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Ontologies in Urban Development Projects

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Ontologies in Urban Development Projects

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Part I
Ontology Fundamentals

Chapter 1
Introduction

Gilles Falquet, Claudine Métral, Jacques Teller, and Christopher Tweed

Ontologies are increasingly recognized as essential components in many fields of information science. Ontologies were first employed in artificial intelligence, as a means to conceptualize some part of the real world. The first aim was to enable software system to reason about real-world entities. The CyC ontology (Lenat 1995) is typical of this perspective, it is comprised of several thousand concepts and tens of thousand facts, expressed as logical formulae. A second aim of ontologies was to provide a common conceptualization of a domain on which different agents agree. It is certainly this aspect of ontologies that triggered widespread interest in this knowledge engineering artifact in fields such as information system design, system integration and interoperation, natural language processing, or information retrieval. For instance, the Gene ontology (The Gene Ontology Consortium 2001) provides a common vocabulary to standardize the representation of gene and gene products.

Although the concept of ontology is now well understood and equipped with an array of theoretical and practical tools (there are currently several dozens of books on ontology engineering), the practical implementation of ontologies in a specific applicative context remains a challenging task. Moreover, the effectiveness

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or cost-benefit evaluation of ontology-based approaches still requires more research. One of the purposes of this book is to explore these questions in the urban domain.

1.1 Ontologies in Information Science

1.1.1 Defining Ontologies

Over the last two decades, several definitions of the term ontology have been proposed (Gruber 1993; Guarino and Giaretta 1995). From a very general perspective, an ontology is a specification of some conceptualization of a domain. A conceptualization is an abstract model that represents the entities of a domain in terms of concepts, relations, and other modelling primitives. In principle, the specification of this conceptualization could take any form. However, the most commonly used ontological languages specify the meaning of concepts with some form of explicit definition. Thus an ontology is comprised of

- a representational vocabulary with different types of symbols (class names, relation names, etc.)
- a set of definitions that specify the meaning of the vocabulary

Each ontological language has its own types of symbols and definition expression language. For instance, in description logics the representational vocabulary consists of concepts, properties, and individuals; definitions are expressed as logical axioms that state, among others, equivalences, inclusions or exclusions between concepts as well as constraints on properties. The vocabulary of an ontology defined by UML class diagrams is made of classes, attributes, associations, etc. Definitions are graphically expressed by diagrams that can represent generalization/specialization or part/whole constraints between classes, as well as constraints on the associations between classes.

In this book, we take a rather broad view of ontologies. We admit that definitions can be expressed in a language that has no formal interpretation, in particular in natural language. Nevertheless, the expression must be sufficiently precise to enable the intended users (human or software agents) to *commit* to the ontology. By committing to an ontology an agent agrees to use the vocabulary in a way that is consistent with the definitions given in the ontology. It is clear that a software agent can only commit to an ontology expressed in a formal language, while a human being can commit to definitions expressed in natural language.

Following this view, it appears that some knowledge resources cannot be considered as ontologies. For instance, a thesaurus whose main purpose is to define an indexing vocabulary for a document corpus does not precisely define the meaning of each term. Hence, an agent cannot commit to meanings defined in this thesaurus. Conversely, other thesauri (such as the English Heritage Thesaurus) provide a much more precise definition (in English) for each term and organize them in a consistent generic-specific hierarchy. In this case a human agent can commit to these definitions and consider these thesauri as ontologies.

1.1.2 Current State of Ontologies and Ontology Engineering

Recent years have witnessed a rapid increase in the number of publicly available ontologies.[1] These ontologies are not all of high quality and some are very restricted in scope. However, this shows that the development of ontologies is no more the preserve of large projects with significant funding. This is probably due to several factors, including:

- the availability of numerous books, tutorials, and courses on ontologies and ontology engineering;
- the semantic web initiative that stressed the importance of ontologies and lead to the development of the RDF/S and OWL web ontology languages. These languages have been widely accepted for the expression and interchange of re-usable ontologies;
- publicly available ontologies certainly create a kind of network effect, helping others to develop and share new ontologies;
- theoretical developments in description logics that lead to a much better understanding of theses logics. We know more precisely which logics have decision procedures for reasoning tasks, and what is the computational complexity of these procedures;
- work on reasoning algorithms resulted in practical reasoners that are highly optimized and applicable on large ontologies; and
- the availability of ontology engineering methodologies and associated tools such as editors, viewers, refactoring tools, etc. have popularized the ontology development process.[2]

Despite all these advances, ontology engineering is not yet an integral component of practical methods and tools in information engineering. For instance, the link between databases and ontologies still requires research and development work, as well as the integration of ontology-based reasoning in business processes.

1.2 Ontologies in the Urban Domain

Arguably, interest in ontologies for use in the urban domain was initially triggered by technological challenges related to interoperability of urban and territorial databases.

[1]For instance the Swoogle ontology search engine (http://swoogle.umbc.edu/) announces more than 10,000 indexed ontologies.

[2]The Protégé ontology editor has more than 100,000 registered users.

As information about urban areas and urban developments became more and more easily available and abundant, the need to interconnect different databases in order to perform complex tasks (traffic modeling, environmental management, urban forecasting etc.) appeared more urgent than ever. Since these databases are usually characterized by different purposes, spatial resolutions and quality of information, their interoperability obviously raised new demands in terms of ontology design and mapping. Difficulties in connecting different urban databases not only appeared in such complex modeling tasks, but also in apparently simple or routine tasks like the interconnection of spatial databases indexed by street names.

Reengineering of existing urban databases constituted another technological challenge that urgently called for urban ontologies. Actually, many of urban databases had been characterized by an incremental development since the diffusion of Geographical Information Systems amongst urban experts. Hence, it appeared that the conceptual schema of some of these databases were no longer consistent, given their progressive and unplanned evolution. A further upgrading of these databases to make them more easily available and to connect them with other data sources hence appeared impossible without a deep restructuring of their content. Given the magnitude and complexity of the task, ontology engineering was seen as a necessary step to manage both conceptual soundness and continuity with previous versions of the database.

European integration of databases constituted a third technological motivation for developing urban and territorial ontologies. It was mainly driven by growing demands related to cross-boundary integration of territorial databases, and the transposition of the INSPIRE European directive in all Member States. Such an exercise rapidly appeared far from trivial given existing discrepancies between national and regional databases. It especially revealed that some of these discrepancies, and especially terminological differences, often concealed serious ontology divergences.

Though, besides such real technological concerns, ontologies were rapidly considered as a conceptual challenge *per se* in the urban domain. Urban sciences have long been characterized by their hybrid nature, in that they usually convey different disciplinary backgrounds: architecture, law making, social sciences, construction, geography etc. Adopting a global conceptual framework, shared by all those disciplines involved in the urban environment, once appeared as neither realistic nor desirable. Though the lack of common grounds to exchange between these different world views should be considered as a major drawback in the circulation of knowledge between these disciplines as well as, and probably more importantly, between scientists, experts and daily urban practitioners.

Furthermore, urban sciences are characterized by the emergence and rapid diffusion of fuzzy concepts, like sprawl or urban sustainability, which by nature resist precise and generalized definitions. Such a profusion of neologisms should always be regarded with skepticism as they often hide a lack of conceptualization and scientific consensus. Still, it should also be acknowledged that they are also nurtured by new ways to frame urban issues, as in the case of urban sustainability, as well as rapid changes in the human-made environment, as in the case of sprawl. Such changes are usually driven by background forces, common to all cities, usually altered by local characters. To keep on the same examples, urban sustainability and sprawl are in some sense both universal and place-driven, which largely explains the difficulty to reach a consensus about related concepts in the urban domain.

Finally, if a number of models have been proposed to characterize urban structures since the early 1960ies and the seminal works of Forrester (1969), it should be acknowledged that the way cities are actually designed and produced by its actors, has hardly been formalized in the past. Here again, this may be related to place-based specificities of urban decision-making. Some authors further relate such a lack of conceptualization to the complex and unpredictable nature of communications in urban development project, while others would rightly raise concerns about the prescriptive nature of any conceptualization model in this domain. Still, the reluctance to propose tentative models to formalize communication flows between actors of urban development is certainly a serious impediment for the transformation and enhancement of existing decision systems. Here again designing urban ontologies has been viewed as a stimulating conceptual challenge in that it would force a clarification of communication means and purpose between the different actors involved in urban development: engineers, urban planners, constructors, architects, citizens, etc. As such, it appears as a way to engage a reflective exercise about the nature and conditions of urban development.

The need for comprehensive models of urban systems as an aid to future urban development has never been more urgent. The challenges policy makers and practitioners face in this turbulent period of human history demand new understandings and new approaches. The emerging "low carbon" agenda, together with the requirements of social and economic sustainability, all suggest systemic approaches, in which we can expect the explicit development of ontologies to play a major role.

Interestingly these two ways to frame the issue, as both a technical and a conceptual challenge, once met in the COST Action C21, which specifically aimed at prospecting the potential of ontologies as a way to enhance communications in urban development projects.

1.3 Structure of the Book

The first part of the book is a presentation of the fundamental concepts and issues of ontology engineering. An introduction to ontologies and ontology engineering provides a detailed view of the different types of ontologies, according to their level of formalization and their purpose. This introduction also presents a typology of the ontology design approaches. The subsequent chapters address issues in ontology engineering that are particularly relevant in the urban domain: using ontologies to ensure interoperability; dealing with heterogeneity and differences in viewpoints; and dealing with multilingualism in ontologies.

The second part focuses on methods and tools to apply ontology engineering in the urban domain. It covers the geographical aspect of urban ontologies; the interconnection of urban models through ontologies; the interconnection through different representation scales; the development of urban knowledge based systems; and the creation of ontologies from existing urban knowledge resources.

The third part is a collection of case studies in the construction and use of urban ontologies. Each case study is described using a common template to facilitate comparison and to ensure a suitable coverage of each case. The cases are drawn from a wide variety of domains loosely related to urban development. Their diversity—ranging from building information models to urban scale public participation—underlines the potential for widespread application of ontology engineering. This part concludes with an overall analysis that highlights lessons learned and questions to solve.

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Chapter 2
An Introduction to Ontologies and Ontology Engineering

Catherine Roussey, Francois Pinet, Myoung Ah Kang, and Oscar Corcho

2.1 Introduction

In the last decades, the use of ontologies in information systems has become more and more popular in various fields, such as web technologies, database integration, multi agent systems, natural language processing, etc. Artificial intelligent researchers have initially borrowed the word "ontology" from Philosophy, then the word spread in many scientific domain and ontologies are now used in several developments. The main goal of this chapter is to answer generic questions about ontologies, such as: Which are the different kinds of ontologies? What is the purpose of the use of ontologies in an application? Which methods can I use to build an ontology?

There are several types of ontologies. The word "ontology" can designate different computer science objects depending on the context. For example, an ontology can be:

– a thesaurus in the field of information retrieval or
– a model represented in OWL in the field of linked-data or
– a XML schema in the context of databases
– etc.

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It is important to distinguish these different forms of ontologies to clarify their content, their use and their goal. It is also needed to define precisely the vocabulary derived from the word ontology. For example what is the difference between a core ontology and a domain ontology? First, we introduce and define the different types of ontologies. Second, we present some methodologies to build ontologies. Some of the illustrative examples will be taken from project presentations made in the context of the COST UCE Action C21 (Urban Ontologies for an improved communication in UCE projects TOWNTOLOGY) or, in general, in the area of Geographic Information Systems (GIS).

2.2 Ontology Classifications

Several classifications of ontologies have been presented in the literature (Lassila and McGuinness 2001; Gomez-Perez et al. 2004; Borgo 2007, etc). Each of them focused on different dimensions in which ontologies can be classified. This section focuses on two of these classifications: the first one classifies ontologies according to the expressivity and formality of the languages used: natural language, formal language, etc.; the second one is based on the scope of the objects described by the ontology.

2.2.1 Classification Based on Language Expressivity and Formality

Depending on the expressivity of an ontology (or, in general, of a knowledge representation language), different kinds of ontology components can be defined (concepts, properties, instances, axioms, etc.). Figure 2.1 presents the set of components that we will use to provide our classification based on language expressivity. For example, if we focus on concepts, which are one of the main components of ontologies, the UML class diagram of Fig. 2.1 shows as that they can be defined in different (and complementary) ways:

- By their textual definitions: For example the concept "*person*" is defined by the sentence "*an individual human being*",
- By a set of properties: for example the concept "*person*" has the property "*name*", "*birth date*" and "*address*"; note that a property can be reused for several concepts.
- By a logical definition composed of several formulae: for example the concept "*person*" is defined by the formula "$LivingEntity \cap MovingEntity$".

A concept can also be defined by the set of instances that belong to it. For example, "*Martin Luther King*" is an instance of the concept "*person*". This last definition is called the extensional definition of a concept and the three former definitions are called intensional definitions of a concept.

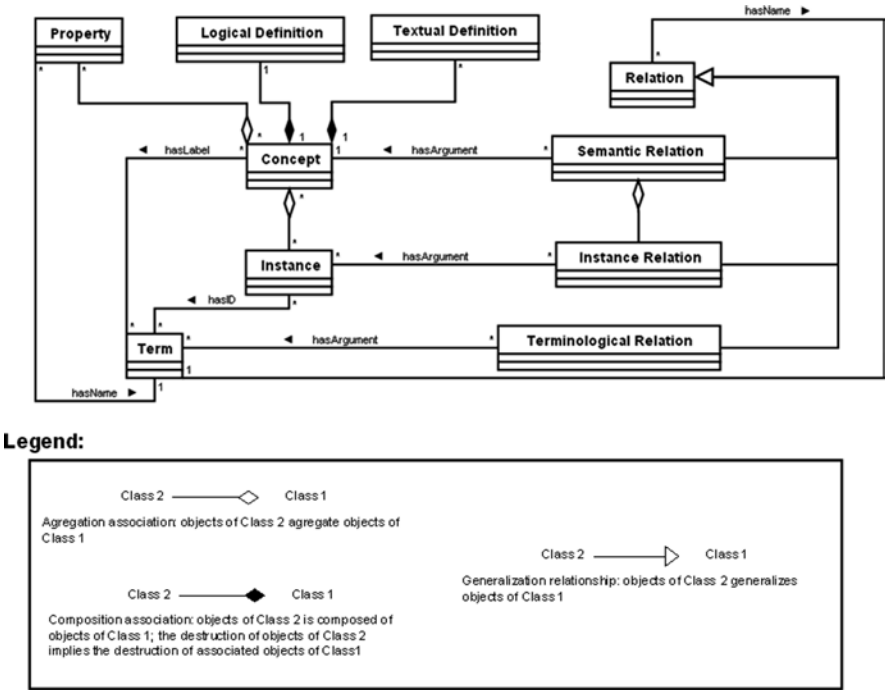

Fig. 2.1 UML class diagram representing ontology components and their relationships

Concepts, instances and properties are referenced by one or more symbols. Symbols are terms that humans can rapidly understand roughly by reading them. And finally all these ontology components are connected through relations. Semantic relations link only concepts together: for example the location relationship indicates that city concept is localized in a country concept. Instance relations connect only instances and instance relations are often instances of semantic relations, although it is not always the case. Some relations between instances can be contextual and cannot be generalized to all instances of their concept. An example of instance relation is that the city instance named Paris is localized in the country instance named France. All cities are localized in a country. A contextual instance relation can be that the person instance named "John Travolta" is localized in the city instance named "Paris" at the point in time 31 January 2010. The terminological relations express the relationships that terms can have: for example the term "*person*" is synonym to the term "*human being*"

According to the usage of these components, in the following sections we present four kinds of ontologies. In each section we explain which type of language is normally used to define the ontology and we provide some examples for illustration purposes. The classification starts using the less formal languages to the more formal one.

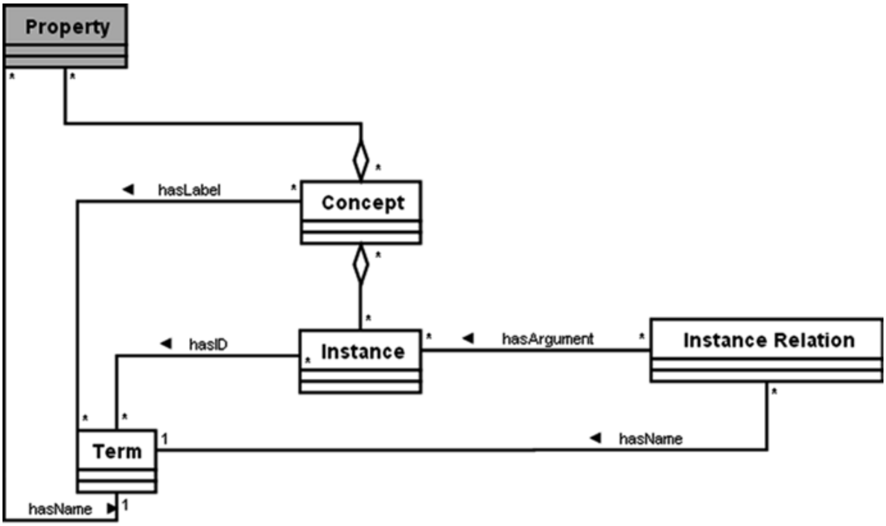

Fig. 2.2 UML schema of information ontology component and their relationships

2.2.1.1 Information Ontologies

Information ontologies are composed of diagrams and sketches used to clarify and organize the ideas of collaborators in the development of a project. These ontologies are only used by humans. The characteristics of information ontologies are:

- Easily modifiable and scalable
- Synthetic and schematic
- They are normally used during a design process of a project: for example, information ontology can be used during the conception phase of information system development project or during the design of floor plan in architectural construction project.

As shown in Fig. 2.2, information ontologies focus on concepts, instances and their relationships. Their goal is to propose an overview of a current project in order to express the state of this project. The grey color of the property elements means that properties are not always well defined by information ontologies.

Information ontologies are normally described by means of visual languages, so that they can be easily understood by humans. A Mind Map is a good example of this type of visual language. For example the OnToKnowledge project about methodology for ontology design propose to add a Mind Map plug-in called Mind2Onto in their ontology editor called OntoEdit (Sure and Studer 1999). They notice that Brain Storming is a good method to quickly and intuitively start a project. Their Mind Map plug-in is a support for discussion about ontology structure. Mind Map descriptions will be followed by three examples of information ontologies: one example will be taken from urban planning project, another one come from architectural design and the latter is used in a construction project.

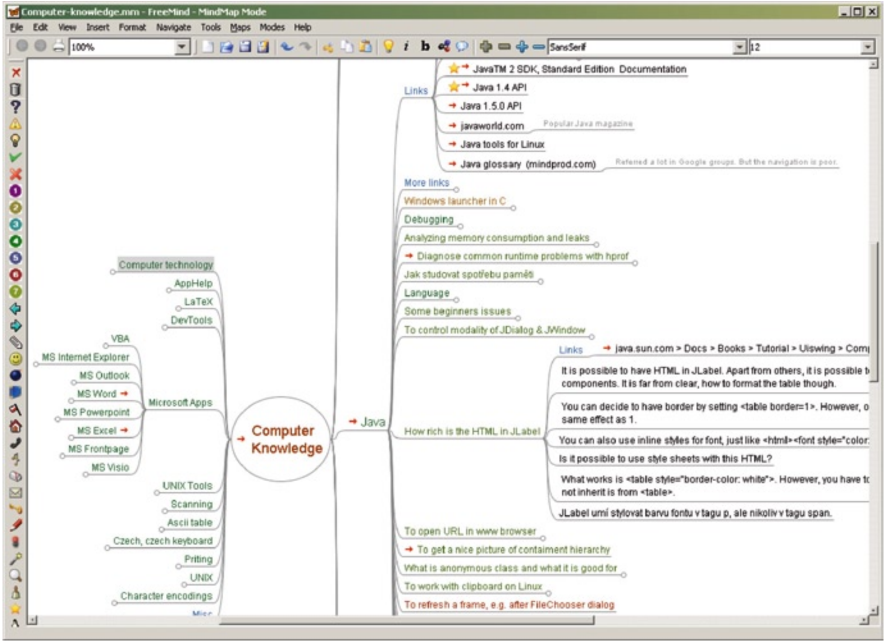

Fig. 2.3 Screenshot of a free mind mapping software called FreeMind (http://freemind.sourceforge.net/wiki/index.php/Main_Page)

Language: Mind Map

Mind Map were originally developed to support more efficient learning and evolved to a management technique used by numerous companies (Buzan 1974). Mind Map provides information about a topic that is structured in a tree (see Fig. 2.3 for example). Mind maps are used to generate, visualize, structure, and classify ideas, and as an aid in study, organization, problem solving, decision making, and writing.

Example: Information Ontology of Architectural Design

Bouattour et al. (2005) propose also a new set of concepts for information ontologies adapted to architectural design. These concepts could be seen as an upper layer of IFC classes (see section "Example: Industry Foundation Classes" (Ferreira da Silva and Cutting-Decelle 2005, p. 9)). Their information ontology is composed of actors, objects, activities and documents. All these components are in relation during the cooperative process of design building. Thus it is preferable to follow the decisions taken by each actor to understand the project development, to save time and to avoid errors. Their information ontology presents the state of architectural design components by following the decision process of each actor about this component.

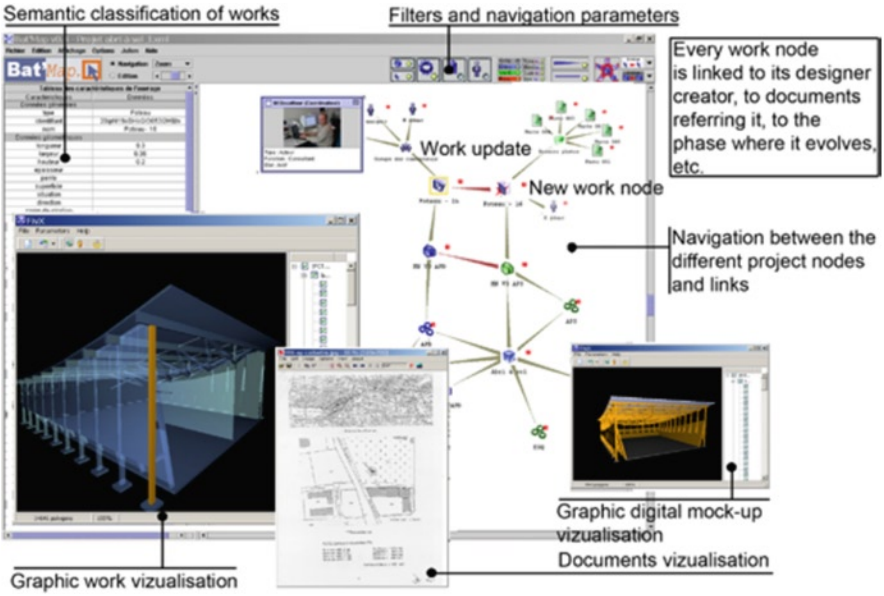

Fig. 2.4 Information ontology about architectural project

The information ontology representing the current state of an architectural project is composed of instantiation of their concepts. These ontologies are implemented in information system in order to compute some 3D representations of the building called mock up. These mock-ups synthesize the evolution of the project. This work is still in development, Bouattour et al. (2007) presents an on-going research aimed at computer-aided cooperative design for architectural project (Fig. 2.4).

Example: Information Ontology of Urban Planning

Kaza and Hopkins (2007) presents a set of concepts to formalize information ontologies used during urban planning process. Their information ontologies show the different alternatives of a decision in a plan. Plans could present effective decisions, alternative decisions and realizations in order to facilitate the communication between several actors. Moreover this type of plans can help stakeholders during their decision process in order to have a general overview of the city evolution. All these concepts (decisions, alternative, actors, etc.) and their instances compose an information ontology of urban planning (Fig. 2.5).

In this example the information ontology does not look like a Mind Map but it still uses a visual language similar to that used in a plan. This type of information ontology focuses on the location of the concept instance not on their internal structure description.

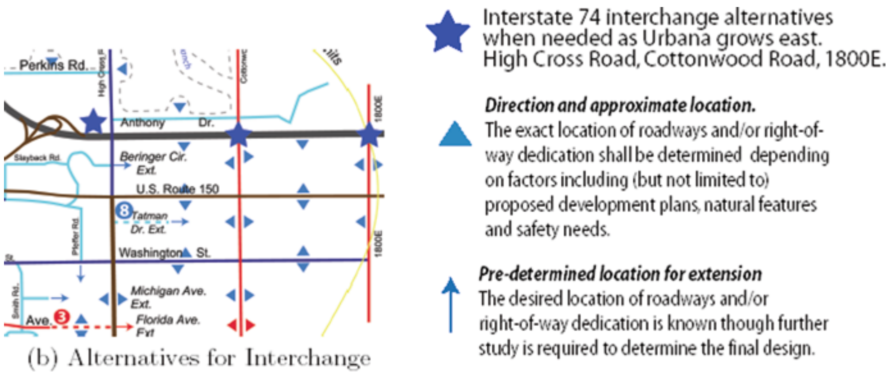

Fig. 2.5 Information ontology about urban planning process

Example: Information Ontology of Construction Project

Lee and McMeel (2007) propose to build an information ontology in order to ease the communication between the different actor groups involved in a construction project. These information ontologies represent some general patterns that have to be modified in order to resolve the specific problem of the construction project. The first stage of problem solving is to understand the language convention of each actor group based on the ontology element. Then negotiation and collaborative works can begin to find the appropriate solution of the construction problem. This type of ontology has to be heavy adaptable and modifiable.

2.2.1.2 Linguistic/Terminological Ontologies

Linguistic ontologies can be glossaries, dictionaries, controlled vocabularies, taxonomies, folksonomies, thesaurii, or lexical databases. As shown in Fig. 2.6 this type of ontology mainly focuses on terms and their relationships.

Unfortunately, terms are ambiguous. A concept can be referenced by several terms (for example: “computer science”, “computing”, “information technology” are synonyms) and a term can reference several concepts (for example the term “bank” can be used to reference a “river bank” or a “commercial bank”). The roles of linguistic ontologies are twofold: The first one is to present and define the vocabulary used. This is achieved by a dictionary for example which list all the terms actually used in language. Secondly, linguistic ontology is the result of a terminology agreement between a users’ community. This agreement defines which term is used to represent a concept in order to avoid ambiguity. This process is called vocabulary normalization. When a concept could be described by two synonym terms, the normalization process selects one of those to be the preferred label of the concept. It means that in Fig. 2.6 the cardinality of the hasLabel and hasID relationship is changed

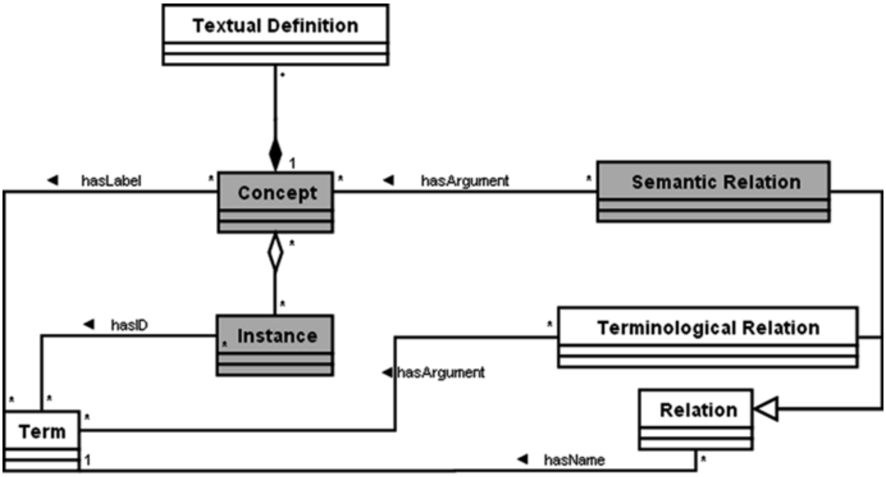

Fig. 2.6 UML schema of linguistic ontology components and their relationships

from * to 1 compared to Fig. 2.1. Taxonomy and thesaurus organized their normalized vocabulary so that the a priori relationships between concepts are made explicit. That is the reasons why in Fig. 2.6 concept and semantic relation are in grey to express that some linguistic ontologies try to explicit these components. Unfortunately the distinction between concepts and their instances are not taken in account: Instances are considered like concepts. A thesaurus has three basic relationships among terms: equivalence, hierarchical and associative. Let us point out that the last two relations hide several semantic relations. Associative relation between two terms means that there exists a semantic link between concepts labeled by these terms but no information is given on this semantic link. Hierarchical relation between two terms can hide an "instance of" relation between a concept and one of its instances (in grey in Fig. 2.6), a "specialization" relation between two concepts, a "part of" relation between concepts and so on. More information on thesaurus development are available in (IS0 2788 and ISO 5964).

Now we describe two languages that can be used to describe this type of ontologies: SKOS is used to define thesaurii and RDF is used the defined web metadata. Next we present four different thesaurii belonging to different domains: urban planning, environmental domain and cultural heritage; followed by a taxonomy used in architectural design.

Language: Simple Knowledge Organization System (SKOS)

Simple Knowledge Organization System (SKOS) is a semantic web activity proposed by the W3C. They are developing specifications and standards based on XML to support the use of knowledge organization systems such as thesauri, classification schemes, subject heading systems and taxonomies within the framework of the Semantic Web [see http://www.w3.org/2004/02/skos/intro for more details].