Computational Ontology of Urban Design

Towards a City Information Model

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Abstract: *The ultimate goal of the project in which the described research evolves is a computer-platform for assisting in the development of urban design proposals at the site planning scale including formulation, generation, and evaluation modules. The paper is concerned with the development of a common ontology that guarantees inter-operability among the three modules. After clarifying the theoretical framework, it describes the methodology used to develop the proposed Urban Design Ontology (UDO), as well as its lexicon, syntax, and semantics. It is argued that such ontology constitutes the bases for a City Information Model (CIM) that permits to elaborate consistent and comprehensive descriptions of urban spaces, thereby enabling the formulation of programs for urban interventions and the generation of corresponding design proposals.*

Keywords: *Ontology; interoperability; BIM.*

Introduction

This study evolves within the context of the City Induction Project. The ultimate goal of this project is to create a full model to generate sustainable urban plans foreseeing three complementary systems: a system for formulating urban programs (Ft); a system for generating formal urban solutions (Gn); and a system for evaluating both urban programs and design solutions towards specified goals (Ev). This paper is concerned with the formulation system and more specifically with the development of a common ontology.

Meaning of ontology

Ontology is a philosophic theory that concerns the study of existence. The Ontology concept was born from the legacy of the Aristotelian classic philosophy, meaning '*a systematic explanation of the existence*'. The production of ontologies allows the specification of a vocabulary for defining entities, classes, functions and relationships among components, aiming at the explanation of concepts. An ontology describes basic concepts in a domain and defines relations among them. The basic blocks of an ontology include: *classes or concepts*; *slots*, sometimes called roles or properties, that is, properties of each concept describing various features and attributes of the concept; and *facets*, sometimes called role restrictions. An ontology, together with a set of individual instances of classes constitutes, a knowledge base (Gennari et al. 2003).

An ontology provides a common vocabulary for researchers who need to share information in the domain (Noy et al. 2001). In addition, an ontology is an accurate mechanism to explicit and increase the knowledge about a specific subject matter. Some of the reasons to create an ontology are: to share a common understanding of the structure of information among people or software agents; to enable the reuse of domain knowledge; to make domain assumptions explicit; to separate domain knowledge from operational knowledge; and to analyze domain knowledge (Noy et al. 2001).

According to Smith and Mark, (cited by Fonseca & Egenhofer 1999), the production of ontologies permits to understand the way different communities share information; to discover certain distortions in the cognitive processes on conception of the world, and to supply patterns towards the development of a process.

One of the essential characteristics of ontologies is the sharing of information, called the 'shared knowledge.' This sharing allows for the creation of common systems. The advantage is to provide an integration of different studies on the same substances of inquiry, through a recurrent general procedure. This focus allows and prevents ambiguities between results.

Model interoperability

The computational implementation of the envisioned common model mentioned above requires the creation of a common vocabulary based on database shared knowledge, envisioning an interoperable environment for the three abovementioned systems. This can be accomplished by developing a common ontology, that is, a theory concerning the clarification of concepts. The advantage is to facilitate integration among assorted while collaborative visions regarding the same subject, through the use of a recurrent general procedure. In turn, this will permit information sharing among such visions and avoid ambiguities within the integrated model.

Computational edition of ontologies

For developing ontological descriptions, domain experts may use ontology editors, which consist in software tools that they may be used to create knowledge-based systems on particular domains. Applications developed with an ontology editor are usually used in problem-solving and decision-making in the covered domains. Its heuristics are based on a recursive procedure platform, where the software places a set of questions to the model agent, asking for new descriptions embedded by its particular contextual metaphors (domain, classes, and semantic attributes). This facilitates a natural emergence of the inner concepts and properties of the model, disclosing its spatial objects, participants, and substances, among other contextual aspects of the domain, the urban design process in our case (Figure 1).

The Protégé editor (http://protege.stanford.edu/,03-01-09) herein used as the descriptor of the Urban Design Ontology (UDO), implements a set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats. Protégé can be extended by a plug-in architecture and a Java-based Application Programming Interface (API) for building knowledge-based tools and applications. Its platform supports two main ways of modeling ontologies: the Protégé-Frames editor that enables users to build and populate ontologies that are frame-based, in accordance with the Open Knowledge Base Connectivity protocol (OKBC); and the Protégé-OWL editor that enables users to build ontologies for the Semantic Web, in particular in the W3C's Web Ontology Language (OWL). Protégé ontologies can be exported into a variety of formats including RDF(S), OWL, and XML Schema (*Figure 2*).

Building ontologies

One might start by determining what the ontology is going to be used for, and how detailed or general the ontology is going to be. Among several viable alternatives, one will want to determine which would work better for the projected task, be more intuitive, more extensible, and more maintainable. Remembering that an ontology is a model of a real domain in the world and the concepts in the ontology must reflect this reality. After defining an initial version of the ontology, one can evaluate and debug it by using it in applications or problem-solving methods or by discussing it with experts in the field. '*As a result, one will almost certainly need to revise the initial ontology. This process of iterative design will likely continue through the entire lifecycle of the ontology*' (Noy et al. 2001).

Consider, for instance, the task of developing urban climatic patterns (Higueras 2006) and suppose one wants to develop a system that facilitates the management and the organization of *urban climatic patterns*. The *urban climatic patterns* subfolder of the *Ontology Editor* installation directory contains a completed *Editor-Frames Project - urban climatic patterns*, which provides one possible ontology for this domain.

Some of the questions one want to answer are:

1. What are the components responsible for each climatic pattern?
2. What is the content of each pattern, and what is the theory behind it?
3. To what matters each pattern is related with?
4. What is the layout of each pattern?

Once one has an idea of what one wants to cover, one can list some of the important terms needed. These can include basic concepts, properties they might have, or relationships among them. To begin with, one can just collect the terms without regard to the role they might play in the ontology. In the *climatic patterns* example one has very particular patterns. Each pattern contains content such as '*type of climatic aspect that is covered*' and '*applicability*' and has a theory behind it that is responsible for the validity of its existence. Each pattern has a form, and that form may or may not be material. For each material one, we want to know its name and subject, and to what it relates with.

As one continues to generate terms, one is implicitly defining the scope of the ontology, by defining what one wants to include and to exclude. For example, upon initial examination of a specified pattern, one might want to add '*sun protected windows*' or '*wind impact on streets*'.

However, one might realize that one wants the ontology to focus on the costs directly associated with the content of the '*sun impact on buildings*'. Therefore, one would decide not to include '*wind impact on streets*' as a term of interest.

After completing the list, one can start to categorize the different terms according to their function in the ontology. Concepts that are objects, such as '*pattern*' or '*site application*', are likely to be best represented by classes. Properties of the classes, such as '*wind*' or '*sun*', can be represented by slots, and restrictions on properties or relationships between classes and or slots, are represented by slot facets (Gennari et al. 2003).

Deciding which elements to control

Developing an ontology is usually an iterative process. One can start with a rough overtake at the ontology, and then revise and refine the evolving ontology by filling in the details. In practical terms, developing an ontology includes tasks such as the definition of classes, the organization of the classes in a subclass-superclass hierarchy, the definition of slots by describing allowed values for such slots, and filling in the values for instances slots. Furthermore, an ontology allows one to act within two complementary levels of description: a *Top Level Ontology* on which are located the concepts and the relations

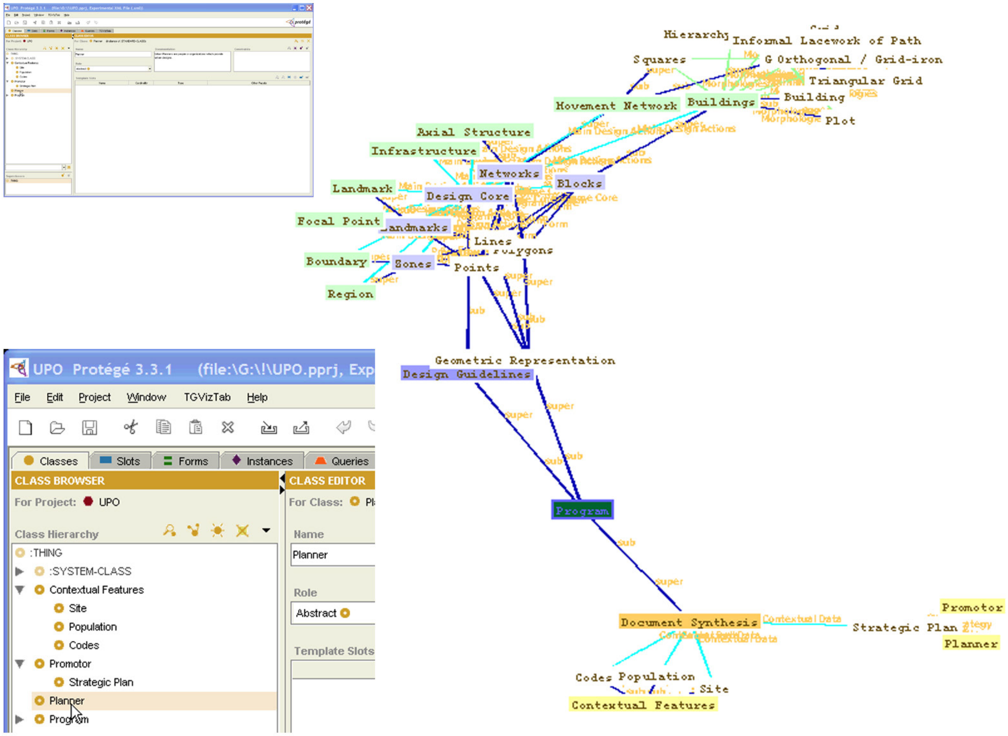


Figure 1
The process of start to build an Urban Design Ontology within the Protégé software

of the model at a macro scale; and an *Application Ontology* which specifies and details the concepts, thereby describing the nature of its particular interactions (Figure 2).

The initial task of this research concerns the selection of core features foreseeing the UDO *Top Level Ontology*. Such a selection requires a disclosure of the crucial components of the urban planning process, that is, *the nature of urban space* (the field of its application), *the nature of design actions* (the field of its proposals), and the interoperability of those within *a supporting computational system* (the field of its administration).

The nature of the urban space

Kevin Lynch (1960) wrote that users understood their surroundings in consistent and predictable ways, by forming mental maps with defined elements: paths, streets, sidewalks, trails, and other channels in which people travel (Networks); edges, perceived boundaries such as walls, buildings, and shorelines (Blocks); districts, relatively large sections of the city distinguished by some identity or character (Zones); nodes, focal points, intersections or loci; and landmarks, readily identifiable objects which serve as reference points (Landmarks). Such classes are hence defined by Networks, Zones, Blocks, and Landmarks.

The nature of the design actions

Urban design guideline books surveyed for the current study recurrently presented similar descriptions as in the Urban Design Compendium (Partnerships 2007) and in the Green Dimensions book (Moughtin & Shirley 2005). The core element that occasionally appears separated from the Lynchian outline is the element *Landscape*, somewhat denoting a tendency of designers to lead its actions based on this additional feature. The directory can be described as *Networks*, *Zones*, *Blocks*, *Landmarks*, and *Landscape*.

The supporting computational system

A GIS (Geographic Information Systems) software platform will support the operability of the full model due to its resourceful spatial descriptors. Its representation standards include *Points*, *Lines*, and *Polygons*.

The correlation with prior components seems to be utterly clear: *Landmarks* can be represented by *Points*, *Networks* by *Lines*, and *Blocks* and *Zones* by *Polygons*.

In summary, Lynch's appraisal matches GIS core description while the element *Landscape* (a design action component) promotes fuzziness within the element *Zones,* which comprise a further comprehensive feature. Therefore the *Top Classes* will be herein defined as *Networks* (Lines), *Zones* (Polygons I), *Blocks* (Polygons II), and *Landmarks* (Points) (*Figure 2*).

Brief description of UDO core components

Networks: According to Lynch (1960) there are three main metaphors which attempt to explain city form through networks: the 'magical' metaphor for the earliest ceremonial centers of religious rituals to link the city to the cosmos and to the environment; the metaphor that expresses the analogy of the machine, and the metaphor that explains form through organic structures. According to Moughtin and Shirley (2005) those three metaphors are linked to five main forms of urban grids: (1) *Hierarchy of boxes, each nesting another*; (2) *Orthogonal geometrical figure or grid-iron plan*; (3) *Directional grid*; (4) *Triangular grid*; and (5) *Informal lacework of paths*. Marshall (2005) describes further and detailed network movement patterns by describing performance correlation between different morphologies.

Blocks: Blocks represents composition of buildings within an urban site. The space confined by blocks generally imply movement grids. The mixture between blocks and grids defines the main structure of urban settlements.

Block buildings can range from housing, office areas, recreation, leisure and sports to education, health, and training to community workspace. Buildings within blocks also provide a secure base for community organizations to establish a presence by developing partnerships within locals and even stakeholders.

Post-modern research (Krier & Porphyrios 1984) correlates blocks within sorts of classic archetypal morphologies while building masses tend today to be more abstract or topologic (concept of convergence, connectedness, and continuity) – sometimes inspired on natural forms, or even developed under conceptual art or technology. The range of block designs is today quite wide and open.

Zones: The component Zones comprise areas within perimeters defining sorts of environments within sites. Zones are defined within boundaries containing groups of meanings (as PL) comprising a sort of matters such as the range of services and facilities, including commercial, educational, health, spiritual and civic services (Partnerships, 2007).

Design under this component is similar to 'planning through portraits' (Lynch, 1960) where concepts such as neighborhood and mixture represent a design core – fluent in Alexander's Pattern Language (1977). Zones also imply planning cautions within the design process in order to avoid zoning apartheids; therefore it is essential to promote diversity in terms of development forms, land use, density, tenure, and market segments.

Landmarks: The development of a plan can start by a definition of landmarks or focal points in space (pre-existing or new one). Those marks act as structures within a plan upon which planners can define networks and masses. The relevance of landmarks and focal points is simple to portray; '*People find it easier to orientate themselves and recognize where they are when new development safeguards important views between places or creates new ones, whilst respecting or adding new local landmarks. To ensure that a particular place reads, assess the relationship between existing elements and, in consulting local people, determine how proposals contribute to a linked series of spaces and markers that make it easy to get from A to B and to C*' (Partnerships, 2007). The design of streets, the concentration of commercial, community and civic uses in centers and the use of distinctive landscaping and building forms will help to create a place that is easy to read. This is crucial if users are to orientate themselves within a place and between different places. This will emphasize the hierarchy of a place.

Ontology lexicon

The UDO lexicon corresponds to the minimum ontological sub-classes (an *Application Ontology*), mainly depicted from the CityGML GIS standards (Kolbe et al. 2005), which consists in vast class definitions for the most important types of objects within 3D city models. Its basic definitions representing the spatial objects and their aggregations are defined by ISO 19109 and GML3 standards, and it comprises different types of interrelationships between *Feature Classes* like *aggregations*, *generalizations* and *associations*. An important outcome of such descriptions is a high degree of semantic interoperability between different applications along their UML mapping, defining feature types, attributes, and data types with a standardized meaning or interpretation.

The base class of all thematic classes is CityObject. CityObject is a subclass of the GML class Feature, thus it inherits its metadata (e.g. information about the lineage, quality aspects, and accuracy). The subclasses of CityObject comprise the different thematic fields of a city model: the *terrain*, the *coverage by land use objects*, *transportation*, *vegetation*, *water bodies* and *sites*, in particular *buildings*. The class CityFurniture is used to represent *traffic lights*, *traffic signs*, *flower buckets*, or similar objects.

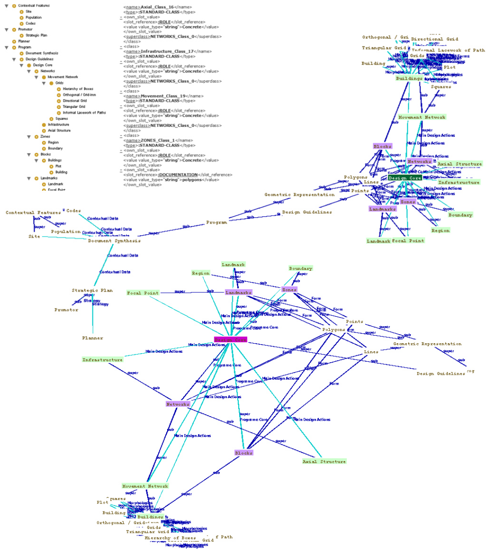
Ontology syntax

The UDO syntax requires an assemblage of a hierarchical tree of features in order to develop ontological class connectors (*Figure 1*). The core of such syntax is depicted by networks, zones, blocks, and landmarks. These components are directly related with main design actions such as *axial structures*, *grids* (movement and infrastructures), *regions* and *boundaries*, *buildings* and *plots*, *landmarks* and *focal points*, each possessing an expression sort with a morphologic nature and a class definition. The catalogue is far extended. An example of such a morphologic classification is given by the five main forms of urban grids described in the Green Dimensions book, that is, *hierarchy of boxes*, *orthogonal geometrical figure*, *directional grid*, *triangular grid*, and *informal lacework of paths*. A final class describes objects. This class follows a simple order, e.g.: a *grid* is composed by *roads*, and *roads* can include *lanes*, *cycle paths*, *bus stops*, etc.

Ontology semantics

The UDO semantics are key attributes representing quantity and quality sorts within its performance properties. These attributes bring up recursive data to fill in slots such as *meaning* and *substance* within the ontology. While a *high semantic level* will coordinate the entire flow of the planning events, the sustainability factor, a further extended high level semantics of the ontology, is described by events upholding the human quotidian life (Social/Safety Patterns); features such as energy and environment control (Bioclimatic Patterns); and features within a value sight (Economic Patterns). Furthermore, the semantic attributes are embedded by ranges, locations, types and constrains, throughout the *instances slots* of the Protégé *instance browser* and *editor*.

Figure 2
Urban Design Ontology (UDO) Syntax class hierarchical tree (above left), exported piece of XML Schema (above centre), UDO diagram classes, subclass-superclass hierarchy, and slots (middle right), UDO diagram zoom - the design core - Networks, Zones, Blocks, and Landmarks (at the bottom). The UDO was built in the Protégé-Frames editor, in accordance with the Open Knowledge Base Connectivity protocol (OKBC)



Towards a city information modelling (CIM)

A *Building Information Modeling* (BIM) (Guarino 1998) comprise a system that aims at incorporating all aspects of design from geographic information, to building geometry, to component relationships, and finally, to the quantities and properties of the building components. BIM requires a purpose-built foundation to manage the amount of data generated. Such a description corresponds to the UDO framework – the idea to build a full relational model, comprising a sort of data collected from the urban space containing its properties. However, urban design must document a wider semantic core and model hundreds of thousands of components more. Such a dissimilar sort demands the creation of a *City Information Modeling* (CIM) system, which is the expected outcome of the work described in this paper.

Conclusion

The research described in this paper evolves within a major research project concerned with the development of a model for a computer platform aimed to support the development of sustainable urban plans. Sustainability is defined as maximized response to identified needs using the least resources. The model foresees three sub-modules concerning the formulation, the generation, and the evaluation of urban plans, and this paper is concerned with the creation of an urban design ontology (UDO), common to the three sub-modules.

The UDO described in this paper represents a contribution for clarifying and defining the general model by providing an organized description of urban design core components using classes, slots, and instances – denoting how urban design actions work within a resourceful planning process. The final goal of such an ontology is the definition of a City Information Model (CIM) to facilitate data management amongst designers towards proficient outcomes.

The desired CIM will be defined by such an ontology, encoded by a computational editor, providing a recursive shared tool used by the three *City Induction* partial models in order to produce integrated results within urban design processes.

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