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Households, The Homeless and Slums
Towards a Standard for Representing City Shelter Open Data

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Abstract

In order to compare and analyse open data across cities, standard representations or ontologies have to be created. This paper defines a shelter ontology that includes concepts of shelters, slums, households and homelessness. The design of the ontology is based upon the data requirements of ISO 37120. ISO 37120 defines 100 indicators to measure and compare city performance. There are three shelter-themed indicators defined, namely 15.1 Percentage of city population living in slums, 15.2 Number of homeless per 100 000 population, and 15.3 Percentage of households that exist without registered legal titles. This ontology enables both the representation of the ISO 37120 Shelter theme indicators' definitions, and a city's indicator values and supporting data. This enables the analysis of city indicators by intelligent agents.

1 Introduction

In the sector of homeless shelter and housing, organizations and government are facing a challenge of how to represent and publish the breadth and depth of homeless shelters and housing related information and knowledge that they possess. Information about shelters & subsidized housing, and their users is in need of standard data models, to enable interoperability, i.e., the sharing, merging and analysis of information form multiple sources and across cities. The goal of this research is to develop a standard representation of homeless shelters, housing, users and related information using ontologies.

In 2014 the international standard ISO 37120 "Sustainable development of communities - Indicators for city services and quality of life" was published. It defined 100 indicators, divided into 17 themes such as Education and Shelters, to be used by cities to measure and compare their performance. If we want the publishing of a city's indicators to be more than "beauty contest", cities will need to publish the underlying data used to derive the indicators. For if we are to determine the root causes of poor performance, just knowing an indicator's value will not suffice. So where does one start? We can start by providing a standard for representing a city's indicator data.

The creation of a standard is a byproduct of the primary goal of our research (PolisGnosis Project (Fox 2015)), namely to create an intelligent agent that is able to take as input: an indicator definition, and the data cities use to derive their indicator values, then analyse it to determine the root causes of their performance. However before we can perform analysis, we have to introduce standards for representing five types of information: 1) How do we represent the meta data associated with a published indicator value? For example, its units, scale, its provenance (when it was created, who created it, what process was used to create it), the degree of certainty in the value, and the degree to which we trust the organization that created it and/or the process they used? 2) How do we represent the definition of an indicator? In order for the analysis of indicators to be automated, the PolisGnosis system must be able to read and understand the definition of each indicator, which may change over time. 3) How do we represent the data used to derive an indicator value? An indicator is the apex of a tree of supporting data that is aggregated across place, time, organizations, etc. How is this represented? 4) How do we represent indicator theme specific knowledge? Each theme, such as Education, Health, Shelter, etc., has a core set of knowledge that has to be represented in both the definition of an indicator and in publishing an instance of an indicator and its supporting data. 5) How do we represent a city's theme specific knowledge? Each city may define concepts such as "primary school", "grades", "teachers", etc. differently. Differences in indicator values may be due to differences in the interpretation of these terms between cities.

This paper defines an ontology for representing shelter theme indicators defined in ISO 37120. The four major concepts defined in this paper are: Household, Slum Household, Shelter, and Homeless Person. These concepts

plus their properties (i.e., axioms) provide a rich representation for city shelter knowledge. It builds on our prior research in GCI Foundation ontologies for representing city Indicators and their meta-data (Fox 2103; Fox 2015b).

In the remainder of this paper we introduce the shelters theme indicators defined in section 15 of ISO 37120. Then we review existing ontologies related to shelter theme knowledge. The next section introduces our Shelters ontology, followed by a demonstration of how the ISO 37120 15.1 shelter indicator was represented using it. Finally, we validate the ontology from a competency perspective.

2 Background

In this section we reprint the 15.1 shelter theme indicator's definition as defined in ISO 37120 and a set of competency questions developed. The competency questions represent the types of knowledge necessary to analyze the indicator. Then we review existing ontologies for possible re-use within the shelter and housing domain.

ISO 37120 Shelter Indicators

There are three shelter theme city indicators defined by ISO 37120. Following is the definition of 15.1 Percentage of city population living in slums (the complete definition of shelter theme indicators can be found in (ISO37120 2014)):

"The percentage of city population living in slums shall be calculated as the number of people living in slums (numerator) divided by the city population (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

The number of people living in slums shall be calculated as the number of slum households multiplied by current average household size.

A slum household shall refer to a group of individuals living under the same roof in an urban area who lack one or more of the following:

1. "Durable housing of a permanent nature that protects against extreme climate conditions.
2. Sufficient living space which means not more than three people sharing the same room.
3. Easy access to safe water in sufficient amounts at an affordable price.
4. Access to adequate sanitation in the form of a private or public toilet shared by a reasonable number of people.
5. Security of tenure that prevents forced evictions."

Below are the competency questions that the Shelter Ontology must satisfy in order to represent this indicator:

1. What city is the indicator for?
2. What is the city's average household size?
3. What is the number of slum households in the city?
4. What's the slum population size of the city?
5. What's the city's total population size?
6. Is household X located in the city?
7. Who are the individuals in household X?
8. What is the household size of household x?
9. Is a household X a slum household?
10. Which living conditions outlined by UN-HABITAT is household X lacking?

Existing Ontologies

The ISO 37120 shelters indicators cover concepts such as slum households, homeless person and households without registered legal titles. In order to represent the definitions of the Shelter indicators, we need additional concepts, properties and axioms that span:

- the definition of a household,
- the living conditions a household lacks to be considered a slum household,
- the types of homeless shelters a homeless person can use, and
- the types of unregistered legal titles that a household has.

Generic Slum Ontology

The generic slum ontology (GSO) (Kohli, Sliuzas, Kerle, and Stein 2011) extended the work of (Hofmann, Strobl, Blaschke, and Kux 2008) to reinforce relevant indicators that can be used for slum identification based on satellite images. The indicator used was "durable housing" defined by UN-HABITAT (UN-Habitat 2000), which defines a slum household as a household that lacks of one or more of the five factors described previously. GSO also uses knowledge from experts to identify slum characteristics, building upon the study by (Ebert, Kerle, and Stein 2009), who used a set of image-derived physical proxy variables to assess urban social vulnerability. GSO uses the slum characteristics of the urban environment such as building characteristics, access network, and density that appeared from images as indicators to characterize slums using the GSO as a basis. These concepts can be incorporated into our GCI Shelter ontology to represent living conditions of a slum household and characteristics of a slum area as described above.

Digital Environment Home Energy Management System

DEHEMS is an initiative to influence energy consumption behavior of household by providing the advice on efficient energy consumption and visibility to their energy consumption data (Shah and Chao 2011). DEHEMS includes a household class which was imported from the Suggested Upper Merged Ontology (SUMO) (Niles and Pease, 2001).

The household class could play a part since slum households and households without registered legal titles are essential components of the definition of ISO 37120 shelter indicators.

We've also selected concepts from upper level ontologies SUMO (Niles and Pease, 2001) and OpenCyc (Matuszek, et al. 2006) that provide definitions for general purpose terms related to shelter and housing concepts. Concepts such as sumo:SocialUnit, sumo:LandArea, and cyc:census were related to GCI Shelter concepts such as gcis:Household, gcis:Slum, and gcis:'Average household size'. Selected axioms were also imported from Schema.org since it contains generalized class and properties such as the class sc:Place and sc:Residence.

3 Architecture of the ISO 37120 Ontology

Architecture of the ISO 37120 Ontology

Figure 1 depicts the organization of files used to define the ISO 37120 ontologies under the PolisGnosis project. At the highest level, i.e., ISO 37120 Ontology level, the ISO 37120 module[1] contains the globally unique identifier (IRI) for each ISO 37120 indicator. For example, for "15.1 percentage of city population living in slums" indicator, the IRI is: "http://ontology.eil.utoronto.ca/ISO37120.owl#15.1".

For each indicator theme in the ISO 37120 specification, for example Shelter, there is a separate file that provides the definition of each indicator in that theme. For example, ISO37120/Shelters.owl[2] provides a complete OWL definition for the shelter theme indicators in the ISO 37120 specification.

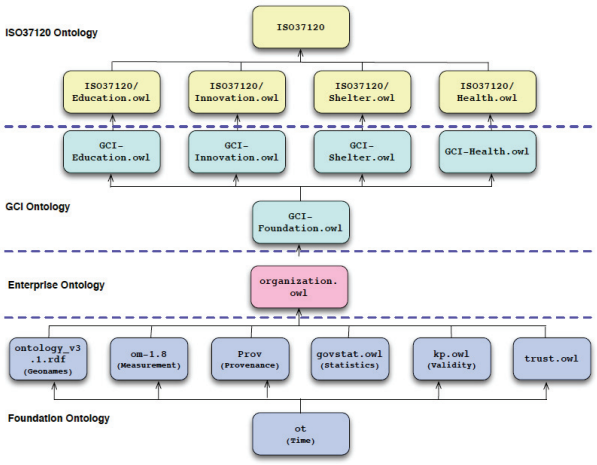

Figure 1 ISO 37120 Ontology Modules, adapted from (Fox 2014)

The GCI Ontology level provides the generic, theme specific ontologies required to define each theme's indicators. For example, to define the ISO 37120 Shelters indicators, we need an ontology covering shelter related concepts such as homeless shelters, homeless person, households, slum areas, etc. GCI-Shelter.owl[3] provides the classes used by Shelters.owl.

All of the theme specific indicator ontologies use the GCI Foundation ontology[4] for generic concepts such as population counts and ratios, meta-information, etc.

The Enterprise Ontology level is based on the Toronto Virtual Enterprise (TOVE) Enterprise Modelling ontologies (Fox and Grüninger 1998). Figure 1 shows the Organization Ontology file (Fox, Barbuceanu, Gruninger and Lin 1998). Finally, the Foundation Ontology level provides ontologies with foundational concepts such as time and space that were included in the GCI-Foundation.owl ontology (Fox 2013; Fox 2015b).

GCI Foundation Ontology Infrastructure

The GCI Foundation ontology imports the Ontology of units of Measure and related concepts (OM) (Rijgersberg, Wigham, and Top 2011). The purpose of OM is to provide the semantics of a number, such as what is being measured and the unit of measurement. A measurement ontology such as OM assures that the numbers are comparable, and the actual measures are of the same type, e.g., the population size of homeless person and population size of city, are of the same scale (i.e., thousands vs millions) and are for the same city.

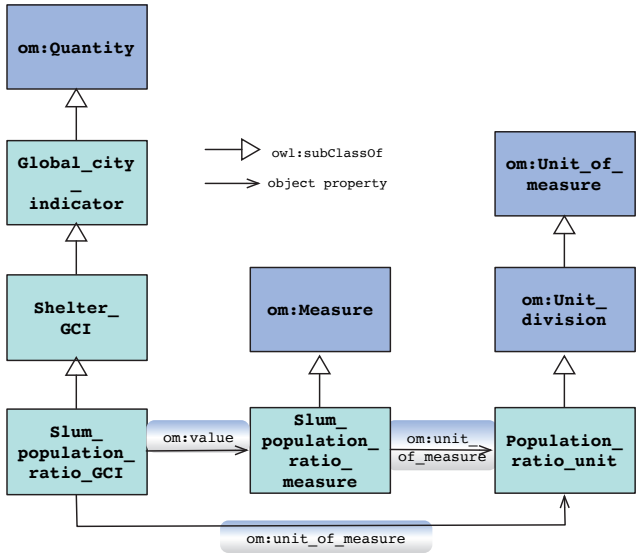

Figure 2 Measurement Ontology, adapted from (Fox 2013)

[1] http://ontology.eil.utoronto.ca/ISO37120.owl
[2] http://ontology.eil.utoronto.ca/GCI/ISO37120/Shelters.owl
[3] http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl
[4] http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl

Figure 2 depicts the basic classes of the OM ontology used to represent an indicator. There are three main classes in OM: a om:Quantity that denotes what is being measured, e.g., diameter of a ball; a om: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, a 'slum population ratio' is a subclass of om:Quantity that has a value that is a subclass of om:Measure whose units are a 'Population cardinality unit' that is a subclass of om:Unit of Measure. The actual value measured is a property of the om:Measure subclass 'slum population ratio measure'.

All shelter indicators are ratio indicators (Fox 2013). All ratio indicators have a numerator and denominator and are both represented by "population" class. A population is a collection of the same object such as people in a city and households. A ratio indicator (Figure 3) has a unit of measure defined to be a 'Population Ratio Unit' that specifies that the indicator is the ratio of the sizes (cardinalities) of two populations. A 'Population Size' is defined as the cardinality of a 'Population', and 'Population' is defined by a 'City' that the population is located in, and by a description of a 'Person' within the 'City' (Fox 2013). This general ontology structure is used in all ratio indicator definitions defined by ISO 37120.

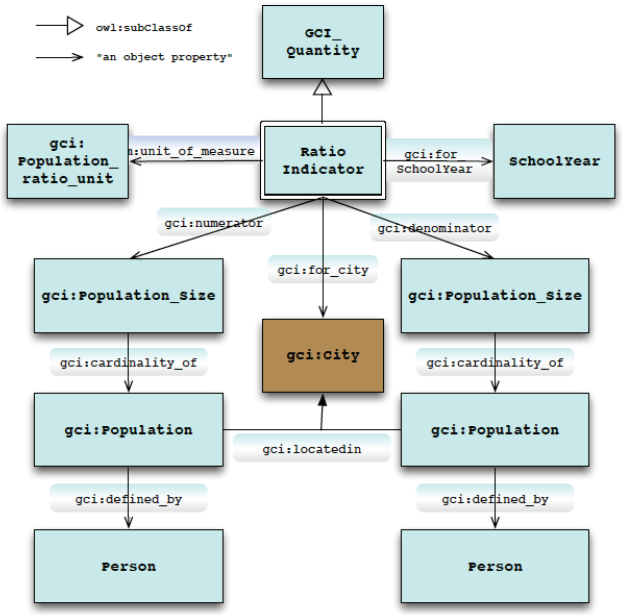

Figure 3 Generic Population Ratio Indicator Definition, adapted from (Fox 2014)

4 GCI Shelters Ontology

The GCI Shelters ontology provides a generalized representation of shelter related concepts that are required to represent the ISO 37120 Shelter theme indicators' definitions. The three main concepts that comprise the GCI Shelters ontology are 'Slum Household', 'Homeless Person', and 'House without Registered Legal Titles'. These three classes were then expanded to cover a wide range of shelter related concepts. Thus the GCI Shelter ontology provides a more precise definition of the three classes and is also able to represent shelter related concepts that are not directly used in ISO 37120 shelter indicators.

The GCI Shelter ontology includes basic classes and properties from the GCI Foundation ontology such as gci:City, gci:Population, gci:locatedIn, and gci:'population cardinality unit', etc. The following classes in SUMO were also imported into the GCI Shelter ontology: sumo:House, sumo:SocialUnit, sumo:LandArea, sumo:Agreement, and sumo:ResidentialBuilding.

The prefix 'gcis'[5] represents the IRI of GCI Shelter ontology, while GCI Foundation ontology has prefix 'gci'[6], classes from OpenCyc has prefix 'cyc'[7], and class definitions from SUMO has the prefix 'sumo'[8].

Household

A household (gcis:Household in Figure 4) is a collection of a group of people. It shall be distinguished from a house which is a physical structure that a household lives in (Statistics Canada, 2012). A household is a subclass of a social unit (sumo:SocialUnit) which is defined to be "a group of people who all have the same home" according to SUMO (Niles and Pease 2001). Note that a gcis:Household does not necessarily possess a sumo:ResidentialBuilding (e.g. homeless households) thus the property gcis:livesIn is not required for the gcis:Household class. A gcis:Household may be linked to a gcis:House via the object property gcis:livesIn. The class gcis:Household has the following subclasses: gcis:'Slum househould' and gcis:'Household without registered legal title'.

A 'Household Size' represents the quantity (om:Quantity) of number of members of a household. It has a measure (gcis:Household_size_measure) which is a subclass of om:Measure that consists of the actual numerical value and a unit of measure. More detailed structure and relationships between om:Quantity class and om:Measure class are described in previous section. The household size needs to be derived from (pr:wasDerivedFrom) an official document such as a census (cyc:census). The census class was implemented from OpenCyc ontology. The cyc:census class was extended to be a subclass of sumo:Document and has a gci:for_city property that links to a city class (gci:City).

[5] http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl#
[6] http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl#
[7] http://sw.opencyc.org/concept/
[8] http://www.ontologyportal.org/SUMO.owl#

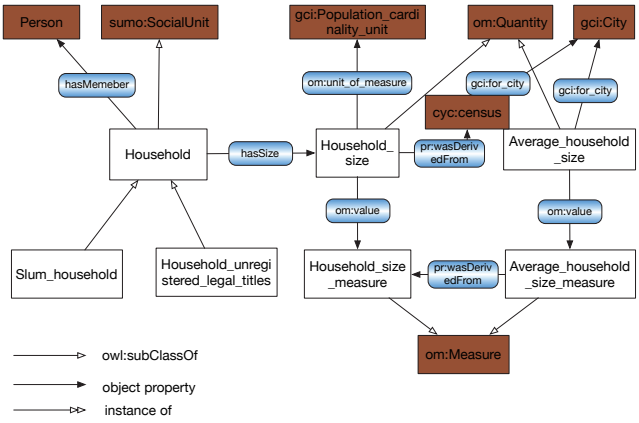

Figure 4 Household

The average household size of a city was constructed in similar manner but with a pr:WasDerivedFrom property from the PROV-O ontology (Lebo, Sahoo, and McGuinnes 2013). This property relates the gcis:Average_household_size_measure class with gcis:Household_size_measure class since the result of the former class is always based on the latter.

Slum Household

A gcis:Slum_household is a household that resides in a slum area. According to UN-Habitat, a slum household is defined to be lack of one or more living conditions (UN-Habitat 2000). These living conditions are grouped under the class gcis:'Living condition' which is linked to the gcis:'Slum household' class by the object property gcis:isLacking which has a minimum cardinality of 1. A distinct class was defined for each of the living conditions: durable housing, sufficient living space, access to improved water, access to sanitation, security of tenure. 'Slum household' class was linked to gcis:Slum class via the object property gci:locate_in. Slum is subclass of gn:Feature from Placenames[9]. Since each city has a different definition for an area to be considered as a slum, a gci:for_city property was used to link gcis:Slum class and gci:City class. The object properties ic:hasGeoCoordinate and gcis:hasGeoShape links the Slum class with the class sch:GeoCoordinate and sch:GeoShape from Schema.org respectively. This gives the ability to represent the slum area in terms of geographical coordinates and shapes that is useful for any researches about urban slum areas.

Homeless Person

A homeless person can live on a street, in a park or other temporary place as well as a homeless shelter. By definition of UN-Habitat a homeless person is defined as follows: "Absolute homelessness occurs when there is neither access to shelter nor the elements of home. A person may be in relative homelessness; that is, they may have a shelter but not a home" (UN-Habitat 2000).

Homeless_person is a subclass of Person class (Figure 5). It is further classified as 'Absolute homeless person' and 'Relative homeless person' as per definition above. Both subclasses of 'Homeless_person' possess an object property gcis:livesIn but with different constraint values. 'Relative homeless person' lives in homeless shelters (gcis:Homeless_shelter) while 'Absolute homeless person' can live in any place throughout the city but not a homeless shelter or a home. We use the class 'sumo:Place' to represent places that an absolute homeless person can live in. But an absolute homeless person does not have access to neither homeless shelter nor a residence. This is represented in Description Logic as follows.

$$\text{Absolute\_homeless\_person} \sqsubseteq \text{Homeless\_person} \sqcap \forall \text{livesIn}\,(\text{PostalPlace} \sqcap \neg(\text{Homeless\_shelter} \sqcup \text{ResidentialBuilding}))$$

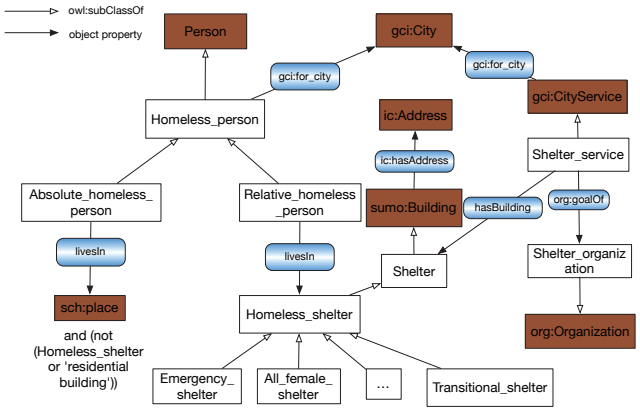

Figure 5 Homeless Person and Shelter Classes

Shelters

gcis:Shelter_service is a subclass of gci:CityService that is defined in GCI Foundation ontology. Shelter services are generally city services that provide a place to live for people in need. The gcis:hasBuilding links gcis:Shelter_service class to the gci:Shelter class which is a subclass of sumo:Building class which was then extended with ic:hasAddress that links the residential building to ic:Address from iContact ontology[10]. We also outlined gci:CityService and its superclass, gci:Service in the table. The gci:Service class is linked to an organization (org:Organization) which operates the shelter service.

gcis:Homeless_shelter is a subclass of Shelter class. It serves as a superclass of different types of homeless shelters such as emergency shelters and all-female homeless shelter. gcis:Homeless_shelter is linked to gcis:'Relative

[9] http://sws.geonames.org/

[10] http://ontology.eil.utoronto.ca/icontact.owl

homeless person' via the object property gcis:livesIn as described earlier.

5 ISO 37120 Shelter Indicators Definitions

In this section we apply the Shelter ontology to one of the three shelter indications. We will use 15.1 indicator as an example. The definitions of all ISO 37120 Shelter theme indicators can be found in (Wang and Fox 2015).

15.1 Percentage of city population living in slums

Figure 6 depicts the 15.1 indicator, which is determined by the ratio of number of people living in slums (isos:15.1_Slum_ population_size) to the city's total population size (isos:City_population_size). Number of people living in slums was then further defined to be the product of number of slum households (15.1_Slum_household_population_size) and the average household size (isos:Average_household_size) of the city. Slum household population size is a cardinality of (gci:cardinality_of) slum household population (isos:15.1-Slum_household_population) which is then defined by the gcis:Slum_household class discussed previously. The class isos:City_population_size was used as the denominator of shelter indicator 15.1. It is a subclass of gci:Population_size and is a 'gci:cardinality_of' isos:City_population which is a subclass of gci:Population. City population is the group of people living in a specific city. It is linked to a City class via gci:located_in property. It is also 'defined_by' by a Person class.

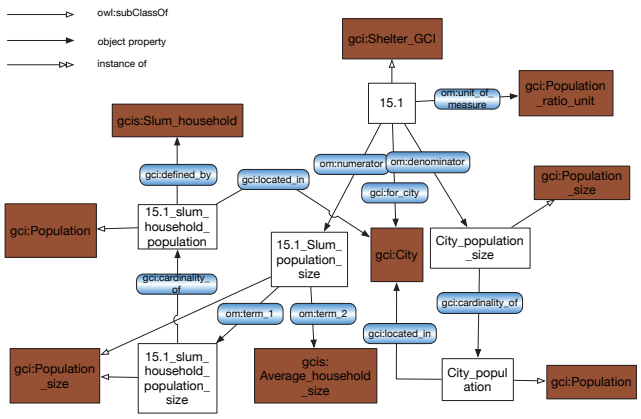

Figure 6 Shelter Indicator 15.1 Definition

This example demonstrates a number of important features: 1) the reuse and integration of existing ontologies, 2) the power of the generic GCI Foundation ontology to represent many types of indicators, and 3) the additivity of knowledge. The specialization of the GCI Foundation population ratio representation (Figure 3) to indicator 15.1, only required the definition of "slum household" to specify the subset of the population of all households that we wish to count.

6 Verification

We use competency questions stated in section II to verify our ontology. The following shows how the first 3 competency questions for '15.1' are implemented in SPARQL.

1. What city is the indicator for?

```
SELECT ?city WHERE{
        :15.1_ex gci:for_city ?city }
```

2. What is the city's average household size?

```
SELECT  ?city (?avghs_m_value AS ?Average) WHERE{
         ?avghs rdf:type gcis:Average_household_size.
         ?avghs gci:for_city ?city.
         ?avghs om:value ?avghs_m.
         ?avghs_m om:numerical_value ?avghs_m_value }
```

3. What is the number of slum households in the city?

```
SELECT ?city ?slumHPopSize_m_value WHERE{
        ?slumHPop rdf:type
        isos:15.1_slum_household_population.
        ?slumHPop gci:located_in ?city.
        ?slumHPopsize gci:cardinality_of ?slumHPop.
        ?slumHPopSize rdf:type
        isos:15.1_slum_household_population_size.
        ?slumHPopSize om:value ?slumHPopSize_m.
        ?slumHPopSize_m om:numerical_value ?slum-
        HPopSize_m_value }
```

7 Conclusion

The goal of this research is to develop a standardized representation of homeless shelters, housings and users using ontologies. The ontologies represent necessary shelter, housing and user related information that comply with the requirements imposed by the ISO 37120 shelter indicators. Towards this end, a Shelter ontology was defined to represent shelter related concepts that were used in the definitions of ISO 37120 shelter theme indicators. Each indicator's definition was then represented using the GCI Shelter ontology, GCI Foundation ontology and other ontologies as described. Key to the design of this ontology were the competency questions derived from the indicator definitions. This allowed us to discern what needs to be represented and what should not.

In summary, this research makes four contributions:

1. Defines a general Shelter ontology;
2. Represents each ISO37120 shelter indicator definition using the GCI Foundation and Shelter ontologies;
3. Enables the publishing of the ISO37120 shelter theme indicator definitions using Semantic Web standards; and
4. Enables the publishing of a city's ISO37120 shelter theme indicators' values along with the supporting data used to derive them using Semantic Web standards.

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