# Toward a Comprehensive Smart Ecosystem Ontology
# Smart Cities, Smart Buildings, Smart Life


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## ABSTRACT

This paper posits a smart ecosystem as a complex system with several interdependent components or subsystems: Natural environment, smart city, smart buildings, smart office, smart manufacturing, smart life. Understanding, design, and operation of such a system can be supported by a comprehensive ontology. We introduce the structure of ontologies as consisting of a schema-level ontology, and entity-value-level ontologies, for each entity type a taxonomy of entity values. One can developing a comprehensive ontology by collecting and integrating specifications from many sources; we illustrate this process by building a very preliminary taxonomy of (smart) ecosystem functions from seven sources. Making ecosystems smart can improve the quality of life and contribute to more sustainable communities.



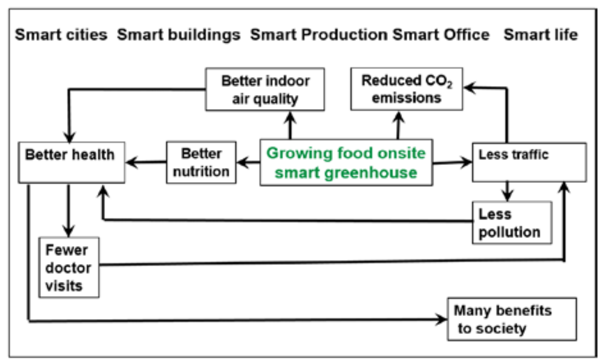
**Keywords**: Smart Ecosystems, Smart Cities, Smart Life, Ontology, Knowledge Organization Systems, Interoperability.


## 1. INTRODUCTION

Making quality existence of humanity sustainable requires smart management of our environment, our cities, our buildings, our factories and offices, and our personal lives. There is much activity in this area, predominantly in the subareas natural environment including climate change, Smart City, Smart Buildings, and Smart Life. These activities are somewhat siloed, each having their own community; cross-communication is present but not prevalent. This is unfortunate since a smart ecosystem is a complex system in which several interdependent components or subsystems interact: Natural environment, smart city (or larger area), smart buildings, smart office, smart manufacturing, smart life (which includes, for example precision medicine). Figures1a and 1b give a few examples of the many interdependencies (in the thousands).

Managing a comprehensive smart ecosystem requires two things:

1) A very large system model that includes all causal and interdependence relationships between elements of the total system, both within and across subsystems. This in turn requires a conceptual framework and definition of many variables. See Figures 1a and 1b for tiny examples
2) The ability to transfer data seamlessly from one computer system to another, or to use data from many sources together, within and across subsystems of the total ecosystem. Figure 2 gives some examples of data transfer / joint use.




Note. The interactions shown are illustrative but somewhat speculative

**Figure 1a. Small segment of an ecosystem model**

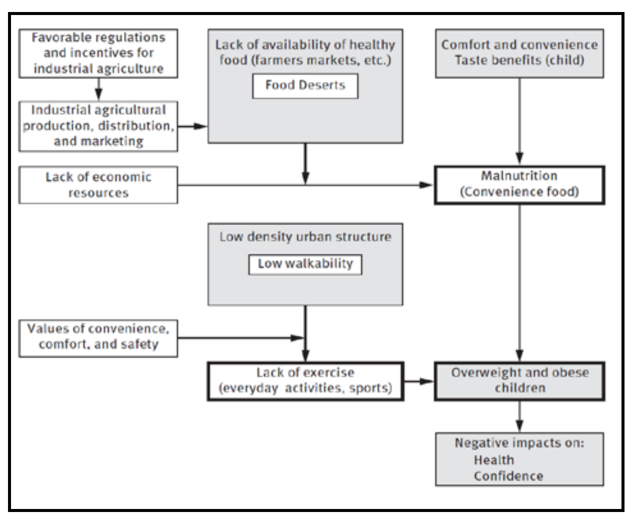



**Figure 1b. Small segment of an ecosystem model. Obesity**

The message from this discussion and the examples ─ and the most important message from this paper is:

1) Understand the functioning of the entire complex ecosystem. Fig. 1a and 1b give small examples, more in [1].
2) Make sure there is one integrated data model for all data in the system, such that for any function, such as transportation or providing health care, all needed data can be assembled and used in combination. Figure 2 gives a few examples.

The comprehensive ecosystem has these subsystems (levels):

- The natural environment
- City provides environment, streets, public transportation, electricity, water, perhaps heating/cooling, security, education, entertainment, health services, ...
- Building: space/shelter for production, office, living.
- Production: Input supplies, output products
- Office: Coordinates activities
- Life of people interacting with all of the above

How to approach creating a common data model across all subsystems is the topic of this paper. We talk about Knowledge Organization Systems (KOS), systems that store and organize information about concepts and terms and their relationships. Some examples of KOS are the Dewey Decimal Classification, a taxonomy of hazardous materials/substances, a classification of the properties and uses of materials, an entity-relationship model of a database, a multi-lingual dictionary for cross-language communication, and gazetteers. The terminology for types of KOS is rather loose; one person's *taxonomy* is another person's *typology* or *classification*. The term *ontology* is now in vogue but used inconsistently. See [2] for more.

**Example 1. Pollution mitigation**
A factory (especially one using process automation) should submit data about emissions and discharge into water every day to an environmental agency that combines all these data with weather data to produce better assessments and forecasts for air and water pollution, plan countermeasures as feasible, or order the factory to slow down production. The factory likely has a production schedule, how much of what product it is making each day, so it can predict emissions at least a week in advance. For any of this to work, the factory and the environmental agency must use the same identifiers for polluting substances and the same units of measurement for quantity.

**Example 2. Hazardous materials**
Similarly, data on warehouses that store dangerous substances and transports of dangerous substances should go to the environmental agency and the fire department.

**Example 3. Smart firefighting and rescue**
The fire department must know for each building in the city the building plans, the building materials used, and the content stored in the building. Also, inhabitants with disabilities. Again, this requires standard taxonomies for all the entities involved (a system for building plan data standardized across all information systems in the city, a common taxonomy of materials, and a common taxonomy for diseases and medical conditions).

**Example 4. Attend to accident victims**
Combine data of many kinds from many systems to support functions
- Place of accident
- Health record of victim
- Medical knowledge: How to assess condition of victim, first aid
- Medical specialties of hospitals (or physicians working at hospital)
- Location of hospitals
- From these: Determine best hospital to take victim to
- Depending on severity of victim's condition / how critical is time:
- Adjust traffic lights to minimize ambulance time to hospital

**Fig. 2. Examples of data transfer requirements**

The design and operation of all levels of a smart ecosystem requires conceptual clarity and a system for organizing data that allows for access to many types of data needed <u>in combination</u> to support smart ecosystem functions. A well-structured ontology which can be understood by people <u>and</u> is suitable for machine processing can serve both to

1) establish conceptual clarity and help people understand the complexity of the entire ecosystem and to
2) uniformly organize or at least map data in multiple disparate information systems kept by different city, state, and national agencies, by non-government organizations, and private citizens.

To capture all interactions in this complex system, an ontology must cover the total ecosystem. Partial ontologies for individual components and specific purposes exist, but mostly they are incomplete and of poor quality. By way of example Section 4 shows a comprehensive entity-value-level ontology of smart ecosystem functions that we built by integrating and reconciling information from many different sources using a conceptually solid approach to structuring a complex ontology.

## 2. THE USES OF KNOWLEDGE ORGANIZATION SYSTEMS INCLUDING ONTOLOGIES

This section gives a few examples of how ontologies can be used.

**1. Uses of an *ontology of smart ecosystem functions***

**1.1 Smart planning**. The city planner can get an overview of all smart city functions as a basis for selecting specific actions or projects to be implemented in a city and for classifying projects in progress or planned and get a better view of the relationships among the projects. The building architect can get an overview of all smart building functions with links to buildings where these functions have been implemented and information on what building functions that require city support have such support. An individual can get a roadmap for healthy living and information how each area of living is supported by her building and the city.

**1.2 Organize a database of smart city and smart building projects** across cities or even countries, such as the EU database [?} this database brings similar projects together and encourages knowledge transfer across cities.

**1.3** As **a guide for performance evaluation** at all levels

**2. Uses of a *fully developed ontology***

**2.1 Help people understand** the structure of the total ecosystem. Construct a comprehensive **system model** (or influence diagram) of a total ecosystem.

**2.2 Organize data in databases** and make them accessible for use in smart city and smart building projects and operations and for planning one's life (with privacy protections)

**2.3 Share data across cities**

**2.4 Use performance data to compare cities, buildings, schools, factories, etc.**

## 3. THE STRUCTURE OF AN ONTOLOGY

At the highest level is a *schema-level ontology*, an entity-relationship model that must allow for representing all kinds of data needed for planning and design, operation, and performance evaluation at all levels smart ecosystem operations. It includes entity types (Fig. 3 at the top) and relationship types (examples in Figure 4).

One level below are many entity-value-level ontologies or taxonomies (Figure 3, lower half), which give for each entity type a list of entity values needed for representing specific data. Each entity value has an identifier, preferably a URI. In the examples we use short identifiers.

Roughly speaking, the entity values serve as nouns and the *relationship types* as verbs to make statements ( Figure 4).

The prevalent approaches to structuring ontologies and tools such as Protégé severely limit what can be expressed conceptually. Our approach is to create a conceptually satisfactory representation of the comprehensive ontology and then work on implementation from there. We also emphasize presentations that are easily understood by human readers, a point that is as important as it is often ignored by computer scientists building ontologies.

Section 4 shows what a well-structured entity-value level ontology (or taxonomy) looks like, using the entity type Function as an example, focusing on (smart) ecosystem functions

Section 5 gives more entity types and relationship types to illustrate what a schema-level ontology for ecosystems looks like.

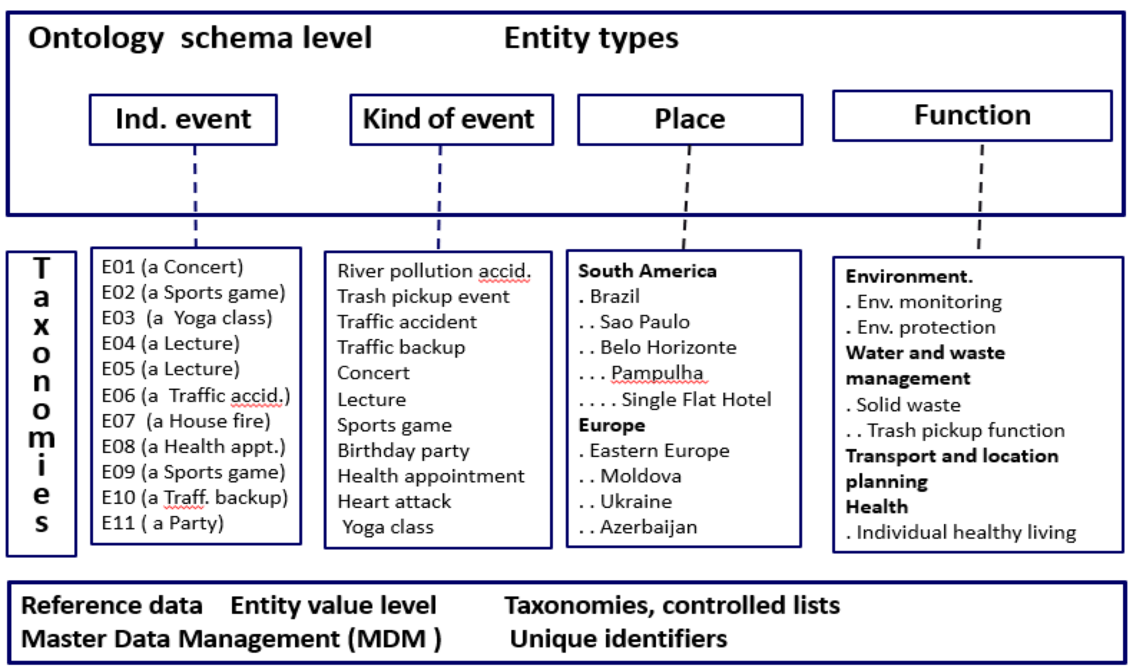



**Figure 3. Entity types and entity values**

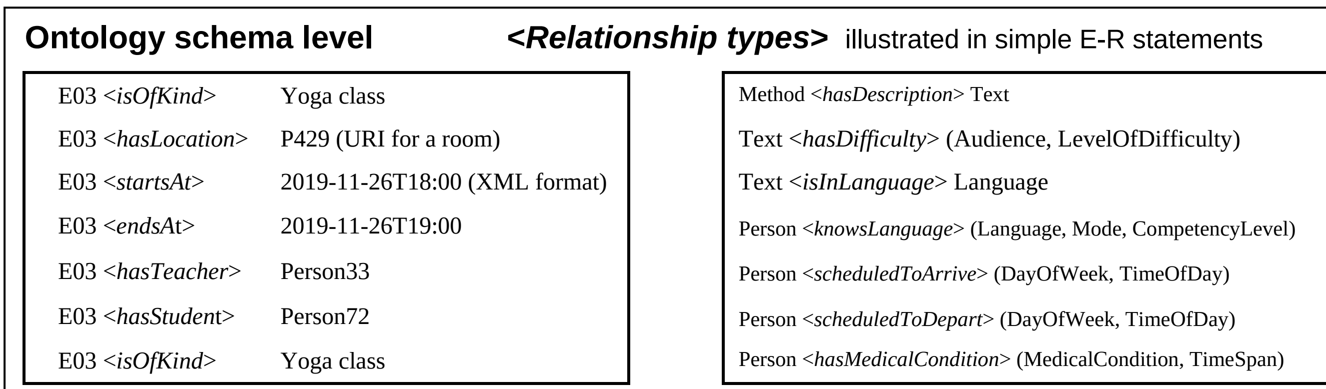



**Figure 4. Relationship types illustrated in sample statements**

## 4. A TAXONOMY (ENTITY-LEVEL ONTOLOGY) OF ECOSYSTEM FUNCTIONS

An important entity type is **ecosystem function**, in our case functions at any level in the smart ecosystem. The entity-value-level ontology (taxonomy) for these functions is a hierarchy of functions arranged by subject domain.

We are not aware of a comprehensive taxonomy of (smart) ecosystem functions. To compile such a taxonomy is a major effort. Before discussing how the formal process of taxonomy development, we give an informal discussion, almost like a brain dump, of smart ecosystem functions to introduce the subject.

As will become clear, many ecosystem functions apply at all levels. Within a subject domain such as health, specific functions at the smart city and smart building levels are seen from the point of view of providing services (in the example health care services), providing an environment conducive to health (for example, preventing bacteria from growing in air ducts), and an environment that supports healthy behavior (such as having accessible parks or a running track on top of a large building). At the smart life level, functions in a domain are seen from a consumer perspective (such as having regular health checkups, regular exercise, and a healthy diet).

The informal discussion shows how these functions are intertwined and can be classified from many perspectives. It also becomes clear that when thinking what functions a smart ecosystem should perform and how to prioritize these functions, one must start with human needs and quality of life. All ecosystem functions must ultimately be evaluated on their direct contribution to quality of life. This is why it is so important to have a comprehensive model ot the ecosystem where many causal chains can be followed. A taxonomy of system function defines variables that form the nodes in he causal model. Relationships types that indicate how the various functions interact are defined in the schema-level ontology (Section 5)

**Baracho & Soergel (2019) [3] defined the classification of functions shown in Table 1.**

| **Table 1. Components of Cities** |
|---|
| **1 People - What people need to live** |
| 1.1 Health Physical & Health Mental |
| 1.2 Knowledge (personal - know yourself know the world |
| 1.3 Love (relationships - Family, friends) |
| 1.4 Maintenance (work, money) |
| **2 Infrastructure - What the city needs to provide** |
| 2.1 Physical (natural - built resources) |
| 2.2 Services |
| **3 Governance - What life in society needs to have** |
| 3.1 Legislation |
| 3.2 Management |

**Elaboration of some of these elements and factors influencing them or needs arising from them**

From the definition of the indicators, a categorization was made in 3 main categories: People, Infrastructure and Governance. Cities exist with urban planning that deals with the inter-relationships between the 3 categories. The physical infrastructure with generation, distribution, maintenance and management of air, water, energy, food, construction, housing, mobility and connection in the physical space. We must also consider people who occupy the built environment and the needs of human life such as health, education, work, culture, justice, security. Governance for the management of the built space, life in society and information with laws, policies, budgets, collection, agreements and decision making must be taken into account. Each indicator contains some initial items that should continue to expand.

**1. People**

**Health – Physical:**
Oxygen-air-breathing (*Pollution***,** *Industries***,** *Vehicles***,** *Air quality***,** *Vegetation***,** *Ventilation***,** *Urban parameters, Removals Buildings, Streets Widths, Heights Buildings, Urban Design, Orientation*);
Water (*Water uptake, Water Treatment, Water distribution*);
Food-nutrition (*Food production, Food distribution*);
Sleep and Rest;
Shelter;
Physical Activity;
Proper temperature;
Sex;
Physical exercises-sport;
Elimination excretion; Sanitary sewage; Solid waste; Security;
Treatment (*Hospital-Places for treatment; Prevention; Educational programs; Information*);
Mobility

**Health – Mental:**
Love; Affection Friendship; Relationships-Interactions (*Social, Groups, Meetings, Parties, Religious, Cults, Prayers/Meditation, Meetings*); Stimulus;
Sexuality;
Education;
Physical Exercises-Sport;
Work

**Knowledge:**
Knowledge of Life;
Education, Learning
Research;

**Happiness:**
Requirements (*Good health-physical; Good health-mental; Knowledge*);
Realization;
Estimate;
Respect

**2. Infrastructure**
**Physical (natural + built resources):**
Air (*Environmental preservation; Pollution Control; Gas emission reduction*);
Water (*Quality and quality control; Rational use; Reuse; Sanitation*);
Energy (*Conscious consumption; Energy efficiency; Generation; Energy Renewable*);

Cleaning (*Urban cleaning, Recyclable, Waste, Collection, Treatment, Recycling, Appropriate disposal of the waste, Landfill to not Recycled*);
Mobility (*Accessibility, Transport, Collective – Car, Bus, Train, Subway ,Boats, Plane*)
Individual;
Public-Private; Easy to walk;
Buildings-Housing; Technology (*Internet, Devices, Systems, IoT, Communication, Connection, Open Data, Data transparency*);
Services (*Education, Health, Citizen – Participation, Inclusion, Digital Inclusion, More assertive*
Attendance; Connectivity; Security; Work)

**3. Governance**
Legislation; Management; Planning; Economy (*Local, Collaborative*); Social justice; Public policy

**Benamrou et al (2016) [4] Indicators of European Ranking gives a similar breakdown**

**1. Smart economy**
Innovative spirit (*R&D expenditure in% of GDP, Employment rate in knowledge-intensive sectors, Patent applications per inhabitant*);
Entrepreneurship (*Self-employment rate, New business registered*);
Economic image and trademarks (*Importance as decision-making center*);
Productivity (*GDP per employed person*);
Flexibility of labor Market (*Unemployment rate, Proportion in part-time employment*);
International embeddedness (*Companies with HQ in the city quotes on national stock Market, Air transport of passengers, Air transport of freight*)

**2. Smart mobility**
Local accessibility; (Inter-)national accessibility;
Availability of ICT-infrastructure;
Sustainable, innovative and safe transport

**3. Smart environment**
Attractiveness of natural conditions;
Pollution; Environmental protection;
Sustainable resource management

**4. Smart people**
Level of qualification;
Affinity to lifelong learning;
Social and ethnic plurality;
Flexibility; Creativity;
Cosmopolitanism/open-mindedness;
Participation in public life

**5. Smart Living**
Cultural facilities;
Health conditions; Individual safety;
Housing quality;
Education facilities; Touristic attractivity;
Social cohesion

**6. Smart Governance**
Participation in decision-making;
Public and social services;
Transparent governance; Political strategies and perspectives

**Table 2: Sources for the Taxonomy of (smart) city functions**

| | **Standards** |
|---|---|
| **IS [5] [6]** | **ISO 37120:2018 Sustainable cities & communities indicators** Table 3 includes the themes listed but not the indicators for measuring how well the goal implied by the theme is achieved |
| **ST [7]** | **STAR Community. A review of ISO 37120's alignment with the STAR Rating System** The classification in S*TAR's-Menu-of-Goals-&-Objectives* gives a different perspective from Table 3; there are many perspectives for classifying (smart) city functions |
| **U [8] [9]** | U**N, "Sustainable Development Goals"(SDGs**) and Alignment between UN SDGs and the STAR Community Framework: STAR lists for each SDG the STAR indicators that the STAR authors consider good measures for the goal's attainment. The alignment is open to question. |
| | **Papers and systems** |
| **A8 [10]** | **Alexopoulos et al. 2018** Very useful. Table 1: Smart Cities developments taxonomy 10 major headings (in our list) with 3 and 9 subdivisions (not recorded in our list). We the paper's numbers. |
| **B7 [11]** | **Bibri & Krogstie 2017**. 13 big data analytics applications. See also [12] |
| **L8 [13]** | **Lim et al. 2018**. Items were extracted from Fig. 3. Hierarchical structure of application areas related to smart cities & Fig. 4. Classification of big data use cases in smart cities. |
| **KM [14** | **Km4City - The Knowledge Model 4 the City Smart City Ontology (ENG)** http://wlode.disit.org/WLODE/extract?url=http://www.disit.org/km4city/schema#d4e8110 The KM4CityOntology does not give an easily identifiable taxonomy or list of (smart) city functions. It does include a class *Service* that has 512 subclasses divided into 20 groups. Table 3 gives the headings of the groups a listed in a table in the document. The KM4CityOntology could profit from a non-redundant presentation in a format that would let a human reader perceive the structure quickly. A plain entity-relationship schema would be very helpful. |

To approach the classification of ecosystem functions more formally, we looked for existing taxonomies and selected the sources shown in Table2. The three standards give criteria for the evaluation of ecosystems or specifically cities; the criteria apply whether a city is operated as a smart city or not. Ecosystem functions pertain to all ecosystems, not just to functions that are fulfilled in smart ways. The standards also give many performance metrics for evaluating how well a city or an entire ecosystem fulfills a function, but these are not included here. The remaining sources are lists we found in papers dealing with smart cities specifically. Some of these lists put "smart" in front of the function name; we kept the terms as they appeared in the source.

Then we arranged the functions mentioned in one or more of these sources into a hierarchy, drawing on hierarchies in the sources and using our own judgment. Where there was more then one term for a function, we listed all the terms in one row.
In Table 3 we present the result. Arranging the ecosystem functions in a meaningful order is not easy. There are many relationships across the functional areas. A simple table is not able to represent such a complex system. A few functions we could not yet fit are listed at the end of the table

**Table 3 - Draft 0 of a comprehensive taxonomy of (smart) city functions. Top level with some detail for illustration**

| Domain, theme, function | Sources | | | | | | |
|---|---|---|---|---|---|---|---|
| | Standards | | | Papers and systems | | | |
| | IS | ST | U | A8 | L8 | B7 | KM |
| **2. Environment**<br>Environmental monitoring and protection<br>Smart environment | . IS | | | A8 | L8 | B7<br>B7 | KM |
| . Environmental monitoring | | | | | | B7 | |
| . . Air pollution monitoring | | | | | L8 | | |
| . . Precipitation monitoring | | | | | | | |
| . Environmental protection | | | | | | B7 | |
| . . Goal 13: Climate Action | | | U | | | | |
| . . Greenhouse Gas Mitigation | | ST | | | | | |
| . . Goal 14: Life Below Water | | | U | | | | |
| . . Goal 15: Life on Land | | | U | | | | |
| . Climate Adaptation | | ST | | | | | |
| . Natural ecosystems | | | | | | B7 | |
| . Climate & Energy | | ST | | | | | |
| **Built Environment** | | ST | | | | | |
| . Ambient Noise & Light | | | | | | | |
| . Housing Affordability | | ST | | | | | |
| . Infill & Redevelopment | | ST | | | | | |
| . Public Spaces | | ST | | | | | |
| **Smart building, smart home** | | | | | | | |
| . Indoor Air Quality | | ST | | | | | |
| . Smart building | | | | | L8 | | |
| . Smart home<br>Shelter | . IS | | | | L8 | | |
| . Accommodation<br>Hotels and similar structures. | | | | | | | KM |
| | | | | | | | |
| **5. Waste Management &Water Resource**<br>Water and waste management | | | | A8 | | B7 | |
| . Solid waste | . IS | | | | | | |
| . . Intelligent trash pickup | | | | | L8 | | |
| . . Waste Minimization | | ST | | | | | |
| . Water resources, water management<br>Goal 6: Clean Water and Sanitation | | | U | | | | |
| . . Community Water Systems | | ST | | | | | |
| . . Drinking water | . IS | | | | | | |
| . . Waste water | . IS | | | | | | |
| . . . Water sanitation | . IS | | | | | | |
| | | | | | | | |
| **Transport and location planning** | | | | | | | |
| . Mobility and accessibility effectiveness | | | | | | B7 | |
| . 3. Transport and mobility<br>Smart transport | . IS | | | A8 | L8 | B7 | |
| . . Transport efficiency and management | | | | | | B7 | |
| . . Traffic management and street light control<br>Smart Traffic<br>Intelligent traffic control | | | | | L8 | B7<br>B7 | |
| . . . Festival congestion prevention | | | | | L8 | | |
| . . Smart public transport routing and scheduling | | | | | | | |
| . . Midnight public transport routing and scheduling | | | | | L8 | | |
| . . Intelligent navigation | | | | | L8 | | |
| . . Transportation Choices | | ST | | | | | |
| . Smart logistics | | | | | L8 | | |
| . tele–working | | | | | | B7 | |
| . Location planning | | | | | | | |
| . . Welfare facility location planning | | | | | L8 | | |
| | | | | | | | |

| Domain, theme, function | Sources | | | | | | |
|---|---|---|---|---|---|---|---|
| | Standards | | | Papers and systems | | | |
| | IS | ST | U | A8 | L8 | B7 | KM |
| **Public safety and civil security**<br>9. Security<br>Smart security<br>Smart safety | . IS | | | A8 | L8 | B7 | |
| . Crime prevention | | | | | L8 | | |
| . Safe Communities | | ST | | | | | |
| . Natural & Human Hazards | | ST | | | | | |
| . Emergency Prevention & Response | | ST | | | | | |
| . Fire and emergency response<br>Emergency | . IS | | | | | | KM |
| | | | | | | | |
| 6. Energy – Sustainable development | | | | A8 | | | |
| **Energy efficiency and management**<br>Goal 7: Affordable and Clean Energy<br>Smart energy | . IS | | U | | L8 | B7 | |
| . Greening the Energy Supply | | ST | | | | | |
| . Electricity | | | | | | B7 | |
| . . Smart power grid | | | | | | B7 | |
| . Community energy management | | | | | L8 | | |
| . Resource efficiency | | | | | | | |
| . . Industrial Sector Resource Efficiency | | ST | | | | | |
| . . Resource Efficient Buildings | | ST | | | | | |
| . . Resource Efficient Public Infrastructure | | ST | | | | | |
| | | | | | | | |
| **1. ICT Infrastructure** | | | | A8 | | | |
| . Communication infrastructure | | | | A8 | | | |
| . . Telecommunication | . IS | | | | | | |
| . . Digital infrastructure | | | | | | | |
| . . . Wi-Fi hotspot optimization | | | | | L8 | | |
| . . . Local network development | | | | | L8 | | |
| . . Local information diffusion | | | | | L8 | | |
| . IT processing power, Servers | | | | A8 | | | |
| . Sensors | | | | A8 | | | |
| . Smart devices | | | | | L8 | | |
| Health & Safety | | ST | | | | | |
| **4. Health**<br>Goal 3: Good Health and Well-Being<br>Smart health | . IS | | U | A8 | L8 | | |
| . Community Health & Health System | | ST | | | | | |
| . Healthcare and social support | | | | | | B7 | |
| . . Smart healthcare<br>HealthCare | | | | | | B7 | KM |
| . Medical and health systems | | | | | | B7 | |
| . Individual healthy living | | | | | | | |
| . . Active Living | | ST | | | | | |
| | | | | | | | |
| EducationAndResearch | | | | | | | KM |
| **Learning, education**<br>Goal 4: Quality Education<br>Smart education | . IS | | U | | L8 | B7<br>B7 | |
| . Educational Opportunity & Attainment | | ST | | | | | |
| | | | | | | | |
| **Arts & Culture** | | ST | | | | | |
| . Historic Preservation | | ST | | | | | |
| | | | | | | | |
| **Entertainment and recreation** | | | | | | | |
| . Entertainment | | | | | | | KM |
| . Recreation | . IS | | | | | | |
| . 7. Tourism - Culture | | | | A8 | | | |
| . . Smart hospitality<br>TourismService | | | | | L8 | | KM |
| | | | | | | | |
| **Food Access & Nutrition** | | ST | | | | | |

| Domain, theme, function | Sources | | | | | | |
|---|---|---|---|---|---|---|---|
| | Standards | | | Papers and systems | | | |
| | IS | ST | U | A8 | L8 | B7 | KM |
| . Goal 2: Zero Hunger | | | U | | | | |
| . WineAndFood | | | | | | | KM |
| **ShoppingAndService** | | | | | | | KM |
| Smart city services | | | | | | | |
| . Intelligent trash pickup | | | | | L8 | | |
| GovernmentOffice | | | | | | | KM |
| TransferServiceAndRenting | | | | | | | KM |
| | | | | | | | |
| **Cross-cutting themes** | | | | | | | |
| Urban infrastructure monitoring and management | | | | | | B7 | |
| Strategic planning and efficient design<br>Urban planning | . IS | | | | | B7 | |
| . Smart planning | | | | | | B7 | |
| . Smart design | | | | | | B7 | |
| Cycle | | | | | | | |
| Preventive local administration | | | | | L8 | | |
| Local operations management | | | | | L8 | | |
| Innovation | . IS | | | | | | |
| **Other** | | | | | | | |
| Economy<br>**Economy & Jobs**<br>Goal 8: Decent Work and Economic Growth<br>8. Economy - Development | . IS | ST | U | A8 | | | |
| . Business Retention & Development | | ST | | | | | |
| . Green Market Development | | ST | | | | | |
| . Local Economy | | ST | | | | | |
| . Targeted Industry Development | | ST | | | | | |
| . Jobs, employment | | | | | | | |
| . . Quality Jobs & Living Wages | | ST | | | | | |
| . . Workforce Readiness | | ST | | | | | |
| | | | | | | | |
| Finance | . IS | | | | | | |
| Governance<br>10. E- Government | . IS | | | A8 | | | |
| . Goal 17: Partnerships for the Goals | | | U | | | | |
| Goal 16: Peace, Justice, and strong Institutions | | | U | | | | |
| **Community** | | | | | | | |
| . Community Cohesion | | ST | | | | | |
| . Compact & Complete Communities | | ST | | | | | |
| . Social & Cultural Diversity | | ST | | | | | |
| **Equity & Empowerment** | | S<br>T | | | | | |
| . Civic Engagement | | S<br>T | | | | | |
| . Civil & Human Rights | | S<br>T | | | | | |
| . Environmental Justice | | S<br>T | | | | | |
| . Equitable Services & Access | | S<br>T | | | | | |
| . Human Services | | ST | | | | | |
| . Poverty Prevention & Alleviation<br>Goal 1: No Poverty | | ST | U | | | | |
| . Goal 5: Gender Equality | | | U | | | | |
| . Goal 10: Reduced Inequalities | | | U | | | | |
| **Sustainability** | | | | | | | |
| . Goal 11: Sustainable Cities and Communities | | | U | | | | |
| , Goal 12: Responsible Consumption and Production | | | U | | | | |
| | | | | | | | |
| **To classify** | | | | | | | |

| Domain, theme, function | Sources | | | | | | |
|---|---|---|---|---|---|---|---|
| | Standards | | | Papers and systems | | | |
| | IS | ST | U | A8 | L8 | B7 | KM |
| | | | | | | | |
| MiningAndQuarrying | | | | | | | KM |
| Advertising | | | | | | | KM |
| Wholesale | | | | | | | KM |
| CivilAndEdilEngineering | | | | | | | KM |
| UtilitiesAndSupply | | | | | | | KM |
| AgricultureAndLivestock<br>Smart farming | | | | | L8 | | KM |
| Goal 9: Industry Innovation and Infrastructure<br>IndustryAndManufacturing | | | U | | | | KM |

## 5. A SCHEMA-LEVEL ONTOLOGY FOR SMART ECOSYSTEMS. SOME EXAMPLES

Building this comprehensive ontology, or family of ontologies, must draw on existing resources. Start with an upper-level ontology, such as BFO (Basic Formal Ontology, https://basic-formal-ontology.org/) or UFO (Unified Foundational Ontology, http://dev.nemo.inf.ufes.br/seon/UFO.html) and use core ontologies, such as the ones under development by CUBRC (https://www.cubrc.org/index.php/data-science-and-information-fusion/ontology) and resources such as the Industrial Ontology Foundry (https://www.industrialontologies.org/). Much detail to flesh out the general ontologies of mostly cross-domain concepts would come from domain-specific ontologies, mostly at the entity value level, from smart city projects, Building Information Model Software, environmental thesauri, etc. Tables 4 and 5 give a smattering of general entity types and relationship types, respectively. Table 6 elaborate on specific entity types and relationship types needed for the onsite food growing system (Figure 1a).

**Table 4. A smattering of entity types**

| Entity type | Source for entity values or comment |
|---|---|
| Material or Substance | |
| . Chemical substance | Chemical abstracts |
| . Material, esp. composite | Various taxonomies |
| Organism | Integrated Taxonomic Information System<br>https://www.itis.gov<br>Need down to varietal |
| Place | https://www.geonames.org/<br>https://geonames.usgs.gov |
| Property | Divided in many entity types, for example, Flammability |
| . Various place properties | For example, building type |
| Condition | |
| . Medical Condition | ICD [15], SNOMED-CT [16] |
| HealthQualityIndex | |
| AirQualityIndex | |
| PointInTime | |
| Duration | |
| Process | |
| Event | |
| MoneyAmount | |
| EnergyAmount | |

**Table 5. A smattering of relationship types**

| Relationship | Inverse relationship |
|---|---|
| *<hasPart>* | *<isPartOf>* |
| *<spatiallyIncludes>* | *<isSpatiallyIncludedIn>* |
| *<temporallyIncludes>* | *<isTemporallyIncludedIn>* |
| *<affects>* | *<isAffectedBy>* |
| *<causes>* | <isCausedBy> |
| *<harms>* | *<isHarmedBy>* |
| *<positivelyRegulates>* | <is*PositivelyRegulatedBy*> |
| *<consumes>* | *<isConsumedBy>* |
| *<locatedAt>* | *<isLocationOf>* |
| *<hasOrganizationMember>* | *<isOrganizationMemberOf>* |
| *<hasClassMember>* | *<isClassMemberOf>* |

**Table 6. Entities and relationships needed to express data needed for the food growing example (Fig. 1a)**
Presented in a narrative that also gives reason for including entity types and relationship types
Entity types from Table 4 are assumed

**Need data on growing food on-site generally**

What methods exist?

For the entity type Method, make sure that entity values, include

**Methods of growing foods onsite**
Growing food on balcony
Growing food in apartment
Growing food in smart green house

**Method <*hasDescription*> Text**

**Need much data about Growing food in smart green house**

**(Organism , Duration, TimeOfDay)
<*needsLightingConditon*> LightingCondition**

Duration here = Time elapsed since planting

The entity type LightingCondition is defined by a combination of light of several colors (wave lengths), each at a given intensity, identified by a number, for example, LC27

Entity type Intensity, scale 0 ... 10

**LightingCondition <*includes*> (Wavelength, Intensity)**

Several statements using this pattern define a LightingCondition

**Purpose: Select vegetables grown according to specific needs of the people living in the building**

**Person <*hasMedicalCondition*> (MedicalCondition, Severity)**

People with some condition might benefit from eating a certain vegetable. But what vegetable and how much to eat may also depend on other factors, such as how severe the condition is and the sex and age of the person. To model this, we need a complex multi-way relationship:

**(MedicalCondition, Severity, Sex, Age) <*benefitsFrom*> Organism**

**Note on complexity and common oversimplification**

The binary (two-way) relationship

**Condition <*benefitsFrom*> Organism**

Does not capture the complexity, but most ontologies are limited to binary relationships.

**RDF triple:**

**(Binary relationship name, entity value 1, entity value 2)**

## 6. ONTOLOGY APPLICATIONS IN TRANSPORTATION EXAMPLES

Urban mobility is a complex system that needs data in different ways to become intelligent. One system tracks bus routes in real time and another monitors waiting time at intersections. The system can optimize traffic flow and better meet the demands of citizens by giving priority to keeping buses in time and gives potential passengers live information on choosing the best bus route and actual arrival times. This can bring countless benefits to the functioning of cities. This type of access to the database may show alternative paths, for example, this system could use data on all kinds of events that affect traffic, such as the times when different schools in the city end their school day. This system needs to combine data from many different sources. It needs to predict traffic to the time when the potential passenger wants to travel, so monitoring current traffic is not enough. This requires a comprehensive model of factors affecting traffic and access to data on the present and expected future states of these factors. It requires an ontology that facilitates combining these data.

Rural areas have even more difficult transportation problems as we will illustrate in the example of planning of rural school transport in the state of Espírito Santo Brazil. [17]

Brazil is a very large country and has small towns in the countryside that have difficult access and scarce resources to solve the essential problem of school transport. Students must travel long distances to school and some roads are in poor condition. This spatial dispersion and lack of resources affect the quality of school transport. Information systems can help with the optimization of resources (vehicles and drivers).

The Federal University of Minas Gerais / UFMG in partnership with the state government has been developing a solution. The project uses an information modeling system with a robust georeferenced database containing data related to the students, schools, vehicles, roads, routes and stops. The dataset includes information modeling from different tables containing entities and their relationships. The Transcolar Rural Project is an intelligent transport system for generating routes and costs for rural school transport - TER. The data presented below correspond to the state of Espírito Santo, Brazil. The information system consists of two modules, information modeling and knowledge extraction. Information modeling consists of the organization of the dataset, modeling and data structure. The extraction of knowledge through data inference and creation of scenarios for decision making by managers.

The information modeling module is composed of data from many sources. The Students Table is composed of data from different sources and contains the register information of the student such as his ID, teaching shift, grade, if he has a special need and the ID (corresponds to the ID of the household energy bill). The information for these students comes from different sources: the State databases (state students) and the municipal databases (municipal students). Each state of Brazil and each of the 5,500 municipalities have their own and independent student registration systems. In the case of Espírito Santo, there are 76 municipalities with students in school transport, different from the data registered in the state system. There are 77 different information systems that need to be consulted to update the tables daily.

The information base - School is obtained from the National Census (IBGE) and can be updated in the system interface. Fundamental information of the grades for each half time at school and the start and end times. These data are managed by city hall. Each school is also provided with the corresponding energy bill ID.

The Energy Company provides the system each quarter with a georeferenced base of the energy poles of the Spatial Location (Geom) base. From this relationship between the energy pole and its spatial location (lat, long) and the energy bill ID, it is possible to geo-reference each student and school with an accuracy of 15 m.

The roads base starts with the OSM (Open Street Map) base of each municipality in the table of road sections, Edges (Links) . From the spatial location of each student and school, new edges are digitized from sets of public images such as BING and Google Earth, in addition to the bases of each municipality.

The vehicle base is maintained by each municipality with information on the municipality's own vehicles and vehicles that will be rented for complementary services.

To calculate the operating costs of each vehicle, cost information is collected in official databases or on the Internet, as an example we have the average price of fuel in each region, the prices of tires, wages of drivers, among others . Municipalities are responsible for validating this data in each region.

The database has a record of 2M Students, 14K school, 3K Vehicles, 2.3M Edges (Links) for a total of 17GB

The system determines an optimized schedule of trips, the optimized set of students for each trip, their stopping points, specifies the vehicles to be used and determine the costs involved. Many factors must be considered. requiring even more data, such as the capacity of vehicle traffic on the road, the speed, the time allowed for students to stay on the bus, the distance individual students can walk to the stops.

In an extension, the system could undertake a broader optimization including modification of school schedules and schedules of individual students (while maintaining educational quality) to further optimize transportation. For example, staggering beginning and end time of schools would improve utilization of the vehicle fleet.

The data in the system are kept in relational tables; see Table 7 for examples. Knowledge can be extracted through queries linking data between the different tables. The studies are carried out by municipalities. All students enrolled in schools in the municipality are selected and need to be grouped to be transported to schools. More complex optimization requires specialized computer programs.

Data can be systematized further by constructing a schema-level ontology that specifies smaller pieces of information (as expressed through entity-relationship statements, see Table 8 for some examples. These chunks of information can then be organized into an improved set of relational tables.

**Table 7. Students, School, trips**

Students: ***Alunos*** *(seq,sre, município,inep,codibge7_escola,**<u>cod_escola</u>**, tipo_ensino, modalidade, submodalidade, serie, período_letivo, período_dia, classe, código_aluno, aluno, data_nascimento, endereço_aluno, numero_aluno, bairro_aluno, município_aluno, estado_aluno, cep_aluno, DDD_telefone_aluno, código_energia, dt_atualiza, utiliza_transporte_rural, codibge7_aluno, geom, sigla_concessionaria, latdec_posicao_original, londec_posicao_original, latdec_posicao_projetada, londec_posicao_projetada, cod_matricula, tipo_dependencia, hora_inicial, minu_inicial, status, informacao_escola, fora_municipio_escola, sigla_tipo_ensino, dt_inclusao, mobilidade_reduzida, veiculo_especial, frota_propria, anobase, registro_aluno, complemento_aluno, possui_deficiencia, forca_processamento_otimizacao, código_energia_manual, label)*

School: ***Escolas*** *(gid, nome, **<u>cod_escola</u>**, **<u>nomeabrev</u>**, siglaexten, classecnae, administra, operacion, situacfisi, **<u>logradouro</u>**, **<u>numero</u>**, **<u>bairro</u>**, **<u>cep</u>**, telefone, **<u>município</u>**, **<u>geocodigo</u>**, zona, data, fonte, origem, geom, codibge7, código_energia, latdec, londec, sigla_concessionaria, nome_sem_acento, movto_fechado_digitacao, dt_atualiza, hr_inicio_manha, hr_fim_manha, hr_inicio_tarde, hr_fim_tarde, hr_inicio_noite, hr_inicio_integral, hr_fim_integral, tempo_max_inicio_aula, aux, tempo_max_inicio_aula_tarde, tempo_max_inicio_aula_noite, estado, dt_inclusao*

Trips: ***Viagens_planejadas*** *(codibge7, sequencial_viagem,identificador_viagem, descrição_viagem, tipo_linha, responsável_viagem, propriedade_veiculo, quantidade_monitores, km_com_alunos, tipo_veiculo, placa_veiculo, ano_fabricacao_veiculo, tipo_combustivel, perc_pavimento_terra, custo_atual_viagem, custo_atual_aluno, custo_atual_km, observação, dt_inclusao, dt_alteracao, responsável_inclusao)*

Query 1: All students, ordered by school, part time and grade

School: ***Escolas_base*** *(cod_escola, nome, logradouro,numero,bairro,cep,município,geocodigo)*

Students: ***Alunos_base*** *(cod_escola, turno, serie, nome, nascimento)*

```
Select e.cod_escola, e.nome, e.geocodigo, a.turno, a.serie, a.nome, a.nascimento
From escolas_base e join alunos_base a on (e.cod_escola = a.cod_escola)
Order by e.codescola, a.turno, a.serie
```

Quey 2: Students, their school and driver

```
Select v.ano, v.viagem, v.motorista, v.tipo_veiculo_otm,  va.nome, va.escola, va.serie, va.possui_deficiencia
From viagem_saida v Join view_alunos_shape  va on (v.requisicao = va.requisicao)
Where v.requisição =
```

**Table 7. Entities and relationships needed to express data required for school transportation planning**

Presented in a narrative that also gives reason for including entity types and relationship types

Entity types from Table 4 are assumed

The system must model

**TrafficRoutes** (including roads, rails, pedestrian walkways, etc.)

**TravelRoutes** (for want of a better term), the route travelled by a bus or other vehicle or walked by a pedestrian, often on a schedule

This modeling is very complex but also very important for traffic analysis, predictions, and recommendations. What follows is not a formulation of final model but just some examples of first attempts at defining entity types and relation ship types that illustrate the complexity

Both types of routes consist of segments

**TravelRoute <includes> (TravelSegment, SeqenceNo)**
A Route is a sequence of segments.
TravelRoutes and TravelSegment have arbitrary IDs

TravelRoute <runsOn> DayOfTheWeek

**TravelSegment <*leadsFromTo*>**
(Place, TimeOfDay, Place, TimeOfDay, TransportMethod)
Note 1: TransportMethod is part of the definition of the TravelSegment . So going from A to B by Bus is one Segment (or sequence of Segments), walking the same path is a different Segment

**Place <*LocatedAt*> (Latitude, Longitude)**

A route has complex geometrical description connecting a series of Points

**(TrafficRouteSegment, Age, MedicalCondition, TrafficConditions, WeatherConditions) <*takesTime*> Duration**

**(TrafficRouteSegment, Age, Sex, TimeOfDay) <*hasSafetyRating*> SafetyRating**

Note: If a child walks from Place A to Place B, both the time required, and the safety rating depend on the age of the child.

Person <*livesAt*> Address

Address <*LocatedAt*> (Latitude, Longitude)

**Person <*attends*> NamedSchool (a specific school**)

NamedSchool <*LocatedAt*> (Latitude, Longitude)

**Statements about prescriptive travel times (scheduled), expected travel times (on a given day while in transit), actual travel times**

Person <*scheduledToDepart*> (Location, DayOfWeek, TimeOfDay)

Person <*scheduledToArrive*> (Location, DayOfWeek, TimeOfDay)

Person <*expectedToDepart*> (Location, Date, TimeOfDay)

Person <*expectedToArrive*> (Location, Date, TimeOfDay)

This gets even more complicated when a student needs to take additional trips, such as traveling to a special lesson every Thursday

**Person <*hasMedicalCondition*> (MedicalCondition, TimeSpan)**

Statements

Person <*hasMedicalCondition*> (Sick, 2020-03-15To2020-03-18)

Person <*hasMedicalCondition*> (UnableToWalk, Permanent)

This medical information is important for transportation; not having to pick up that student may change how trips are scheduled. But it is also of interest to the school nurse, for attendance record keeping, for the health department to discover disease outbreaks, an example of how interconnected systems are. To illustrate this further, when student A is known to be sick but no further details are available, and student B, a class mate, is known to have measles (or the Corona virus), the parents of student A should be notified right away. The world is a highly interconnected and complex place. We need to use a piece of data in any of the many ways it can do good.

## 7. CONCLUSION

We have shown the need for a comprehensive smart ecosystem ontology as the basis for

(1) better understanding and design of smart ecosystems and

(2) implementing planning and day-to-day operations, especially sharing and combining data needed to support smart ecosystem functions.

Managing the interdependent ecosystem of the natural environment, smart city, smart buildings, smart office, smart manufacturing, smart life requires dealing with multiple information systems This information is record in different sectors of the city and in various types of information systems. Connecting the many information systems requires correct relationships and concepts, creating indicators that can similarly defining the objects.

The importance of standardizing the indicators can reflect on the weight, importance or priority for each region. For example, an indicator considered universal by consensus: Energy. We need energy to live and while some are interested in increasing electricity generation, others are interested in reducing consumption. How can managers decide priorities and investments in cities and the environment: Improve and increase energy generation (renewable) or encourage reduction in use? We have an indicator that interests everyone: people, cities and the world all need energy.

Our first attempt at developing a taxonomy of ecosystem functions shows the diversity of concepts, initiatives and projects and the importance of advancing in more globalization solutions. Under-standing the indicators seeks interoperability between differ-ent sources of information and obtain inferences. Advanced studies of indicators and ontologies are needed.

Developing a comprehensive ontology for smart ecosystems — both schema-level and entity-value / taxonomy level — should build on many sources and be undertaken as a community effort. Even when building on existing work, developing this comprehensive ontology would require a substantial investment. We believe that such an investment is justified by enabling smarter ecosystems with improvements of sustainability and quality of life in countries across the globe.

## 8. EPILOGUE

Considering the current moment when the whole world is affected by an overwhelming threat, we need to reflect on the importance of continuing with research to increase the understanding of city and larger ecosystem data. We have arrived at the crucial moment when we need data connected from different systems, different sources, different locations on the planet in search of more global solutions. It is imperative to provide the population and their respective managers with the highest quality and quantity of information possible. This information will provide support for decision making at all levels.

The growth of cities and the increase in population in urban centers makes it urgent to find innovative solution. The world's population reached 7.8 billion people. Surveys estimate that 65% of the world’s population lives in cities, with thousands of people moving from rural to urban areas each week – the impact of reducing labor in agriculture. By 2050, more than 6 billion people will live in urban agglomerations. Cities need to present solutions to prepare for challenges. In this scenario, cities, citizens, managers, builders, investors, industries, manufactures and decision makes must find ways to solve these problems.

The term smart cities comes from the use of technologies, more specifically, information systems applied to solutions for city improvements. This article posits that smart, intelligent city operation will happen only with the design and deployment of smart city knowledge organization system. Residents, workers, and visitors in cities now bring their own mobiles. City infrastructure is littered with sensors monitoring everything from the flow of traffic, energy, water and people to the state of sewer valves, lighting, and parking spaces. All these devices and sensors generate massive data.

The question facing city leaders, planners, service providers, business, and citizens is how does all that inform and thereby improve my life? How will it go from disparate data to intelligence in ways that truly create new knowledge? And how can I use that knowledge to move, live, work, play, and prosper more completely than ever before in my city?

These data need to be used intelligently to improve the quality of urban life and, consequently, the quality of life of people living in cities. Cities are spaces for social relationships between people and the capabilities of smart cities can improve connections through technology. A comprehensive ontology supports making these connections.

## 9. ACKNOWLEDGEMENTS

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