IEC JTC 1/SC 29, ISO/IEC JTC 1/SC 32, ISO/IEC JTC 1/SC 38. IEC has one committee involving in ontology standardization, which is IEC TC 3/SC 3D. ITU-T has one committee involved in ontology standardization, which is ITU-T Study group 20. IEEE has two committees involved in ontology standardization activities including IEEE Robotics and Automation Society, IEEE Consumer Technology Society. W3C and OGC also participated in the standardization recommendation and evaluation on ontology.

6.2 Ontology-related standardization activities in ISO

6.2.1 ISO/TC 46/SC 4

ISO/TC 46/SC 4 develops ontology standards in the area of libraries, documentation and information centres, publishing, archives, records management, museum documentation, indexing and abstracting services, and information science. Table 4 lists ISO/TC 46/SC 4 ontology deliverables and their status.

Table 4 – ISO/TC 46/SC 4 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/TC 46/SC 4 Technical interoperability	ISO 21127:2014	Information and documentation – A reference ontology for the interchange of cultural heritage information	Published

6.2.2 ISO/TC 184/SC 4

ISO/TC 184/SC 4 develops ontology standards in the area of content, meaning, structure, representation and quality management of the information required to define an engineered product and its characteristics at any required level of detail at any part of its life cycle from conception through disposal, together with the interfaces required to deliver and collect the information needed to support any business or technical process or service related to that engineered product during its life cycle.

Table 5 lists ISO/TC 184/SC 4 ontology deliverables and their status.

Table 5 – ISO/TC 184/SC 4 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/TC 184/SC 4 Industrial data	ISO 13584-32:2010	Industrial automation systems and integration – Parts library – Part 32: Implementation resources: OntoML: Product ontology markup language	Published
2		ISO 13584-42:2010	Industrial automation systems and integration – Parts library – Part 42: Description methodology: Methodology for structuring parts families	Published

6.2.3 ISO/TC 211

ISO/TC 211 develops ontology standards in the area digital geographic information.

Table 6 lists ISO/TC 211 ontology deliverables and their status.

Table 6 – ISO/TC 211 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/TC 211 Geographic information/Geomatics	ISO 19150-2:2015	Geographic information – Ontology – Part 2: Rules for developing ontologies in the Web Ontology Language (OWL)	Published
2		ISO/TS 19150-1:2012	Geographic information – Ontology – Part 1: Framework	Published
3		ISO 19150-2:2015/ Amd.1:2019	Geographic information – Ontology – Part 2: Rules for developing ontologies in the Web Ontology Language (OWL) – Amendment 1	Published
4		ISO 19150-4:2019	Geographic information – Ontology – Part 4: Service ontology	Published
5		ISO 19150-6:2023	Geographic information – Ontology – Part 6: Service ontology register	Published

6.2.4 ISO/IEC JTC 1/WG 11

ISO/IEC JTC 1/WG 11 develops ontology standards and the ontology-based standards in the area of information technology for smart cities.

Table 7 lists ISO/IEC JTC 1/WG 11 ontology deliverables and their status.

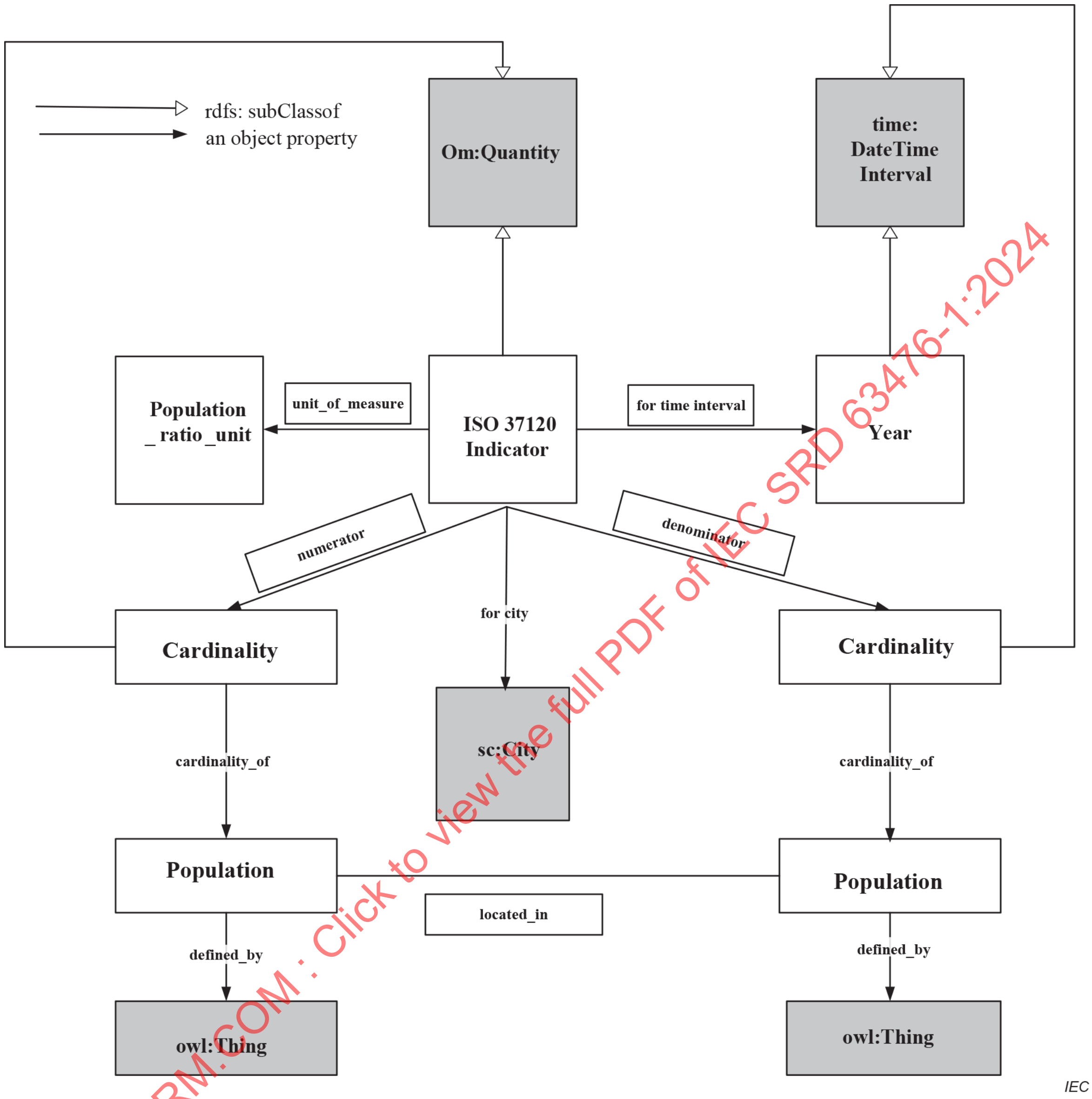
Table 7 – ISO/IEC JTC 1/WG 11 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/IEC JTC1/WG11 Smart city	ISO/IEC 21972:2020	Information technology – Upper level ontology for smart city indicators	Published
2		ISO/IEC 5087-1:2023	Information technology – City data model – Part 1: Foundation level concepts	Published
3		ISO/IEC 5087-2	Information technology – City data model – Part 2: City level concepts	Under development (DIS)
4		ISO/IEC 5087-3	Information technology – City data model – Part 3: Service level concepts – Transportation planning	Under development (AWI)
5		ISO/IEC 30182:2017	Smart city concept model – Guidance for establishing a model for data interoperability	Published

ISO/IEC JTC 1/WG 11 is a professional and important SDO which concentrates on smart city standardization. It not only presents a great number of standards related to smart city, but also provides effective and efficient methodologies of smart city standardization with ontology building for a number of liaisons who are involved in smart city standardization. For instance, the ISO/IEC 5087 series provides a city data model with three level ontologies for smart city data process, management and usage.

The works of ontology building and application of ISO/IEC JTC 1/WG 11 are in two areas in terms of ISO/IEC 21972 and the ISO/IEC 5087 series.

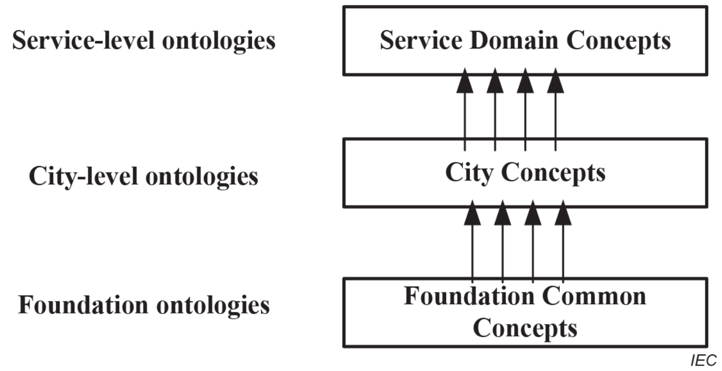
In ISO/IEC 21972:2020, there are several general indicators presented by OWL languages. It is also constructed as a framework to demonstrate how the certain indicators are categorized (see Figure 6).



SOURCE: ISO/IEC 21972:2020.

Figure 6 – Framework to demonstrate certain indicators of ontology work

The ISO/IEC 5087 series consists of three levels of ontologies: foundation ontologies, city-level ontologies and service-level ontologies. Figure 7 identifies the three levels of the series of the standards.



SOURCE: ISO/IEC 5087-1.

Figure 7 – Framework of the ISO/IEC 5087 series formed by three levels of ontologies

1) Foundational ontologies deal with foundational and common concepts. Foundational and common level refers to units of measure, resource, activity, recuring event, agent, agreement, location, time, change, mereology, organisation structure, provenance. Foundation level spans very general concepts, upon which other levels are based.
2) City-level ontologies deal with city concepts at the top. Based on city data model perspective, city-level refers to a number of elements such as sensors, indicator, land use, household, city service, law, building, contract, person, organisation, city resident, city, infrastructure and transportation infrastructure. City level spans concepts that are general to cities and spans all services. City level can be read and updated by multiple services.
3) Service-level ontologies deal with service domain concepts. Service level is regarded as top-level ontologies which could be a part of standards dealing with different services. Service level refers to transportation network, parking, trip, public transport and vehicle. Service level spans concepts commonly associated with a particular service but still shared with other services. Service level can be read by multiple services, but updated only by one service.

Therefore, the ISO/IEC 5087 series consists of the three levels (see Figure 8):

- ISO/IEC 5087-1: *Information technology – City data model – Part 1: Foundation level concepts*
- ISO/IEC 5087-2: *Information technology – City data model – Part 2: City level concepts* (in CD stage)
- ISO/IEC 5087-3: *Information technology – City data model – Part 3: Service level concepts – Transportation planning* (working draft stage)

A further part is planned:

- ISO/IEC 5087-4: *Information technology – City data model – Part 4: Service level concepts for public health emergencies* (potential project)

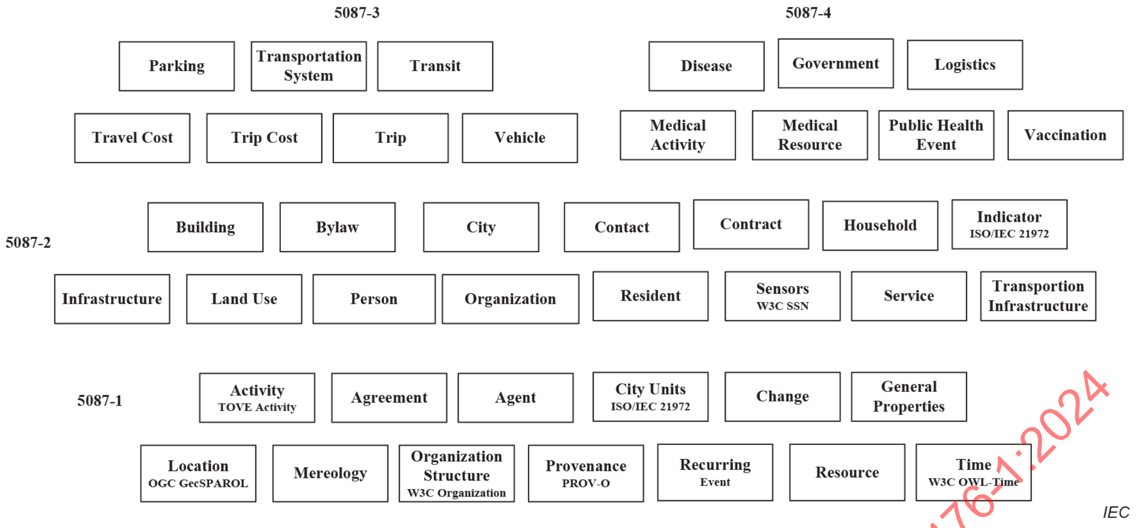


Figure 8 – Example concepts for the three levels of ontologies according to the ISO/IEC 5087 series

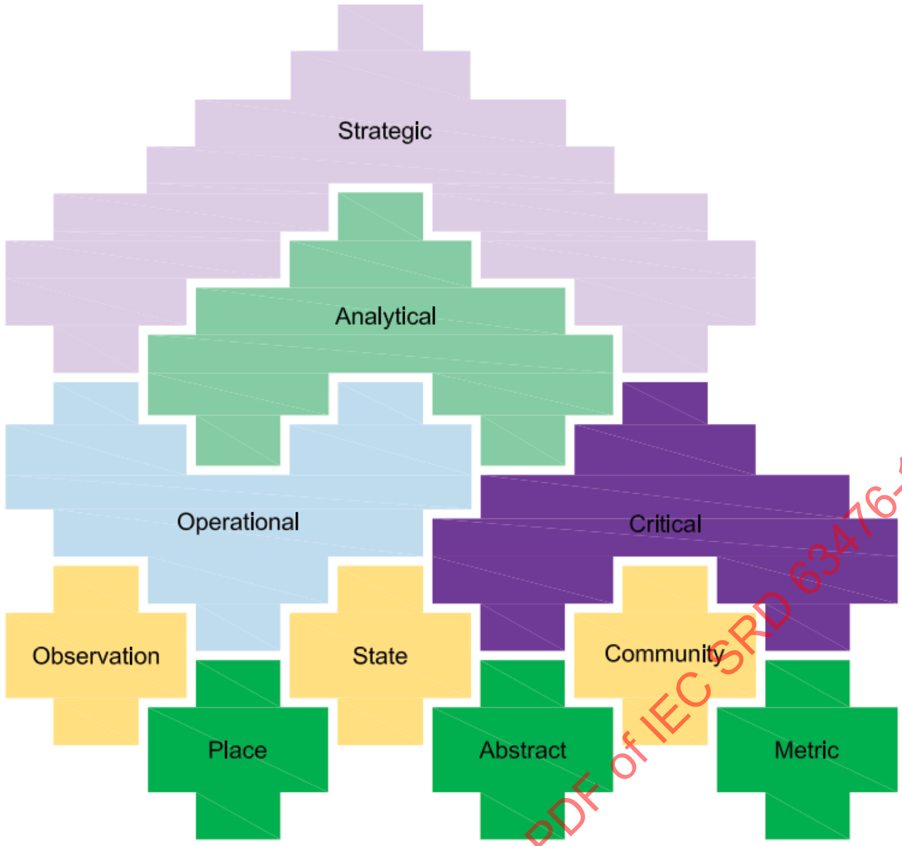
IEC SyC Smart Cities WG 1 and ISO/IEC JTC 1/WG 11 shared same vocabulary in terms of city, service and organization. However, there are different definitions for these terms, which can cause problems in communication and connectivity of data, information and knowledge. There is demand for collaboration and harmonization of terminology-ontology from different SDOs.

6.2.5 ISO/IEC 30182:2017, Smart city concept model (SCCM) for data interoperability

A smart city concept model (SCCM) that defines an overarching framework of concepts and relationships is given in ISO/IEC 30182:2017, which aligns ontologies to discover where data from different sectors are about the same thing or are related in a useful way. Ontology refers to formal representation of phenomena of a universe with an underlying vocabulary including definitions and axioms that make the intended meaning explicit and describe phenomena and their interrelationships (ISO /IEC 30182:2017, 2.11).

Figure 9 illustrates the four levels of insight identified as present in a city. Four key types of insight have been assumed to be required when sharing data in a city.

- Strategic insight – an overarching approach that examines outcomes related to strategic objectives, decisions and plans.
- Analytical insight – the exploration of the data ecosystem to determine patterns, correlations and predictions. This allows the development or innovation of systems or services, impact assessment of proposed changes to systems or services, or the evidencing of challenges and opportunities for the city.
- Operational insight – which examines characteristics of things such as buildings, communities and organizations, using data to evidence and improve their value for the city.
- Critical insight – the real-time monitoring of incidents and current cases, involving all relevant organizations from across sectors, who work together to achieve the desired outcome or response.



SOURCE: ISO/IEC 30182:2017

Figure 9 – Smart city levels of insight

6.2.6 ISO/IEC JTC 1/SC 29

ISO/IEC JTC 1/SC 29 develops ontology standards in the following areas:

- efficient coding of digital representations of images, audio and moving pictures;
- conventional (natural, computer-generated and immersive) images, moving pictures and audio;
- invisible light and other sensory (such as medical and satellite) images;
- static and dynamic graphic objects;
- efficient coding of other digital information, including:
  - multimedia, environment and user related metadata;
  - sensor and actuator information related to audio/visual information;
  - other digital data in agreement with the relevant committee, such as genomics;
- digital information support, including:
  - synchronization, presentation, storage and transport of single or combinations of media;
  - media security and privacy management;
  - quality of experience evaluation and system performance metrics.

Table 8 lists ISO/IEC JTC 1/SC 29 ontology deliverables and their status.

Table 8 – ISO/IEC JTC 1/SC 29 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/IEC JTC 1/SC 29 Coding of audio, picture, multimedia and hypermedia information	ISO/IEC 21000-8: 2008/Amd.2:2011	Reference software for Media Value Chain Ontology (MVCO)	Published
2		ISO/IEC 21000-8: 2008/Amd.3:2015	Contract Expression Language (CEL) and Media Contract Ontology (MCO) Reference Software	Published
3		ISO/IEC 21000-8: 2008/Amd.4:2018	Media Value Chain Ontology extensions on time-segments and multi-track audio	Published
4		ISO/IEC 21000-19: 2010	Information technology – Multimedia framework (MPEG-21) – Part 19: Media Value Chain Ontology	Published
5		ISO/IEC 21000-21: 2017	Information technology – Multimedia framework (MPEG-21) – Part 21: Media contract ontology	Published
6		ISO/IEC 24800-2: 2011	Information technology – JPSearch – Part 2: Registration, identification and management of schema and ontology	Published

6.2.7 ISO/IEC JTC 1/SC 32

ISO/IEC JTC 1/SC 32 develops ontology standards in the area of data management within and among local and distributed information systems environments. SC 32 provides enabling technologies to promote harmonization of data management facilities across sector-specific areas. Specifically, SC 32 standards include:

- reference models and frameworks for the coordination of existing and emerging standards;
- definition of data domains, data types, and data structures, and their associated semantics;
- languages, services, and protocols for persistent storage, concurrent access, concurrent update, and interchange of data;
- methods, languages, services, and protocols to structure, organize, and register metadata and other information resources associated with sharing and interoperability, including electronic commerce.

Table 9 lists ISO/IEC JTC 1/SC 32 ontology deliverables and their status.

Table 9 – ISO/IEC JTC 1/SC 32 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/IEC JTC 1/SC 32 Data management and exchange	ISO/IEC TR 20943-6:2013	Information technology – Procedures for achieving metadata registry content consistency – Part 6: Framework for generating ontologies	Published
2		ISO/IEC 15944-4:2015	Information technology – Business Operational View – Part 4: Business transaction scenarios – Accounting and economic ontology	Published
3		ISO/IEC 19763-3:2020	Information technology – Metamodel framework for interoperability (MFI) – Part 3: Metamodel for ontology registration	Published
4		ISO/IEC 21838-1:2021	Information technology – Top-level ontologies (TLO) – Part 1: Requirements	Published
5		ISO/IEC 21838-2:2021	Information technology – Top-level ontologies (TLO) – Part 2: Basic Formal Ontology (BFO)	Published
6		ISO/IEC 21838-3	Information technology – Top-level ontologies (TLO) – Part 3: Descriptive ontology for linguistic and cognitive engineering (DOLCE)	Under development (DIS)
7		ISO/IEC 21838-4	Information technology – Top-level ontologies (TLO) – Part 4: TUpper	Under development (DIS)

6.2.8 ISO/IEC JTC 1/SC 38

ISO/IEC JTC 1/SC 38 develops ontology standards in the areas of cloud computing and distributed platforms including:

- foundational concepts and technologies,
- operational issues, and
- interactions among cloud computing systems and with other distributed systems.

SC 38 serves as the focus, proponent, and systems integration entity on cloud computing, distributed platforms, and the application of these technologies.

Table 10 lists ISO/IEC JTC 1/SC 38 ontology deliverables and their status.

Table 10 – ISO/IEC JTC 1/SC 38 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/IEC JTC 1/SC 38 Cloud computing and distributed platforms	ISO/IEC 18384-3:2016	Information technology – Reference Architecture for Service Oriented Architecture (SOA RA) – Part 3: Service Oriented Architecture ontology	Published

6.2.9 ISO/IEC JTC 1/SC 41

ISO/IEC JTC 1/SC 41 develops ontology standards in the areas of interoperability for IoT systems including:

- requirements of the core ontologies for interoperability;
- best practices and guidance on how to use ontologies and to develop domain-specific applications, including the need to allow for extensibility and connection to external ontologies;
- cross-domain specification and formalization of ontologies to provide harmonized utilization of existing ontologies;
- relevant IoT ontologies along with comparative study of the characteristics and approaches in terms of modularity, extensibility, reusability, scalability, interoperability with upper ontologies, and so on;
- use cases and service scenarios that exhibit necessities and requirements of interoperability.

SC 41 serves as the focus and proponent for JTC 1's standardization programme on the Internet of Things and Digital Twin, including their related technologies.

Table 11 lists ISO/IEC JTC 1/SC 41 ontology deliverables and their status.

Table 11 – ISO/IEC JTC 1/SC 41 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/IEC JTC 1/SC 41 Internet of Things and Digital Twin	ISO/IEC 21823-3:2021	Internet of Things (IoT) – Interoperability for IoT systems – Part 3: Semantic interoperability	Published

6.2.10 ISO/IEC JTC 1/SC 42

ISO/IEC JTC 1/SC 42 develops ontology standards in the areas of artificial intelligence including:

- important elements of knowledge engineering and the relationship between knowledge engineering and artificial intelligence system;
- knowledge engineering stakeholders and concerns, including safety and security, reliability, availability, construction quality, responsibility and bias reduction;
- key technologies of knowledge engineering and computational methods, including knowledge representation, knowledge modelling, knowledge acquisition, knowledge storage, knowledge fusion, knowledge computing, knowledge visualization, knowledge maintenance and knowledge exchange;
- enabling technologies and digital infrastructure of knowledge engineering.

SC 42 serves as the focus and proponent for JTC 1's standardization programme on artificial intelligence.

Table 12 lists ISO/IEC JTC 1/SC 42 ontology deliverables and their status.

Table 12 – ISO/IEC JTC 1/SC 42 ontology deliverables

No.	Committee	Reference	Title	Status
1	ISO/IEC JTC 1/SC 42 Artificial intelligence	WG5 Computational approaches and computational characteristics of AI systems	Ontologies, Knowledge Engineering, and Representation (OKER) Report	Published
2		ISO/IEC 5392	Information technology – Artificial intelligence – Reference architecture of knowledge engineering	Under development (DIS)

6.3 Ontology-related standardization activities in IEC

6.3.1 IEC SyC Smart Energy

IEC SyC Smart Energy is developing a guide and plan to develop a smart energy ontology and other domain-based ontologies within smart energy through interoperability (see Table 13). This refers to:

- inventory and assessment of existing ontologies for the purpose of smart energy applications;
- reuse of existing ontologies in the smart energy domain;
- evaluation of developed smart energy ontologies;
- cross domain interoperability support and mapping to other ontologies;
- guide and development plan for smart energy ontology development and usage included;
- definition of smart energy ontology life-cycle process;
- guidance for smart energy ontology use cases;
- definition of a governance process;

Domain-based ontologies have been developed for interoperability in a specific domain but the interaction of all equivalent objects in different ontologies has not been defined. IEC SRD 63417 helps users and ontology developers to conclude the complete relationship in different domains and different ontologies for the purpose of smart energy applications.

Table 13 – IEC SyC Smart Energy ontology deliverables

No.	Committee	Reference	Title	Status
1	IEC SyC Smart Energy	IEC SRD 63417	Guide and plan to develop smart energy ontologies	Under development (CD)
NOTE IEC SRD 63417 is based on IEC MSB White Paper: “Semantic interoperability: challenges in the digital transformation age” (ISBN 978-2-8322-7321-0).				

6.3.2 IEC TC 3/SC 3D

IEC TC 3/SC 3D develops ontology-based standards in the area of representation of technical information along the life cycle of a product including service, device, system or plant, covering rules, principles and methods associated with the machine sensible representation of the technical information (see Table 14). This refers to:

- definition, structuring and identification of classes and properties;
- structural design of product data dictionaries and ontologies;
- consistent methodology for the purpose of structuring technical information and its exchange;
- support for the design of classes and properties in all domains and industries and their publication in IEC Common Data Dictionary (IEC CDD);
- maintenance and quality control of the IEC Common Data Dictionary (IEC CDD);
- supporting semantic interoperability.

Table 14 – IEC TC 3/SC 3D ontology deliverables

No	Committee	Reference	Title	Status
1	IEC TC 3/SC 3D – Classes, Properties and Identification of Products – Common Data Dictionary (CDD)	IEC 61360-1: 2017	Standard data element types with associated classification scheme – Part 1: Definitions – Principles and methods	Published
2		IEC 61360-2: 2012	Standard data element types with associated classification scheme for electric components – Part 2: EXPRESS dictionary schema	Published
3		IEC 61360-4 ED0	Maintenance of IEC CDD through the corresponding database	Database standard VT IEC CDD
4		IEC 61360-6: 2016	Standard data element types with associated classification scheme for electric components – Part 6: IEC Common Data Dictionary (IEC CDD) quality guidelines	Published
5		IEC 62656-1: 2014	Standardized product ontology register and transfer by spreadsheets – Part 1: Logical structure for data parcels	Published
6		IEC TS 62656-2:2013	Standardized product ontology register and transfer by spreadsheets – Part 2: Application guide for use with the IEC common data dictionary (CDD)	Published
7		IEC 62656-3: 2015	Standardized product ontology register and transfer by spreadsheets – Part 3: Interface for Common Information Model	Published
8		IEC 62656-5: 2017	Standardized product ontology register and transfer by spreadsheets – Part 5: Interface for activity description	Published
9		IEC 62656-8: 2020	Standardized product ontology register and transfer by data parcels – Part 8: Web service interface for data parcels	Published

6.3.3 IEC SyC Smart Cities

6.3.3.1 SCRAM

According to IEC SRD 63188, the Smart Cities Reference Architecture Methodology (SCRAM) is an adaptation of the summary of the IEC System Resource Group (SRG) work on systems approach for the smart cities system domain.

The SCRAM is a set of SCRAM viewpoints, SCRAM model-types and SCRAM artefacts-types. Each SCRAM viewpoint comprises one or more SCRAM model-types. It is likely that any SCRAM model-type will be in one or more SCRAM viewpoints. Any SCRAM model-type is a relationship between various SCRAM model-types and SCRAM artefact-types. Table 15 lists IEC SyC Smart Cities SCRAM deliverables and their status.

Table 15 – IEC SyC Smart Cities SCRAM deliverables

No	Committee	Reference	Title	Status
1	IEC SyC Smart Cities	IEC SRD 63188:2022	Smart Cities Reference Architecture Methodology	Published

6.3.3.2 IEC SyC Smart Cities and SCRAM

1) Scope

The SCRAM has a viewpoint JUSTIFICATION. The JUSTIFICATION viewpoint comprises text and keywords, nomenclatures or dependency matrixes and problem space description nomenclatures are part of the nomenclatures.

One of the problem space description nomenclatures of the JUSTIFICATION viewpoint is considered as the scope of IEC SyC Smart Cities: to foster the development of standards in the field of electrotechnology to help with the integration, interoperability and effectiveness of city systems.

2) Strategic goals

The strategic goals nomenclatures of the JUSTIFICATION viewpoint present IEC SyC Smart Cities' strategic goals to some extent:

– commonly agreed multidisciplinary concept system to enable all the stakeholders to use the same "language";

NOTE 1 Such a concept system is developed in separate documents of IEC SyC Smart Cities.

– map of existing standards to the SCRA to quickly navigate to find standards pertinent for city systems;

NOTE 2 Such mapping is developed in separate documents of IEC SyC Smart Cities.

– map of potential standards to the SCRA to list standards to be developed for city systems.

NOTE 3 Such mapping is developed in separate documents of IEC SyC Smart Cities.

3) Ontology

An ontology is a formally presented commonly agreed concept system. According to the strategic goals of the JUSTIFICATION viewpoint of the SCRAM, to generate smart cities ontologies is a goal of IEC SyC Smart Cities and IEC SyC Smart Cities WG 1 aims to generate smart cities ontologies.

In terms of the relationships between the SCRAM and IEC SyC Smart Cities, the SCRAM provides a generic methodology for the development of SCRA and provides an upper-level template for the development of smart cities ontologies.

To be specific:

For the JUSTIFICATION viewpoint of SCRAM, its

- problem space description dimension helps identify the scope of IEC smart cities, which is the upper-level scope of the smart cities ontology scope;
- strategic goals include the development of smart cities ontologies;
- stakeholders are consistent with the stakeholders for smart cities ontologies.

For the standards viewpoint of SCRAM, it specifies existing and future standards applicable for the system-solution. This viewpoint comprises existing and potential standards nomenclature. The two main clauses of this Part 1 of the smart city system ontology describe existing standards on ontology (Clause 6) and gaps in ontology standards (Clause 7) for smart cities and smart city systems. Therefore, the standards viewpoint gives a methodology basis for the gap analysis.

Some viewpoints of SCRAM have typical model-types related to terminologies, which are:

- Value viewpoint –> Problem space terminology
- Big picture viewpoint –> Solution space terminology
- Platform engineering viewpoint –> Platform terminology
- Platform component engineering viewpoint –> Platform component terminology
- Solution engineering viewpoint –> Solution terminology

The SCRAM identifies these five main aspects where terminologies are important and for smart cities ontology building, we can refer to these five aspects.

The SCRAM describes the coverage and aspects of smart cities ontologies, and the smart cities ontologies could be used with SCRAM to generate general smart cities views, models, and artefacts or specific views, models, and artefacts for any specific smart cities.

6.4 Ontology-related standardization activities in ITU-T

6.4.1 ITU-T Study Group 20

ITU-T Study Group 20 (SG20) develops ontology-related standards in the area of the Internet of Things (IoT) and its applications, and smart cities and communities (SC&C). This includes oneM2M base ontology (see Table 16).

Table 16 – ITU-T Study Group 20 ontology deliverables

No	Committee	Reference	Title	Status
1	ITU-T Study Group 20 Internet of things (IoT) and smart cities and communities (SC&C)	Rec. ITU-T Y.4500.12(03/2018)	oneM2M base ontology	Published
2	ITU-T Study Group 20 Internet of things (IoT) and smart cities and communities (SC&C)	Rec. ITU-T Y. 4484 (08/2022)	Framework to support Web of Objects ontology based semantic data interoperability of e-health services	Draft

6.5 Ontology-related standardization activities in IEEE

6.5.1 IEEE Robotics and Automation Society

IEEE Robotics and Automation Society develops ontology standards to foster the development and facilitate the exchange of scientific and technological knowledge in Robotics and Automation (see Table 17).

Table 17 – IEEE Robotics and Automation Society ontology deliverables

No	Committee	Reference	Title	Status
1	IEEE Robotics and Automation Society	IEEE 1872-2015	Standard for Ontologies for Robotics and Automation	Published
2		IEEE P1872.1:2017	Robot Task Representation.	Published
3		IEEE 1872.2:2021	IEEE Approved Draft Standard for Autonomous Robotics (AuR) Ontology.	Published
4		IEEE P1872.3	Standard for Ontology Reasoning on Multiple Robots	Under development

6.5.2 IEEE Consumer Technology Society

IEEE Consumer Technology Society develops ontology standards for the global technical exchange of engineering and scientific information on advancements in consumer technologies (see Table 18).

Table 18 – IEEE Consumer Technology Society ontology deliverables

No	Committee	Reference	Title	Status
1	IEEE Consumer Technology Society	IEEE P2896:2020	Standard for Open Data: Open Data Ontology	Published

In addition to the above domain-specific ontology standardization activities, IEEE has other ontologies standardization activities, such as web methodologies, best practices and ontology engineering applied to Internet of Things.

6.6 Ontology-related standardization activities in W3C OGC

W3C develops ontology-related standards in the area of Open Web Platform for application development that has the unprecedented potential to enable developers to build rich interactive experiences, powered by vast data stores, that are available on any device (see Table 19). Although the boundaries of the platform continue to evolve, industry leaders speak nearly in unison about how HTML5 will be the cornerstone for this platform. But the full strength of the platform relies on many more technologies that W3C and its partners are creating, including CSS, SVG, WOFF, the Semantic Web stack, XML, and a variety of APIs. W3C develops these technical specifications and guidelines through a process designed to maximize consensus about the content of a technical report, to ensure high technical and editorial quality, and to earn endorsement by W3C and the broader community.

Table 19 – W3C OGC ontology deliverables

No	Group/Sub group	Reference	Title	Status
1			VSSo: Vehicle Signal Specification Ontology	Working draft
2			VSSo Core: Vehicle Signal Specification Core Ontology	Working draft
3			W3C Workshop on smart cities 2021 Useful reference: https://www.w3.org/2021/06/smartcities-workshop/report.html Ontology related topic "Many of the possible technical components are already done by W3C, e.g. RDF, OWL, SHACL, ODRL and WoT. On the other hand, actual vocabulary definition is done outside W3C, e.g. SAREF ontology by ETSI. So work should be done with those related SDOs to see how to integrate necessary components for Web-based Smart Cities."	Working draft
4			Thing Description (TD) Ontology	Working draft
5	Spatial Data on the Web Interest Group	OGC 20-023	Extensions to the OWL-Time Ontology – entity relations	Interest Group Note
6	Spatial Data on the Web Interest Group	OGC 20-022	Extensions to the OWL-Time Ontology – temporal aggregates	Interest Group Note
7	Spatial Data on the Web Interest Group	OGC 16-071r3	Time Ontology in OWL	Candidate Recommendation
8	Spatial Data on the Web Interest Group		Extensions to the Semantic Sensor Network Ontology	Working draft
9	Spatial Data on the Web Interest Group	OGC 16-079	Semantic Sensor Network Ontology	Recommendation
10	Semantic Web Interest Group		vCard Ontology – for describing People and Organizations	Interest Group Note
11	Government Linked Data Working Group		The Organization Ontology	Recommendation
12	Provenance Working Group		PROV-O: The PROV Ontology	Recommendation
13	OWL Working Group		OWL 2 Web Ontology Language Document Overview (Second Edition)	Recommendation
14	OWL Working Group		OWL 2 Web Ontology Language Direct Semantics (Second Edition)	Recommendation
15	OWL Working Group		OWL 2 Web Ontology Language Primer (Second Edition)	Recommendation
16	OWL Working Group		OWL 2 Web Ontology Language Structural Specification and Functional-Style Syntax (Second Edition)	Recommendation
17	OWL Working Group		OWL 2 Web Ontology Language Profiles (Second Edition)	Recommendation
18	OWL Working Group		OWL 2 Web Ontology Language Conformance (Second Edition)	Recommendation

No	Group/Sub group	Reference	Title	Status
19	OWL Working Group		OWL 2 Web Ontology Language Data Range Extension: Linear Equations (Second Edition)	Recommendation
20	OWL Working Group		OWL 2 Web Ontology Language Quick Reference Guide (Second Edition)	Recommendation
21	OWL Working Group		OWL 2 Web Ontology Language Manchester Syntax (Second Edition)	Recommendation
22	OWL Working Group		OWL 2 Web Ontology Language RDF-Based Semantics (Second Edition)	Recommendation
23	OWL Working Group		OWL 2 Web Ontology Language XML Serialization (Second Edition)	Recommendation
24	OWL Working Group		OWL 2 Web Ontology Language Mapping to RDF Graphs (Second Edition)	Recommendation
25	OWL Working Group		OWL 2 Web Ontology Language New Features and Rationale (Second Edition)	Recommendation
26	Media Annotations Working Group		Ontology for Media Resources 1.0	Recommendation
27	Semantic Web in Health Care and Life Sciences Interest Group (HCLS)		Ontology of Rhetorical Blocks (ORB)	Interest Group Note
28	Media Annotations Working Group		Use Cases and Requirements for Ontology and API for Media Resource 1.0	Working Draft
29	Semantic Web in Health Care and Life Sciences Interest Group (HCLS)		Semantic Web Applications in Neuromedicine (SWAN) Ontology	Interest Group Note
30	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language Semantics and Abstract Syntax	Recommendation
31	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language Reference	Recommendation
32	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language Test Cases	Recommendation
33	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language Use Cases and Requirements	Recommendation
34	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language Overview	Recommendation
35	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language Guide	Recommendation

No	Group/Sub group	Reference	Title	Status
36	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language Parsing OWL in RDF/XML	Recommendation
37	Web Ontology Working Group part of W3C Semantic Web Activity		OWL Web Ontology Language XML Presentation Syntax	Recommendation
38	W3C Workshop on smart cities 2021		W3C Workshop on Smart Cities Report	Published

6.7 Ontology-related standardization activities in ETSI SmartM2M

ETSI SmartM2M develops ontology-related standards in the area of ETSI SmartM2M SAREF City (see Table 20). The document is a technical specification of SAREF4CITY, an extension of SAREF for the Smart Cities domain. This extension has been created by investigating resources from potential stakeholders of the ontology, such as standardization bodies, associations, IoT platforms and European projects and initiatives. In addition, the use cases were also taken into account, namely:

- Use case 1: eHealth and Smart Parking;
- Use case 2: Air Quality Monitoring and Mobility;
- Use case 3: Street Lighting, Air Quality Monitoring and Mobility.

Table 20 – ETSI SmartM2M ontology deliverables

No	Group/Sub group	Reference	Title	Status
1	ETSI	ETSI TS 103 410-4 V1.1.2 (2020-05)	ETSI SmartM2M SAREF City	Published

6.8 Ontology related standardization activities elsewhere

There are many standardization activities elsewhere. Table 21 gives some examples.

Table 21 – Ontology deliverables elsewhere

No	Group/Sub group	Reference	Title	Status
1	IERC Cluster Interoperability Best Practices and Recommendations (IERC AC4)		IoT Semantic Interoperability: Research Challenges, Best Practices, Recommendations and Next Steps. M. Serrano, P. Barnaghi, F. Carrez, P. Cousin, O. Vermesan, P. Friess	Published
2			Semantic web methodologies, best practices and ontology engineering applied to Internet of Things. Amelie Gyrard, Martin Serrano, Ghislain Atemezing. IEEE World Forum on Internet of Things (WF-IoT 2015).	Published
3	Alliance for Internet of Things Innovation (AIOTI)	White paper	AIOTI Ontology Landscape	Published
4		White paper	Semantic IoT Solutions – A Developer Perspective	Published
5		White paper	Towards semantic interoperability standards based on ontologies	Published

6.9 Types of ontology standardization issues and concerns

There is a growing recognition that ontological principles and concepts need not be restricted to the traditional domains of knowledge inquiry, and can be fruitfully applied and developed further in various fields within the broader information systems area, especially in the field of standardization work, including the establishment of smart city concept model for data interoperability and portability and the improvement of semantic interoperability.

There are 12 aspects of ontology issues and concerns synthesized from the Virtual Seminar Workshop of ontology held from 22 to 23 September 2022.

1) Produce semantic web compliant artifacts of standards in an automated way (UML to OWL); content of the standards as semantic web object; consolidate exposure of ISO/TC 211 assets to the web, these include: content (objects, codelists, ...), requirements, recommendations, permissions, ontologies, XML encodings; semantic web alignment, ontology alignment, knowledge representation alignment. The collaboration concerns are towards geographic domain knowledge web access.
2) Information modelling and information ontology, knowledge continuum, UML conceptual models, UML knowledge models and ontologies, domain ontology register, registry and service ontology register, registry with geographic features. The collaboration concerns include framework, rules, methodologies, accessible, interpretable, reusable ontologies, use case, case studies, global solutions.
3) Identify common elements through common ontologies, use Metamodel for Ontology Registration and Standardization and interoperable access. The collaboration concerns include: step by step approach to standards collaboration, develop an integrated conceptual framework to clarify the relationship among various domain-specific standards and position them to provide a well-harmonized information standard infrastructure for cross-domain interoperability, cooperation on use cases and building shared information models, meta-model and ontology repository.
4) Design and deployment of shareable and reusable ontologies, different ontology representation languages and logics, insufficient axiomatizations of ontologies, inability to compare ontologies. The collaboration concerns include: convergence and relationships of multiple and different ontologies, ontologies support shareability and reusability, better foundation for evaluating consistency and conformance with standards, criteria for top-level or general level, generic class ontologies.
5) Ontology-based data modelling methodology and its applications in industries, semantic interoperability, common data dictionary, also called domain ontology and the contributions to machine-interoperable standards, digital transformation, digital representation of and interoperability issues in Industry 4.0. The collaboration concerns include SMART standard, different stakeholders can share interoperable data, data format, properties, information models.
6) Design is fragmented across time and disciplines and based on tools from different vendors and contractors; lack of integration of domain knowledge, information modelling knowledge and IT knowledge; interoperabilities of organizational, technological, semantically domain knowledge; integration of domain knowledge, semantic modelling knowledge, and IT knowledge, different ontologies and data elements, common data dictionary, ontology driven realization, implementation and application. The collaboration concerns include data driven asset life-cycle management, both human and machine easier understandable ontologies, RDF.
7) Development of standard vocabularies; development of a functional ontology for robotics and automation for different contractors; checking or validation of relationship using functions as a basis for relationship checking; using AuR ontology for conceptual design of robotic applications. The collaboration concerns include: ontological concepts, domain-specific and scenario-specific use case or case studies, shared solutions and connected service.

8) Develop a common language to communicate smart cities across cities, nations, global regions, based on a multi-disciplinary approach which is served by existing technology-based ontologies; identification of correlations between all objects in the Smart City Ontology, based on AI/ML and similar processes to those used in web semantics; from basic interoperability (data models) to semantic interoperability (smart cities ontology, digital twin for smart cites). The collaboration concerns include: Build global observatory for urban intelligence, AI + data commons for data distribution + interoperable data sharing, digital public good standard for digital transformation.

9) Semantic interoperability, standardized vocabulary and ontologies that should be defined to achieve Web-based Digital Twin for smart cities in an interoperable manner. The collaboration concerns include W3C as central hub for collaborative discussions and open standards resource sharing, standardized vocabulary and format, e.g. WoT + DID + VC，RDF, OWL, RIF, DCAT, SOSA, SSN, etc.

10) Ontologies to the representation and utilization of urban knowledge in a machine-readable form using Semantic Web Ontology language OWL, representing descriptions of indicators using a semantically precise representation, enables automated comparison/analysis of indicators, city data standard enables the sharing of data between city decisions/services and with external stakeholders, as core component of digital twins, technical location and server for storing ontology standards, data platform to share and converge on data patterns, shared consensus of community city data model, minimum set of core concepts and the properties of existing object and data. The collaboration concerns include: Global collaboratory consensus on components of common city data model, sharing city data models.

11) Demands for machine-readable and machine-executable standards, lack of dedicated tools (there are many software tools for software), lack of methodology expertise (there is no group to manage this complexity), lack of unified and integrated model for smart city, different viewpoints about smart city, reference architecture brings different viewpoints together for harmonization. Its collaboration concerns include: system of systems approach and reference architecture to complexity and changeability of city needs.

12) Gaps in terminology-based ontologies and gaps in cross-domain ontology framework for cities; gaps in building both human and machine readable, executable, interpretable and auditable ontologies. The collaboration concerns include: building road map and framework for coordination of existing ontologies for city-wide use and collaboration on human-machine under readable, executable, interpretable and auditable ontologies and use case of ontologies in smart cities and smart city systems.

6.10 Processes and activities of ontology building

Table 22 shows common processes and activities (PA refers to process and activities) in ontology building, mapped with existing ontology standards.

Table 22 – Common processes and activities in ontology building

Code	Process and activities	ISO/IEC 18384-3: 2016	ISO 19150-4: 2019	ISO/TS 19150-1: 2012	ISO/IEC TR 20943-6: 2013	ISO/IEC 21972:2020	ISO/IEC 19763-3: 2020	ISO 19150-2: 2015
PA1	Choice and abstraction level	√	√					
PA2	Ontology language representation			√				
PA3	Ontology registry			√			√	√
PA4	Define constraint (annotation)							√
PA5	Define data types (data property)							√
PA6	Define class	√	√	√	√	√		√

Code	Process and activities	ISO/IEC 18384-3: 2016	ISO 19150-4: 2019	ISO/TS 19150-1: 2012	ISO/IEC TR 20943-6: 2013	ISO/IEC 21972:20 20	ISO/IEC 19763-3: 2020	ISO 19150-2: 2015
PA7	Define namespace					√		√
PA8	Define property				√	√		√
PA9	Define relationship				√	√	√	√
PA10	Ontology mapping		√	√				√
PA11	Aggregation and composition			√				
PA12	Architectural abstraction	√	√					
PA13	Capture the abstraction	√	√					
PA14	Construct class relationship matrix	√	√					
PA15	Increasing with other elements	√	√					
PA16	Define ontology using OWL	√	√	√		√		
PA17	Translation of ISO harmonized model for UML or OWL			√				
PA18	Exemplifying the difference							
PA19	Define multiplicity relationship						√	
PA20	Ontology identification							√
PA21	Retrieval application	√						√
PA22	Define notation							√
PA23	Reuse the metadata in registry				√			
PA24	Generate concept				√			
PA25	Specify the conceptualization domain				√			

6.11 Framework for generating and constructing ontologies

Among the standards found relevant to ontology construction are ISO/TS 19150-1:2012 and ISO/IEC TR 20943-6:2013. ISO/TS 19150-1 proposes an ontology framework for geographic information (see Figure 10); ISO/IEC TR 20943-6:2013 covers the framework for generating ontologies based on ISO/IEC 11179-3 and provides the procedure and mapping model for generating ontologies.

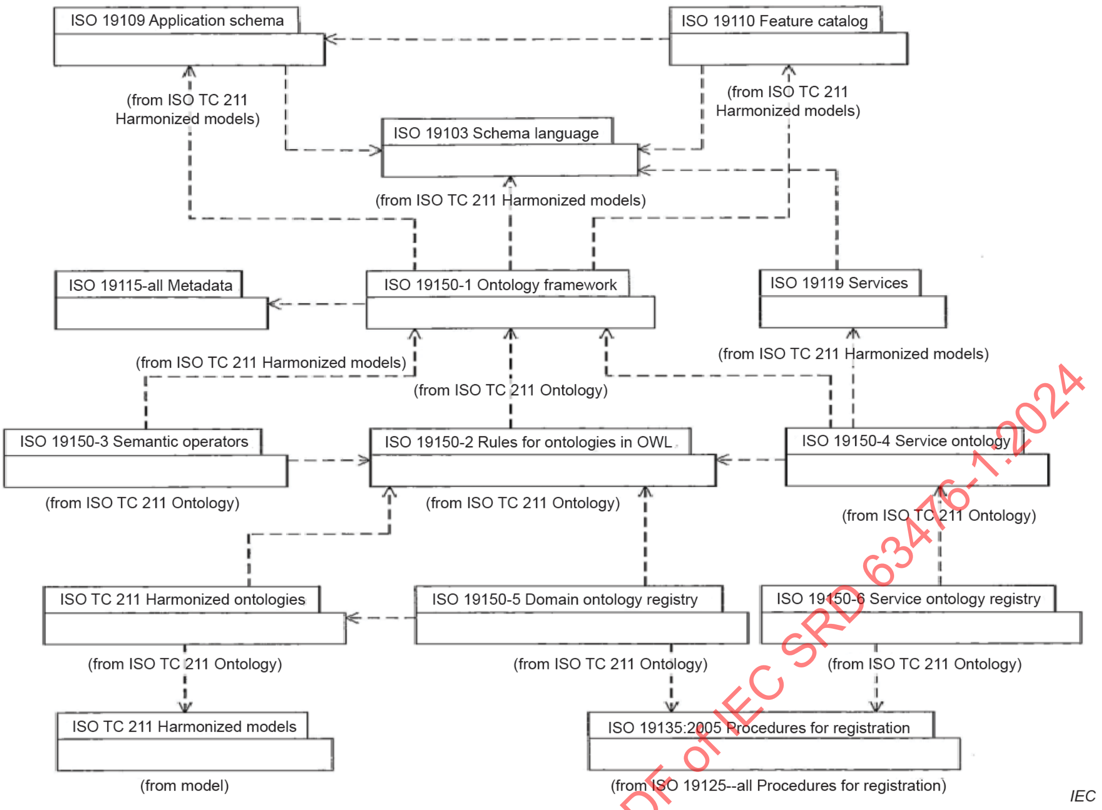
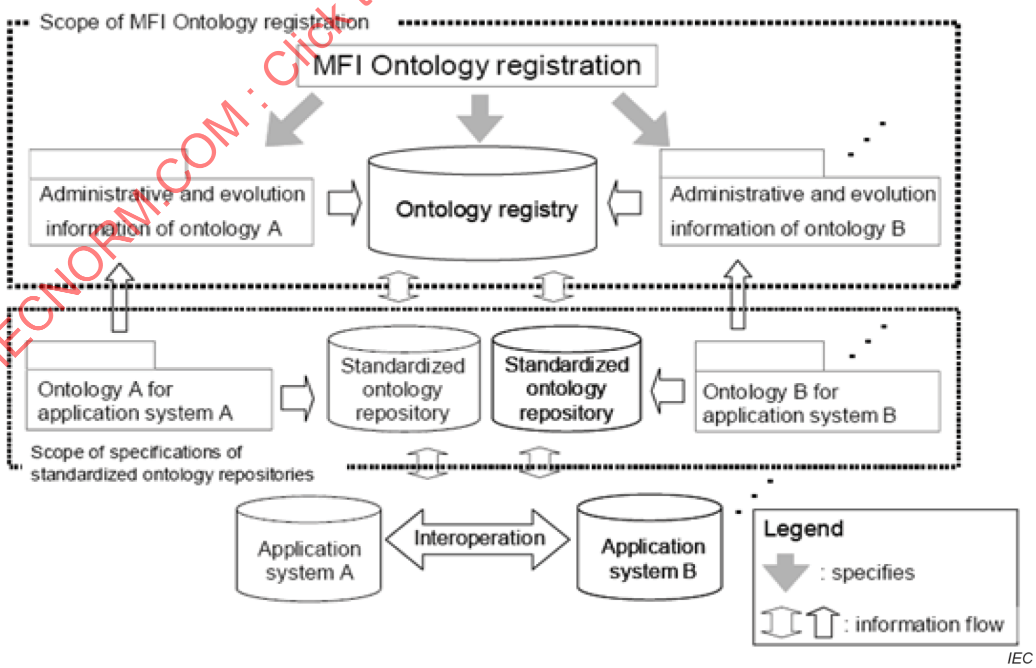


Figure 10 – Framework decomposition in packages and dependencies

The main type of standards about ontology framework is top-down, which belongs to top-level design in the domain of standard development. ISO/IEC 19763-3 specifies the metamodel that provides a facility to register administrative and evolution information related to ontologies (see Figure 11).



SOURCE: ISO/IEC 19763-3:2020

Figure 11 – Scope of MFI ontology registration

6.12 Stakeholders and concerns about ontology standards

Existing ontology standards are limited to targeted domains and specific areas, which lacks cross-domain concerns about multiple stakeholders for smart cities and smart city systems.

6.13 Ontology standard scenarios mapping with IEC SRD 63235:2021

From the perspective of a social–digital–physical system, in the existing standards on ontology, types of scenario include:

1) society, stakeholder, etc. (in social perspective);
2) data, information, platform, digital system, etc. (in digital perspective);
3) cyber information, etc. (in digital and physical perspectives).

See Table 23 for details.

Table 23 – Existing ontology standards mapping with IEC SRD 63235:2021

Perspective	Standard	Scenario		Description of standard
		Type	Detail	
Social system	ISO/IEC 18384-3: 2016	society	Ontology: for service oriented architecture	This part of ISO/IEC 18384 defines a formal ontology for service-oriented architecture (SOA), an architectural style that supports service orientation.
	IEC 62656-5: 2017	Stockholder (Enterprise or organization, etc.)	Ontology: for interface and activity	This part of IEC 62656 specifies a method for representing activities and relations among the activities by a tabular ontology representation, called ‘parcellized activity model’, or PAM for short, which is a specialized use of a generic tabular ontology data model, known as the parcellized ontology model (POM).
Digital system	ISO/IEC 21000-1: 2017	data	Ontology: for media contract	This part of ISO/IEC 21000 specifies an ontology for representing contracts in the Multimedia Framework formed for the transaction of MPEG-21 Digital Items or services related to the MPEG-21 Framework. Media Contract Ontology (MCO) aims to digitally express agreements made in environments using ISO/IEC 21000. These agreements are contracts for transactions of content packed as Digital Items, as well as for services provided around this content by means of a semantic presentation.
	ISO 13584-32: 2010		Ontology: for markup language and product	

Perspective	Standard	Scenario		Description of standard
		Type	Detail	
	IEC 62656-1: 2014		Ontology: for structure and model and data parcels	This part of IEC 62656 specifies the logical structure for a set of spreadsheets, used as 'data parcels', to define, transfer and register product ontologies. Such ontology descriptions in other literatures or disciplines are sometimes called 'reference dictionaries'. Thus the logical data structure described in this standard is named 'Parcellized Ontology Model' or 'POM' for short, and each vehicle of transport of the model is called a 'parcel', and may be used for definition, transfer, and registering of a reference dictionary as a collection of metadata, or for similar purposes for instances belonging to a certain class of the reference dictionary. Moreover, this ontology model allows for modelling or modifying an ontology model per se as a set of instance data, thus it enables an ontology model to evolve over time.
	ISO/IEC 24800-2: 2011		Ontology: for metadata representation, querying and management of images	This part of ISO/IEC 24800 provides a standardized set of technologies for metadata representation, querying and management of images. It specifies the JPSearch's Core Metadata Schema as the cornerstone of metadata interoperability in ISO/IEC 24800. It also specifies the structure and rules to which any metadata annotation of images must conform in order to be considered valid within a JPSearch compliant system.
	ISO/IEC 24800-2: 2011/Amd.1: 2015		Ontology: for JPEG image	This clause specifies the set of classes, properties, and restrictions that constitute the JPSearch Metadata Ontology (JPOnto). This ontology specification provides the foundation to implement applications in different domains that can represent, exchange, and integrate digital image information generated in different systems and under different contexts.
	ISO/IEC TR 20943-6:2013		Ontology: for methodology and metadata	This part of ISO/IEC TR 20943 describes a method of generating ontologies for a context using concepts in ISO/IEC 11179-3. Most ontologies are basically composed of classes (concepts), properties, relations between classes, and instances (objects or individuals). This part considers the generation of ontology consisting of a subset of ontology components required for defining ontologies at the conceptual level which is called 'FGO_Ontology'.
	IEC TS 62656-2: 2013		Ontology: for technical specification and application guide for IEC CDD	
	ISO/IEC 15944-4: 2015	information	Ontology: for accounting and economic	This part of ISO/IEC 15944 provides a set of UML class diagrams and conceptual explanations that circumscribe the Open-edi Business Transaction Ontology (OeBTO). It explains the mechanics of a business transaction state machine, the procedural component of an OeBTO, and the (internal) constraint component of OeBTO, its repository for business rules.

Perspective	Standard	Scenario		Description of standard
		Type	Detail	
	ISO/TS 19150-1: 2012		Ontology: for geographic semantic information	This part of ISO 19150 defines the framework for semantic interoperability of geographic information. This framework defines a high-level model of the components required to handle semantics in the ISO geographic information standards with the use of ontologies.
	ISO 19150-2: 2015		Ontology: for geographic information	
	ISO 19150-4: 2019		Ontology: for geographic information	
	ISO/IEC 21972: 2020		Ontology: for smart city indicators	
	ISO 21127:2014		Ontology: for cultural heritage information	
	ISO/IEC 21000-19: 2010		Ontology: for media value chain	This part of ISO/IEC 21000 specifies MPEG-21 Media Value Chain Ontology (MVCO). The MVCO may be used to capture knowledge about media value chains and to represent, in a computer readable way, concepts in the domain and the relationships between those concepts.
	ISO/IEC 21000-21: 2017		Ontology: for media contract	This part of ISO/IEC 21000 specifies an ontology for representing contracts in Multimedia Framework formed for the transaction of MPEG-21 Digital Items or services related to the MPEG-21 Framework.
	ISO/IEC 19763-3: 2020	platform	Ontology: registration	This part of ISO/IEC 19763 specifies the metamodel that provides a facility to register administrative and evolution information related to ontologies.
	IEC 62656-3: 2015		Ontology: for interface and information	This part of IEC 62656 specifies an interface between IEC 62656 series and meta-model for CIM originally defined in the IEC 61968 and IEC 61970 series of standards; this standard defines a forma mapping between the IEC 62656 and meta-model for CIM in order to import the CIM ontology into the IEC CDD, and to ensure the interoperability of ontologies of two standards, or even among a wider spectrum of standards.
	Rec. ITU-T Y.4500.12	digital system	Ontology: one M2M system	
digital and physical system	ISO/IEC 21000-8:2008/ Amd.2:2011	cyber infrastructure	Ontology: for software and media value chain	
	ISO/IEC 21000-8:2008/ Amd.3:2015		Ontology: for software and media contract	
	ISO/IEC 21000-8:2008/ Amd.4:2018		Ontology: for software and media value chain	

7 Gap analysis and recommendations for future work

7.1 Limitation of ontology definitions and concepts for smart city systems

The current ontology in the smart city domain has limitations that are more focused on operational level ontology (see Figure 12). A terminological analysis of ontology concept shows that there is a demand for harmonization of various definitions of ontology from system of systems thinking for smart cities and smart city systems at the top-down level.

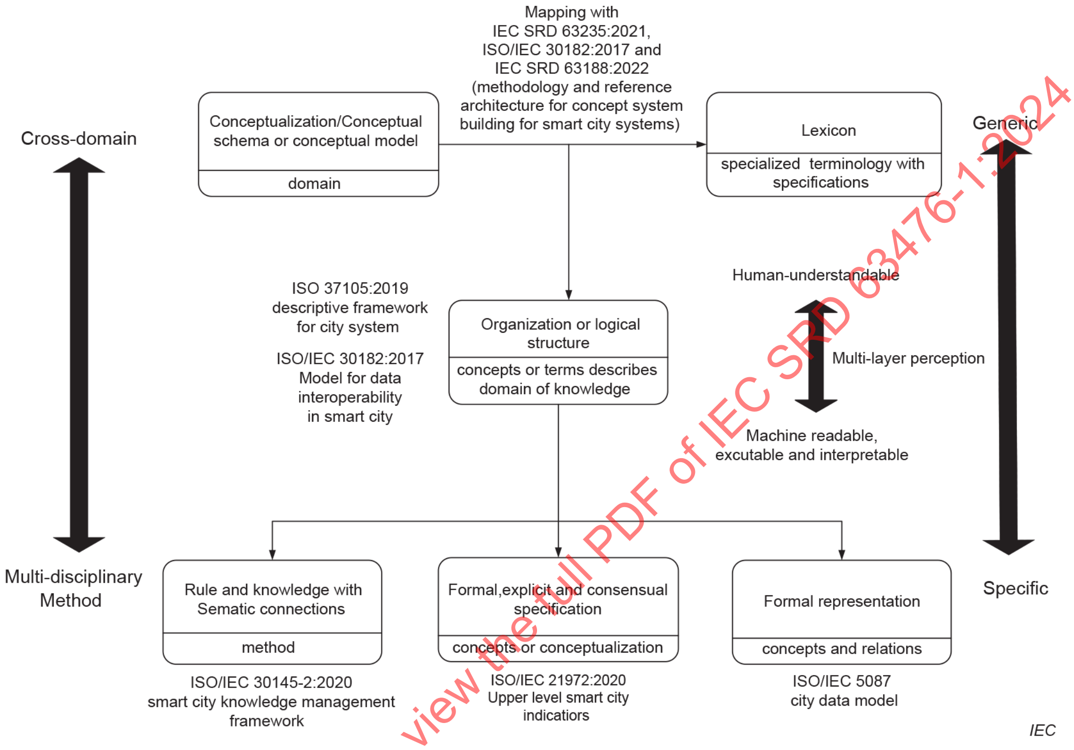


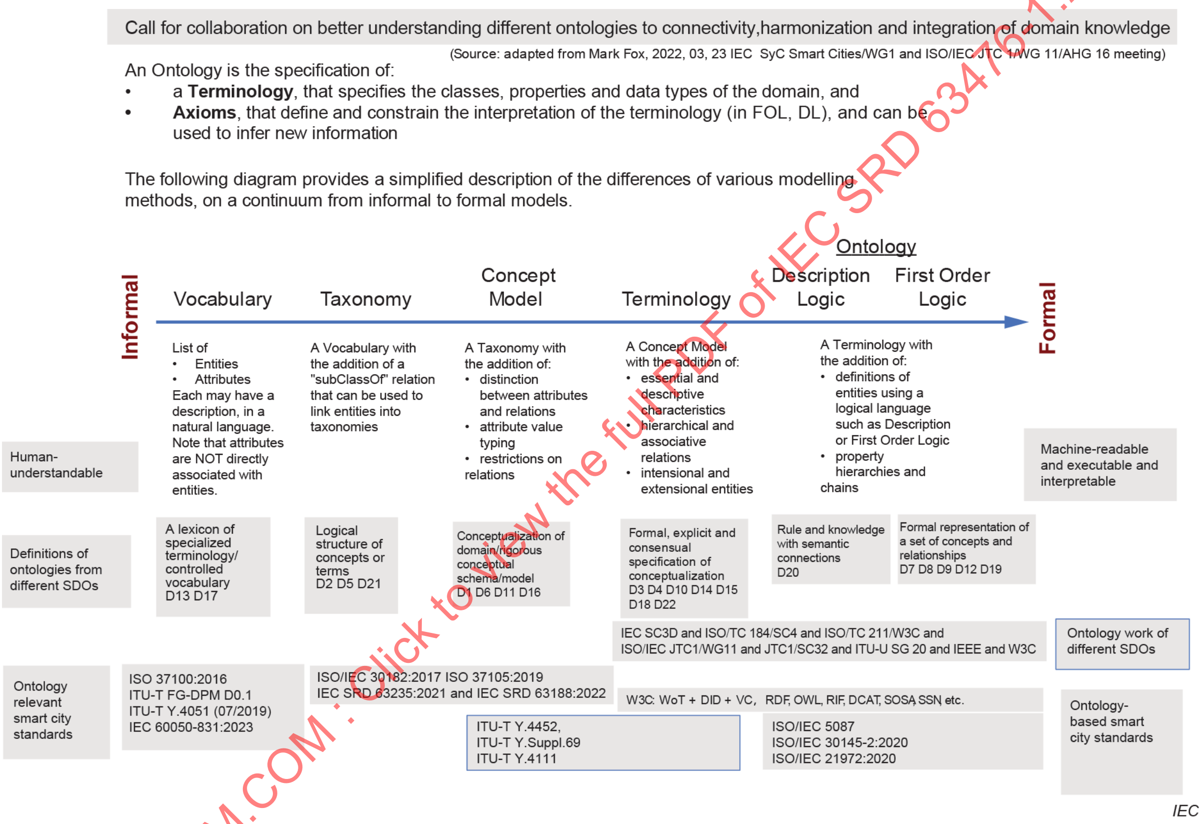
Figure 12 – A harmonized ontology concept system for smart city systems

There is a demand for common understanding about smart city systems based on a harmonized concept system of ontology from generic to specific. A multi-disciplinary, multi-domain and multi-layer coordination for ontology concept system to smart city systems building is recommended. Developing and maintaining a multidisciplinary, multi-domain and multi-layer coordinated concept system of 'ontology' for smart city systems to enable cross-domain stakeholders to use the same 'language' for smart city systems are recommended.

The demands for cross-domain ontology for smart cities can be fulfilled by interaction between domain and method. From the domain perspective, ontology is relevant to conceptualization or conceptual schema or conceptual model. While from the method perspective, ontology is relevant to rule and knowledge with semantic connections. Therefore, ontology is an organization or logical structure for describing domain of knowledge. In addition, specifically, the demands for machine-readable, machine-executable, machine-interpretable and machine-auditable ontology involves terminology-ontology building covering lexicons, formal, explicit and consensual specification as well as formal representations.

7.2 Lack of harmonization of ontology concepts for smart city systems

Figure 13 shows there are different concepts about ontology from human understandable to machine readable, executable and interpretable from left to right from different SDOs. On the left at the bottom of Figure 13, the blackened words show there are ontologies relevant standards in smart city domain in terms of their relevance to concept models of smart cities. On the right at the bottom of Figure 13, the blackened words show there are ontologies-based standards in smart city domain in terms of their relevance to the representation of concept models in machine-readable, executable and interpretable ways. This indicates that there is a need of an ontology continuum thinking for bringing existing ontology definitions, concepts and methodologies together for smart cities and smart city systems. Respecting many views on ontology from various dimensions and reaching consensus on a holistic approach to harmonization of terms and definitions relevant to ontology across IEC TCs, other SDOs are recommended.



SOURCE: Adapted from Mark Fox, 2022, 03, 23 IEC SyC Smart Cities/WG1 and ISO/IEC JTC 1/WG 11/AHG 16 Meeting; International Virtual Seminar Standards Collaboration on Ontologies for Smart Cities and Smart City Systems, 22–23 September, 2022.

Figure 13 – An ontology continuum model mapping with ontology concepts

7.3 Lack of integrated ontology framework for smart city systems

Figure 14 shows that there are four categories of ontology standards from different areas of interests and concerns. There is lack of ontology framework for adaptability and applicability of existing ontology standards for smart cities and smart city systems. Current existing ontology standards applicable to smart cities and smart city systems are limited to the area of upper-level smart city indicators and city data models.

1) General ontology

General ontology standard includes guidance and rules for development of ontology which can be applied to a wide area of fields.

2) Ontology framework

Ontology framework standards are limited to domain of geographic information and area of metadata registry.

3) Specific domain ontology

A number of ontology standards are related to specific areas or domains that are for special functions, services and usages. However, there is only one published ontology standard for upper-level smart city indicators.

4) Ontology-relevant standards

Additionally, there are some standards indirectly related to ontology, which means the standards have no ontology in the title of standards but use ontology as foundation for their data modelling, information management, knowledge management framework, etc.

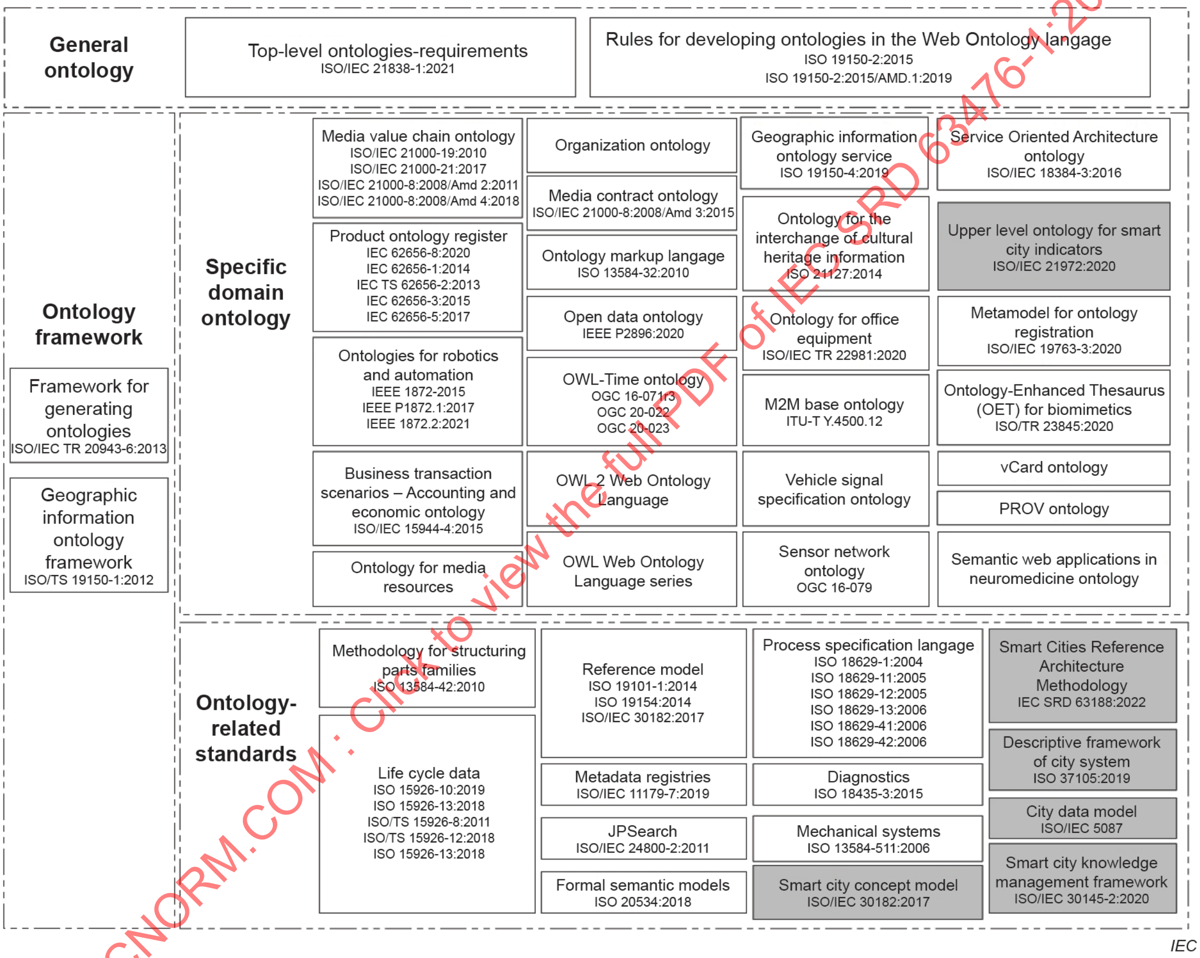


Figure 14 – Gaps in ontology standards for smart city systems

Figure 14 shows there are general ontology and the ontology framework in the geographic information domain and there many ontologies or ontology-relevant standards in specific domains related to specific tasks and to specific scenario applications. However, whether they are applicable to the smart city domain needs to be further studied and validated.

There is only one ontology named standard in the smart city domain and it is specific to smart city indicators. However, there are ontology-relevant standards (ISO/IEC 30182:2017, ISO 37105:2019, IEC SRD 63188:2022) and ontology-based standards (ISO/IEC 5087, ISO/IEC 30145-2:2020) in the smart city domain.

Studies and workshop results agreed that there is need of standards collaboration among different SDOs on sharable and reusable ontologies across domains for city-wide use.

7.4 Recommendations for future work

7.4.1 Potential new work items

Findings from survey conducted during the workshop held from 22 to 23 September 2022 show that there are four potential work item projects for future collaborations across different SDOs.

- Systems Reference Deliverable (SRD) Smart city system ontology – Part 1: Gap analysis;
- Systems Reference Deliverable (SRD) Smart city system ontology – Part 2: Common terminology-ontology for smart cities;
- Systems Reference Deliverable (SRD) Smart city system ontology – Part 3: Collaboration framework on ontologies for smart cities;
- Systems Reference Deliverable (SRD) Smart city system ontology – Part 4: Use cases of cross-domain ontologies in smart cities.

7.4.2 Recommendations from the international virtual seminar on ontology

(NOTE The International Virtual Seminar on Standards Collaboration on Ontologies for Smart Cities and Smart City Systems was jointly hosted by IEC Academy, IEC SyC Smart Cities and ISO/IEC JTC 1 on 22 and 23 September 2022. Web seminar presentations and recordings of September 22-23, 2022 are available at https://www.iec.ch/academy/webinars)

1) Awareness in communities of importance of ontologies for connectivity, harmonization and integration of domain knowledge.
   - The best way is to demonstrate benefits of ontologies to support connectivity, harmonization and integration; possible approach is to identify benchmark problems and practical issues that can be contributed by design of ontology to support common characteristics, interoperability and consistency of data sets, data spaces, data space centres for sharing and reuse of data.
   - Awareness of existing ontologies standards aligned with ontology terminology across-domain is necessary. A concern that focusing on existing standards rather than developing new things should be considered in the future work of ontology standardization.
   - Ontology should be human understandable. It should be aware that there is lack of ontology tools for project data sharing in daily practice. Besides, ontologies need to be practical for engineering and project practice.
   - Awareness of upper ontology, domain ontology and cross-domain ontology available and needs of different use cases and different approaches to interface.
   - Broader education and better understanding of what is ontology, how to design and use it.
2) Collaboration on ontologies for smart cities:
   - Need awareness of what ontologies are used, developed by different SDOs, where they are, what can be used together; be more proactive to collaborate, have a culture of collaboration, build some standards ontologies which can work together but not one size fits for all.
   - Need collaboration on gap analysis and overlap analysis, real active participation of different SDOs to look together from top-down to tap overlaps and gaps.
   - Need to create special interest groups, build collaboration including informal and formal communication, share use cases, share articles and undertake workshop on what to share and to harmonize.
   - Joint international seminar or workshop is a good way to recognize importance of collaboration, and to identify which SDOs are interested in developing data sharing, sharing ontologies and data models. Need to start from small with specific targets, e.g. smart city service, specific domains which need to be harmonized, identify which SDOs are involved in data models and ontologies and which standards need to be harmonized, then to start targeted specific tasks and share the semantics and data models between these different domains.

- Smart city is too complex, which needs to address many challenges not only as a whole architecture, but also for different domains, such as logistics, transportation, human resource management, social affairs, and many solutions are needed even for one single department within the big environment of smart cities. The suggestion is to develop a one size fit or maybe a yellow page or similar, where it is possible to find some fine classified ontologies that are publicly accessible and reusable. And this classification of the existing ontologies must be aligned with the functions of city for connectivity of different domains, and raise awareness of existing ontologies in the domains and upper ontologies which can be reused by people from different domains. FAIR approaches to standardize ontologies to make them findable, accessible, interoperable, reusable, realize their true values in the development of cities. Defining their applications and the implementation mechanisms is important.
- How can ontologies be made findable, accessible, interoperable and reusable? Different SDOs are working on the same thing but they are not collaborating with or aware of each other. Where can consensus be achieved and how can issues be addressed to converge consensus?
- To develop good, reliable, mutable, replicable ontologies or terminology, they need to be aligned with architecture approach, components of ontologies and its validation.
- Deep and rich review ontologies need to work together and be aligned with each other. Different SDOs are developing different ontologies but are not aware of each other, and they need urgent coordination to know each other. Need to set up special programmes for coordination group of IEC, ISO and IEC and joint working with JTC 1, W3C, IEEE, etc. Need both top-down and bottom-up approaches to collaboration.
- On issues of fairness approach within ISO, there is not an agreement that the ontology should be published using OWL or just straight RDF; requirements need to be purchased. Issues of openness of standards for ontologies sharing and reuse should be stressed.
- JTC 1/ WG 11 Seminar on Standards Collaboration on Ontologies for Smart Cities and Smart City Systems reported an ontology catalogue for IoT that references more than 800 ontology-based IoT projects including smart cities, which is a good foundation for collaboration. The knowledge of this entire ontology catalogue for smart cities is https://lov4iot.appspot.com/?p=lov4iot-city. See Gyrard (2018) in the Bibliography.

3) Engagement in cities to develop smart city ontologies:

- Education, promotion to raise awareness of the importance of smart city ontologies and the benefits to data sharing and connectivity, interoperability and harmonization of data models.
- Need both top-down and bottom-up approaches, understand complexity of city and need different stakeholders to participate and collaborate under same reference architecture, need system of systems approach and systematic way for integrated framework to enable ontologies to work in a consistent and harmonized way, need harmonization methodology and framework for different SDOs to be able to work together.
- Identify standardized vocabulary, time and place definitions already used in cities and that are relevant for cities.
- Conducting a survey of economic benefits of ontology and ontology standards would be an effective approach. Highlighting the economic benefits of ontology standards can attract cities and city administration to participate in the standardization process and to adopt or implement standards.
- Need to reduce the use of the term ‘ontology’ in real world practice; the nature of conversation is data model and data sharing and data interoperability, data connectivity and discoverability, which is easier for people to understand and communicate.
- Need engagement at application level, city level, district level and device level.

4) Adoption of ontologies to smart city:

- Openness of different SDOs is important for engaging cities and to let everyone access standard.
- Adoption of ontology can help improve semantic interoperability of cities, merge multi-disciplinary areas and domains together, deepen the integration of many and various data models in a consistent way to reduce complexity. See Hardin (1998) in the Bibliography. The top-down approach of a modelling language for: regulated actions -> use case examples -> business process descriptions -> data flow -> data models.
- Need to standardize data models of various parameters at devices irrespective of the use cases to get comprehensive semantic interoperability.
- Sharing data models and building data models repository would help cities to adopt smart city ontologies, e.g. https://smartdatamodels.org as the site for smart data models, a repository based on agile standardization. And this is the Agile Standardization Manifesto (see Bibliography).

5) Major challenges of ontology standards development and adoption of smart city ontologies:

- ‘What’ being whatever the aim is: as a city, that would be to manage data in a way that helps improve sustainability; as an SDO it would be a step more abstract: to advise cities (and their suppliers) on how to do that: advise or standardize an ontology for a city, or an approach to creating an ontology which a city should use, or something else? Standardize a collection of existing ontologies that ‘can actually be used’ – or advise a city (or region, or country) on how to achieve that? Currently there are many different ontologies and approaches that each works in its own area; there is no ‘best practice’ (ontology or method for creating ontologies) ready for standardization in this space.
- No server where sharable and reusable ontologies can be deposited for implementation.
- No agreement that the ontology should be published using OWL or just straight RDF.
- Many standards need to be purchased, which is not good for adoption of existing standardized ontologies.

7.4.3 Future collaboration

- Convene joint annual (or semi-annual) workshop where SDOs working on city relevant ontologies can share ideas and cooperate.
- Build joint programme or special interest groups that are interested in developing data sharing, sharing ontologies and data models among ISO, IEC, ITU, JTC1, IEEE, W3C. Start from small with specific targets, e.g. smart city service, specific domains which need to be harmonized; identify which SDOs are involved in data models and ontologies and which standards need to be harmonized; then start with joint specific tasks and share the semantics and data models between these different domains and SDOs.
- Enhance collaboration among different SDOs on use cases, sharable and reusable ontologies, data models, collaboratory platforms, collaboratory observatory, data centres, data spaces, data lakes.
- Invite different SDOs to actively participate in gap analysis and overlap analysis, roadmap analysis when an SDO is developing a new ontology project.

Annex A
(informative)

A survey of shared understandings on smart city

1) What definition of smart city do you prefer that reflects the concerns and interests of a wide group of SDOs? [Multiple choice]

No	Definition	Account	Result
1	effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens.	6	42,86 %
2	a smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspect. NOTE 1 City competitiveness refers to policies, institutions, strategies and processes that determine the city's sustainable productivity. NOTE 2 'Smart sustainable city' is also called 'smart city' in some other SDOs. [Rec. ITU-T Y.4900 (06/2016)]	3	21,43 %
3	city that increases the pace at which it provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability by fundamentally improving how it engages society, applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies to deliver better services and quality of life to those in the city (residents, businesses, visitors), now and for foreseeable future, without unfair disadvantages of others or degradation of the natural environment. NOTE 1 A smart city also faces the challenge of respecting planetary boundaries and taking into account the limitations these boundaries impose. NOTE 2 There are numerous definitions of smart city; however, the definition that is used with TC 268 is the official one agreed to by the ISO Technical Management Board. [ISO 37122:2019; ISO/IEC 30145-2:2020]	4	28,57 %
4	city where improvements in quality of life, services, sustainability and resilience are accelerated by the effective integration of many and various types of physical, digital and social systems and the transformative use of data and technology. NOTE 1 This is a general definition of a smart city. The IEC looks at these aspects from the perspective of electrotechnology. NOTE 2 The effective integration of physical, digital and social systems requires the development and integration of digital twins of all these systems.	3	21,43 %

No	Definition	Account	Result
5	city which is systematically addressing concerns of citizens leveraging international standards and digital transformation. NOTE 1 Typical citizens' concerns are, by their nature, subjective, contradictory, partial and changing over the time. Such concerns form views representing how citizens see and perceive the city. Usually, different stakeholders (e.g. groups of citizen) may have different views on the same fragment or aspect of a city. NOTE 2 Any city (therefore any smart city) is a self-organising system; thus it is able to transform itself. NOTE 3 The complexity of smart cities requires building them via digital transformation as digitally coordinated systems. NOTE 4 Each smart city is carrying out its digital transformation with its own pace. NOTE 5 The concept "digitally coordinated system" is critical for providing various smart cities with ready-to-deploy (standard) solutions which can be used (together with some local solutions) to create unique smart cities. Such digitally coordinated systems are qualified as repeatable. This feature is necessary to achieve the UN Sustainable Development Goal (SDG) 11 quickly and effectively because there are many cities and any making each of them smart in a different way would be very unsustainable. NOTE 6 International standards are critical for repeatability and scalability of digital solutions for smart cities. NOTE 7 The shortest form of the definition of smart city is 'city built as a digital system'. NOTE 8 Various improvements for citizens, business and administration can be quantified via internationally recognised metrics. Examples of such metrics are the World Bank's B-READY project and EIU's Global Liveability Index.	0	0 %
6	city where electrotechnical systems and information technology are employed to improve city services.	1	7,14 %
Validated answers for this question		14	

2) Do you agree with the following characteristics in terms of stakeholder's concern about smart city? [Multiple choice]

Characteristics	Account		Result
citizen	13		92,86 %
present generation	9		64,29 %
future generation	9		64,29 %
Other	6		42,86 %
	JP-1	all stakeholders in a city	
	AU-8	business, government	
	AU-10	Cities exist to benefit citizens. They are the customer	
Validated answers for this question	14		

3) Do you agree with the following characteristics in terms of domain's aspect about smart city? [Multiple choice]

Characteristic	Account		Result
economic aspect	12		85,71 %
environmental aspect	12		85,71 %
social aspect	11		78,57 %
built environment	10		71,43 %
natural environment	10		71,43 %
cultural aspect	10		71,43 %
city	9		64,29 %
information technology	8		57,14 %
digital transformation	7		50 %
electrotechnical systems	5		35,71 %
international standards	4		28,57 %
Other	2		14,29 %
	AU-7	coordinated and reflexive systems	
	AU-10	data and technology	
Validated answers for this question	14		

4) Do you agree with the following characteristics in terms of smart object of smart city? [Multiple choice]

Characteristic	Account		Result
integration of physical, digital and human systems	12		85,71 %
city	6		42,86 %
Other	3		21,43 %
	AU-7	decision makers	
	AU-8	environmental/sustainable	
	AU-10	communities	
Validated answers for this question	14		

5) Do you agree with the following characteristics in terms of smart status about smart city? [Multiple choice]

Characteristic	Account	Result
increases the pace	3	21,43 %
improvements accelerated	5	35,71 %
self-organizing system	5	35,71 %
digital transformation as digitally coordinated systems with its own pace	5	35,71 %
innovative	8	57,14 %
improvements for services	11	78,57 %
effective integration	12	85,71 %
Other	4	28,57 %
	AU-7	Learning, Reflexive
	AU-10	Most of these are not essential or are not definitive
Validated answers for this question	14	

6) Do you agree with the following characteristics in terms of visions and goals of smart city? [Multiple choice]

Characteristic	Account	Result
a sustainable, prosperous and inclusive future	11	78,57 %
fundamentally improving	3	21,43 %
provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability, to deliver better services and quality of life	9	64,29 %
improve quality of life, efficiency of urban operation and services, and competitiveness	8	57,14 %
improvements in quality of life, services, sustainability and resilience	10	71,43 %
repeatability and scalability of digital solutions	4	28,57 %
systematically addressing concerns	5	35,71 %
city services	6	42,86 %
Other	3	21,43 %
	AU-7	Liveability, Sustainability and Resilience
	AU-10	Sustainability (economic, environmental, social, technological) and Resilience (economic, environmental, social, technological) and Liveability
Validated answers for this question	14	

7) Do you agree with the following characteristics in terms of approaches to and means of smart city? [Multiple choice]

Characteristic	Account	Result
effective integration of physical, digital and human systems	8	57,14 %
engages society, applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies	7	50 %
information and communication technologies (ICTs) and other means	7	50 %
by the effective integration of many and various types of physical, digital and social systems and the transformative use of data and technology	9	64,29 %
internationally recognized metrics	6	42,86 %
electrotechnical systems and information technology	3	21,43 %
Other	1	7,14 %
Validated answers for this question	14	

8) Besides the above understandings about smart city, do you have any recommendations about smart city and its characteristics? [Note fulfilment]

Code	Time	Quotation
JP-1	2021/4/29 16:28:58	The definition of a smart city should describe its ideal state and should not include any part of its methodology. In other words, only the part of what is acceptable. The method is a How to, which can be followed by an approach. They can be different at ISO, IEC, JTC1, or ITU, and there are many ways. Whether it's digital or analogue, all we need is a 'smart' city. Focusing on systems is focusing on methods. It is also a way to integrate various systems. The definition of a smart city describes only the ideal state. That way, each standard can show different ways of doing it. As a definition of a smart city, I propose to consider the following: "Cities are places where people live, work and have fun. It is smart city that can maintain, improve and change the environment so that people can carry out appropriate activities, while grasping various problems that arise and predicting the future."
AE-3	2021/4/30 15:16:18	Governance and leadership are also important.
JP-4	2021/5/2 10:42:31	Question 1 is not complete. There should be other good definitions, for example the definition from ISO TC 268.
IN-5	2021/5/2 19:37:11	A City should be Citizen centric, fundamentally looking at the following end-goals: 1. Quality of life, 2. Improvement in services, 3. Sustainable, 4. Environmentally friendly.
AU-6	2021/5/3 7:53:30	Interconnected technologies
AU-7	2021/5/3 8:45:23	A smart city will make smart decisions. This can only be done if decision-makers are well informed see: https://doi.org/10.1016/j.envsci.2015.12.004 Making more data available and having integrated systems will only get us so far, we need to have the right rules and values in place, and critically decision-makers need to be willing to learn (from data) and adapt.
US-9	2021/5/4 4:09:57	the definition should be as short, simple, and clear as possible. Explanations of various Smart City attributes and characteristics do not belong in the definition, but rather in the text of the document.
AU-10	2021/5/4 10:05:58	if I tick a box above am I agreeing that something is a concern or am I agreeing something is important to a definition? My ticks mean I agree they are useful concepts, but I wouldn't insist they are in a definition. The literature is full of definitions for the smart city. There is a reason why... A smart city definition usually consists of: LIST OF CITY GOALS enabled by advances in DATA AND TECHNOLOGY.* The first issue is that the GOALS differ widely depending on who you talk to. Everyone wants to include their favourites. My preferred high-level goals are: Sustainability, Resilience and Liveability. 1) A second issue is the scope. Where do regional towns fit? Some people prefer or want to include COMMUNITIES. 2) Often definitions want to include the CITIZEN explicitly as a reminder that the purpose of the city and the data and technology is to serve citizens/customers. 3) Some want to (wrongly in my opinion) be prescriptive about process or technology, e.g. digital twins, digital transformation, IoT, increasing pace, standards, integration of systems, metrics, self organizing, etc. These don't belong in a definition. It may be 'smarter have a generic' definition. Then add an explanatory paragraph(s). Something like this: 'A smart city achieves its goals by leveraging advances in data and technology to benefit citizens in cities and communities.' The goals of a smart city include benefiting citizens by being sustainable, resilient and liveable: sustainable (economically, environmentally, socially, technologically) and resilient (economically, environmentally, socially, technologically) and liveable. [People can add more specific or expand on these if they want...]

Annex B
(informative)

Existing definitions of ontology from SDOs and authoritative sources

NOTE D refers to definition, and D1 refers to code of the first definition.

No	Definition	Source
D1	a conceptualization of a domain	ISO/TS 21526:2019, 3.36
D2	organization of concepts for which a rational argument can be made Note 1 to entry: Adapted from ISO/TS 17117.	ISO/TR 13054:2012, 2.6 ISO/TR 12300:2014, 2.1.15
D3	explicit and consensual specification of concepts of an application domain independent of any use of these concepts Note 1 to entry: In the ISO 13399 series, a dictionary is the formal and computer-sensible representation of an ontology.	ISO/TS 13399-50:2013, 3.19 ISO/TS 13399-2:2021, 3.16 ISO/TS 13399-4:2021, 3.16 ISO/TS 13399-5:2014, 3.19 ISO/TS13399-60:2014,3.20 ISO 18435-3:2015, 3.1 ISO/TS 13399-3:2021, 3.16
D4	specification of concrete or abstract things, and the relationships among them, in a prescribed domain of knowledge Note 1 to entry: The specification should be computer processable	ISO/IEC TR 20943-6:2013, 3.2.1 ISO/IEC 19763-1:2023, 3.16] ISO/IEC TR 19763-9:2015, 3.1.3 ISO 37105:2019, 3.2 ISO/IEC 19763-3:2020, 3.1.1.1 ISO/IEC TR 22981:2020, 3.2 ISO 21597-1:2020, 3.1.7
D5	logical structure of the terms used to describe a domain of knowledge, including both the definitions of the applicable terms and their relationships	ISO/IEC/IEEE 24765:2017,3.2691 ISO 20534:2018, 3.36] ISO 4454:2022, 3.11
D6	rigorous conceptual schema representing the subject domain	ISO/TR 25100:2012, 2.1.5
D7	formal representation of phenomena of a universe of discourse with an underlying vocabulary including definitions and axioms that make the intended meaning explicit and describe phenomena and their interrelationships	ISO/TS 19150-1:2012, 4.10 ISO 19101-1:2014, 4.1.26 ISO 19154:2014, 4.16 ISO 19150-2:2015, 4.1.29 ISO/IEC 30182:2017, 2.11 ISO 19150-4:2019, 3.1.19 ISO/IEC 21972:2020, 3.6
D8	formal statement of an understanding of the world Note 1 to entry: An ontology can be represented in any language. It need not be represented in a language specifically designed for ontologies, such as OWL. An ontology can have different representations. Note 2 to entry: An ontology does not specify what data need to be recorded about the world. Note 3 to entry: The ontology defined by this document is principally concerned with the world outside a computer system.	ISO/TS 15926-12:2018, 3.1.3 ISO 15926-13:2018, 3.1.19 ISO 15926-10:2019, 3.6

No	Definition	Source
D9	formal, structured, and explicit description of concepts in a domain of discourse and the relations between them in the fields of knowledge management and artificial intelligence Note 1 to entry: An ontology together with a set of individual instances of classes constitutes a knowledge base.	ISO/TR 23845:2020, 3.6 ISO/TR 23846:2022, 3.5
D10	formal, explicit specification of a shared conceptualization Note 1 to entry: An ontology typically includes definitions of concepts and specified relationships between them, set out in a formal way so that a machine can use them for reasoning.	ISO 5127:2017, 3.1.2.03] ISO/TR 23262:2021, 3.12
D11	model that represents a domain and is used to reason about the objects in that domain and the relations between them Note 1 to entry: This part of ISO/IEC 18384 is high level and not meant to be used for formal reasoning.	ISO/IEC 18384-3:2016, 3.1.2
D12	formal representation of a set of concepts within a domain and the relationships between those concepts Note 1 to entry: Ontologies are usually used to reason about the properties of that domain, and can be used to define the domain. Note 2 to entry: Ontologies are usually expressed in a logic-based language, but this is not a requirement, neither is the need for reasoning capability. In addition to relationships, classes, properties, instances and axioms can be used.	ISO/TS 15926-8:2011, 2.1.21
D13	a lexicon of specialised terminology along with some specification of the meaning of terms in the lexicon Note 1 to entry: Structured set of related terms given with a specification of the meaning of the terms in a formal language. The specification of meaning explains why and how the terms are related and conditions how the set is partitioned and structured. Note 2 to entry: The primary component of a process specification language such as ISO 18629 is an ontology. The primitive concept is the ontology according to ISO 18629 is adequate for describing basic manufacturing, engineering, and business processes. Note 3 to entry: The focus of an ontology is not only on terms, but also on their meaning. An arbitrary set of terms is included in the ontology, but these terms can only be shared if there is an agreement about their meaning. It is the intended semantics of the terms that is being shared, not simply the terms. Note 4 to entry: Any term used without an explicit definition is a possible source of ambiguity and confusion. The challenge for an ontology is that a framework is needed for making explicit the meaning of the terms within it. For the ISO 18629 ontology, it is necessary to provide a rigorous mathematical characterisation of process information as well as a precise expression of the basic logical properties of that information in the ISO 18629 language.	ISO 18629-1:2004, 3.1.17 ISO 18629-11:2005, 3.1.17 ISO 18629-12:2005, 3.1.17 ISO 18629-13:2006, 3.1.16 ISO 18629-41:2006, 3.1.13 ISO 18629-42:2006, 3.1.11
D14	Formal specification of a conceptualization, i.e., defining concepts as objects with their properties and relationships versus other concepts.	Rec. ITU-T Y.4500.12 (03/2018)
D15	An explicit specification of a conceptualization.	Rec. ITU-T X.1570 (09/2011)
D16	Following a more technical perspective, ontology can be defined as a specification of the kinds of entities that exist or may exist in some domain or subject area. Formally, an ontology is specified by a collection of names for concept and relation types organized in a partial ordering by the type/subtype relation.	Sowa, J. F. (1995); Javier Lacasta et al. (2010)