TECHNICAL SPECIFICATION

ISO/IEC TS 5147

First edition
2023-07

Information technology — Computer graphics, image processing and environmental data representation — Guidelines for representation and visualization of smart cities

Technologies de l'information — Infographie, traitement d'images et représentation de données environnementales — Lignes directrices relatives à la représentation et à la visualisation des villes intelligentes

Reference number
ISO/IEC TS 5147:2023(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work.

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

ISO and IEC draw attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO and IEC take no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO and IEC had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents and https://patents.iec.ch. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

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

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

This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 24, *Computer graphics, image processing and environmental data representation*.

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

Introduction

Developers and users of a smart city need tools to evaluate and examine options and trade-offs and predict outcomes. Parts or all of a smart city may need to be modelled, and smart city functions need to be simulated to evaluate possible outcomes. The modelling and simulation of smart city functions and processes require representation and visualization of the data. Representation and visualization of smart cities enable prototyping, demonstration and analysis of smart city concepts for further development. Both physical/geometric and semantic data can be represented and visualized. Representation and visualization of smart cities is a prime application for an integrated approach to leverage standardization since no single standard may address all requirements. This document provides guidance as to what needs to be represented for smart cities and how this can be achieved.

This document describes categories of data associated with smart cities and guidelines for their representation and visualization. It describes how standards can be applied to represent and visualize urban infrastructure, services and features. Use cases are presented that explore how these standards could be applied in smart city analysis and visualization applications.

Information technology — Computer graphics, image processing and environmental data representation — Guidelines for representation and visualization of smart cities

1 Scope

This document specifies guidelines for the representation and visualization of smart cities. This document:

a) describes the concepts of a smart city, smart city object and smart city data,

b) describes categories of data associated with smart cities,

c) provides guidance for representation of smart cities,

d) describes guidance for visualization of smart cities,

e) provides guidance in selecting the appropriate representation and visualization technique for different categories of smart city data using standards, and

f) provides use cases for applying standards to the representation and visualization of smart cities.

2 Normative references

There are no normative references in the document.

3 Terms, definitions and abbreviated terms

3.1 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:

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

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

3.1.1
3D city model
representation of an urban environment with a 3D geometry of typical or specific urban objects and structures, with buildings as the most prominent features

3.1.2
analytical data
data that has been derived from properties or applications of a smart city

Note 1 to entry: Examples of analytical data include data describing car traffic and pedestrian movements obtained from sensors.

3.1.3
big data
extensive datasets, primarily with characteristics of volume, variety, velocity and/or variability, that require a scalable technology for efficient storage, manipulation and analysis

Note 1 to entry: Big data is commonly used in many different ways, for example as the name of the scalable technology used to handle big data extensive datasets.

[SOURCE: ISO/IEC 20546:2019, 3.1.2]

3.1.4
built environment
human-made environment that includes buildings, roads, bridges, tunnels and city artefacts

3.1.5
Data Representation Model
DRM
standardized representation of the relationships and organization of environmental objects and content within SEDRIS

Note 1 to entry: SEDRIS refers to the ISO/IEC 18023 series.

3.1.6
Internet of Things
IoT
infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and the virtual world and to react

[SOURCE: ISO/IEC 23093-1:2022, 3.2.9]

3.1.7
physical property
measurable quantity that describes the state of a system

Note 1 to entry: Physical properties can be categorized as mechanical, electrical, optical or thermal and may be scalar values (such as temperature) or vector quantities (such as wind flow).

3.1.8
presentation
organization of data into textual, tabular or graphical format

Note 1 to entry: This can include non-visual modes of presentation such as audio and haptics.

3.1.9
representation
description of a real-world event, system, behaviour or natural phenomenon

Note 1 to entry: In this document, representation refers to the digital description of an event, object or system.

3.1.10
semantic property
property that does not have a physical basis

Note 1 to entry: Building ownership is an example of a semantic property.

3.1.11
smart city
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 the foreseeable future, without unfair disadvantage of others or degradation of the natural environment

Note 1 to entry: A virtual smart city is its digital/simulated representation.

[SOURCE: ISO 37122:2019, 3.4, modified — The original Notes to entry have been deleted and replaced by a new Note to entry.]

3.1.12
smart city data
data that is associated with a smart city

Note 1 to entry: This refers to data that may be consumed or produced by a smart city function or application.

3.1.13
smart city object
representation of a distinct object that is part of a real or virtual smart city

Note 1 to entry: A smart city object may not necessarily contain smart technology. It is used as a general descriptor for a component of a smart city.

3.1.14
spatiotemporal
associated with both space and time

3.1.15
visualization
rendering of an object, situation or set of information as a chart or image

Note 1 to entry: Visualization is a subset of presentation restricted to the visual medium.

3.2 Abbreviated terms

2D	two dimensional
3D	three dimensional
API	application programming interface
AR	augmented reality
BIIF	basic image interchange format
BIM	building information modelling
CCTV	closed circuit television
DICOM	digital imaging and communications in medicine
DIS	distributed interactive simulation
DRM	data representation model
EDCS	environmental data coding specification

GIS	geographic information system
GKS	graphical kernel system
GPS	geospatial positioning system
HAnim	humanoid animation
ICT	information and communications technology
IoT	internet of things
JPEG	joint photographic experts group
JSON	JavaScript object notation
MAR	mixed and augmented reality
MPEG	moving picture experts group
OGC	open geospatial consortium
PHIGS	programmer's hierarchical interactive graphics system
PNG	portable network graphics
SEDRIS	synthetic environment data representation and interchange specification
SRM	spatial reference model
VR	virtual reality
VRML	virtual reality modeling language
X3D	extensible 3D
X3DOM	X3D document object model
XML	extensible markup language

4 Representation and visualization standards

4.1 Standards overview

ISO standards for imagery, environmental representation, visualization and mixed and augmented reality can be applied to smart cities. These are described in the following subsections.

4.2 Representation standards

The SEDRIS series (ISO/IEC 18023 series) provides a suite of standards for environmental representation. SEDRIS is an infrastructure technology that enables information technology applications to express, understand, share and reuse environmental data. SEDRIS technologies provide the means to represent integrated environmental data (terrain, ocean, air and space), and promote the unambiguous, loss-less and non-proprietary interchange of environmental data. It is a means of organising environmental and feature data, yet leaves the (graphical) presentation of that data to other applications, such as X3D[1)] and other visualization tools. SEDRIS was developed for military training simulation and has mainly been applied in that domain. An introduction to SEDRIS is provided in Reference [1].

1) X3D is a trademark of the Web3D Consortium. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC.

The components of SEDRIS are:

— functional specification (ISO/IEC 18023-1)

— abstract transmittal format (ISO/IEC 18023-2)

— transmittal format binary encoding (ISO/IEC 18023-3)

— SEDRIS language bindings – Part 4: C (ISO/IEC 18024-4)

— environmental data coding specification (EDCS) that provides identification (designation) of objects and their attributes (ISO/IEC 18025)

— spatial reference model (SRM) that handles position, orientation and spatial reference frames (ISO/IEC 18026)

— data representation model (DRM) that models the relationships between objects and their representations as described in ISO/IEC 18023 series

— application programming interface (API) as described in ISO/IEC 18023 series

EDCS, DRM and SRM all have ISO/IEC managed registries. The EDCS standard and its corresponding registry contain entries for environmental concepts, objects and attributes, with about 1 500 classifications (types of environmental objects) and 1 900 attributes. These entries include a wide range of environmental concepts, from natural phenomena to human-made objects, and a large array of attributes and units of measure. Many of the EDCS entries are relevant to smart city modelling and simulation, and new entries can be added through registration to ISO as these are required. Since SEDRIS was developed primarily for military environments, a considerable number of entries can be included to populate civilian urban environments.

SEDRIS is extensible through the ISO registration system for EDCS and SRM for new objects, features and coordinate systems. It includes Levels of Detail and georeferencing. While developed for military use SEDRIS can also represent civil assets and systems such as a smart city.

The HAnim standard[2,3] was developed for humanoid representation. HAnim supports a wide variety of articulated figures, including anatomically correct human models, incorporating haptic and kinematic interfaces to enable shareable skeletons, bodies and animations. HAnim extensions to facial animation and internal organs are under development.

4.3 Visualization standards

X3D and HAnim can be used for visualization of smart cities. X3D standards comprise three series: ISO/IEC 19775 (architecture), ISO/IEC 19776 (encodings), and ISO/IEC 19777 (language bindings). HAnim standards are ISO/IEC 19774-1 (architecture) and ISO/IEC 19774-2 (motion data animation).

X3D is a standard for 3D web graphics and is designed for viewing 3D content.[4] Existing models of cities, such as those using CityGML, can be converted to X3D for viewing on the web. X3D provides a system for the storage, retrieval and playback of 3D scenes within an open architecture to support a wide array of domains and user scenarios. It has componentized features that can be tailored for applications such as engineering and scientific visualization, medical visualization, training and simulation.

The most basic X3D part is a *node.* Typical nodes are box, colour and shape. X3D *components* are groups of nodes that perform similar operations. The shape component, for example, includes nodes for shape appearance, material, fill properties, line properties and two-sided material. *Profiles* are collections of components.

X3D has a variety of encodings, namely XML, VRML, Compressed Binary and also JSON[4] and has language bindings for C, C++, C#, JavaScript2), Python3) and Java4) consistent with app development for mobile devices.[5] X3D includes georeferencing, appearance, topology, fast rendering and its node/component/profile approach leads to extensibility. X3D v4 will use HTML5 while the JavaScript framework X3D document object model (X3DOM) removes the need for plugins and runs on any browser.

HAnim can also be considered as a visualization standard supported by X3D as described above.

Many graphics standards such as the graphical kernel system (GKS) ISO 7942 and the programmer's hierarchical interactive graphics system (PHIGS) ISO/IEC 9592 and ISO/IEC 9593 are supported as they are still in use although now obsolescent. The most relevant imagery standards that can be used for smart cities are:

— ISO/IEC 15948 portable network graphics (PNG): a raster graphics file format that is widely used on web browsers. It was first standardized in 2004.[6] PNG has advantages over other common graphics formats such as GIF and JPEG with wider ranges of transparency options and colour depths[6].

— ISO/IEC 12087-5 basic image interchange format (BIIF): a standard for image interchange used principally for military surveillance applications[7].

4.4 Mixed and augmented reality standards

MAR spans the spectrum from reality to virtuality. It combines real and virtual data for visualization, rendering and other uses. The MAR standards implicitly include both representation and visualization. Several mixed and augmented reality standards are emerging, including:

— sensor representation in MAR (ISO/IEC 18038)

— MAR reference model (ISO/IEC 18039)

— live actor and entity representation in MAR (ISO/IEC 18040)

— information model for MAR content (ISO/IEC 3721-1)

The MAR reference model (ISO/IEC 18039) defines the scope and concepts for representing mixed and augmented reality, and provides a general system architecture for MAR applications, components, systems, services and specifications. However, it does not specify how a particular MAR application should be designed, developed or implemented, nor does it specify MAR implementation bindings to programming languages.

For a virtual smart city, ISO/IEC 18040 can be applied to include human interaction. A human could be immersed into a computer representation of a city.

For a real smart city, MAR standards such as the reference model and information model, combined with the use of SEDRIS and X3D standards, could assist a resident with many tasks such as navigation, points of interest (for example, restaurant locations and menus) selection, traffic warnings and shopping through apps on smart phones.

2) JavaScript is a registered trademark of Oracle Corporation. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC.

3) Python is a registered trademark of the Python Software Foundation. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC.

4) Java is a registered trademark of Oracle Corporation. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC.

5 Concepts

5.1 Overview

A smart city exploits modern information and communication technology (ICT) capabilities to provide greater efficiencies for urban areas. The smart city concept integrates ICT and various physical devices that can be connected to the Internet of Things (IoT) to optimize the efficiency of city operations and services and connect to citizens. Smart city technology allows city officials to interact directly with both community and city infrastructure to monitor city activities.

Some smart city concepts are illustrated in Figure 1. The illustration shows smart city concepts such as smart energy management, smart industry, smart government, smart office, smart traffic management and parking, smart health and smart buildings. Vast amounts of data can be streamed from devices embedded in a smart city, such as cameras, wearable health and fitness devices, environmental sensors and smartphones. Some of this data can be processed and visualized in near real time to aid decision makers for immediate action. This is an example of big data that requires specialised analysis tools to process it.

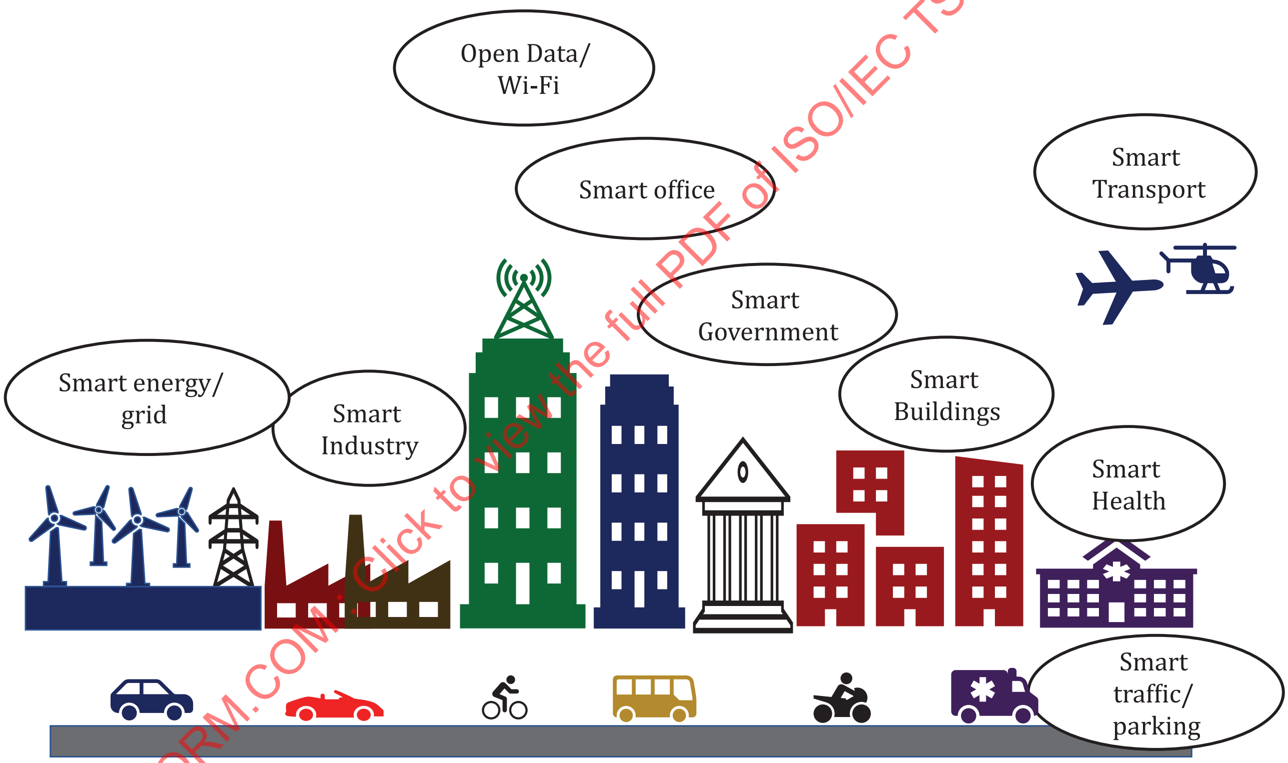

Figure 1 — Smart city concepts

5.2 Modelling, representing and visualizing smart cities

Developers and users of any smart city need tools to evaluate and examine options and predict outcomes. Parts or all of a smart city may need to be modelled and smart city functions need to be simulated to evaluate possible results. Such models and simulations may also need to be networked to produce larger integrated models and simulations. In addition, models and simulations developed during the design phase may be reused/repurposed during the execution and operation phases.

A smart city collects vast amounts of data through its sensor systems. These data can include weather readings (temperature, pressure, humidity, precipitation), environmental readings such as air quality, transport features and parking availability, energy consumption and waste management, solar irradiance, utility data related to buildings, measures for pedestrian levels and crowd behaviour, commercial data (such as financial transaction data) and likely air traffic control data for drones and other aerial vehicles. Modern cities already have networks of cameras for security, and this further creates large quantities of video data for analysis. Data generated from social media and health and fitness devices can also be considered smart city data and may also need to be visualized. For example, analysis of social media data can be used for monitoring sentiment about current issues[8].

The ability to visualize complex data, events and interactions within a smart city is a key factor in evaluations and assessments. To interact with pertinent data and parameters, models and simulations of a smart city should be able to provide access to the underlying information. Therefore, visualizations are not just a rendered scene.

The simulations may require standardized ways for representing an integrated environment (that can include weather, terrain, objects, buildings, building interiors and multi-levels, etc.), with rich attribution of their objects and content. That content can be depicted visually, using AR, VR or traditional visualization applications. Standards such as the ISO/IEC 18023 series, ISO/IEC 19775 series, and the ISO/IEC 19774 series focus on solving these representation and visualization problems and are used in a variety of applications for modelling and simulating complex events, including networked modelling and simulation with thousands of players/entities.

The term 'smart city' is used to refer to a real smart city and 'virtual smart city' to describe its digital/simulated representation. A smart city can be either *real* (a built functioning smart city), *experimental* (a city that is planning and testing smart systems for future integration) or *conceptual* (referring to a yet to be built smart city that is in the planning stage). To represent and visualize such a smart city, a *virtual* (computer generated) smart city can be developed.

5.3 Smart city object

Smart city objects include representations of 'smart' objects such as sensors, smart buildings and smart cars but can also include the many objects that are not intrinsically 'smart' such as naturally occurring hills, rivers and clouds. These natural and artificial smart city objects can be further decomposed. Natural objects include terrain, geographic features, life forms, vegetation, water bodies and weather artefacts while artificial objects include the built environment (buildings, roads, city furniture, lights), vehicles, sensors and other miscellaneous items.

A real or virtual smart city can then be considered to consist of (real or virtual) smart city objects each with associated geometry, spatial properties and other attributes. For example, a building's attributes could include type of building, height, number of levels and construction details. A smart city object can also have functions, such as mobility for a vehicle or sensing operation for a sensor.

A virtual smart city is encapsulated in a spatial reference frame with an associated coordinate system. A virtual smart city object is located and oriented within this reference frame and can be considered as a base class. In general, a smart city object can be either a naturally occurring object or an artificial (human-made) object that inherits its properties from the base smart city object as shown in Figure 2.

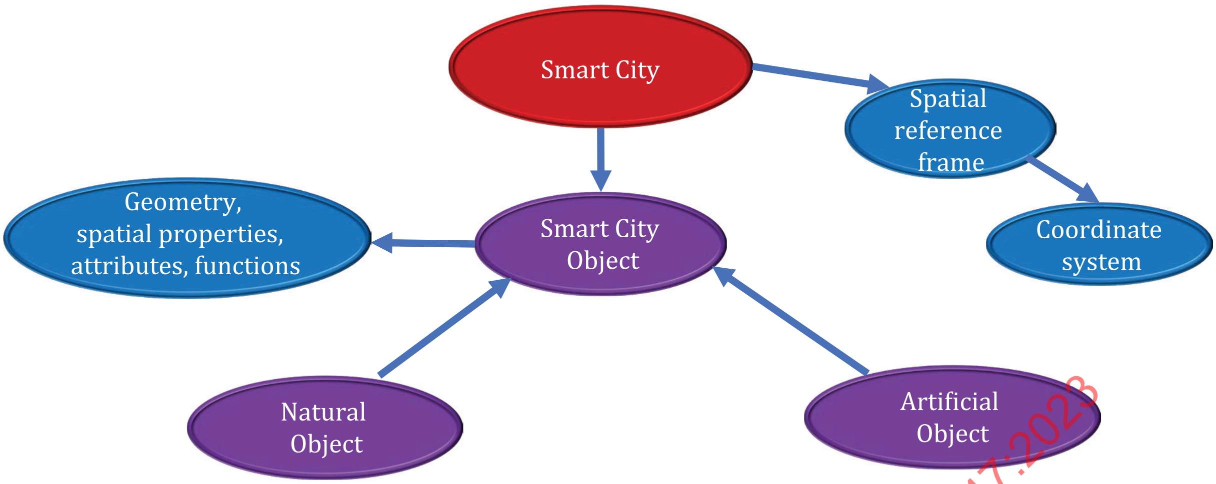

Figure 2 — Concept of smart city object with relation to smart city

The smart city object can be extended to include additional subtypes that need to be represented and visualized as shown in Figure 3. These smart city objects can be identified as either:

a) An **environmental** feature representation that includes geographical features of terrain, water bodies and mountains and also weather such as cloud, rain or fog. Each feature includes spatial information and also descriptors for its specific characteristics such as extent and strength.

b) A **life form** representation that includes location/orientation and information such as level of articulation and animation state. Semantic information could include features such as gender, age, employment status and role.

c) An **urban feature** that is typically a building or vehicle. Its representation consists of shape, material, location/orientation and semantic information. An interactive visualization displays these geometric and appearance properties as well as the semantic information such as building or car ownership.

d) A **sensor** representation that consists of sensor type, function and location/orientation. It is assumed that material is not generally required for visualization of smart city sensors. Sensors are generally small so that their appearance is less important than their functionality in a smart city representation. Semantic information describes the type and function of the sensor.

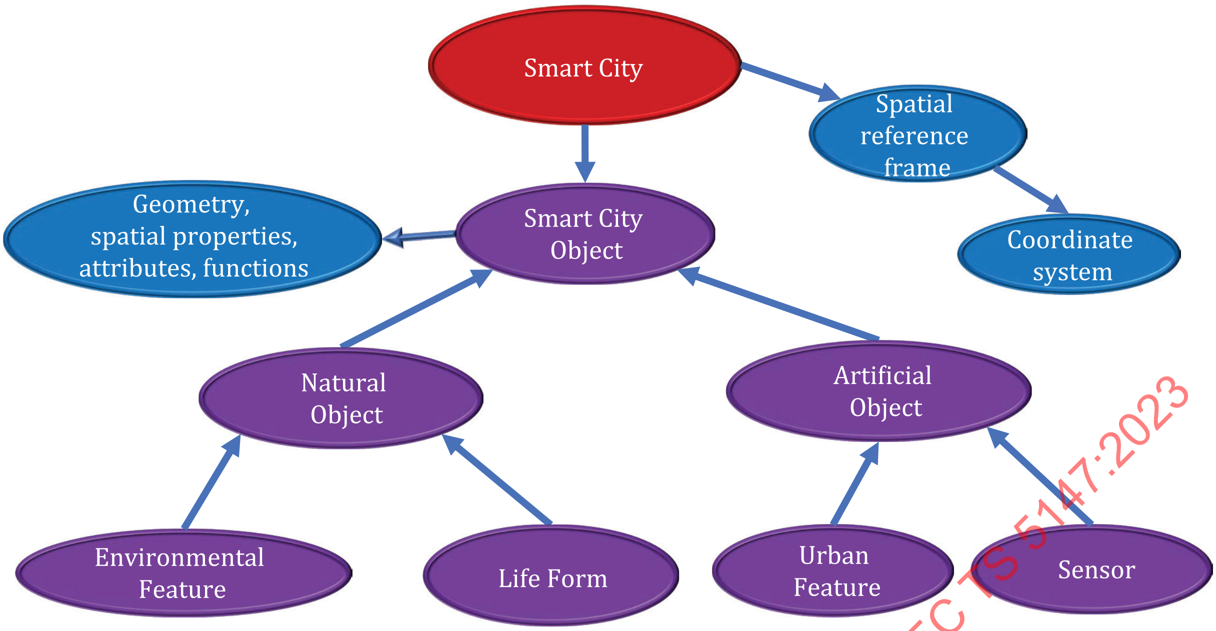

Figure 3 — Further decomposition of smart city objects

5.4 Guidance for representation of smart city objects

To study representation and visualization for smart cities, the state of 3D city modelling is first reviewed. 3D city modelling is actively being pursued by many nations and being applied to tasks such as urban planning, visualization, energy use modelling and decision making.

See Reference [9] for an examination of the state of 3D city modelling. This reference defines a hierarchical terminology (spatial operations, use cases, applications) to develop an approach to segment and categorize the diverse uses of city models. The computer representations and models are referred to as (3D) virtual cities.

Representation of a smart city needs to include both physical/geometric data such as buildings, roads, water bodies, as well as semantic data and physical properties. Semantic data comprises information such as property ownership, laws and traffic rules. Physical properties comprise quantities such as air quality, traffic noise, weather state and pedestrian flow. Further, this data needs to be geospatially associated with the (3D) virtual city.

Smart city data can be categorized as being associated with the following five sources:

a) the natural environment of terrain features such as hills, water bodies and also weather artefacts (clouds, rain etc)

b) the built environment of city infrastructure, such as buildings, roads, tunnels, bridges and their physical and semantic properties

c) dynamic entities, such as vehicles and life forms (humans and animals) that move around the urban environment

d) sensors including IoT sensors, e.g., for pollution, security and traffic noise

e) other sources, such as smart devices that produce and consume online social media data

Table 1 lists the categories of data that may be required and used in representing a smart city, along with examples. Physical and semantic properties are associated with many of the categories listed, including natural (such as terrain) and human-made objects (such as buildings). The table also includes categories of data that may not necessarily be associated with a smart city object, but can be important in smart city applications. Data from social media networking platforms are examples of such data.

Table 1 — Categories of data associated with smart cities

Data source	Example
Natural environment entity	Hills, water bodies, terrain
Built environment entity	Buildings, roads, bridges
Dynamic entity	Cars, aircraft, humans, animals
Network	Transport systems, utility networks
Sensor	Temperature, pressure sensors, bio-sensors, chemical sensors
Weather	Clouds, rain
Physical property	Noise levels, pollution readings, wind flow
Semantic property	Legal information, traffic rules
Analytical	Traffic as time series, energy use over time
Imagery	Photos, maps
Video	CCTV footage
Audio	Traffic noise, crowd noise, machinery, emergency warnings
Haptics	Interaction with surfaces in virtual world
Multidimensional	Health data (x, y, z, t, pulse rate.) such as might be generated by a wearable health monitor
Social media	Twitter™, Facebook™, Instagram™
Twitter™, Facebook™, Instagram™ are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of these products.	

A means of representing, modelling and simulating smart city objects and their associated data follows these guidelines:

— Capability of generating digital representations of real-world objects. These can be either 2D or 3D depending on circumstances.

— Capability of mapping relationships and interactions among objects in the real world into the virtual world

— Capability of using multiple coordinate systems and reference frames

— Capability of associating semantic data with the relevant smart city object

— Capability of georeferencing virtual smart city objects with their location in the real world

— Ensuring laws of physics are followed; for example, a virtual car drives on the road rather than over or under it.

An integrated approach to representation is required so that the various (virtual) smart city objects exhibit the same behaviours or functions and maintain the same inter-relationships as their real-world counterparts. For example, buildings need to be integrated with both natural and built environments (in their representation) and dynamic entities need to access that representation to behave properly during simulations. In the virtual world, significant virtual buildings are located at specific fixed locations corresponding to their real-world locations; virtual cars obey physical laws and behave the same way as their real-world counterparts; virtual lamp posts are at ground level on streets; virtual tunnels are placed underground; virtual water bodies are separate from buildings, and so on.

This highlights the importance of an integrated approach to representation, where data categories such as spatiotemporal and physical properties are associated with the built and natural environment.

5.5 Guidance for visualization of smart city objects

All the items listed in Table 1, once represented digitally, can be visualized/presented (including audio and haptic rendering) using appropriate techniques that are described below in Clause 6. A visualization system used in smart city applications follows these guidelines[10,11]:

a) Capability of representing and rendering virtual smart city objects as sets of geometric polygons.

b) Capability of representing and rendering virtual smart city objects to display properties such as colours, textures and materials through appropriate graphics functionality.

c) Rotation and translation of virtual smart city objects and/or the user's viewpoint so that objects can be viewed from different perspectives. This can allow users to move through a virtual smart city and view events from different perspectives and under different conditions. 2D and 3D geometric transformation functionality is required.

d) Interactivity with virtual smart city objects. A user needs to be able to interact with a virtual smart city object (such as hovering over a building model with a mouse) and querying its properties (for example, dimensions and occupancy).

e) Animation for many virtual smart city objects/models such as vehicles.

f) Levels of detail (LOD) to enable visualization load balancing for different distances.

g) Support for different coordinate systems and spatial reference frames. For example, a 2D reference frame may suffice for some applications, while multiple 3D reference frames may be needed for others.

h) Mathematical functions to enable analysis and visualization of data such as time series.

i) Appropriate lighting / shading functionality to enable visualizations in different weather and at different times of day.

These guidelines all refer to visual presentation. Other modalities such as audio and haptics have different modes of presentation.

5.6 Guidance for representation and visualization of smart cities

A smart city is composed of smart city objects. The previous clauses describe guidelines for smart city object representation (5.4) and visualization (5.5). This clause describes guidelines for representing and visualizing smart city content.

To represent and visualize a smart city, firstly a virtual (computer generated) smart city needs to be developed that contains a data representation of all the information related to the smart city. Secondly a process is required to make the information in the data model available to the end user. This process is visualization, or more generally presentation to include non-visual information.

To represent and visualize a smart city, these guidelines can be followed:

a) Representation and visualization of smart city objects as described in the previous clauses.

b) Mapping of semantics and functions for each smart city object into the virtual world.

c) Mapping of relationships and interactions among smart city objects into the virtual world.

The first guideline implies the need for accurate spatial and temporal representation of objects in the virtual world. Objects in the virtual world have identical characteristics (or as close as required for the fidelity needed) to those in the real world. A building in the virtual world, for example, has the same geometric features, location and orientation as its real-world counterpart relative to the scale in the virtual world.

The second guideline demands proper definitions, concepts and characteristics for each smart city object such that it can be recognized and analysed in the virtual world. These can include characteristics such as materials, units and specified or measured values of the object's characteristics and functions. The functions are related to the reason why the object exists in the real and virtual worlds.

The third guideline includes appropriate representation of relations and interactions between objects in the smart city. Objects can have cause and effect depending on their functions in the real world. These relations and interactions can be represented in the virtual world in an identical manner.

When visualizing and interacting with a virtual smart city, a representation model is necessary to describe its functioning. As shown in Figure 4, a virtual smart city can include components such as simulated buildings and roads, natural features, people and sensors such as cameras. Some objects, particularly unique buildings, are geo-specific, such as a representation of the Empire State Building in New York or the Eiffel Tower in Paris, while for other objects, such as trees, geo-typical (generic) representations suffice for most use cases.

Figure 4 — Smart city visualization: a 3D cityscape with a virtual humanoid wearing a wrist smart sensor [12]

6 Representation and visualization methods for smart city data categories

6.1 Guidelines for representation and visualization

Based on the discussion in Clause 4, guidelines can now be developed for smart city representation and visualization or more generally presentation to include non-visual data categories. In Reference [13], seven possible data types for visualization were described: 1D, 2D, 3D, temporal, multidimensional, tree and network data types. This can be used as a guide to the different categories of smart city data that are required to be visualized. A further useful guide to the types of charts used for data visualization is provided by Reference [14] that identifies 16 different chart types that are commonly used.

Considering these approaches, a comprehensive list of the categories of data and corresponding representation and presentation / visualization techniques for smart cities is provided in Table 2. This list is not exhaustive as smart cities evolve with associated new smart systems and apps, new categories of data or variations within the same categories. The categories listed in this table are identical to those in Table 1 with the provision that physical properties have been split into scalar and vector properties.

Where they are several methods for presentation / visualization, primary and secondary methods are described.

Table 2 — Representation and visualization methods for smart city data categories

Category	Example	Representation method	Presentation / visualization method
Natural environment entity	Natural environment - terrain, geographic features such as valleys, ridges, trees	Polygons, GIS formats-raster, vector, point clouds	3D visualization / 2D visualization
Built environment entity	Built environment - building, bridge, road, tunnel, fire hydrant, sidewalk, etc.	Polygons, GIS formats-raster, vector, point clouds, BIM standards such as ISO 19650 [15]	3D / 2D visualization
Dynamic entities (vehicles and life forms)	Movement of vehicles, people, animals	Polygons	3D / 3D visualization
Network	Transport network; utility networks	Polygons	2D / 3D map or 2D /3D object
Sensor	Electronic sensor, chemical sensor, CCTV camera	Polygons	Generally not visualized, but some such as cameras may fall into the Built environment entity category
Weather	Clouds over city; rain/snow, wet roads	Polygons, contours, attributes	Overlaid imagery; contours on map
Spatiotemporal	Implicit in all data categories	Set of attributes	Not visualized explicitly
Physical property (scalar)	Noise levels, pollution readings, energy use	Attribute	Text, symbol or shape, overlay, heatmap etc
Physical property (vector)	Wind flow, flow of data around city	Vector data	2D or 3D Vector field (lines)
Semantic property	Legal information; traffic rule	Text data	Text, 2D or 3D symbol or shape, overlay, heatmap etc
Analytical	Traffic as time series, energy use over time	Structured or unstructured data	Graph (2D / 3D)
Imagery	Photo ID, map	Imagery formats – png, gif, jpg, map file	2D images
Video	CCTV surveillance footage	Video formats – MPEG, AVI etc	Video
Sound	Traffic noise, emergency warnings	Audio formats - MP3, AAC etc	Audio
Haptics	Interaction with control system (e.g., of train), playing field surface	Emerging standards from ISO TC 159 – ISO 9241 series	Data glove
Multidimensional	Can include combinations of above categories of data, e.g., (x, y, z, t, pulse rate) as generated by a wearable health monitor	Multidimensional arrays	Varied; nD visualization approaches
Social media	Social media feeds such as Twitter™	Html and media formats	Heatmaps, graphs, word clouds

Physical objects can be represented internally as polygons, point clouds or in Geographic Information System (GIS) formats while properties can be represented by descriptors such as colour. 3D graphics systems generally work with polygons. Most categories of data may also have time variance. Traffic levels, for example, can be represented both spatially and in time. Semantic properties, such as ownership and population density, can also vary over time. Both these static and dynamic data need to be modelled and visualized using appropriate techniques.

For the physical characteristics, OGC standard CityGML provides an outline of what is needed to model a city and potentially a smart city.[16] CityGML is organized into a set of modules, with a core module and extension modules. The core module contains the components of the city data model, while the extension modules contain templates for artificial and natural objects that comprise a modern city. CityGML provides a static representation of a city and does not include dynamic components such as vehicles, humans and changing weather.

The European COST (European Cooperation in Science and Technology) Project "Semantic Enrichment of 3D City Models for Sustainable Urban Development" was established to explore ways to enrich 3D models with urban knowledge to extend their functionality for sustainable urban development. This approach maps data features to abstract visual objects and then maps these objects to concrete visual objects for rendering. Selected visualization techniques include cones representing pedestrian traffic,[19] coloured spheres used to show air quality[17] and glowing roads to indicate traffic flow[20].

Details on categories of data identified in Table 2 and their appropriate representation and presentation techniques are provided in the following clause. Note that not all data categories require representation in a virtual smart city.

6.2 Representation and visualization methods

6.2.1 Natural environment

The natural environment comprises all naturally occurring animate and inanimate things. In the urban context, the natural environment refers to the physical configuration of landscape including elevation, slope and the shape of natural features. These can be visualized using 2D / 3D graphics. Relief can be represented by techniques such as contouring, layer tinting and shading.[21] Internally, natural environment objects are represented as sets of polygons, point clouds or in various GIS raster or vector formats.

Representation of the natural environment needs to include geospatial information, semantic data associated with the natural environment objects and georeferencing of these with their location in the real world. This can be a mix of specific models for significant items like rivers and generic models for trees and vegetation.

6.2.2 Built environment

The built environment includes buildings, roads, bridges, tunnels and city artefacts such as lamp posts, awnings, trash bins, kiosks, etc. The geometry and appearance of these 3D objects can be presented using 3D graphics with standardized rendering capabilities such as X3D that has a library of primitives (nodes) for shapes, components (sets of nodes) and profiles for different applications[4].

Representation of the built environment needs to include spatial information, semantic data associated with the built environment objects and georeferencing of these with their location in the real world. A virtual New York has a specific model of a significant building like the Chrysler Building at the same relative location as its real-world counterpart. Generic models could be used for the many residential dwellings. These can be similarly represented internally like natural environment objects.

Building Information Modelling (BIM) standards include ISO 19650-1:2018.[15] These provide guidance on concepts and principles for information management for built assets across their life cycle.

6.2.3 Dynamic entities

City models such as CityGML have generally focussed on the static aspects of cities. At additional detail, moving vehicles and life forms (people and animals) could also be visualized using 2D / 3D graphics and animation. Individual humans can be represented using the HAnim standard (ISO/IEC 19774) that defines body segments as meshes of polygons.[2] Crowd behaviour in a virtual smart city would require a means of representing and simulating groups of people in the virtual world.

These dynamic entities need to be represented in the virtual world so that they have the same characteristics and behaviours as their real-world counterparts. In a simulation of a smart city, vehicles are constrained to roadways and have similar characteristics (speed, acceleration etc) to real vehicles; pedestrians, birds and animals move like their real-world counterparts. Generic vehicle models are normally used for traffic and parking simulations, except for cases involving significant vehicles such as a motorcade. These models are represented internally as sets of polygons.

6.2.4 Networks

Utility, information and transport networks are important components of modern cities and are increasingly significant in smart city applications. Such networks are often hidden from sight since they are generally below ground but are vital components of the infrastructure. Representation and visualization of such networks in both 2D and 3D is required for smart cities. The London Underground provides an example of a city transportation network.

Networks need to be integrated with both the natural and built environments (in their representation). A tunnel, for example, frequently has complex geometry that is integrated with city transportation and safety systems. In a smart city, a tunnel could have additional features such as providing traffic advice and warnings to drivers by augmented reality or using smart lighting to convey important information.

6.2.5 Weather

Weather effects like rain, mist or fog can change visibility and vehicle behaviour. This needs to be represented internally in a smart city simulation so that, for example, simulated traffic moves slower in rain or fog. Roads can become slippery after rain or snow affecting vehicle movement. A detailed simulation of weather uses mathematical models to represent weather effects in the virtual world.

Weather can also alter the appearance and other properties of city objects. Buildings can change their appearance, while clouds can affect visibility. Weather maps use contours for properties such as pressure and temperature.

6.2.6 Sensors

Sensors in virtual smart cities can be represented as in ISO/IEC 18038, which defines how a sensor is located and oriented in a virtual world with its appearance and properties. Some sensors, such as CCTV cameras, can be visualized in the same manner as 3D built environment entities or dynamic entities. Figure 4 includes a wearable wrist sensor that may be a fitness or health monitoring device.

However, visualization of sensors in smart cities is less important than representing their functionality. A smart city deploys vast numbers of sensors to monitor the environment, traffic, parking, energy use and many other applications. Seoul, for example, is installing 50 000 IoT sensors to gather environmental and social movement data across its urban area.[22] Visualization of this myriad of sensors is unlikely to be required in the virtual world.

6.2.7 Spatiotemporal data

Spatiotemporal data is implicitly required for all smart city data categories. Positional, orientational and temporal information is required to geolocate all smart city objects, features and other data in the virtual world. Many of the data categories in Table 2, such as pollution levels or noise readings, include spatiotemporal data.

6.2.8 Physical properties

Physical properties such as temperature, air pressure and air quality can be presented in various ways. If a single value is required at a specific location, textual presentation can suffice. If properties across a region are required, more complex representation and respective presentation, such as coloured overlays or symbols, can be used as shown in Figure 6.

Noise or sound, from vehicle traffic for example, can also be considered a physical property (or a set of physical properties such as intensity and frequency) that could be presented in text or symbolic format (such as decibel level). Sound is further discussed in subclause 6.2.13.

Vector physical properties such as wind flow around buildings can be represented and presented as flow diagrams such as wind flow in the City of London[5] shown in Figure 5.[23] The lines show the direction and strength of wind flow (wind vectors) across the city.

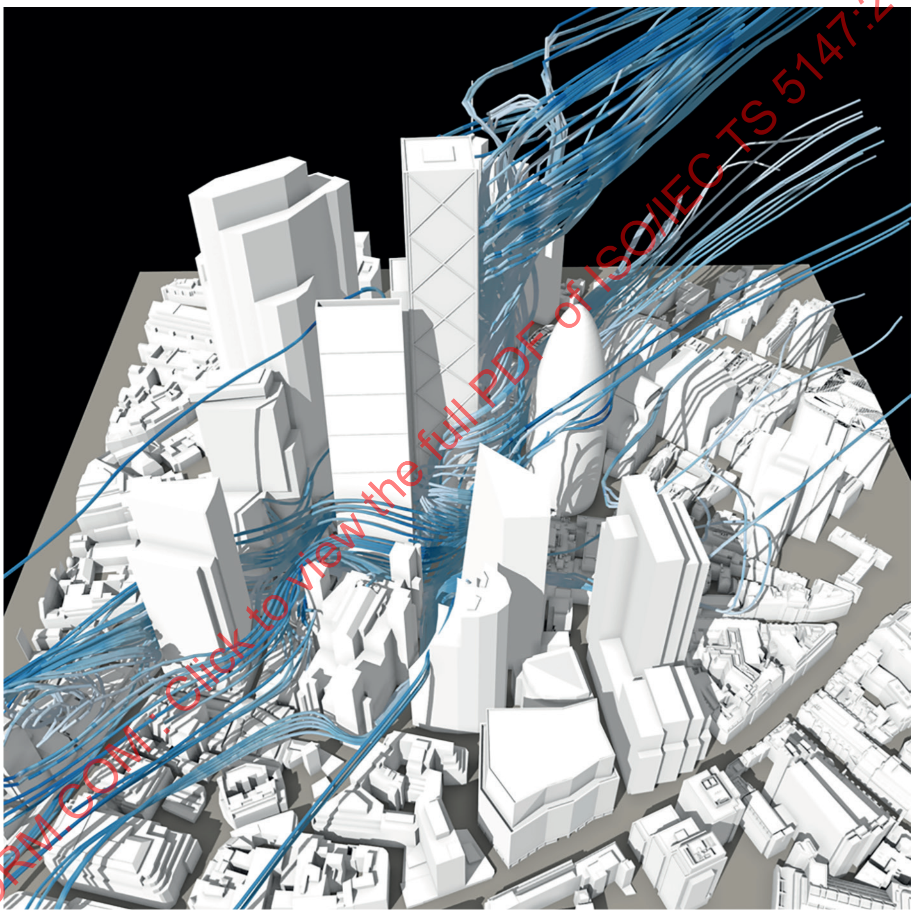

Figure 5 — Computer simulated wind flow in City of London (reproduced from[23] with permission)

While this example shows the physical flow of air around a city, a similar approach could be adopted for the flow of financial transactions or internet traffic data around a smart city.

6.2.9 Semantic properties

Semantic properties can be presented as text, probably in a popup caption overlaid on the virtual smart city. Figure 6 shows smart city properties represented and presented as shapes (cones for traffic), symbols (Wi-Fi cover) and text (labels for buildings and features).

5) The City of London refers to the historic centre and central business district of London.

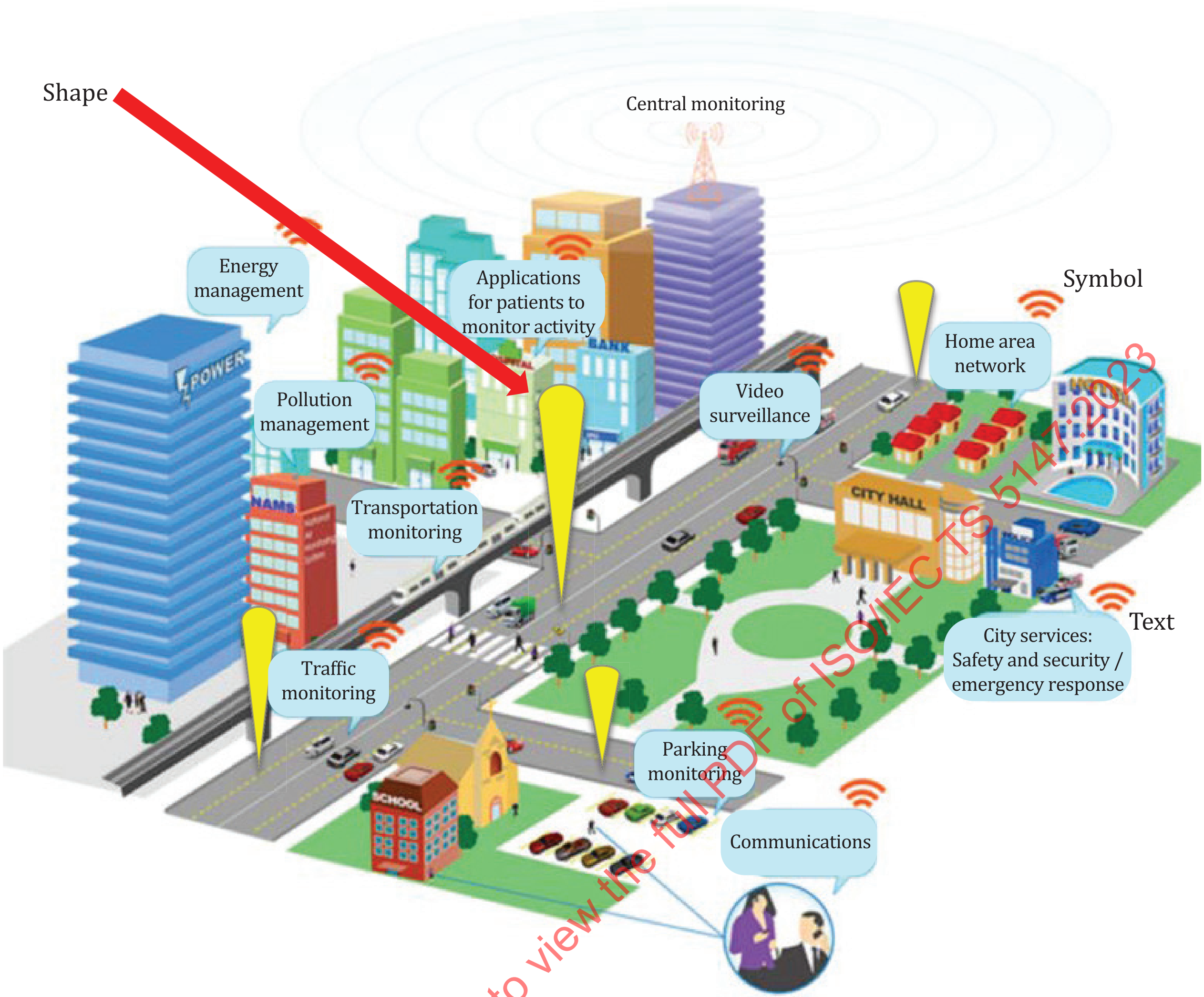

Figure 6 — Presentation of city properties as shapes, symbols and text

More complex urban data can be displayed using heatmaps as done to show occupied and vacant dwellings and lots for visualization of property vacancies across the Louisville (US) metro area[24].

6.2.10 Analytical data

Analytical data can be presented in image or graphical form. As an example, the City of Melbourne, Australia has a pedestrian counting system shown schematically as Figure 7 that takes data from an array of sensors that record when pedestrians pass a specific location.[25] The user clicks on a sensor location where traffic is measured and a time series graph of pedestrian traffic over a given period is produced.

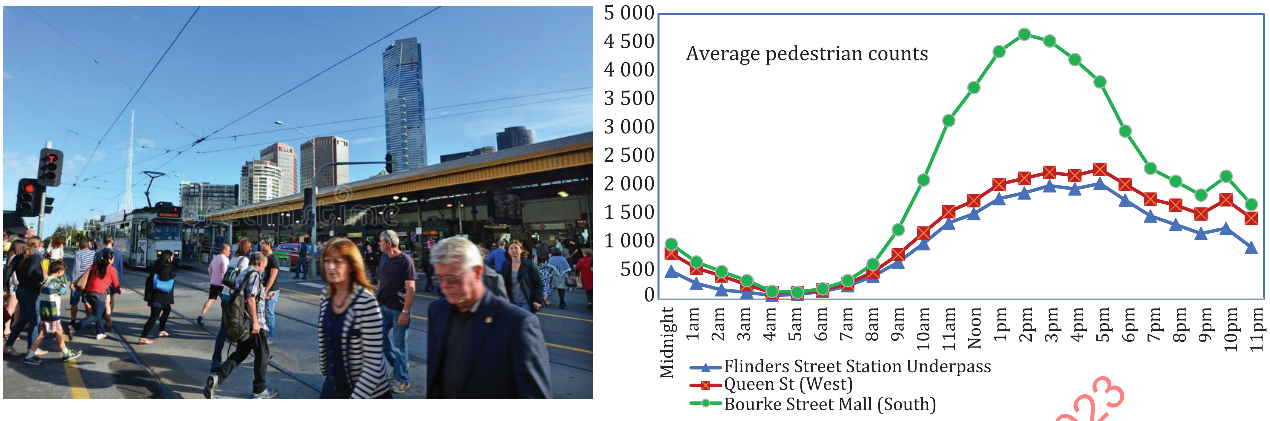

Figure 7 — Pedestrian counting system for City of Melbourne, Australia showing analytical data

Other smart city analytical data may be visualized according to techniques such as tree maps, circle packing, sunbursts, stream graphs and network diagrams[26].

6.2.11 Imagery

Imagery, for example captured from cameras located throughout the smart city and/or virtual smart city, is presented in standard formats such as JPEG (ISO/IEC 10918 series).

6.2.12 Video

Video output is needed to display Closed Circuit Television (CCTV) footage from a smart city and/or a virtual smart city. Standard video formats such as MPEG (ISO/IEC 11172) are used to store and display video.

6.2.13 Sound

Traffic noise, speech or emergency warnings are played/presented using the inbuilt audio players on PCs, tablets, etc. Standardized formats such as MP3 (ISO/IEC 13818-3) and AAC (ISO/IEC 14496-3) are used. Internally, sound files are stored in these formats. Sound was discussed earlier as a physical property in 6.2.8 since it is generally associated with a specific object such as a vehicle. However, there may be applications where a sound object, such as a sonic boom or munitions detonation, can be considered as an entity in a simulation. The concept of a sound object has been described in music[27].

6.2.14 Haptics

Haptics refers to interaction involving the sense of touch. There may be a need to interact with parts of a smart city model using simulated touch via data gloves. Standards for haptics and tactile interaction have been developed within the ISO 9241 series. The emerging tactile internet standards may be applied for interacting with virtual smart cities.[28] A tourist could touch and feel virtual objects in a virtual smart city using haptics with the touch sensation being provided through smart gloves or other wearable devices.

6.2.15 Multidimensional data

Some smart city data can be stored and processed in formats that contain multidimensional content rather than simply 1D, 2D or 3D (e.g. a smart city healthcare system may employ wearable devices that provide data with many dimensions [*x, y, z, t, heart rate, blood pressure,* etc.]) so that an individual's health can be monitored remotely in real time at any location. Figure 8 shows a visualization of multidimensional data using stacked columns on a 2D grid. Location is represented using the X-Y 2D grid while the stacked columns represent additional dimensions.

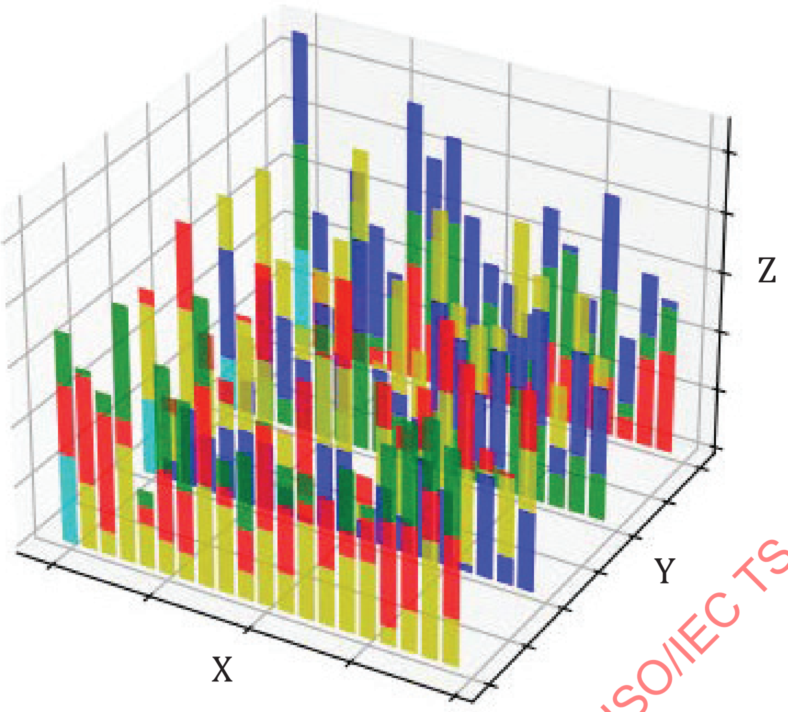

Figure 8 — Representation of multidimensional data using stacked columns on a 2D grid

6.2.16 Social media

Social media data can also be considered as smart city data. Such data can be analysed and presented as heatmaps of usage or other graphical types as shown in Figure 9. For example, Twitter™6) posts in the Brazilian city of Natal during the 2014 World Cup are represented as heatmaps in Figure 4 of Reference [29] showing where the fans were most intensely congregated.

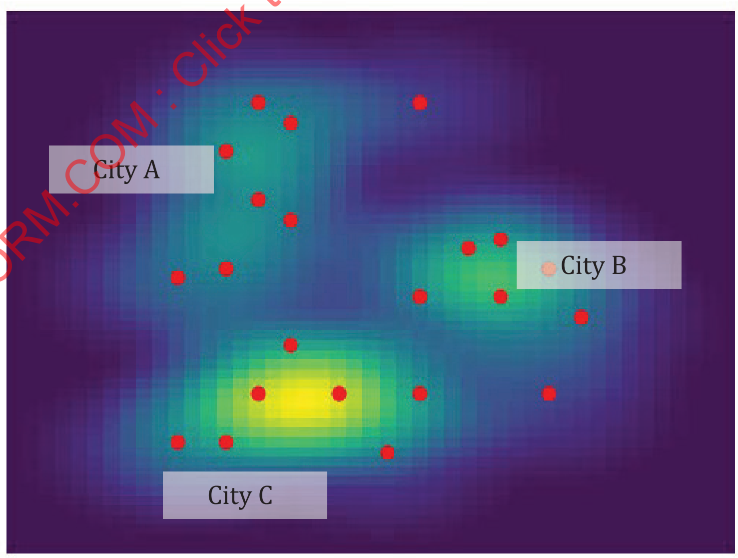

Figure 9 — Schematic heatmap of social media use in several urban areas

6) Twitter™ is the trademark of a product supplied by Twitter, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Social media data is generally unstructured unlike much of the other data categories discussed here. Twitter™ data, for example, is regarded as big data and is classified as raw unstructured data that requires specialised data analytics tools to interpret it. Social media content uses a variety of data formats including audio, imagery and video integrated within web (HTML) environments.

6.3 Mapping of data categories to presentation / visualization methods

From Table 2, it can be seen that there are limited ways to internally represent smart city objects. However, there are diverse ways to present / visualize these objects including non-visual methods. Figure 10 shows a mapping of data category on the left side to presentation method on the right side for smart city data for the various data types. Some data categories, such as physical property, can map to several presentation methods. Physical properties can be variously presented as coloured overlays, symbols or text. Audio and haptic modes are also included. This mapping is for guidance and is not exhaustive.

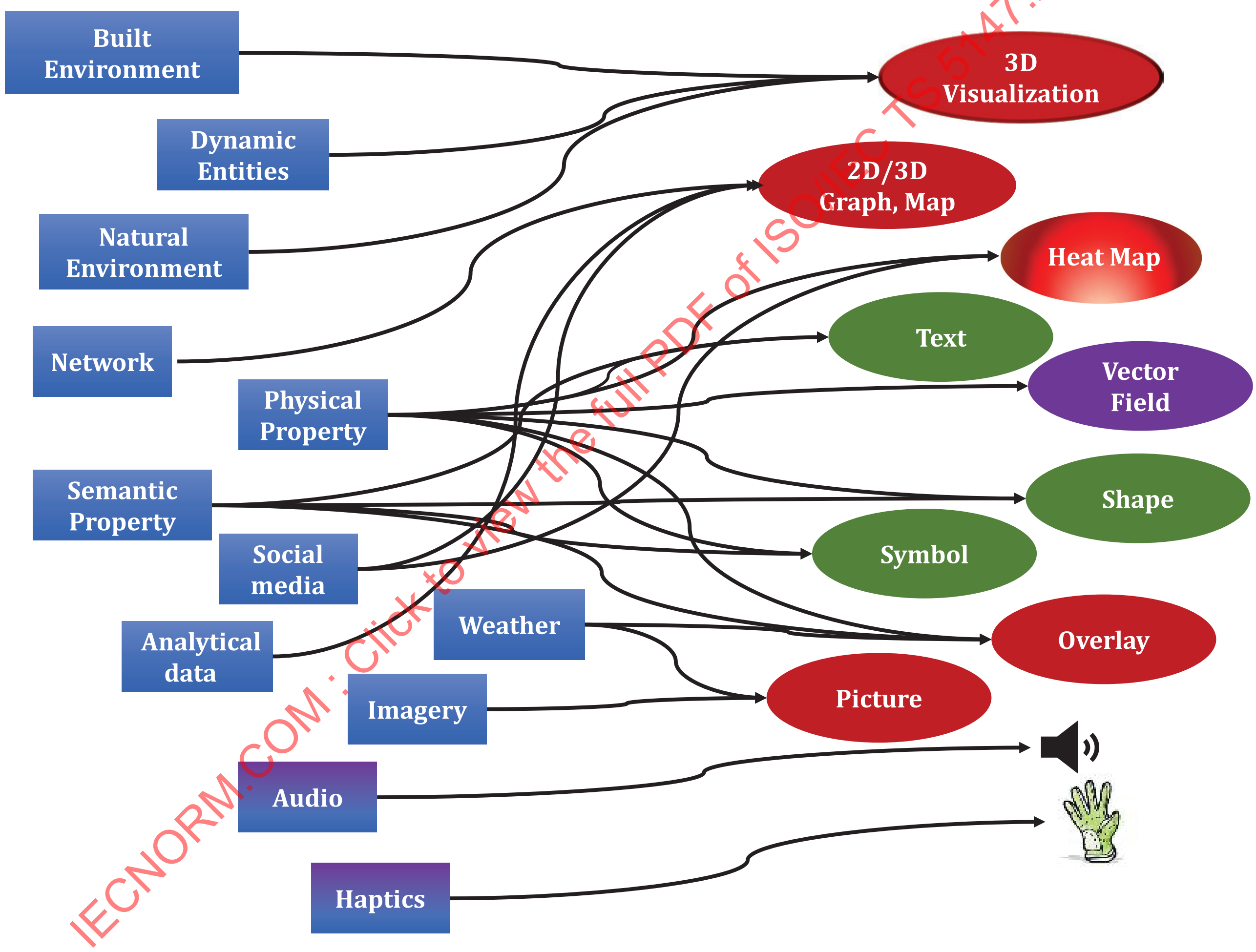

Figure 10 — Mapping of data categories to presentation methods

7 Representation and visualization of smart cities using standards

A standard means of representing smart city objects including humans, devices and environmental aspects is required for the virtual world. This would need to provide an integrated representation of all these features consistent with their behaviours and relationships in the real world. For example, simulated vehicles in a simulated (virtual) smart city are constrained to roadways in the virtual world and obey traffic laws; bad weather would affect traffic behaviour and also appearance in the virtual world; buildings are placed in distinct locations.

From Clause 4, it can be seen that SEDRIS, HAnim, and X3D meet the guidelines in subclauses 5.4, 5.5, 5.6 for representing and visualizing smart city objects and data.

SEDRIS (ISO/IEC 18023 series) provides a rich set of standards that can meet the guidelines for representation. The SEDRIS DRM can represent smart city objects and the environment. The SEDRIS EDCS (ISO/IEC 18025) can provide semantic information for MAR objects as well as 3D objects. The SEDRIS SRM (ISO/IEC 18026) can represent location and orientation with specific coordinate systems and temporal frames. X3D can be used for representing and also visualizing 3D smart city objects.

The semantic information contains concepts and characteristics that represent the properties of smart city objects. This can also have units and values which are necessary for representing the objects with the same functions and characteristics as in the real world. EDCS would be used to provide semantic information for the smart city 3D objects. Sensors need information concerning type and function that can be provided by EDCS. For humans, articulation and animation state can be provided by HAnim.

HAnim (ISO/IEC 19774 series) can be used for representing people in a smart city to the required level of articulation. HAnim extensions for facial animation and internal organs may be required for representing detailed social interactions and healthcare applications.

Figure 11 shows the schematic relationship between these standards. X3D and HAnim combine both visualization and representation capabilities whereas the SEDRIS components relate solely to representation.

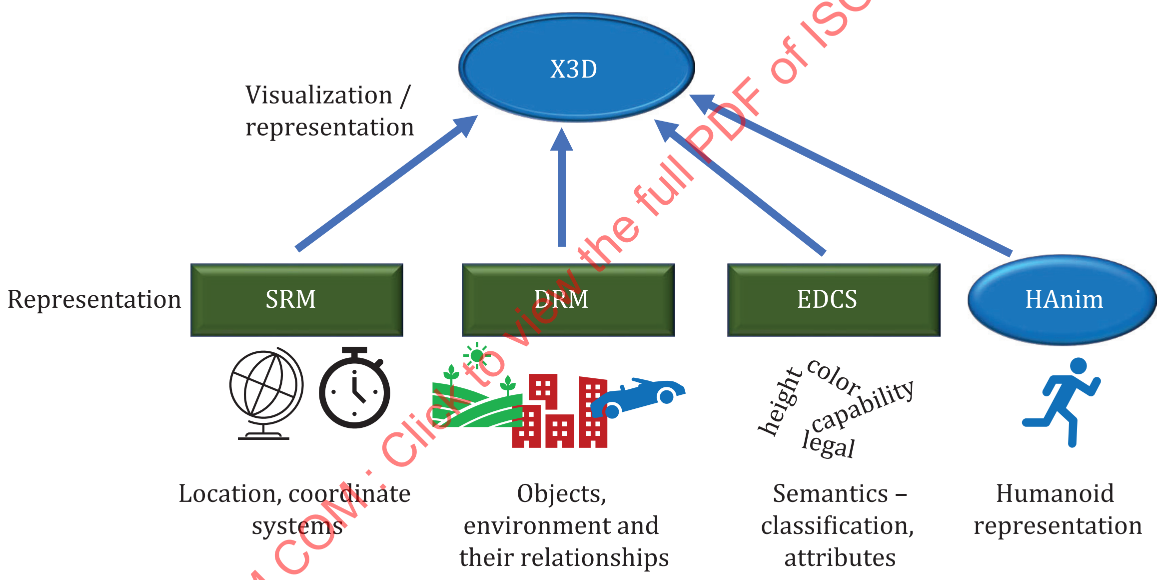

Figure 11 — X3D, HAnim and SEDRIS standards for smart city representation and visualization

8 Use cases

This clause describes a set of use cases for which these standards can be applied.

Smart city use cases generally address city-wide enterprise aspects such as utilities management, public transport, environmental monitoring, healthcare, safety, waste management, traffic and parking. The article at Reference [30] touches on some of the better-known use case examples. Smart cities are highly complex systems that require integration of many standards to adequately address their requirements. Appropriate standards, along with other relevant standards, can be applied to represent, model and visualize smart cities and their systems and processes.

The use cases include: (1) environmental monitoring, (2) parking and transport, (3) tourism, (4) healthcare, and (5) smart city indicators. Details on these are provided in Annex A.

Annex A
(informative)

Use cases for applying standards to smart cities

A.1 Overview

This Annex provides sample use cases for smart city representation and visualization, and highlights how standards can be applied.

A.2 Use case 1 – Environmental monitoring

A smart city has networks of integrated environmental monitoring sensors for parameters such as air quality, temperature, relative humidity, CO, SO_2, $PM_{2.5}$, PM_{10}, UV, noxious organic compounds and noise. These IoT sensor networks can be linked to cloud computing and enable near real time awareness of environmental conditions on devices such as smartphones[31].

Monitoring energy consumption, harmful emissions or water use are important metrics for a city enterprise. The data is collected via (IoT) sensors and fed into a database of environmental data. Such a database is an integration hub for not only the sensory inputs, but also the representation of cityscape data, including terrain, weather, roads, buildings and all the relevant urban content. This integrated database can then be visualized and queried by users to gain insights across time and space. To answer what-if questions, models of the cityscape can be infused with additional parameters to explore the effects and relationships between different factors. This integrated content can be used for analysis, answering higher-level questions, and the results can be interactively inspected.

For this class of use case, SEDRIS (ISO/IEC 18023 series) and X3D (ISO/IEC 19775 series) can be used to represent, present and interact with data. The underlying data model is provided by the SEDRIS DRM to handle all the terrain, weather, urban objects and the relations between them, as well as the required attributes that reflect the measured/sensed data associated with objects and areas/spaces. This integrated data can contain 2D and 3D geometry of the objects, as well as time-based data associated with those objects.

X3D is then used to visualize this integrated data that may be dynamic in nature. The dynamic aspect is then used to visualize either time-varying data that has been captured, or to explore changes injected by the user to evaluate what-if questions.

Figure A.1 provides a very high-level view of the data flow, from IoT sensors collecting environmental data, to an integrated SEDRIS database, to X3D visualization for rendering on a device such as a smartphone. In reality, some physical quantities such as temperature could be fed directly into the smartphone display without needing to be included in an environmental database.

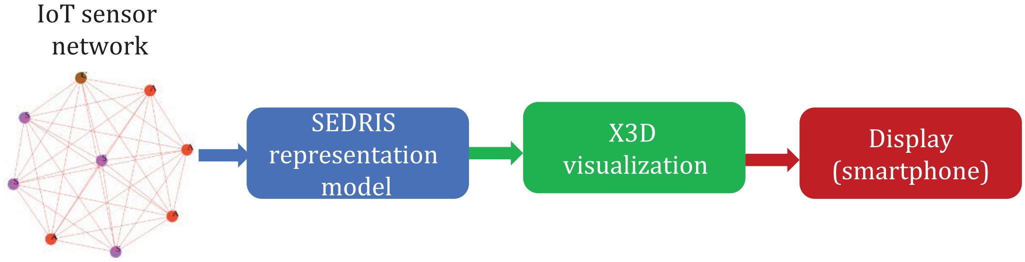

Figure A.1 — Data flow for environmental monitoring

Using the implementations of the SEDRIS standards, the integrated database would provide a 3D model of the city with all the environmental conditions captured and associated with the appropriate objects within that 3D model, including the representation of the objects and their attributes at different times. The implementation of the X3D standards would access and interact with this database to provide the visualization of not only the dynamic cityscape, but also the type and strength of the relevant environmental feature such as harmful emission levels, vehicle traffic patterns, wind vectors and other metrics of interest. X3D implementations also allow connections to other simulation systems over the simulation network that can inform other smart city simulations of these environmental conditions (such as a connecting smart city parking simulation/analysis to environmental monitoring).

Representation of the environmental state, such as air quality, humidity and other atmospheric conditions, is provided by the EDCS and DRM components of SEDRIS. EDCS provides more than 100 feature entries and more than 300 attribute entries associated with atmosphere and airborne particles alone. In addition, there is a significant number of feature and attribute entries related to buildings, urban content and other related concepts. Of course, any required features or attributes currently not in the EDCS can be easily added via registration. The SEDRIS DRM provides an integrated approach for representing and connecting the various objects, features and phenomena. The DRM can also use one or more of the many reference frames and coordinate systems provided by the SRM standard to support the position representation of 2D and 3D city features, atmospheric data and other related content.

Such an integrated environmental database is used to visualize 2D, 3D and 4D content using the X3D standards and its components. These components include the appropriate scene graph nodes for depiction of colour, material and other characteristics of interest; interactive access to scene graph elements for control of viewpoints and scene content; and the desired profiles for use in various visualization applications, including support for handheld devices such as mobile phones.

A.3 Use case 2 – Smart city transport and parking

Efficient and effective transport and parking systems are key components of the smart city vision. Transport and parking are related use cases. Here they are first considered separately and then the application of specific standards to each is discussed.

A.3.1 Use case 2a – Smart transport

Smart transport applies to both public (e.g., buses and trains) and private transport (e.g., cars). The goal of smart transport is to reduce traffic congestion, enable easier city access for public transport commuters and enhance public safety.[32] Further benefits would be to increase productivity by reducing commute times and decrease greenhouse gas emissions through more efficient traffic flow.

Smart transport systems are also known as Intelligent Transport Systems. Many nations are investigating ways to achieve effective and efficient transport systems for their expanding populations.[33] Figure A.2 shows examples of smart transport concepts for smart cities using IoT sensors, satellites, cloud and GPS. These include vehicle-vehicle, vehicle-grid, signal-vehicle, vehicle-pedestrian and vehicle-sensor communication to optimize traffic flow by informing drivers of the best routes and providing warnings about hazards, helping commuters make informed choices about public transport, and enhancing their safety[34].

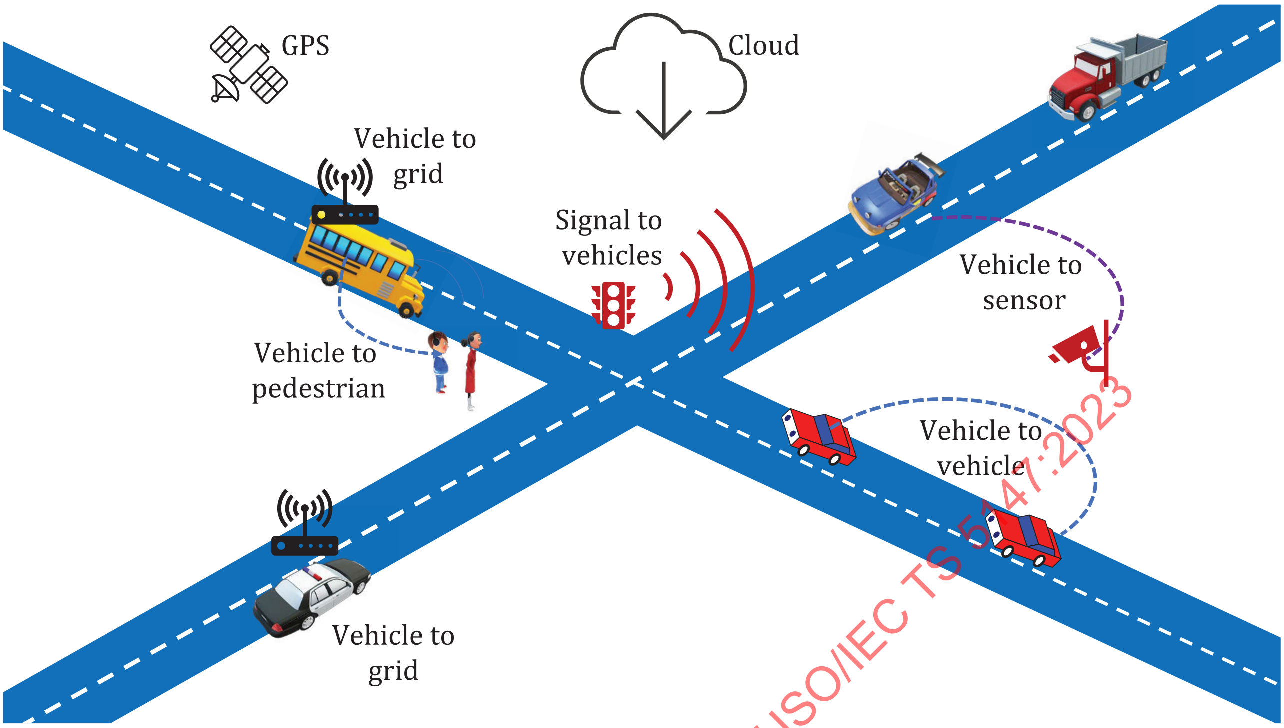

Figure A.2 — Examples of smart transport system concepts in smart city

A.3.2 Use case 2b: – Smart parking

A smart parking system is shown in Figure A.3. Here the car spaces are instrumented and can signal their status as occupied (red), vacant (green), becoming vacant (orange) or electric charge capable (blue). Incoming vehicles would communicate with the car parking system and be routed to the most appropriate parking spot or be advised on other appropriate action such as waiting for a vacancy. For this system, a 2D visualization would be adequate since there is no requirement for 3D.

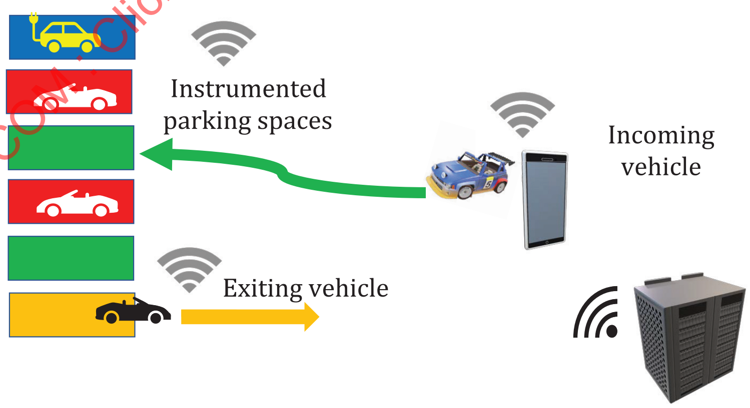

Figure A.3 — Smart parking system concepts

A.3.3 Standards for transport and parking

Both these use cases (2a and 2b) require models of transport and parking infrastructure (roads, traffic lights, parking lots) as well as vehicles (cars, buses, trains) and even human pedestrians. These need to be geospatially referenced with locations of dynamic elements (vehicles) continuously being updated. Visualization would be essential for city planners and managers to develop, trial and demonstrate such systems using simulation.

To provide models of the transport and parking assets, DRM and EDCS, along with suitable coordinate systems from SRM (local to city and parking areas) can be used to represent the required content. EDCS has feature and attribute entries related to vehicles, roads, traffic and transportation that provide the semantic data. DRM constructs can provide the data organization and relationship semantics. As appropriate, 2D and 3D references frames from the SRM would be used to support local and global coordinates and orientations of vehicles. For the parking model, a rigorous 3D geospatial coordinate system may not be needed – a local 2D flat earth system may suffice. Likewise, detailed 3D representations of vehicles, roads and parking facilities may not be required – 2D renditions or even representative symbols can suffice.

If additional features are required such as different vehicle or road types, these can readily be added to EDCS via registration. Further, new coordinate systems can also be included through the SRM registration process. Representation of pedestrian movement, whether typical or actual (sensor based), can be modelled using HAnim that provides the capability to animate humanoid figures, in this case pedestrians walking around city streets, an often-neglected feature of city transport systems.

X3D can be used to visualize these objects in real or faster than real time. The X3D archive has examples of visualizing vehicles and transport infrastructure.[35] X3D has sophisticated 3D geometry, georeferencing, appearance and extensibility that can be applied to render parking and transportation systems[36].

Further, the Distributed Interactive Simulation (DIS) X3D component enables simulation data to be broadcast to other simulations and also receive updates from those simulation.[37] A transport system could communicate its status with other smart city models and simulations such as weather to continually update users and city managers on weather conditions likely to affect mobility and traffic conditions.

Figure A.4 shows a schematic view of how SEDRIS can represent a city transport / parking system and enable visualization by X3D.

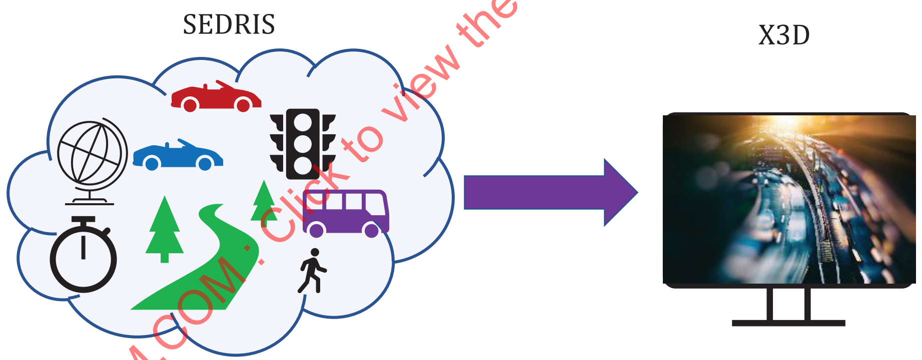

Figure A.4 — Schematic view of SEDRIS and X3D for transport model representation and visualization

In summary, X3D and SEDRIS have the capability to support both representation and visualization of smart city transportation. These robust ISO standards have over 20 years of evolution and industrial use and can readily be extended to handle future smart city modelling applications.

A.4 Use case 3 – Smart city familiarization and tourism

A key feature of a smart city is the ability to inform its citizens and visitors of its attributes. A first-time visitor to a smart city can navigate, locate tourist attractions and restaurants, attend business, entertainment and sporting events, and even be able to converse with the residents through smartphone apps if unfamiliar with the local language. The visitor can also be informed of crowd behaviour and receive warnings of incidents, such as traffic issues or crime in areas where he/she is travelling. While some of this functionality is available now through systems such as Google Maps, it is still in its infancy.

Similar to the previous use cases, SEDRIS and X3D could be applied to represent city properties and visualize city features on smartphones and tablets to enable these functions. Figure A.5 shows a 3D visualization of Suwon University in the Republic of Korea using X3D that can be used for visitor familiarization.[12] X3D runs on mobile devices such as smartphones and tablets and can thus be readily applied for walking tourists.

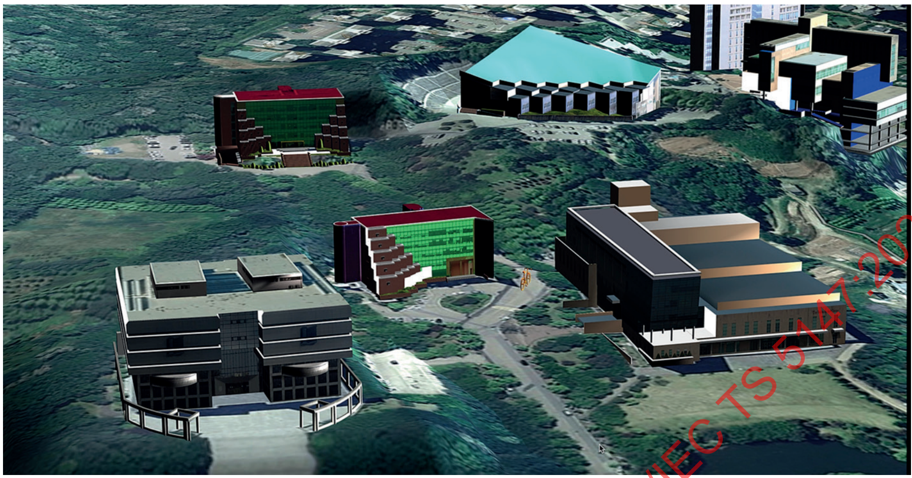

Figure A.5 — X3D representation of Suwon University (from[12])

A more interesting application is mixed and augmented reality to enhance the user experience. Using AR, one could see how the ancient Colosseum in Rome looked in 100 AD by superimposing a virtual Colosseum on the existing arena. The MAR Reference Model (ISO/IEC 18039) and Information Model for MAR Content standards ISO/IEC 3721-1 can be applied to create an augmented tourist scene and provide visualization through a headset. As an example, an X3D visualization of Suwon Palace in the Republic of Korea (a UNESCO World Heritage site) is shown in Figure A.6. This shows design aspects of the historic site. Further X3D examples of city models are available from the Web3D consortium[38].

Figure A.6 — X3D representation of historic Suwon Palace Suon-Seong. The coloured buildings show the separateX3D models (from[12])

Virtual reality is already being used for tourism.[39] An example using X3D of virtual tourism in the French city of Dijon, can be seen at Reference [40]. VR can be used to immerse a virtual tourist in a remote location and even allow tourists to handle precious artefacts using headsets and gloves fitted with sensors.[41]