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Short Term Scientific Mission Report – Ontologies
of Urban Models

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1. INTRODUCTION

The Short Term Scientific Mission for COST Action C21 “*Towntology - Urban Ontologies for an Improved Communication in Urban Civil Engineering Projects*” took place from 12th to 26th of May 2006 in Finland. The host institution was TTY Tampere University of Technology, Department of Architecture, Urban Planning and Design, in Tampere, Finland.

This scientific mission has been really useful both on the theoretical level, because I have improved my knowledge about ontology field through discussions with my STSM host professor Anssi Joutsiniemi, and on the operational level, because we started to create an urban ontology, using different available tools and different languages for ontology building. Moreover those exchange visits allowed us to compare different kind of urban sprawl, which is one of the main aspects of our STSM, in particular prof. Joutsiniemi had the possibility to analyse the urban dynamics of different Italian metropolitan areas, like Milan and Turin, during his past STSM, while for the period of my STSM in Finland I have seen the traces of the urban evolution through years of Helsinki metropolitan area, and of other cities like Tampere and Turku.

In the following report I’ll show at first the aim of this mission and the theoretical bases used to start to build an urban ontology, like ontology definition, its proprieties and suitable languages to create it, then I’ll describe our remarks and results in order to better understand the ontology building process for an urban system.

2. AIM OF THE STSM

Our proposal for this STSM was concerning development of ontologies for urban models, with a special reference to the case of urban sprawl. Due to its world wide diffusion, urban sprawl is the most suitable candidate for the modelling activity (and ontology definition).

Urban modelling, in particular GIS based urban modelling, is again a rapidly growing activity. The new models are based on concepts (e.g. self-organization) and methods (e.g. multi-agent systems) of the ‘*science of complexity*’. For basic scientific principles, this fact strictly implies that the ontology of the model has to be carefully defined¹. This activity needs international comparative studies, also through vis-à-vis contacts.

What we proposed to do during this STSM is:

- Comparing modelling activities and urban sprawl in two countries (Italy and Finland).
- Starting operational work to build an ontology of urban sprawl.
- Defining an ontology for the urban sprawl model (through European towns) based on prof. R. Laurini’s software, *Towntology*².

Our objective is building a shared and reusable ontology, both in a operational and more conceptual sense, but to do that we need a precise definition of system of interest,

¹ See also G. A. Rabino (2005) *Ontology of multi-agent systems*, in Proceedings of 14th ECTQG ‘05 colloquium, Tomar, Portugal.

² *Towntology* software is available at <http://liris.cnrs.fr/~townto/>.

classification of its relations by means of topological analysis, and explanation of the concepts through mereological tools (for example decomposition of an object in its parts, or a class in its subclasses). This report presents an attempt to apply these procedures to urban systems, beginning from the corpus of theories developed in urban system analysis to achieve an ontology of the city with the already mentioned suitable features, underlining in particular three levels (physical, socio-economical, and mental level) through which it's possible to observe the city.

3. GUIDELINES FOR URBAN ONTOLOGY

This work starts from, and it is based on a bibliographic study of Catherine Roussey, made for COST meeting 2005, in order to provide guidelines for ontology building [16]. I'll explain here what we consider as Ontology, how it can be specified, what its significant features are, and how it can be used. We will see that different kinds of knowledge can be distinguished and that knowledge can be modularized in small, manageable pieces. This makes it possible to construct large and complex ontologies out of smaller and more reusable ones.

3.1 Ontology definition

The word ontology comes from Greek *ontos* (of being), and *logos* (study, science, theory) is the most fundamental branch of metaphysics. It studies being or existence and their basic categories and relationships, to determine what entities and what types of entities exist. The more traditional term is referred to Aristotle's theories.

Artificial Intelligence (AI) has borrowed the word from philosophy and has given its meaning a change. For AI the main question is not what the nature of being is, but what an AI system has to reason about to be able to perform a useful task. An often used and paraphrased definition of ontology is that one of Gruber [9]:

'An ontology is an explicit specification of a conceptualization'

Or we can use a more precise and detailed definition of ontology introduced, starting from the previous one, by Studer [18]:

'An ontology is a formal and explicit specification of a shared conceptualization'

In order to understand these definitions, it must be clear what a conceptualization is. A conceptualization is a structured interpretation of a part of the world that people use to think and communicate about the world. In other words conceptualization contains objects, concepts, all other entities that are assumed to exist in a particular area of interest, and all the relationships among them.

In these ontology definition we encounter other really important terms like *explicit* (concept type and their usage constrains are explicitly defined), *formal* (machine understandable), and *shared* (consensual knowledge accepted by group).

3.2 Formal language

In according with Studer's definition [18], we propose to build a formal ontology, using an artificial formally defined language, in order to get as much expressiveness as possible of a natural language, and have the possibility to perform a reasoner on information related with the system to obtain new knowledge.

Objects in ontology have to be defined using their proprieties, which are other concepts linked themselves with other concepts through relationships, in order to built the ontology structure. Natural languages aren't able to describe in a powerful way concept definitions and relationships, which should be represented with another kind of language, more formal.

Currently most the information is written using syntactical machine readable languages such as HTML. These languages are limited in that they are only intended for human consumption. To fully unlock the potential of such a vast resource of information, we need to make the information not only machine readable but *machine-understandable*. In order to gain machine understanding we need semantic languages which are able to define meaning to the information being stored. Agents (human or machine) could then use this information in variety of different ways [17].

In order to built an Application Ontology we purpose to adopt Heavyweight characteristics [16], because an ontology with simple taxonomic structure (kind-of or part-of relationships) of concepts, with associated definitions in a natural language (Lightweight ontology), has the same expressiveness of a conceptual map, and it cannot be (re)used in other applications. During this STSM we have analysed different kinds of formal languages, and we can assert that OWL (*Ontology Web Language*) seems to be a really suitable language in ontology building.

3.3 Shared and reusable ontology

Ontology building process is characterized by its very high cost and elaborate overlapping activities of development. To build ontology from scratch is too cost-effective. Thus, an approach of ontology construction requires the capture of the key concepts (and their relationships) of a domain. Researchers have proposed many approaches namely bottom-up, top-down, and middle-out. A bottom-up approach for example seems very attractive for many scientific and engineering. The approach focuses on building complex concepts from their primitive (basic) concepts and a list of construction rules.

Research in ontology building from existing ontology sources is motivated by cost and reliability. The recent trend toward ontology library systems to manage, adapt, and control for the purpose of re-use of the great amounts of existing ontologies. Reusability of what exists has proven its success in many areas such as software engineering, medical systems, and environmental information systems. There is, however, limited number of research work in re-use of ontology sources embedded in legacy systems and databases [2].

Starting an urban Geographic Information System (GIS) project presents many challenges. Describing the detail-rich urban environment is one of them. To face this challenge, the use of existing knowledge from previous GIS projects is a necessity.

Beyond that, the use of existing data is also desirable. But the lack of formal methods to reuse knowledge and data makes this task really difficult [7].

Reusability can be applied not only to some parts of ontology, or different kinds of data inside that, but we propose to reuse also the reference ontologies, which are used during development time of applications for mutual understanding and explanation between (human or artificial) agents, belonging to different communities in order to establish consensus about concepts [16].

Always in according with Studer's definition [18], an ontology should be shared, and reusability, as we have just seen it, can be an useful tool to obtain this suitable feature. In this work a shared knowledge is a consensual knowledge accepted by a group, and in particular we refer to the corpus of theories developed in urban system analysis, that is at the base of a systemic vision of the city.

3.4 Semantic relationships

The most common way to represent objects in an ontology is through use of semantic relationships between concepts, which give a hierarchical structure to the whole system. The main semantic relationships between concepts are:

- Taxonomy (Hyperonymy, Hyponymy), X is a kind of Y (or Y has a kind X)
This relationship is transitive and anti-symmetric, and characterizes the relation between classes and sub-classes, where subclasses inherit all proprieties of the their class (i.e. hospital, flat, house are kind of a building).
- Partonomy (Meronymy, Olonymy), X is a part of Y (or Y has a part X)
This relationship is transitive and anti-symmetric, and the sum of parts of an object constitutes the object itself (i.e. window, door, roof are parts of a house).

Not only semantic relationships are between concepts, but there are also other kind of semantic relationships between verbs:

- Troponymy, a verb is a troponym of another one, when the first expresses a particular manner of the second (march - walk).
- Implication, an action implies another one, when the first action can't be performed without to perform also the second (snore - sleep).

Lexical relationships are important relations between concepts that depend by phrases in which they are:

- Synonymy, two concepts are synonyms, if substituting one concept with the other one inside a phrase, the value of truth of phrase doesn't change.
- Antinomy, the antonym (or contrary) is a concept having a meaning opposite to that of another concept. A word and its antonym can't be substitute in a phrase, and the negation of antonym preserve the value of truth of the phrase.
- Polysemy, the polysemous is a concept with more than one meaning.

Semantic relationships are easy to use into an ontology, also because we already know their proprieties and their formal representation, however there are many other kinds of relationships that can be added in an ontology structure, but we need to do an effort to define and characterize them in a formal way.

3.5 Entitation and Conceptualization

I'll briefly introduce here two issues really important not only for ontology building, but also in general for each model building process. Described what an ontology is, we need now to connect the real world, what we observe and we want to model, with the world of concepts, which are at the base of an ontology. Entitation is an abstraction process which produces entities starting from objects in real world (usually called instances). It is a fundamental process in model building. The entity-relationship model is a data model for high-level descriptions of conceptual data models, and it provides a graphical notation for representing such data models in the form of entity-relationship diagrams (ERD). Such models are typically used in the first stage of information-system design; they are used, for example, to describe information needs and/or the type of information that is to be stored in the database during the requirements analysis. The data modelling technique, however, can be used to describe any ontology (i.e. an overview and classifications of used terms and their relationships) for a certain area of interest (domain). Moreover, these entities could be considered not only like static objects inside a model, but also like interacting agents (active complex objects)³.

Conceptualization, instead, is the process producing concepts, abstract ideas or mental symbols in our mind, typically associated with a corresponding representation in natural language. A concept can be associated with an entity or many entities related together.

We will see in the following chapter how a concept can be represented in ontology, but it's important to say that a concept can be associated with physical, ideal and social objects, where for example social objects can be seen, at a different abstraction level, like physical objects related together by a particular function [5][6][21]. Moreover we can identify a bi-univocal correspondence between natural language and aggregate concepts, and as well an isomorphism between concepts in an ontology and entities in a model. Still in the next chapter it's possible to recognise the same isomorphism also between relationships, defined and represented in ontologies, and the equations which link different entities in a mathematical form.

4. THE CITY AND URBAN ONTOLOGY

Urban sprawl, an uncontrolled and ungovernable growth of low density urbanized areas, is the result of a localization process, determined by complex urban dynamics acting on territory. In order to study this element, it's necessary to start from the urban system which generates it, to define the concept of city, and to consider a simple urban model that describes this process, like the Lowry Model [14]. Even though the urban sprawl looks morphologically similar in many metropolitan areas, it could be determined by different socio-economical aspects.

³ See also G. A. Rabino (2005) *'Processi Decisionali e Territorio nella Simulazione Multi-Agente'*, Società Editrice Esculapio, Bologna; and S. Occelli, G. A. Rabino (2003) *'Facing urban complexity: towards cognitive modeling. Part 2. Modelling as an ALC (Action, Learning, Communication) agent'*, XIII European Colloquium on Theoretical and Quantitative Geography, Lucca.

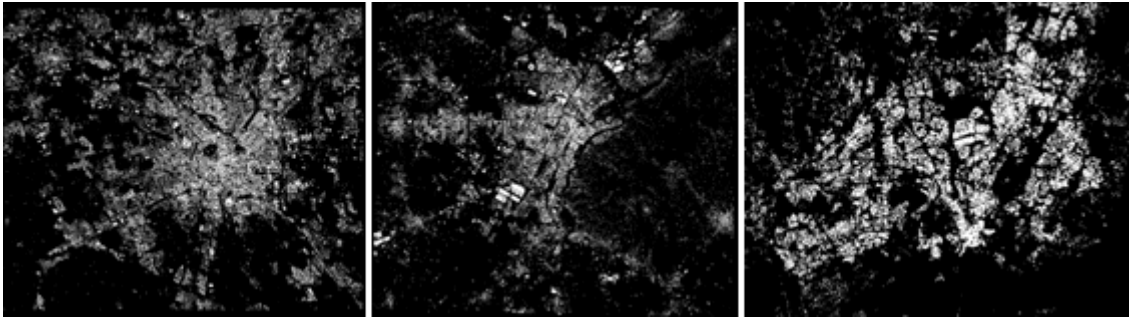


Fig.1. Urban sprawl: Images of Milan, Turin, and Helsinki metropolitan area.

Urban ontology building, proposed in this work, starts from a systemic view of the city: ‘city’ has been seen like a *machine*, a system therefore, modified by man, inside of which he lives, where for living we mean the performance of all those activities characterising human being (i.e. eating, sleeping, working, having social relationships, thinking, and having opinions and emotions).

Using this kind of definition, a city can be studied at three observation levels, which represent three different domains, used in urban ontology building: physical level, to which all structures, networks, artefacts on territory belong; socio-economical level, which is related with all activities performed by people into the city and their relationships with other individuals; and mental level pertinent for example with ethics and aesthetics concepts, or with consciousness.

Every one of these levels is important and constitutes three different ways to observe the urban system; in particular the third level is related with the consciousness of the system about itself, referring therefore to scientists’ reflections about the city. This consciousness generates mental objects, which have own relationships among them. In detail these objects determine the intentionality of acting, for example architects or town planners design the city in a certain manner, following their idea of beauty, functionality, or optimum.

As previously said, ontology building, in this case the ontology of the city, has to start from a shared knowledge, and for this purpose we have profited of contribute of theory about urban system analysis, and the corpus of territorial methods and models, as informative sources for realization of our urban ontology, moreover we have tried to extract, from these sources, reference ontologies, which were implicit or hidden inside them, and for sure the urban planning scientists have considered them in formulation of their theories.

4.1 Ontology representation

Ontologies could be represented through graphs or diagrams, where objects are punctual elements, and relationships are figured as links or lines which connect different objects. In accordance with several philosophers the objects which could be represented through concepts, are three kinds: physical objects that are entities limited in space and in time, social objects that are entities limited only in time (as a contract, or a promise), and ideal objects that are entities not limited in time and space [4][5][6][21].

About relationships, as already said before, the most used ones into ontology representations, are semantic relationships, which give a first hierarchical structure to all considered concepts (they provide a complete and efficacious vision of the used concept catalogue), but we have to say that there are many other types of relationships which can be visualized and which have to be formally defined.

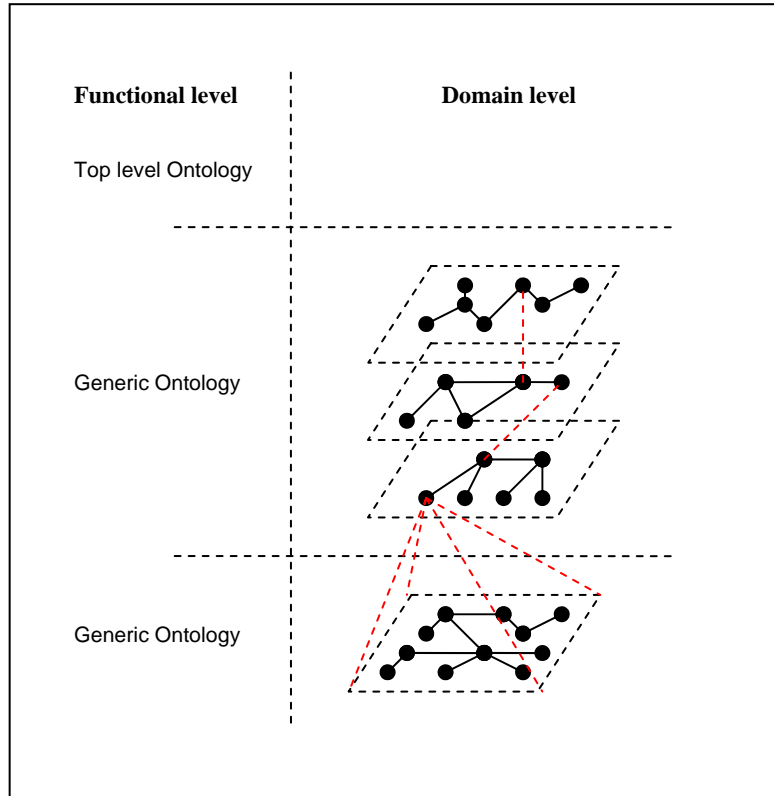


Fig. 2. Concept and relationships representation in an ontology. In this figure is shown also the functional and domain levels, at which we can observe a system.

Where Functional level corresponds to a high level abstract view of the operations (functionalities) of the ontology layer. Typically, it is a generic ontology represented by an abstract functional structure consisting of high level ontological concepts and corresponding abstract functional descriptions, which are used to define operations and specify constraints that must be in the domain ontologies. A Domain level consists of one or more domain ontologies that are consistent with the functional level of the ontology layer. Domain ontologies represent the semantics of real world features [2].

Rather than diagrams, ontologies in their entirety should be seen as different layers overlapped, taking into account that an ontology always can be inserted in another one with an higher functional level, or vice versa an ontology can always be decomposed in other smaller ontologies (for mereological difference). Each layer of the same level can be considered like a different visualization of the same concepts: what changes is the

relationships which are represented, and connect in a different way the same nodes (or concepts). Moreover passing from a functional level to another one, it's possible that a concept considered in the higher level, instead, constitutes a set of other concepts and relationships in a lower level.

Regarding visual representation of these ontologies, we need a computerized tool which allows us to choose a kind of relationship rather than another one, in order to analyze how concepts are connected between them, or allows us to see which relationships are available for a particular selected concept. In this direction we have the feeling of a lack of suitable tools.

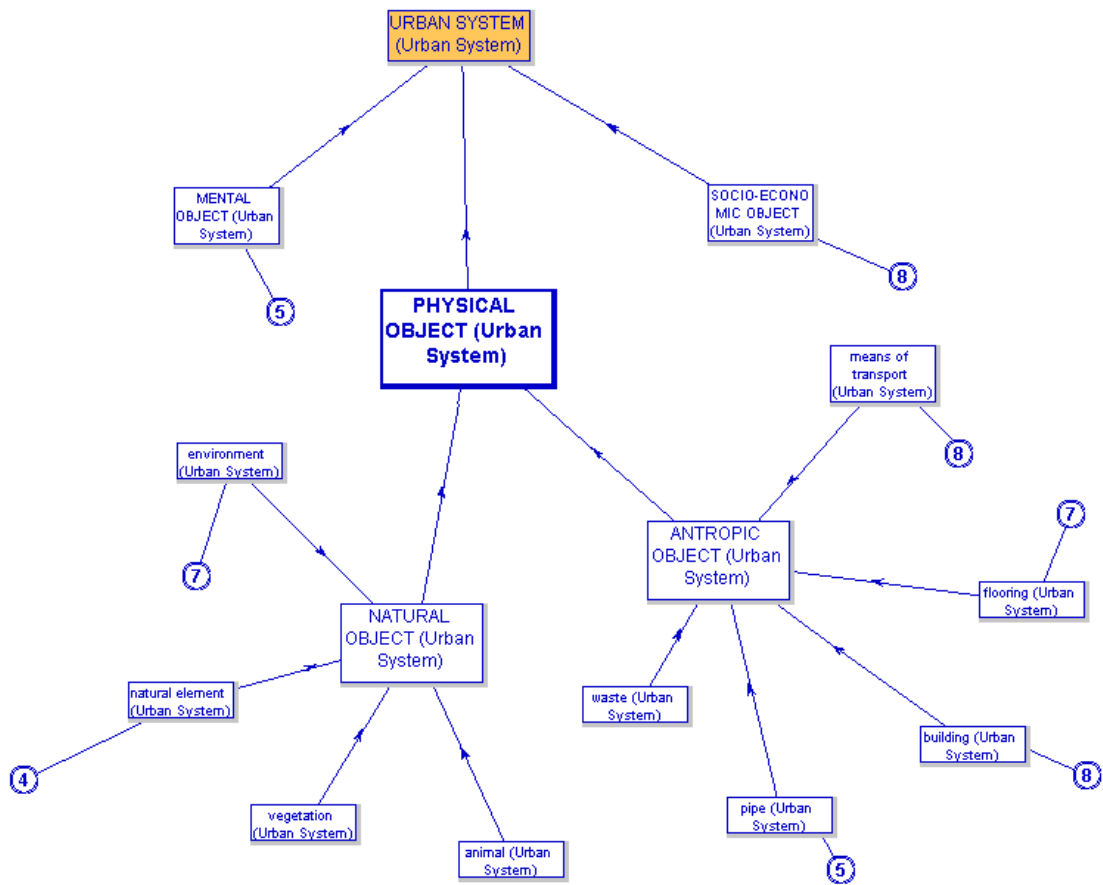


Fig. 3. Example of taxonomy for the Urban System, built using Towntology software. Physical, Socio-economical, and mental objects are linked to the Urban System with part-of relationships. Moreover it's possible to observe the first two levels of Physical objects taxonomy.

4.2 An urban system and its ontological representation

The whole set of concepts in our urban ontology can be organized with a hierarchical structure, through the semantic relationships of taxonomy and partonomy, as already explained before, but this is not the only way to arrange concepts. In accordance with our systemic view of the city, we propose to build an ontology using a classical input-output structure of the urban system. This kind of representation is much more suitable in order to show all mechanisms which act inside the city, and are responsible of its growth: in particular we want to observe and classify all concepts and relationships which determine the so called urban sprawl.

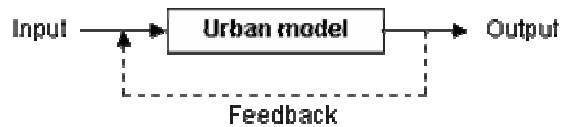


Fig. 4. Input / Output representation of the urban system.

The input we can consider in our urban system are for example incoming fluxes of people and vehicles, goods, water, electricity, gas, money, which enter inside a particular model of the city and are transformed into output, like waste, outgoing fluxes of people and vehicles, products, and more important for us, the changes in land use and location of new urbanized areas. Usually this kind of systems isn't linear, but complex, and they have many feedbacks which modify the nature of input.

For an easy understanding, we take into account a simplified model of the city: in particular we refer to the Lowry Model [14]. Even if its formulation is rather simple, it provides the relationships between transportation and land use. The core assumption of the Lowry model is that regional and urban growth (or decline) is a function of the expansion (or contraction) of the basic sector. This employment is in turn having impacts on the employment of two other sectors, retail and residential.

- Basic sector. Employment that meets non-local demand. It produces good and services, which are exported outside the urban area. It generates a centripetal flow of capital into the city generating growth and surpluses. Most industrial sector employment is within this category. It is generally assumed that this sector is less constrained by urban location problems since the local market is not the main concern. This consideration is an exogenous element of the Lowry model and must be given.
- Retail sector (non-basic sector). This employment meets the local demand. It does not export any finished goods and services and use the region as its main market area. It accounts mostly for services such as retailing, food and construction. Since this sector strictly serves the local / regional demand, location is an important concern. Employment levels are also assumed to be linked with the local population. This consideration is an endogenous element of the Lowry model.

- Residential sector. The number of residents is related to the number of basic and retail jobs available. The choice of a residential area is also closely linked to the place of work. This consideration is an endogenous element of the Lowry model.

Employment in the basic sector influences the spatial distribution of the population and of service employment. This level of influence is related to transport costs, or the friction of distance. The higher the friction of distance, the closer places of employment (basic and non-basic) and residential areas are.

This model can be described in its mathematical form by the following equations, which represent the core of the whole system:

$$L_i^{tot} = L_i^b + L_i^r \quad \text{total employment for each zone}$$

$$F_{ij} = \frac{L_i^b \cdot W_j \cdot e^{-\beta d_{ij}}}{\sum_j W_j \cdot e^{-\beta d_{ij}}} \quad \text{commuting rate of each zone}$$

$$R_j = \frac{\sum_i L_i^b \cdot W_j \cdot e^{-\beta d_{ij}}}{\sum_j W_j \cdot e^{-\beta d_{ij}}} \quad \text{employees for each zone}$$

$$P_i = \frac{\sum_j P_j \cdot W_j \cdot e^{-\beta d_{ij}}}{\sum_j W_j \cdot e^{-\beta d_{ij}}} \quad \text{population for each zone}$$

Where W_j is the attraction rate for each zone, and d_{ij} the travel costs.

The Lowry model has obviously several limitations. It is notably a static model, which does not tell anything about the evolution of the transportation / land use system. Furthermore, current economic changes are in the service (non-basic) sectors, forming the foundation of urban productivity and dynamics in many metropolitan areas. A way to overcome this issue is, for example, to consider some non-basic service employment as basic.

Beside the mathematical formalization of the Lowry model, we can describe it through the whole set of concepts and relationships which constitute the urban system. Not only we have a collection of concepts and relations (lightweight ontology), but also we have the possibility to formalize definitions and relationships to build a heavyweight ontology.

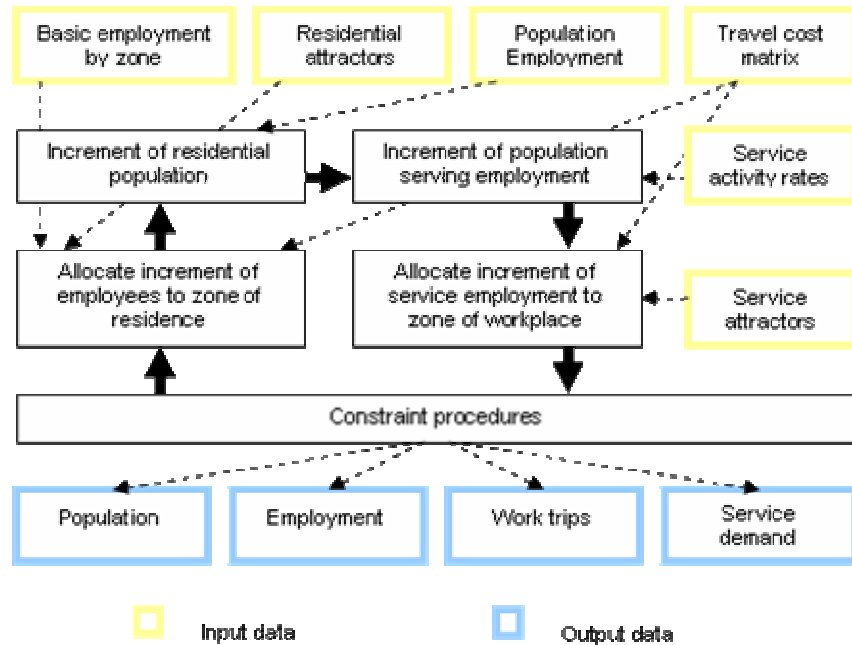


Fig. 5. Ontological representation of the Lowry model.

5 CONCLUSION

In ontology building, it's necessary to begin form a coded set of laws and theories which explicitly or implicitly subtend other reference ontologies. It's quite significant to obtain all the information related with own specific domain, using a kind of shared knowledge. This information provides both concepts and relationships, which should be organized in order to build the ontology structure of the system, and an adequate formal language has to be used. In our case, corpus of urban systems theories, coded and shared, provide us the structure of our ontology of the city.

Once built an ontology of a particular domain, we have the necessity to obtain visual tools which permit us a grater comprehension of the structure of ontology itself. In particular the representation of concepts and their relationships become really important to understand better the nature of the system itself.

Towntology software is really powerful tool in order to build and visualize lightweight ontologies, it allows us to surf through the ontology graph and also through the pictures which represent concepts, however Laurini's software should be improved to have the possibility to create Heavyweight ontologies, using for example OWL language, with a more detailed visualization, which allows us to distinguish different kinds of relations.

Urban sprawl can be easily classified in an ontology through a taxonomy, but we think that a systemic representation of the concepts and relationships is more suitable for this kind of process. In fact urban sprawl isn't a static concept, but the result of a complex dynamic process acting inside the city. Therefore, to better understand urban sprawl not only we have to study the classes related with this concept, but also we have to

formalise all relationships connecting this concept with the other ones inside the urban system domain.

Like we have already said previously, ontology building process is a high cost procedure, above all in term of spent time, so we wish a realization of ontologies which can be reusable, as we already defined it previously, in all those fields that aren't the starting system, which the ontology has been developed for.

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