Recreation Ontology for Global City Indicators (ISO 37120)

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1. Introduction

Many cities across the world are similar in certain respects and different in other forms and therefore comparing any 2 cities results in an immense analytical challenge. Currently, cities use various metrics to evaluate themselves. The problem with this approach is that these metrics are usually not standardized, and may thus, provide skewed analytical results based on a city's perspective.

With the introduction of ISO37120, which contains over 100 indicators for measuring a city's quality of life and sustainability, it is now possible to consistently measure and compare cities. These indicators span major concepts like Public Safety, Education, Health and Recreation which are widely accepted themes of focus in cities across the world. This makes the approach of measuring a city's performance or quality of life standardized and reproducible across cities.

The World Council on City Data[1] validates reported data from cities through a certification process. The process includes data compliance according to ISO37120 standards.
This working paper is part of the PolisGnosis project (Fox, 2015) to create a semantic web-based representation of major city themes of ISO37120 indicators and to automate the longitudinal analysis (i.e. how and why a city's indicators change over time) and the transversal analysis (i.e. how and why the cities differ from each other at the same time), in order to discover the root causes of differences. In order for analysis to be effective on city data that complies with ISO37120, it has to be represented using standard representation formats on the semantic web.

This paper examines standard definitions employed by our Recreation ontology and theme indicators and how they may be used to gauge a city's performance in terms of the recreation structures available in a city. We start this by specifying a set of competency questions that our ontology must be able to answer based on the Recreation indicators defined in ISO37120.

[1] http://www.dataforcities.org/global-cities-registry/

We proceed to explore existing vocabularies that pertain to recreation and determine whether they provide related concepts. The next section introduces our Recreation ontology and how the ISO37120 Recreation indicators are represented using these ontology definitions. Finally, our ontology is evaluated using the competency questions established earlier.

2. Indicators and their competency requirements

The Recreation theme indicators' definitions are explored in this section as provided in ISO 37120. For each indicator, competency questions are developed based on its definition. These competency questions should be able to represent the types of knowledge required to analyze these indicators and our recreation ontology must be able to answer them. Note that competency questions that refer to measurement theory, statistics, provenance, validity and trust are not included as they are addressed in the GCI Foundation ontology (Fox, 2013). We will use the following to categorize the competency questions (Fox, 2013b):

- Factual (F): Questions that ask what the value of some property is.
- Consistency - Definitional (CD): Determine whether the instantiation of an indicator by a city is consistent with the ISO 37120 definition.
- Consistency - Internal (CI): Determine whether different parts of the instantiation are consistent with each other.
- Deduced (D): A value or relationship that can be deduced form the instantiation. Following are the ISO 37120 recreation theme indicators.

In the following subsections, the ISO 37120 definitions are provided for each indicator and a set of competency questions are generated based on their definitions.

2.1 Square meters of public indoor recreation space per capita (ISO 37120: 13.1)

"Square meters of public indoor recreation space per capita shall be calculated as the square meters of indoor public recreation space (numerator) divided by the population of the city (denominator), and shall be expressed as the number of square meters of indoor recreation space per capita.

NOTE The need for indoor public recreational spaces varies depending on local climatic and cultural conditions. Public recreation space is defined broadly to mean land and buildings open to the public for recreation. Recreation space shall include only space that primarily serves a recreation purpose.
Indoor public recreation space should include:
a) city-owned or maintained buildings;
b) other recreation buildings within the city not owned or operated by the city, provided they are open to the public. This category may include state or provincially owned buildings, schools and colleges, as well as non-profit. If cities report only city-owned recreation space, this shall be noted.

For multi-story buildings the floor area of all floors in the building should be counted if known. For multi-use facilities only the portion of the building devoted to recreation shall be counted (the play areas at a school or college, for example, not the entire school site). The area of the

entire recreation site shall be included (including, for example, building maintenance and utility areas) but shall exclude parking areas."

Competency Questions:

1. (F) What are the buildings that provide recreational activities?
2. (F) What are the non-for-profit buildings that provide recreation?
3. (D) Does building X have more than 1 floor?
4. (D) Does building X provide more than one recreation activity?
5. (F) Which floors in a building provide recreational activities?
6. (F) Which rooms provide recreational activities for each floor?
7. (D) What is the number of square meters of room X that provides a recreation activity?
8. (F) Does a recreation space provide only recreational activities?
9. (F) Does a recreation space include an area in a building or an area of land?
10. (F) Which parts of a building make up a recreation space?
11. (D) Is recreation space X available to the public?
12. (CD) Is recreation space X owned by the city?
13. (F) What is the city's total population?

2.2 Square meters of public outdoor recreation space per capita (ISO 37120: 13.2)

"Square meters of public outdoor recreation space per capita shall be calculated as square meters of outdoor public recreation space (numerator) divided by the population of the city (denominator), and shall be expressed as the number of square meters of outdoor recreation space per capita. Public recreation space is defined broadly to mean land and open space available to the public for recreation. Recreation space shall include only space that primarily serves a recreation purpose.
Outdoor recreation space should include:
a) city-owned or maintained land;
b) other-recreation lands within the city not owned or operated by the city, provided they are open to the public. This category may include state or provincially owned lands, school and college grounds, as well as non-profit. If cities report only city-owned recreation space, this shall be noted.

For multi-use facilities, only the portion of the land devoted to recreation shall be counted (the play areas at a school or college, for example, not the entire school site). Double counting shall be avoided. For example, do not include indoor facilities on parkland.
The area of the entire outdoor recreation site shall be included (including, for example wooded areas of parks, building maintenance and utility areas) but shall exclude parking areas."

Competency Questions:

1. (F) What are the outdoor spaces that provide recreational activities?
2. (F) How many of these outdoor spaces are owned by non-city authorities?
3. (CI) For any outdoor spaces that provides recreational activities, are there buildings on the premise that provide recreational activities indoors?

4. (F) Does an outdoor space include lands and water bodies located outside a building?
5. (D) What is the number of square meters of outdoor space X available for recreation?
6. (F) What are the parks available for recreation?
7. (D) What areas of park X are available to the public?
8. (F) What are the school grounds that provide recreation?

3. Background

3.1 Ontologies

Existing ontologies that fully or partially address some of the concepts addressed in the competency questions mentioned above are researched. In order to build our ontology it is helpful to know how some of the related concepts are developed in other ontologies to facilitate the design of ours. The lack of competency questions and documentations in most of the ontologies impacted the thoroughness of the examination, however they did provide some overall insights. The main source of research is performed on Google and LOV (Linked Open Vocabularies)[2] by searching available ontologies with keywords relevant to out theme. Keywords like recreation, tourism and travel were instrumental in narrowing down the most relevant ontologies. Below are the ontologies we found that contain certain aspects related to the competency questions.

SUMO

SUMO (Niles & Pierce, 2001)[3] is a broad ontology that covers several concepts and serves as a foundation for more niche ontologies. SUMO covers important concepts related to our competency questions. These include recreation, building and land area classes that directly apply to what we want to represent. Room and building level are also important classes found in the ontology, albeit the limited number or lack of axioms. The ontology presents an upper level taxonomy of the classes however there are not enough properties that explain relationships between entities. Below are some of the classes available in the ontology and their sub classes.

[2] LOV rdf/owl downloads can be retrieved at https://old.datahub.io/dataset/linked-open-vocabularies-lov

[3] The SUMO ontology can be found at http://ontologyportal.org/sumo.owl. We will use the prefix "sumo" where needed.

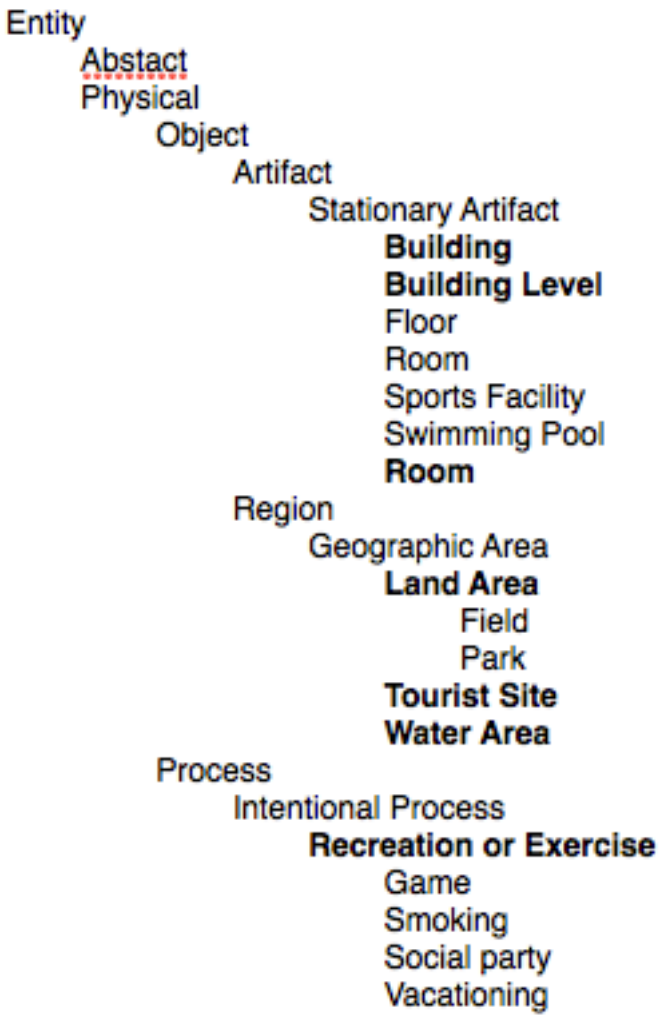


Figure 1: SUMO Class Taxonomy

Properties that relate classes in SUMO are very limited and do not really elaborate the connections they posses. Below is a table showing the property of class building, which is the only relevant property found that relates to our ontology.

Class	Property	Value
sumo: Building	owl: DisjointWith	sumo: Room

OpenCYC

OpenCYC (Matuszek et al., 2006)[4] is a large ontology source for several terms covering everyday common knowledge. OpenCYC provides classes that describe building, room, recreational activity and tourism. This helps us understand the taxonomy of the ontology and provides a discerning perspective. The concept of space is covered in OpenCYC which aids in addressing our concept of a recreation space. Finally, the ontology provides an outdoor recreation area class that includes playground and park. Below is

[4] The OpenCYC ontology can be found at http://sw.opencyc.org/. We will use the prefix "cyc" where needed.

how the topography of the ontology is represented showing only classes we are interested in.

owl: Thing
- **Room**
- Spatial Thing
  - Location
    - Geographical Thing
      - Fixed Freestanding Structure
        - **Building**
      - Place that is also a geographical thing
        - Geographical Region
          - Outdoor Location
            - **Outdoor Recreation Area**
              - Park
              - Playground
                - Sports Course
                - …
    - Place
      - **Facility**
        - Facility Intended for Human Occupation
          - **Indoor Space**
        - **Outdoor Recreation Area**
          - Park
          - Playground
          - Sports Course
            - …
      - Region of Space
        - Chunk of Empirical Space
          - Interior
          - **Space**

thing
- Actions
  - Action
    - Intentional Action
      - Cultural Activity
        - **Recreational Activity**
          - bungee jumping
          - canoeing
          - paragliding
          - …
      - Purposeful Composite Physical and Mental Activity
        - **Recreational Activity**
          - bungee jumping
          - canoeing
          - paragliding
          - …
      - Travel
        - Tourism

Figure 2: OpenCYC Class Taxonomy

The table below shows object properties for the classes (Domain).

Class	Object Property	Range
cyc:Building	cyc: numberOfLevels	cyc: PositiveInteger
	cyc: numberOfStories	cyc: PositiveInteger
cyc:Room	cyc: roomFaces	cyc: SpaceInAFixedHOC

COSMO

Cosmo[5] is an upper level ontology that provides general conceptual definitions for a broad range of topics in several fields. The ontology is available in OWL and provides the most thorough entities relevant to our Recreation theme. Parts of the ontology use elements from SUMO, OpenCYC and other popular ontologies and therefore provides a hub for many important concepts along with their axioms. The necessary concepts for our theme including recreation area, recreation activity, recreation facility and building are all found in the ontology with their property relationships to other classes provided. Our recreation ontology will therefore largely rely on some of the concepts identified. Below are some of the classes identified and their properties.

Class	Property	Value Restriction
cosmo: RecreationalActivity	owl: subClassOf	cosmo: HumanActivity
	owl: subClassOf	cosmo: PurposefulPhysicalAction
	cosmo: causes	value cosmo: Pleasure
cosmo: RecreationalArea	owl: subClassOf	cosmo:LandArea
	owl: subClassOf	cosmo: RecreationalFacility
	cosmo: isLocated	some cosmo: OutdoorRecreatioArea
cosmo: Building	owl: subClassOf	cosmo: FixedStructure
	owl: subClassOf	cosmo: HumanOccupationConstruct
cosmo: Room	owl: subClassOf	cosmo: PartofBuilding
	owl: subClassOf	cosmo: SpaceInAFixedHOC
cosmo: Storey	owl: subClassOf	cosmo: PartofBuilding
	owl: subClassOf	SpaceInAFixedHOC
cosmo: IndoorLocation	owl: subClassOf	cosmo: InsideLocation
	cosmo: isContainedIn	value cosmo: HumanOccupationConstruct
	owl: disjointWith	cosmo: OutdoorLocation
cosmo: OutdoorLocation	owl: subClassOf	cosmo: Outdoor

Schema.org

Schema.org[6] is an ontology that provides schemas for structured data on the internet

[5] The Cosmo ontology can be found at http://www.micra.com/COSMO/COSMO.owl. We will use the prefix "cosmo" where needed.

[6] The Schema.org ontology can be found at http://www.schema.org/ . We will use the prefix "sc" where needed.

and promotes a vocabulary of concepts that may be embedded in webpages. This ontology does not provide reliable schemas that directly relates to the concepts identified in the competency questions. The civic structure class in this ontology contains subclasses like zoo and aquarium as recreation areas, however they passively relate to our theme and have limited influence on our ontology design.

Km4City (Knowledge model for City)
Km4City[7] is an ontology that provides information about services, features and other important variables for a smart city. The ontology provides class concepts for services like Entertainment and Tourism, however these have no axioms or object property relationships that may help explain the concepts further.

ProtOn (Proto Ontology)
ProtOn[8] is a small upper ontology that extends some popular ontologies from Linked Open Data like DBPedia or GeoNames. The ontology nevertheless provides limited entities for exploring our competency questions. Recreation Facility and and Building classes are available, however there are no axioms to support them. There are object properties that are derived from inheritance that cover ownership, operation and location.

DBpedia & Wikidata
DBpedia[9] and Wikidata[10] provide general and high level concepts extracted from sources like Wikipedia to be used by anyone under a public domain license. It contains almost all basic concepts to be addressed in our ontology however they are too broad and mostly available in RDF and JSON dumps with minimum documentation.

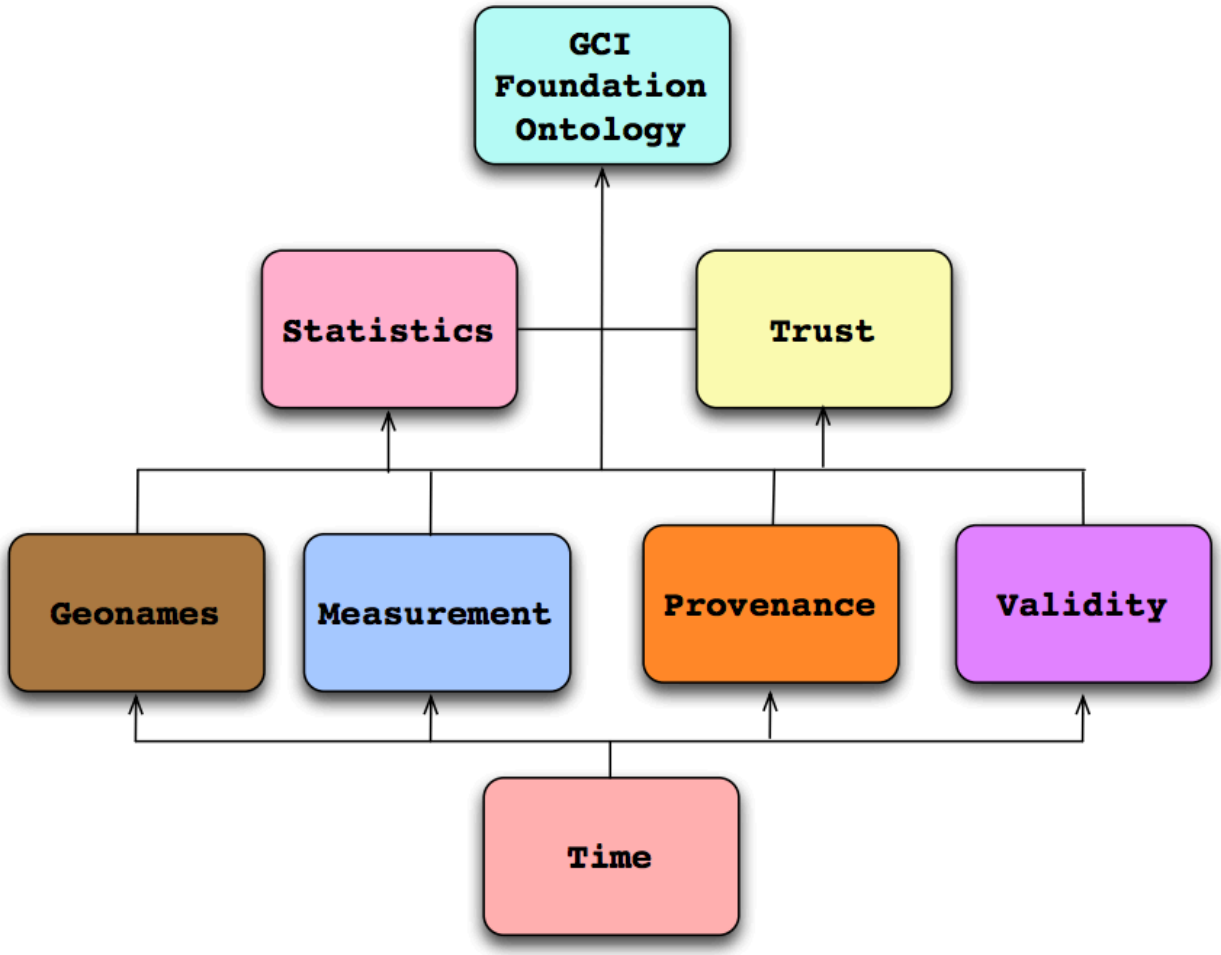
CitySDK
CitySDK[11] is a set of APIs for accessing data provide by cities. These data span different domains including Tourism, which is the most relevant to our ontology. The available open data provides developers with the means to create applications that may serve cities across the world. The applications will guide tourists to experience interesting attractions, thematic walks and available services. A POI (Point of Interest) is a basic element in the API indicating places of interest and is modeled in xml covering concepts like location and geometric coordination. It could also be modeled in other syntax formats like JSON. This effort indicates the growing need to centralize and formalize open data for smart cities.

3.2. Global City Indicator Foundation Ontology

[7] The Km4City ontology can be found by navigating http://www.km4city.org
[8] The ProtOn ontology can be found at http://ontotext.com/products/proton/
[9] The DBPedia ontology can be found at http://mappings.dbpedia.org/server/ontology/classes/
[10] Wikidata can be accessed from https://www.wikidata.org/wiki/Wikidata:Main_Page
[11] CitySDK is accessible from http://www.citysdk.eu

The Foundation Ontology (Fox, 2013)[12] provides a basis for our ontology design and integrates several existing ontologies. The ontology defines the representation of metadata that explore indicator metrics like units and placenames and provides classes and properties for representing them. The Foundation ontology integrates and extends the following ontologies:

- Time (Hobbs & Pan, 2006)
- Measurement (Rijgersberg et al., 2011)
- Statistics (Pattuelli, 2009)
- Validity (Fox & Huang, 2005)
- Trust (Huang & Fox, 2006)
- Provenance (Lebo et al., 2013)
- Placenames (www.geonames.org)



[12] The GCI Foundation ontology can be found at http://ontology.eil.utoronto.ca/GCI/Foundation/GCI- Foundation.owl along with its documentation at http://ontology.eil.utoronto.ca/GCI/Foundation/index.html. We will use the prefix "gci" where needed.

Figure 3: GCI Foundation Ontology Components

4. Architecture of the Global City Indicator Ontology

At the highest level, ISO 37120 defines many global city indicators including our Recreation theme indicators using the modules depicted in Figure 4. The international resource identifier (IRI) for each ISO 37120 indicator is found at the top level. For example, the IRI for the Recreation indicator “Square meters of public indoor recreation space per capita” is identified as “http://ontology.eil.utoronto.ca/ISO37120.owl#13.1”

For each category of indicators in the ISO 37120 specification, for example Recreation, there is a separate file that provides the definition of each indicator in that category. For example, ISO37120/Recreation.owl provides a coherent OWL definition for the 2 indicators in the ISO 37120 specification.

The GCI Ontology level provides specific ontologies needed to define the indicators of each theme. For example the ISO 37120 Recreation concepts cover concepts like indoor space, outdoor space, buildings, recreation activities, etc. GCI-Recreation.owl provides the classes used by ISO 37120/Recreation.owl.

All of the category specific indicator ontologies rely about the GCI Foundation ontology for more generic concepts such as population counts and ratios, meta-information, etc.

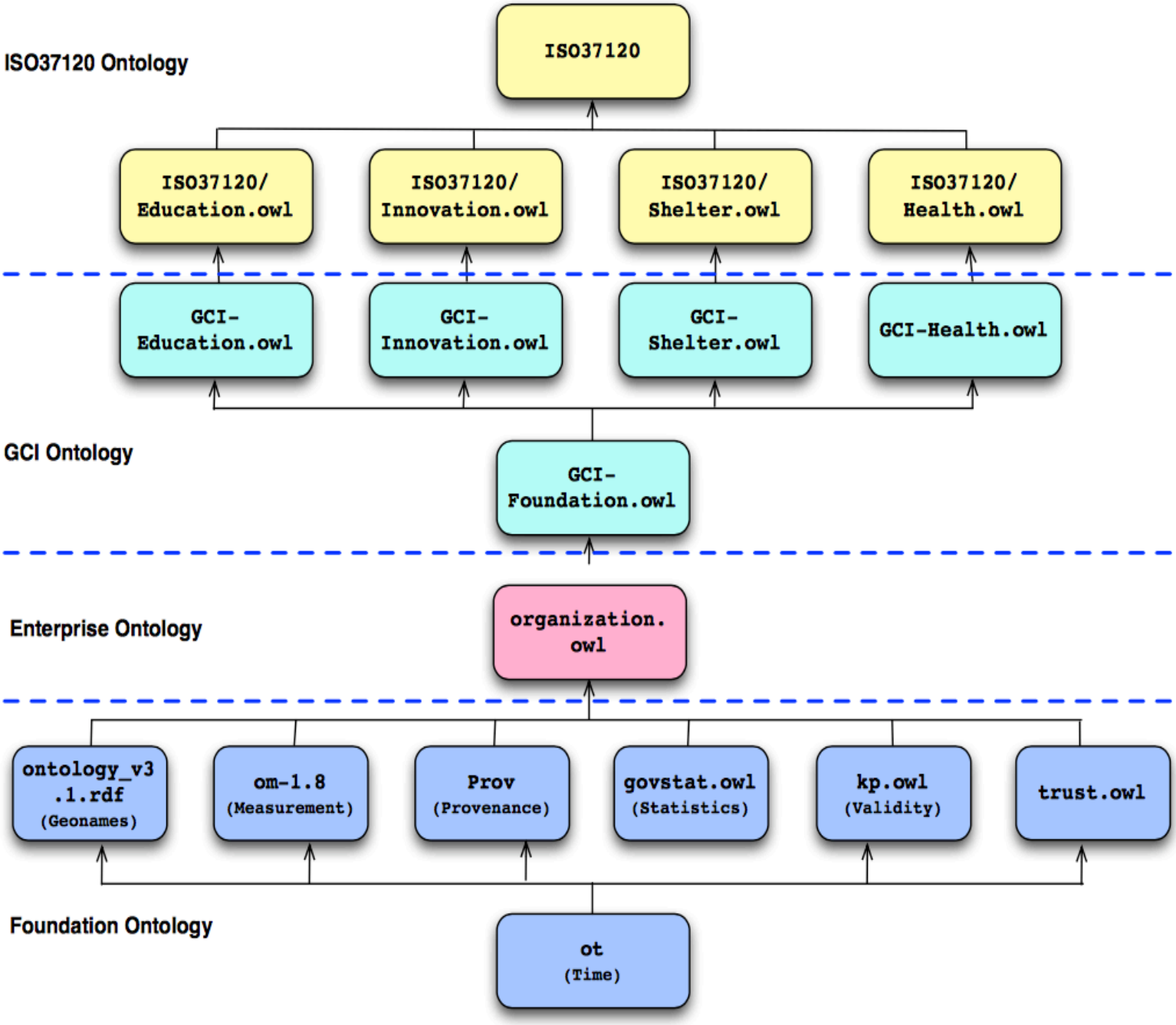


Figure 4: ISO 37120 Ontology Modules

The Enterprise Ontology level builds on the TOVE Enterprise Modeling ontologies (Fox, 1992; Fox & Gruninger, 1998). In this figure we only show the Organization Ontology file (Fox et al., 1998)[13], which is one of the TOVE Enterprise Modeling ontologies. In addition

[13] The Organization ontology can be found at http://ontology.eil.utoronto.ca/organization.owl along with its documentation at http://ontology.eil.utoronto.ca/organization.html. We will use the prefix "org" where needed.

to the Organization ontology, TOVE has ontologies spanning:

- Activities and States (Gruninger & Fox, 1994)
- Resources (Fadel et al., 1994; Fadel, 1994)
- Quality Measurement (Kim & Fox, 1994)
- Activity-Based Costing (Tham et al., 1994)
- Product (Lin et al., 1997)
- Product Requirements (Lin et al., 1996)
- Human Resources (Fazel-Zarandi & Fox, 2012).

Finally, the Foundation Ontology level provides very basic ontologies that were selected as the foundation for the GCI-Foundation.owl ontology described in section 3.

5. GCI Recreation Ontology

As discussed in the previous section, in order to computationally represent the definitions of the ISO 37120 Recreation indicators and answer their competency questions, we need to add recreation concepts not included in the GCI Foundation ontology. This section defines the GCI Recreation ontology that can found at http://ontology.eil.utoronto.ca/GCI/Recreation/GCI-Recreation.owl. The GCI Recreation Ontology addresses the following main concepts covered by the competency questions: **Indoor Space, Outdoor Space, Recreational Activity and Recreation space**. A recreation space constitutes an outdoor space or an indoor space that provides a recreational activity. Below is how the relevant concepts are elaborated in the GCI Recreation Ontology (gcir) and their related competency questions.

A. Indoor Space:

The competency questions below explore the indoor space concept:

1. (F) What are the buildings that provide recreational activities?
2. (F) What are the non-for-profit buildings that provide recreation?
3. (D) Does building X have more than 1 floor?
4. (D) Does building X provide more than one recreation activity?
5. (F) Which floors in a building provide recreational activities?
6. (F) Which rooms provide recreational activities for each floor?
7. (D) What is the number of square meters of room X that provides a recreation activity?
8. (F) Does a recreation space provide only recreational activities?
9. (F) Does a recreation space include an area in a building or an area of land?
10. (F) Which parts of a building make up a recreation space?
11. (D) Is recreation space X available to the public?
12. (CD) Is recreation space X owned by the city?
13. (F) What is the city's total population?

To cover the idea of an indoor space, the ontology describes the concept of a building. We borrow cosmo's ontology hierarchy relation of building and its corresponding axioms. Cosmo:

Building is a subclass of cosmo:FixedStructure and cosmo:HumanShelterConstruct that has properties indicating 'number of levels'. We also extend the properties by including gcir: numberOfRooms to indicate the count of rooms in a building. A building is owned by some 'Intelligent Agent' that has subclasses including government organization, entertainment or recreation organizations and private sector organizations.

Class	Property	Value Restriction
cosmo:Building	owl: subClassOf	cosmo:FixedStructure
	owl: subClassOf	cosmo: HumanShelterConstruct
gcir:Building	owl: subClassOf	cosmo:Building
	cosmo: isOwnedBy	some cosmo: IntelligentAgent
	gcir: numberOfLevels	exactly 1 xsd: positiveinteger
	gcir: numberOfRecRooms	exactly 1 xsd: positiveinteger
	cosmo: contains	some gcir: BuildingLevel
	gci: for_city	exactly 1 gci: City

The concept of indoor space can now be related to a building via property cosmo: containedIn and is a subclass of cosmo: IndoorLocation. The concept of Recreational Activity is imported from cosmo ontology and has a property value cosmo: Pleasure that explains the purpose of recreation. Recreational Activity is also a subclass of Activity from the activity ontology (act). Below, we show the relation of indoor space and room. To specify that the recreational activity is available to the public we employ the participatesIn property from the activity ontology and the Public class from cosmo. Cosmo defines public as "of concern to or open to participation by an unlimited number of people; there may be some qualifications for those who can participate, but there are no limited list of individuals who are concerned. Opposite of Private."

Class	Property	Value Restriction
gcir: IndoorSpace	owl: subClassOf	cosmo: IndoorLocation
gcir: BuildingLevel	owl: subClassOf	gcir: IndoorSpace
	cosmo: isContainedIn	only 1 gcir: Building
	gs:has_Name	exactly 1 xsd: string
gcir: Room	owl: subClassOf	cosmo: Room
	owl: subClassOf	gcir: IndoorSpace
	geo: locatedIn	some gcir: BuildingLevel
gcir: RecreationRoom	owl: subClassOf	gcir: Room
	cosmo: hasDesignFunction	some gcir: RecreationalActivity
	gcir: hasFloorArea	exactly 1 gcir: FloorArea_Quantity
gcir: RecreationalActivity	owl: subClassOf	act: Activity
	owl: subClassOf	cosmo: RecreationalActivity
	cosmo: hasParticipant	some gcir: Public
gcir: Public	owl: subClassOf	cosmo: Public

	cosmo: participatesIn	some gcir: RecreationalActivity

As shown in the figure below, an intelligent agent owns a building that contains recreation rooms. This intelligent agent class has an authority subclass that includes organizations that are government (ie: city government), non profit organizations or entertainment entities.

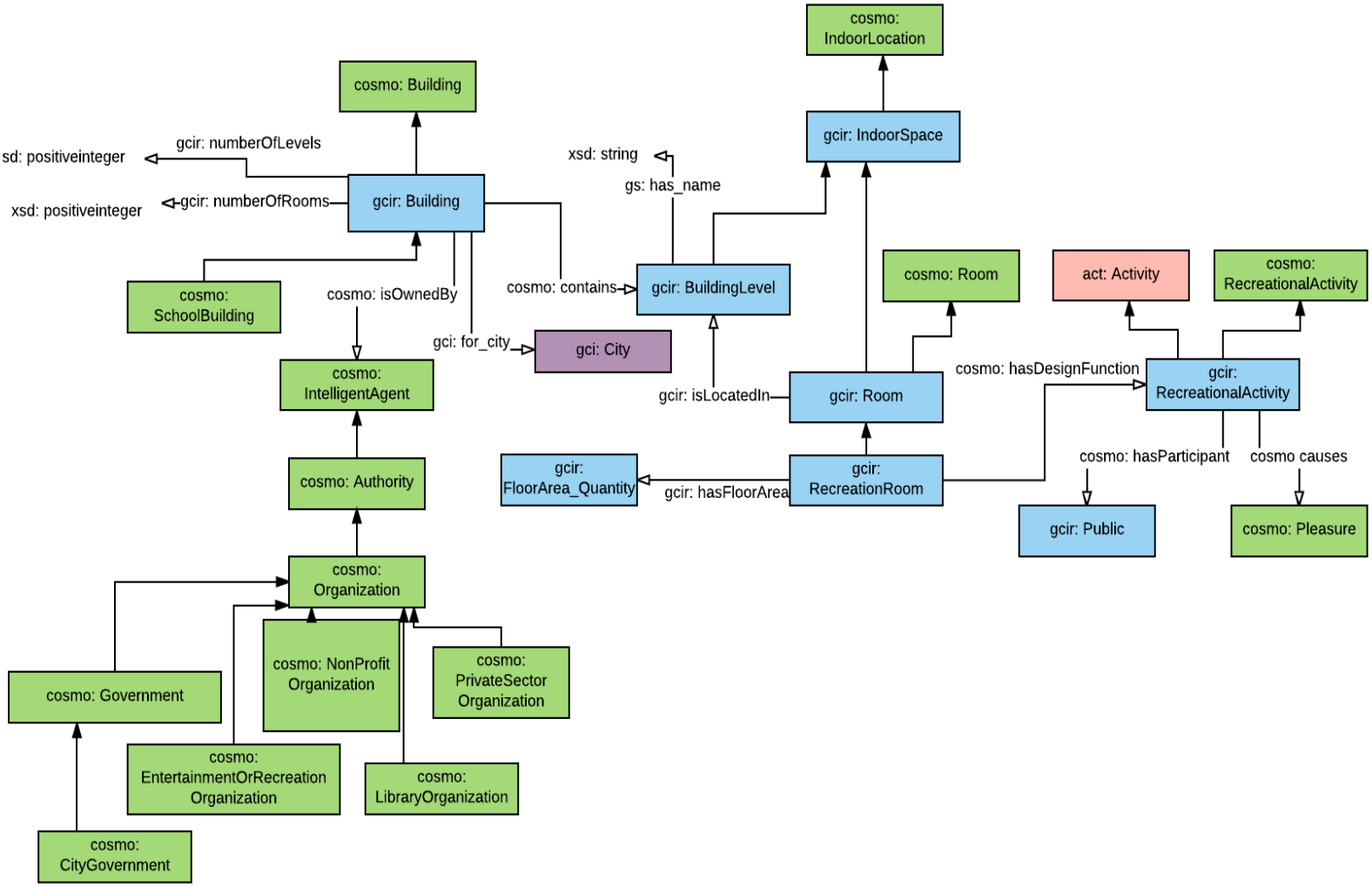


Figure 5: Indoor Space Taxonomy

B. Outdoor Space:

The description of outdoor space is a core concept of the second recreation indicator. The following competency questions cover all knowledge relating to outdoor space.

1. (F) What are the outdoor spaces that provide recreational activities?
2. (F) How many of these outdoor spaces are owned by non-city authorities?

3. (CI) For any outdoor spaces that provides recreational activities, are there buildings on the premise that provide recreational activities indoors?
4. (F) Does an outdoor space include lands and water bodies located outside a building?
5. (D) What is the number of square meters of outdoor space X available for recreation?
6. (F) What are the parks available for recreation?
7. (D) What areas of park X are available to the public?
8. (F) What are the school grounds that provide recreation?

The outdoor space concept in the GCI Recreation Ontology is a subclass of outdoor location in Cosmo. OutdoorSpace has subclasses OpenArea. WoodArea, Wetlands, and BuiltOnArea. We define BuiltOnArea as an outdoor space that contains a building or any artifact that is built or put together on the premise including amusement park rides. Wetlands are defined as an outdoor space that have standing water, which includes beaches and pools.“ The remaining outdoor space sublasses OpenArea and WoodedArea have their definitions borrowed from Cosmo ontology as shown below:
OpenArea :"An outdoor space, exposed to the sky, where things can move unimpeded in any direction."
WoodedArea : "A wooded area is a Region of space place with a lot of trees.”

An OutdoorLocation is also defined as “for locations that are in the atomosphere on or near the surface of the Earth, but not inside a structure." An outdoor location extends high in the atmosphere/ skies and has subclass OpenArea which has a limited height to the skies and closer to the earth.

Class	**Property**	**Value Restriction**
gcir: OutdoorSpace	owl: subClassOf	cosmo: OutdoorLocation
	cosmo: isOwnedBy	some cosmo: IntelligentAgent
	gcir: hasFloorArea	exactly 1 gcir: FloorArea_Quantity
	cosmo: hasDesignFunction	only act:Activity
	gci: for_City	exactly 1 gci:City
gcir:RecreationOutdoorSpace	iwk:subClassOf	gcir: OutdoorSpace
	cosmo: hasDesignFunction	min 1 cosmo: RecreationalActivity
gcir: RecreationalActivity	owl: subClassOf	act:Activity
	cosmo: causes	some cosmo: Pleasure
	act: hasParticipant	some gcir: Public
gcir: Public	owl: subClassOf	cosmo: Public
	act: participatesIn	some gcir: RecreationalActivity

gcir: BuiltOnArea	owl: subClassOf	gcir: OutdoorSpace
	owl: DisjointWith	gcir: (WoodedArea, Wetlands, OpenArea)
	cosmo: contains	some gcir: (Building or NonBuildingStructure)
gcir: NonBuildingStructure	owl: subClassOf	cosmo: Artifact-NonAgentive
	cosmo: hasDesignFunction	some cosmo: RecreationalActivity
	owl: DisjointWith	gcir: Building
gcir: WoodedArea	owl: subClassOf	gcir: OutdoorSpace
	owl: DisjointWith	gcir: (BuiltOnArea, Wetlands, OpenArea)
gcir: Wetlands	owl: subClassOf	gcir: OutdoorSpace
	owl: DisjointWith	gcir: (BuiltOnArea, WoodedArea, OpenArea)
gcir: OpenArea	owl: subClassOf	gcir: OutdoorSpace
	owl: DisjointWith	gcir: (BuiltOnArea, WoodedArea, Wetlands)
gcir: Park	owl: subClassOf	gcir: WoodedArea
	owl: subClassOf	sc: Park
gcir: Zoo	owl: subClassOf	gcir: BuiltOnArea
	owl: subClassOf	sc: Zoo
	owl: DisjointWith	gcir: (Playground, StadiumOrArena)
gcir: Playground	owl: subClassOf	gcir: BuiltOnArea
	owl: subClassOf	sc: Playground
	owl: DisjointWith	gcir: (Zoo, StadiumOrArena)
gcir: Beach	owl: subClassOf	gcir: Wetlands
	owl: subClassOf	sc: Beach
gcir: Field	owl: subClassOf	gcir: OpenArea
	owl: subClassOf	cosmo:Field
gcir: StadiumOrArena	owl: subClassOf	gcir: BuiltOnArea
	owl: subClassOf	sc: StadiumOrArena
	owl: DisjointWith	gcir: (Playground, Zoo)

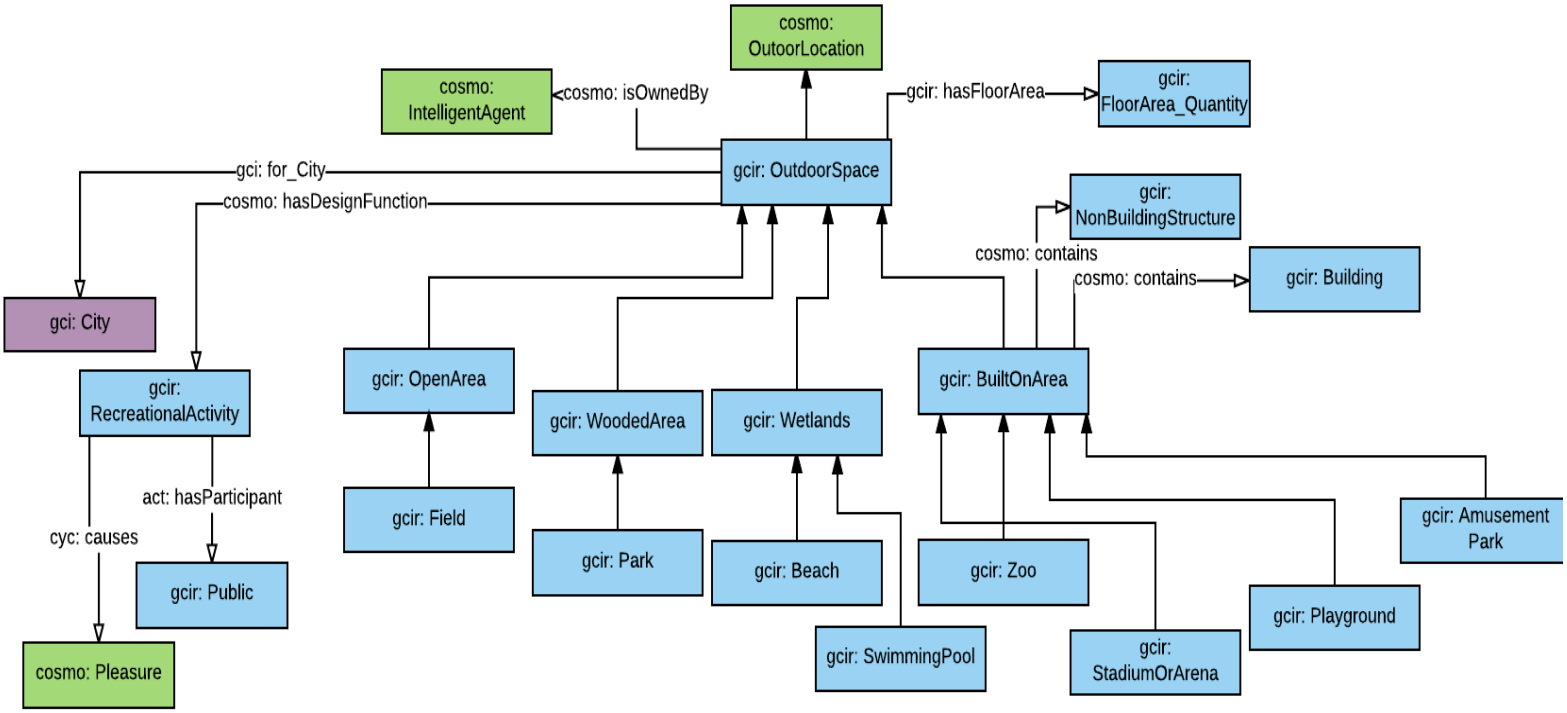


Figure 6: Outdoor Space Taxonomy

The concept of a floor area for both indoor & outdoor is further elaborated in the table below:

Class	Property	Value Restriction
gcir: FloorArea_Measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value om:square_metre
gcir: FloorArea_Quantity	owl:subclassOf	gci:GCI_quantity
	om:unit_of_measure	value om:square_metre
	om:value	only FloorArea_Measure
gcir: floorAreaVar	rdf:type	gs:Variable
	gs:has_Name	value "hasFloorArea"

C. Recreation Space

Finaly, we define a RecreationSpace as the union of RecreationOutdoorSpace and RecreationRoom.

Class	Property	Value Restriction
gcir: RecreationSpace	owl:subclassOf	gcir:RecreationOutdoorSpace or gcir:RecreationRoom

6. GCI Foundation Ontology Infrastructure

The design patterns for the Recreation indicators are covered in this section. The basic structure of a ratio indicator has already been defined in the GCI Foundation ontology (Fox, 2013), and upon which the Recreation indicators are based.

The OM measurement ontology (Rijgersberg et al., 2011) is the core of Foundation ontology. The purpose of measurement ontology is to provide the underlying semantics of a number, such as what is being measured and the unit of measurement. The importance of grounding an indicator in a measurement ontology is to assure that the numbers are comparable, i.e., the actual measures are of the same type; the population size of indoor recreation spaces and population size of the city, are of the same scale (i.e., thousands vs millions).

The figure below depicts the basic classes of the OM ontology used to represent an indicator value. There are three main classes in OM: a 'Quantity' that denotes what is being measured, e.g., Diameter of a ball; a 'Unit of Measure' that denotes how the quantity is measured, e.g., Centimeters; and a 'Measure' that denotes the value of the measurement which is linked to the both 'Quantity' and 'Unit of Measure'. For example, Recreation Area Population Ratio is a subclass of 'Quantity' that has a value that is a subclass of 'Measure' whose units are a 'Population ratio unit' that is a subclass of 'Unit of Measure'. The actual value measured is a property of the 'Measure' subclass 'Recreation Area Population Measure'.

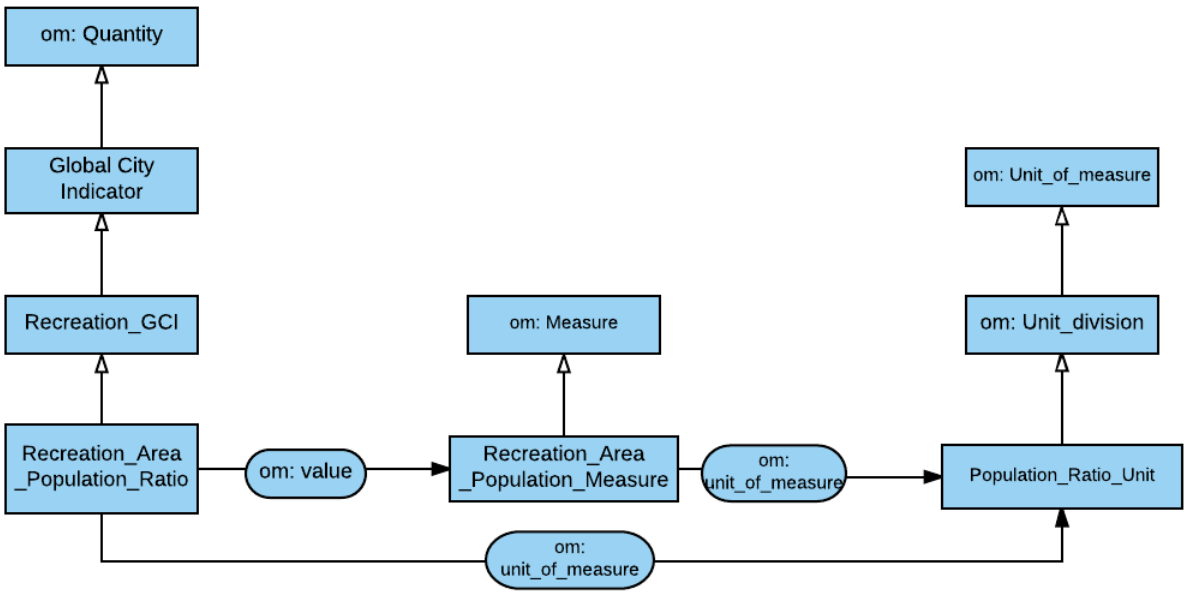


Figure 7: Measurement Ontology

The 'Recreation Area Population ratio' indicator is based on a measure of the number of recreation spaces that satisfy the indicator's definition within a city. This measure can be viewed as a statistical measure in that the population we want to perform a measurement of, is determined by the definition of what a recreation space is that includes indoor space and outdoor space. In order to define what portion of a city we are determining the size of, the GCI Foundation ontology extended the GovStat ontology (gs) with the property 'located_in' that identifies the 'City' that the Population is drawn from, and the property 'defined_by', that

identifies the class that all members of the Population are included based on the indicator definition and in the figure below, we define a pattern for the size of a city's population, which is used as the denominator for the Recreation indicators.

The indicators are ratios and the figure below has a unit of measure defined to be a 'Population Ratio Unit' and for both specifies that the indicator is the ratio of the sizes (cardinality) of two populations. A 'Population Size' is defined as the cardinality of a 'Population', and 'Population' is specified by a 'City' that the population is located in, and by a description of a population definition. For example, the 'Population Size' could be the number of 'Recreation Spaces' in a particular 'City' or the number of 'Residents' in the 'City'. The indicators definition has been structured as follows:

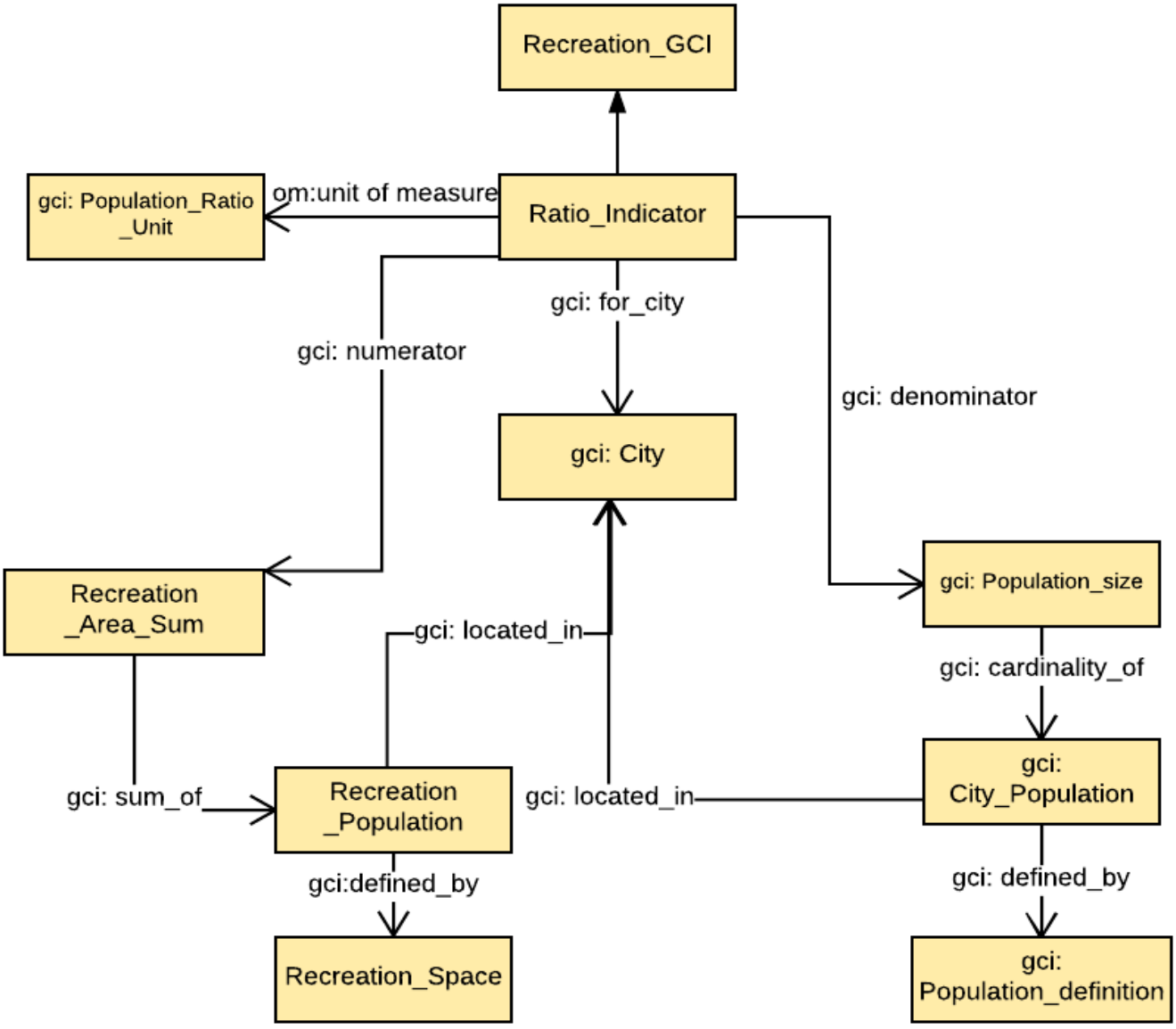


Figure 8: Foundation Ontology Ratio Definition

7. ISO 37120 Recreation Indicators Ontology

With the GCI Recreation and Foundation ontologies defined, we now have the classes and properties necessary to represent the definitions of the ISO 37120 Recreation indicators. In this section we represent the two ISO 37120 Recreation indicators. The OWL 2 definitions can be found in http://ontology.eil.utoronto.ca/GCI/ISO37120/Recreation.owl.

7.1 Square meters of public indoor recreation space per capita

The following diagram shows a partial definition of ISO37120:13.1. Some of the subClassOf links have been omitted but can be found in the OWL definition file.

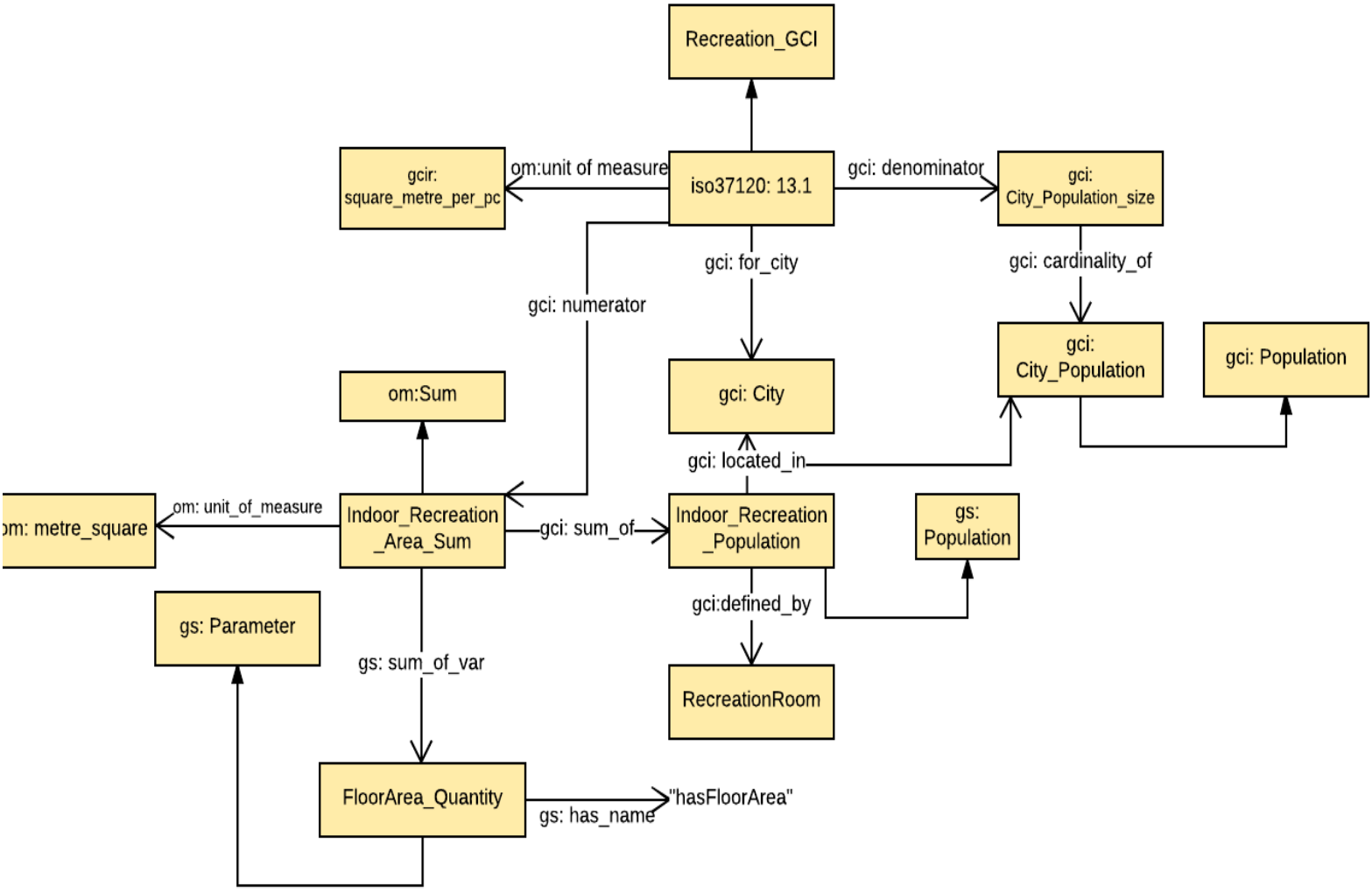


Figure 9: ISO37120:13.1 Definition

Class	Property	Value Restriction
iso37120: 13.1	owl: subClassOf	iso37120: Recreation

	om: unit_of_measure	value gci:square_metre_per_pc
	gci: numerator	exactly 1 13.1_ Indoor_Recreation _Area_Sum
	gci: denominator	exactly 1 gci:City_Population_Size
13.1_ Indoor_Recreation _Area_Sum	owl: subClassOf	gs:Sum
	om: unit_of_measure	value om:square_metre
	gci: sum_of	exactly 1 13.1_ Indoor_Recreation _Population
	gs: sum_of_var	value floorAreaVar
13.1_ Indoor_Recreation _Population	owl: subClassOf	gci: Population
	gci: defined_by	only gcir: RecreationRoom
	gs:is_composed_of	some gcir: RecreationRoom
	gci: located_in	exactly 1 gci:City

7.2 Square meters of public outdoor recreation space per capita

The basic structure of the ratio is the same as in '13.1', but the definition is derived for outdoor space. The OWL definition file contains all the property values that may be omitted in the table below.

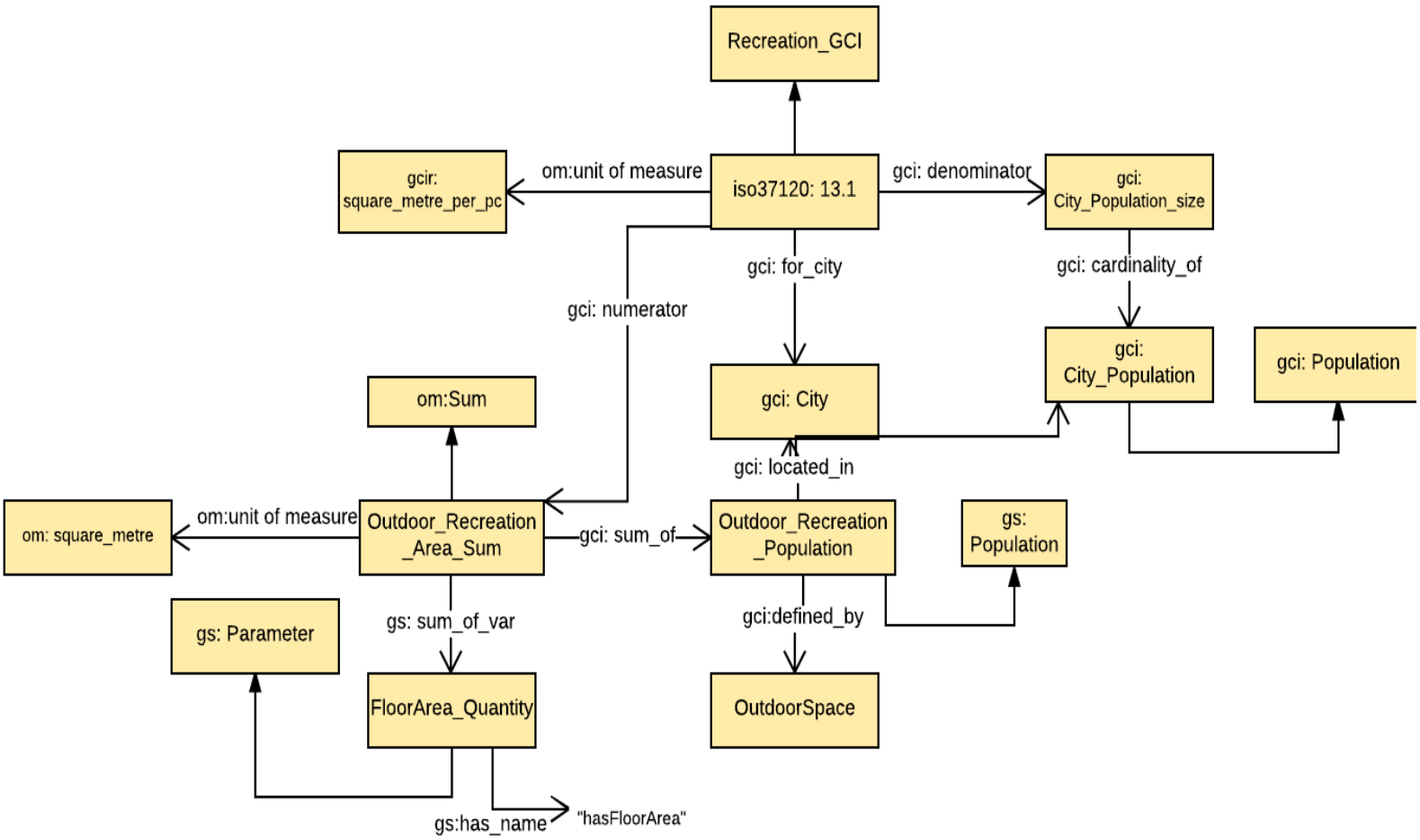


Figure 10: ISO37120:13.2 Definition

Class	Property	Value Restriction
iso37120:13.2	owl: subClassOf	iso37120: Recreation
	om: unit_of_measure	value gci:square_metres_per_pc
	gci: numerator	exactly 1 13.2_ Outdoor_Recreation _Area_Sum
	gci: denominator	exactly 1 gci:City_Population_Size
13.2_ Outdoor_Recreation _Area_Sum	owl: subClassOf	om: Sum
	om: unit_of_measure	om:square_metre
	gci: sum_of	exactly 1 13.2_ Outdoor_Recreation _Population
	gs: sum_of_var	value floorAreaVar
13.2_ Outdoor_Recreation _Population	owl: subClassOf	gci: Population
	gci: defined_by	only gcir:OutdoorSpace
	gci: located_in	exactly 1 gci:City

8. Evaluation

In this section, the City of Toronto in the Province of Ontario, Canada will be used to answer the 13.1 Recreation indicator's competency questions.The following table defines the instances for the Toronto 13.1 indicator (Square metres of public indoor recreation space per capita):

Instance	Property	Value
gn:6167865	rdfs:label	"Toronto"
	rdfs:type	gn:Feature
	rdfs:type	sc:City
ex *(instance of 13.1)*	rdfs:type	iso:13.1
	gci:numerator	iras_size
	gci:denominator	cpop_size
	gci:for_City	gn:6167865
	om:phenomenon	gn:6167865
	om:value	ex_value
ex_value *(the value of 13.1)*	rdfs: type	om:Measure
	om:numerical_value	0.154
	om:unit_of_measure	isor: square_metres_per_pc
iras_size	rdfs:type	isor: 13.1_ Indoor_Recreation _Area_Sum
	gci: sum_of	ir_pop
	om:value	iras_size _value
iras_size _value	rdfs:type	om:Measure
	om:numerical_value	426,960
	om:unit_of_measure	isor: square_metre
cpop_size	rdfs:type	gci: City_Population_Size
	gci:cardinality_of	cpop
	om:phenomenon	cpop
	om:value	cpop_size_value
cpop_size_value	rdfs:type	om:Measure
	om:numerical_value	2,771,770
	om:unit_of_measure	gci:population_cardinality_ unit
ir_pop	rdfs:type	isor: 13.1_ Indoor_Recreation _Population
	gci: located_in	gn:6167865
	gci: defined_by	recreation_room
	gs: is_composed_of	rec_room1, rec_room2
cpop	rdfs:type	gci: City_Population
	gci: located_in	gn:6167865
	gci: defined_by	resident
resident	rdfs:type	gci: Resident
recreation_room	rdfs:type	gcir: RecreationRoom

rec_building1	rdfs:type	gcir: Building
	cosmo: contains	rec_building1_floor_level1
	cosmo: isOwnedBy	non_profit
	gcir: numberOfLevels	1
	gci:for_City	gn:6167865
rec_building2	rdfs:type	gcir: Building
	cosmo: contains	rec_building2_floor_level1, rec_building2_floor_level2
	cosmo: isOwnedBy	gov_org
	gcir: numberOfLevels	2
	gci:for_City	gn:6167865
gov_org	rdfs: type	cosmo: CityGovernment
rec_building1_floor_level1	rdfs:type	gcir: BuildingLevel
	cosmo: isContained	rec_building1
	gs: has_Name	value “1st Floor”
rec_building2_floor_level1	rdfs:type	gcir: BuildingLevel
	cosmo: isContained	rec_building1
	gs: has_Name	value “1st Floor”
rec_building2_floor_level2	rdfs:type	gcir: BuildingLevel
	cosmo: isContained	rec_building1
	gs: has_Name	value “2nd Floor”
rec_room1, rec_room2	rdfs:type	gcir: RecreationRoom
rec_room1	cosmo: hasDesignFunction	rec1
rec_room2	cosmo: hasDesignFunction	rec3, rec2
rec_room1	gcir: hasFloorArea	rec_room1_floor
	geo: locatedIn	rec_building1_floor_level1
rec_room2	gcir: hasFloorArea	rec_room2_floor
	geo: locatedIn	rec_building2_floor_level2
rec_room1_floor	rdfs: type	gcir: FloorArea_Quantity
	om: value	rec_room1_floor _value
rec_room1_floor _value	rdfs: type	gcir: FloorArea_Measure
	om: unit_of_measure	om: square_metre
	om: numerical_value	820
rec_room2_floor	rdfs: type	gcir: FloorArea_Quantity
	om: value	rec_room2_floor _value
rec_room2_floor _value	rdfs: type	gcir: FloorArea_Measure
	om: unit_of_measure	om: square_metre
	om: numerical_value	1050
rec_space	rdfs: type	gcir: RecreationSpace
	cosmo: hasDesignFunction	rec2
	cosmo: isOwnedBy	gov_org
non_profit	rdfs: type	cosmo: NonProfitOrganization
rec1, rec2, rec3	rdfs: type	gcir: RecreationalActivity
	cosmo: hasParticipant	public
public	rdfs: type	gcir: Public
	cosmo: isaParticipantIn	rec1, rec2, rec3

The following illustrates how the competency questions for ISO37120:13.1are implemented in SPARQL:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl:<http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX gcir: <http://ontology.eil.utoronto.ca/GCI/Recreation/GCI-Recreation.owl#>
PREFIX gci: <http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation-v2.owl#>
PREFIX ic: <http://ontology.eil.utoronto.ca/icontact.owl#>
PREFIX isor: <http://ontology.eil.utoronto.ca/GCI/ISO37120/Recreation.owl#>
PREFIX org: <http://ontology.eil.utoronto.ca/organization.owl#>
PREFIX geo: <http://www.geonames.org/ontology/ontology_v3.1.rdf#>
PREFIX geonames: <http://sws.geonames.org/>
PREFIX cosmo: <http://micra.com/COSMO/COSMO.owl#>
PREFIX isori:
<http://ontology.eil.utoronto.ca/ISO37120/Toronto/2013/ISO37120_13_2013_TO.owl#>
PREFIX gs: <http://ontology.eil.utoronto.ca/govstat.owl#>
PREFIX om: <http://www.wurvoc.org/vocabularies/om-1.8/>
```

1. (F) What are the buildings that provide recreational activities?

```
SELECT ?building { isori:ex gci:numerator ?ir_pop_size.
?ir_pop_size gs:sum_of ?ir_pop.
?ir_pop gs:is_composed_of ?rec_rooms.
?rec_rooms geo:locatedIn ?floor.
?floor cosmo:isContainedIn ?building}
```

Answer: rec_building1, rec_building2

2. (F) What are the non-for-profit buildings that provide recreation?

```
SELECT ?building ?owner { isori:ex gci:numerator ?ir_pop_size.
?ir_pop_size gs:sum_of ?ir_pop.
?ir_pop gs:is_composed_of ?rec_rooms.
?rec_rooms geo:locatedIn ?floor.
?floor cosmo:isContainedIn ?building.
?building cosmo:isOwnedBy ?owner.
?owner rdf:type cosmo:NonProfitOrganization.}
```

Answer:

rec_building1	non_profit

3. (D) Does building X have more than 1 floor?

```
SELECT ?floors WHERE {
isori:rec_building2 gcir:numberofLevels ?floors.
FILTER(?floors > 1)}
```

Answer: 2

4. (D) Does building X provide more than one recreation activity?

```
SELECT distinct ?roomA ?recA WHERE {
?floorA cosmo:isContainedIn isori:rec_building2.
?floorB cosmo:isContainedIn isori:rec_building2.
?roomA geo:locatedIn ?floorA.
?roomB geo:locatedIn ?floorB.
?roomA cosmo:hasDesignFunction ?recA.
?roomB cosmo:hasDesignFunction ?recB.
?recA rdf:type gcir:RecreationalActivity.
?recB rdf:type gcir:RecreationalActivity.
FILTER (?recA != ?recB)}
```

Answer:

rec_room2	rec2 , rec3

5. (F) Which floors in a building provide recreational activities?

```
SELECT distinct ?building ?floor_name WHERE {
isori:ex gci:numerator ?ir_pop_size.
?ir_pop_size gs:sum_of ?ir_pop.
?ir_pop gs:is_composed_of ?rec_rooms.
?rec_rooms geo:locatedIn ?floor.
?floor cosmo:isContainedIn ?building.
?floor gs:has_Name ?floor_name
}
```

Answer:

rec_building1	“1st Floor”
rec_building2	“2nd Floor”

6. (F) Which rooms provide recreational activities for each floor?

```
SELECT ?building ?floor_name ?rec_rooms
SELECT ?building ?floor_name ?rec_rooms
{ isori:ex gci:numerator ?ir_pop_size.
```

?ir_pop_size gs:sum_of ?ir_pop.
?ir_pop gs:is_composed_of ?rec_rooms.
?rec_rooms geo:locatedIn ?floor.
?floor cosmo:isContainedIn ?building.
?floor gs:has_Name ?floor_name.}
GROUP BY ?building ?floor_name ?rec_rooms

Answer:

rec_building1	“1st Floor”	rec_room1
rec_building2	“2nd Floor”	rec_room2

7. (D) What is the number of square meters of room X that provides a recreation activity?

SELECT distinct ?building ?rec_room ?x WHERE {
?rec_room gcir:hasFloorArea ?floorArea.
?rec_room cosmo:hasDesignFunction ?rec.
?rec rdf:type gcir:RecreationalActivity.
?floorArea om:value ?floorVal.
?floorVal om:numerical_value ?x.
?rec_room geo:locatedIn ?floor.
?floor cosmo:isContainedIn ?building}

Answer:

rec_building1	rec_room1	820
rec_building2	rec_room2	1050

8. (F) Does a recreation space provide only recreational activities?

We attribute the concept of a recreation space to a room that provides some recreation activity in a building. The concept is applied to indoor space for this set of competency questions in the indicator that refer to indoor ‘recreation space’.

SELECT distinct ?rec_building ?room ?act WHERE {
?room geo:locatedIn ?floor.
?room cosmo:hasDesignFunction ?act.
?act rdf:type gcir:RecreationalActivity.
?rec_building cosmo:contains ?floor.
}

Answer:

rec_building1	rec_room1	rec1
rec_building2	rec_room2	rec2, rec3

9. (F) Does a recreation space include an area in a building or an area of land?

An area of land in this context refers to any outdoor space.

```
SELECT distinct ?room ?area WHERE {
?room cosmo:hasDesignFunction ?act.
?act rdf:type gcir:RecreationalActivity.
?room geo:locatedIn ?floor.
?area cosmo:contains ?floor.
?area rdf:type ?areatype
FILTER(?areatype = gcir:Building ||  ?areatype = gcir:OutdoorSpace)}
```

Answer:

rec_room1	rec_building1
rec_room2	rec_building2

10. (F) Which parts of a building make up a recreation space?

```
SELECT ?building ?floorname ?rec_rooms { isori:ex gci:numerator ?ir_pop_size.
?ir_pop_size gs:sum_of ?ir_pop.
?ir_pop gs:is_composed_of ?rec_rooms.
?rec_rooms geo:locatedIn ?floor.
?floor gs:has_Name ?floorname.
?floor cosmo:isContainedIn ?building.}
```

Answer:

rec_building1	“1st Floor”	rec_room1
rec_building2	“2nd Floor”	rec_room2

11. (D) Is recreation space X available to the public?

```
SELECT ?room ?act ?available_to WHERE {
isori:rec_building2 cosmo:contains ?floor.
?room geo:locatedIn ?floor.
?room cosmo:hasDesignFunction ?act.
?act rdf:type gcir:RecreationalActivity.
?act cosmo:hasParticipant public. }
```

Answer:

rec_building2	rec_room2	rec2	public
rec_building2	rec_room2	rec3	public

12. (CD) Is recreation space X owned by the city?

```
SELECT ?room ?owner WHERE {
isori:rec_building2 cosmo:contains ?floor.
?room geo:locatedIn ?floor.
?room cosmo:hasDesignFunction ?act.
?act rdf:type gcir:RecreationalActivity.
isori:rec_building2 cosmo:isOwnedBy ?owner.
?owner rdf:type cosmo:CityGovernment}
```

Answer:

rec_room2	gov_org

13. (F) What is the city's total population?

```
Select ?city_pop_value WHERE {
isori:ex gci:denominator ?city_pop_size.
?city_pop_size om:value ?city_pop_size_value.
?city_pop_size_value om:numerical_value ?city_pop_value}
```

Answer: rec1: 2771770 xsd

9. Conclusions

The goal of this research was to define an ontology for the representation of ISO37120 Recreation theme indicator definitions and which shall enable analysis by PolisGnosis for any given city.
The GCI Recreation ontology was defined for making indicators representation comprehensible and easy for analysis. Major concepts relating to recreation space are spread across some ontologies on the web however there is no single coherent source.

In summary, this research has made the following contributions:

1) Defines a recreation ontology that covers a broader range of concepts than any existing recreation ontologies while still focused on supporting the definition of ISO37120 recreation indicators.

2) Defines each ISO37120 recreation indicator using the foundation and recreation ontologies, thereby providing a computationally precise definition.

3) Publishes the ISO37120 recreation indicator definitions using Semantic Web Standards, hence making it possible to port using existing ontology tools.

4) Provides a standard representation for general recreation knowledge related to indicators, city specific versions of recreation knowledge and the data used to derive an indicator's value.

10. Acknowledgements

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11. References

Basel Registry of Thesauri, Ontologies and Classifications, BARTOC.org. Cosmo Ontology https://bartoc.org/en/node/657

CitySDK project concept http://www.citysdk.eu

DBPedia ontology classes http://mappings.dbpedia.org/server/ontology/classes/

Fadel, Fadi G., Fox, M.S., and Gruninger, M. (1994) "A Resource Ontology for Enterprise Modelling", *Proceedings of the Third Industrial Engineering Research Conference*, Institute of Industrial Engineers, pp. 455-460.

Fazel-Zarandi, M., Fox, M.S., (2012), "An Ontology for Skills and Competency Management." *Proceedings of the 7th International Conference on Formal Ontologies in Information Systems (FOIS 2012)*, Graz, Austria.

Fox, M.S., (2013), “A Foundation Ontology for Global City Indicators”, Working Paper, Enterprise Integration Lab, University of Toronto, Revised: 31 January 2017. http://www.eil.utoronto.ca/applications/smartcities/papers/ GCI-Foundation-Ontology-v9.pdf.

Fox, M.S., Barbuceanu, M., Gruninger, M., and Lin, J., (1998), "An Organisation Ontology for Enterprise Modeling", In *Simulating Organizations: Computational Models of Institutions and Groups*, M. Prietula, K. Carley & L. Gasser (Eds), Menlo Park CA: AAAI/MIT Press, pp. 131-152.

Fox, M.S., and Grüninger, M., (1998), "Enterprise Modelling", *AI Magazine*, AAAI Press, Fall 1998, pp. 109-121.

Fox, M.S., and Huang, J., (2005), “Knowledge Provenance in Enterprise Information”, *International Journal of Production Research,* Vol. 43, No. 20., pp. 4471-4492. http://www.eil.utoronto.ca/km/papers/fox-ijpr05.pdf

Gruninger, M., and Fox, M.S. , (1994), "An Activity Ontology for Enterprise Modelling", *Workshop on Enabling Technologies - Infrastructures for Collaborative Enterprises* , West Virginia University.

Grüninger, M., and Fox, M. S., (1995), “Methodology for the Design and Evaluation of Ontologies.” *Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing*, IJCAI-95, Montreal, Canada.

Hobbs, J.R., and Pan, F., (2006), “Time Ontology in OWL”, http:www.w3.org/TR/owl-time/.

Hoornweg, D., Nunez, F., Freire, M., Palugyai, N., Herrera, E.W., and Villaveces, M., (2007), “City Indicators: Now to Nanjing”, World Bank Policy Research Working Paper 4114.

ISO37120, (2014), “ISO 37120: Sustainable Development of Communities – Indicators for City Services and Quality of Life”, *International Organization for Standardization*, First Edition, 2014-05-15, ISO37120:2014(E).

Kim, H., and Fox, M.S., (1994), "Formal Models of Quality and ISO 9000 Compliance: An Information Systems Approach", *American Quality Congress (AQC) Conference*, American Society for Quality Control, Las Vegas NV.

KM4CITY, Open Urban Platform For A Sentient Smart City http://www.km4city.org

Lin, J., Fox, M.S., and Bilgic, T.,, (1997), "A Product Ontology", Enterprise Integration Laboratory Technical Report .

Lin, J., Fox, M.S., and Bilgic, T., (1996), "A Requirement Ontology for Engineering Design", *Concurrent Engineering: Research and Applications* , Vol. 4, No. 4, pp. 279-291, Sept. 1996.

Matuszek, C., et al., (2006), “An Introduction to the Syntax and Content of Cyc”, In *Proceedings of the 2006 AAAI Spring Symposium on Formalizing and Compiling Background Knowledge and Its Applications to Knowledge Representation and Question Answering*.

McCarney, P. L., (2012), “Global City Indicators (GCI)©: Standardization of City Services and Quality of Life Indicators, Methodologies and Definitions”, Draft submission to the International Organization for Standardization (ISO) for the standardization of the Global City Indicators and corresponding definitions and methodologies entitled: Global City Indicators (GCI): Standardization of City Services and Quality of Life Indicators, Methodologies and Definitions©.

McCarney, P. L., (2013), “Why Cities? Why Metrics? – Tracking Cities in the 21st Century” Global Cities Institute Working Papers, Vol. 1 No. 1, pp. 1-32, University of Toronto.

Mohamed, A., Liu, D., Summerfield, J., Rissen, P., Lee, R., and Rose, Z., (2013), “Curriculum Ontology”, http://www.bbc.co.uk/ontologies/curriculum/, 2013-04-03.

Niles, I. & Pease, A., (2001), “Towards a Standard Upper Ontology”, In *Proceedings of the 2nd International Conference on Formal Ontology in Information Systems FOIS-2001*, Ogunquit, Maine. New York: ACM Press.

OntoText Proton http://ontotext.com/products/proton/

Pattuelli, M.C., (2003), “The GovStat Ontology: Technical Report”. The GovStat Project, Integration Design Laboratory, School of Information and Library Science, University of North Carolina at Chapel Hill, http://ils.unc.edu/govstat/papers/govstatontology.doc.

Pease, A., Suggested Upper Merged Ontology (SUMO) http://www.adampease.org/OP/

Rijgersberg, H., Wigham, M., and Top, J.L., (2011), “How Semantics can Improve Engineering Processes: A Case of Units of Measure and Quantities”, *Advanced Engineering Informatics*, Vol. 25, pp. 276-287.

Schema.org Community Group https://schema.org/

Tham, D., Fox, M.S., and Gruninger, M., (1994), "A Cost Ontology for Enterprise Modelling", *Proceedings of the Third Workshop on Enabling Technologies - Infrastructures for Collaborative Enterprises*, West Virginia University.

Uceda-Sosa, R., Srivastava, B., and Schloss, B., (2012), “Building a Highly Consumable Semantic Model for Smarter Cities”, *In Proceedings of the workshop on AI for an Intelligent Planet,* ACM.

Wikidata https://www.wikidata.org/wiki/Wikidata:Main_Page

World Council On City Data, Toronto's 2013 Results Under ISO 37120 Indicators of City Service Delivery and Quality Of Life https://www1.toronto.ca/City%20Of%20Toronto/City%20Managers%20Office/Toronto%20Progress%20Portal/ISO%2037120/Final%20-%20Summary%20of%20Toronto%27s%20WCCD-%20ISO%2037120%20Results-6%20.pdf

12. Appendix

All Global City Indicator ontologies can be found at: http://ontology.eil.utoronto.ca

The Global City Indicator Foundation ontology can be found in:
http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Founation-v2.owl.

The Global City Indicator <theme> ontology can be found in:
http://ontology.eil.utoronto.ca/GCI/Finance/GCI-<theme>.owl.

URIs for all of the ISO37120 indicators can be found in:
http://ontology.eil.utoronto.ca/ISO37120.owl.

Definitions of the ISO37120 <theme> indicators, using the GCI Foundation and Finance ontologies can be found in:
http://ontology.eil.utoronto.ca/GCI/ISO37120/<theme>.owl.

Representation of the City of Toronto 2013 ISO 37120 <theme> values can be found in:
http://ontology.eil.utoronto.ca/ISO37120/Toronto/2013/ISO37120_<theme number>_2013_TO.owl