The city as a street system: A street description for a city ontology

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Abstract. *The street system is an important component of the city ontology created for a generative urban design tool and should be able to integrate the many visions or interpretations that designers or other urban design agents may have about streets. This paper describes several characteristics of the street system, with its components organized into object classes which are the shape sets of algebras used by a generation module to generate street network representations that can be assessed by a GIS platform.*

Keywords. *Ontology, urban design, shape grammars, planning*

Introduction

Street configurations may vary according to many factors, from cultural and social to topographic or functional factors. Some may not be found at all outside the cultural context. Many researchers have tried to define and classify such characteristics but a universal consensus seems difficult to achieve (Marshall, 2005). The current paper attempts to find an acceptable ontology for the street system that may be used for the purpose of integrating programme formulation, urban design and urban evaluation. The underlying question is: what are the descriptions and components of the street system that should form part of a design tool integrating programme formulation, urban design generation and urban evaluation?

Research context

The current work evolved in the context of the City Induction research project which aims at developing an urban design tool composed of three interrelated modules: (1) the formulation module which formulates context dependent urban programmes, (2) the generation module, which generates design solutions for the urban programme and (3) the evaluation module, which evaluates the evolving design solutions against the programme (Beirão et al, 2008).

To guarantee the integration of the three modules, an ontology is needed as a common representation protocol. The representation of new plans is intended to be generated by a shape grammar (Stiny and Gips, 1972), which is in fact a compound grammar composed of several discursive grammars (Duarte, 2001) each one taking for their shape set one of the object classes in the ontology. The shape grammar rules operate on the objects of the ontology generating designs that fit the urban programme descriptions provided by the formulation module using a description grammar (Stiny, 1981). The description grammar uses the description components found in the ontology to prescribe the requirements for a particular design context. This approach allows the generation of layered representations of the urban environment amenable to be imported into a GIS topological representation to be assessed by the evaluation module.

The city ontology

In computer science, according to Gruber (1993), an ontology is a formal representation of concepts from real or imagined domains and the relationships between them. The city ontology defines and organizes the significant relations among the various types of objects and features found in urban space to be used in the urban design process. The city ontology is divided into sub-ontologies or systems, each one containing features from a specific domain of the city structure, namely 'Networks', 'Blocks', 'Zones', 'Landscapes' and 'Focal Points'. 'Networks', for instance, describe the domain of connectivity and city morphology (Montenegro and Duarte, 2009) in which we may identify the street system. We call systems the autonomous semantic units within the ontology describing a well known domain. The street system is one of such units within the 'Networks' sub-ontology. Other systems can be considered in 'Networks' such as 'train networks' or 'waterways networks'.

Systems are subdivided in object classes, each class has object types and each object has a set of parameters and attributes. The objects types are defined through their shape representation and shape description, and they are the instances of their respective object classes. Classes are denoted with two bold capitals. The systems are part of the ontology as branches or interlaced branches of it depending on the specific relationships between classes, and they have a particular meaning in terms of the understanding of cities. This paper details the street system. The same principles may be used to define and detail the other sub-ontologies.

An ontology for networks

Networks are a first level branch of the top ontology for cities in the City Induction project. The street system is a semantic unit within the 'Networks' sub-ontology. The street system is divided into 5 major object classes involving a class of axial representations called Axial Network (AN) which are compositional representations, a Transportation Network (TN) for the hierarchical and functional system definition, Street Nomenclature (SN) for cognitive classification of streets, Street Descriptions (SD), providing a set of descriptions of the components composing the street types and Street Components (SC), a finite set of profile components for designing streets. Table 1 shows the allowed relationships between object types found in classes AN, TN and SN.

Axial Network (**AN**)	**TN** classification	**SN** classification
Composition structure		
$a1$	**R1, R2, S1, S2**	**av, bv, ms, pr, gr, rr**
$a2$	**R2, S1, S2**	**st, av, bv, ms, pr, gr**
$a3$	**R2, S1, S2**	**st, av, la**
$a4$	**S1, S2, S3, B1**	**st, la, al, cu**
Interlaced (with traffic) networks		Can be part of…
a_b Bicycle network	**B1**	**st, la, al, av, bv, ms, pr, gr, rr**
a_p Pedestrian network	**P1**	**st, la, al, av, bv, ms, pr, gr**
a_{bu} Bus network	**B2**	**st, av, bv, ms, pr, gr**
a_{tr} Tram network	**Tr**	**st, av, bv, ms, pr, gr**

Table 1 – Relations between AN, TN and SN classes

Axial Network (AN) – a hierarchy of compositional axes

The axial network is a symbolic representation of the street structure or a representation of compositional directions. Although we know that every street has a particular width defined by its bounding buildings it is common to represent them as lines at large scales. On a territorial scale the width becomes null compared to its length. These lines represent networks of connections and also, from the designer's point of view, the composition lines defining the main directions and grids used to structure the design. The objects – lines – in AN are defined as compositional axes. a1 to a4 is a hierarchy of compositional street axes used to define the street network (see table 1). ab, ap, atr and abu belong to a thematically independent domain partially overlapping the street network. For instance, the bicycle network can be defined as a continuous independent system eventually using reserved parts of the traffic system. They can be represented as autonomous networks on distinct layers.

Transportation Network (TN) – functional representation for streets

Many studies have been developed for classifying streets. It is common to find a hierarchical classification of street types defined in terms of traffic speed and other functional requirements. Marshall shows an extensive comparative study on this subject (Marshall, 2002, 2005).

Pedro (2002) defines objective design requirements for public spaces at the neighbourhood scale including street hierarchy detailing the quality requirements for streets at this scale and defining their relationships within the overall street system and public transport system. He defines four types of streets: main streets, distribution streets, local distribution streets and local access streets. The definition of the design parameters in this street hierarchy comes from the restrictions resulting from the maximum speed use attributed to each type. These are functional criteria.

R2, S1, S2 and S3 in table 1 correspond to Pedro's classification. On the urban scale another street type was considered above these ones promoting long distance connections within the city: we will call them ring roads following Alexander's pattern, rr in the SN object class and R1 roads in the TN object class. We will not consider for our purposes street types above this, although we could talk about higher types for metropolitan interconnectivity. Direct equivalence between Pedro's classification and Marshall's stratification by speed can be demonstrated.

Street Nomenclature (SN) – a cognitive classification of streets

Considering the common citizen the perception of streets is essentially made of symbolic features found in streets or from the continuity of the street spaces. Dimension, continuity, symbols and use, including relationship with buildings and traffic use, classify the different types of streets.

The cognitive classification is therefore based on different principles. In order to achieve such goal we adopted vocabulary from common language because common words carry the cultural background that allows people to refer to different types of street in their current speech. However, different languages use slightly different names or concepts for streets. We used the English vocabulary selecting terms that could be applicable to all our case studies and to common European urban structures. Particular street types might be added later.

We considered the following words as being representative of different street types: street (st), avenue (av), boulevard (bv), promenade (pr), grove (gr), main street (ms), lane (la), alley (al) and cul-de-sac (cu) or impasse (Table 2).

"street" is the most generic and abstract of these types, so we will consider it as not one of the others. "avenue", "boulevard", "promenade" and "grove" are defined as large thoroughfares with one or more lanes of trees or shrubs. The French terms "boulevard" and "promenade" also used in several European countries, tend to be associated with larger streets. "promenade" is also defined as a leisure walkway usually including a green area and leisure facilities. "grove" is usually associated with a greater densification of trees. A "main street" is essentially characterized through its social and commercial activity and therefore it may have different configurations, many times not planned at all but, as the result of an informal development. The previous 6 types usually end up in important public spaces like main squares or crossroads which may contain referential landmarks, buildings or other urban features such as monuments, statues or fountains. "Lanes" and "alleys" are small streets. "Lanes" might be associated with old rural paths long time embedded in the city street structure. "Alleys" are more reserved streets, sometimes dead-ends giving access to quarter interior spaces. The "cul-de-sac" or "impasse" concepts are streets ending up in a dead end with a turn over enlargement. "Ring-roads" are usually perceived by people more or less in the same way as through the functional criteria. However complex classification methods for streets may be, the important here is to establish a consensual classification embedding common language perception of streets (Marshall, 2002).

The descriptions of streets found in the classes above are usually enough to enable us to design their sections with reasonable detail. Nevertheless, some interpretations of the same concept might have

Street Nomenclature (**SN**) – street concepts according to common language	Street descriptions (**SD**) – Minimum requirements as collections of profile components from **SC**	Possible relations to Transportation Network (**TN**) Can be a…
st – street	② | ⑤ | ②	**R2; S1; S2; S3**
av – avenue	② | ⑧ | 2 x ⑤ | ⑧ | ②	**R2; S1; (S2 + S1 + S2); (S3 + S1 + S3); (S2 + R2 + S2)**
bv – boulevard	② | ⑤ | ②* | 2 x ⑤ | ②* | ⑤ | ② * with tree alignment or green stripe	**(S2 + S1 + S2); (S3 + S1 + S3); (S2 + R2 + S2)**
ms – main street	② | 2 x ⑤ | ②	**R2; S1; S2**
pr – promenade	**(S2 + ⑪ + S2); (S3 + ⑪ + S3)**	**(S2 + ⑪ + S2); (S3 + ⑪ + S3)**
gr – grove	**(S2** or **S3 + ⑪ + S2** or **S3); (S2** or **S3 + ⑪)**	**(S2** or **S3 + ⑪ + S2** or **S3); (S2** or **S3 + ⑪)**
la – lane	② | ⑤ | ②	**S2; S3; P1; B1**
al – alley	② (strictly pedestrian) ② | ⑤ | ②	**S3; P1; B1**
cu – cul-de-sac or impasse	② | ⑤ | ②	**S3; P1; B1**
rr – ring roads	⑦ | ⑫ | 4 x ⑤* | ⑫ | ⑦ * with central protection rail or green stripe	**R1**

Table 2 – SN and SD classes

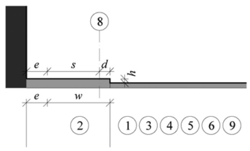
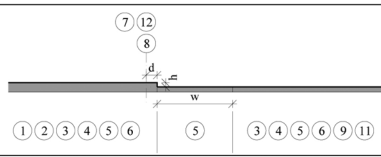
Street Components (**SC**) – a collection of street profiles	Profile schema – indicates profile parameters and possible adjacent profiles	Profile parameters
① - street parking		
② - sidewalks	 	$1.25 \leq w \leq 5.0$ $s \geq 1.2$ $w = s +$ ⑧$width + d$ $0.3 \leq d \leq 0.75$ *e* is an extra space for additional functions. E.g. – esplanade, benches, commercial activities, etc. $0 \leq e \leq 2.5$ And can be used also as tolerance *w* value is further restricted depending on the street type to which it belongs.
③ - bicycle lanes		
④ - bus lanes		
⑤ - car lanes	 	$2.5 \leq w \leq 3.75$ Variations depending on street type ⑦ and ⑫ apply only to **R1** $0 \leq h \leq 0.2$ $h = 0$ when next to ①,④ or ⑤
⑥ - green stripes		
⑦ - noise protection		
⑧ - tree alignments	Tree alignments can be placed on ②; ⑥; ⑪	(according to parameters in street types)
⑨ - tram lanes		
⑩ - canal (**) big – b / small – s		
⑪ - leisure walkway		
⑫ - protection rails		

Table 3 – Street Definitions (SD) – street profile components

different representations within a valid range of parameters, which is the designers' freedom of choice. By decomposing streets into a finite set of profile components we can define every street as a different arrangement of these components. The descriptions of streets are defined through the minimum arrangements of their components. Table 2 shows minimum requirements for SN street types defining their minimum profile components and their possible relation to TN object types.

Street Components (SC) – a collection of street profile components

The selection of components used in this object class is taken from the available technical literature, again Pedro (2002) and others (Marshall, 2002; Steiner and Butler, 2007), and confronted with the case studies we considered in order to guarantee their applicability. It is curious to point that elemental components of streets are consistent among most technical literature. Table 3 shows the street profile components and how they can be used to define street sections. Tables were simplified due to space constrains.

Conclusions

In order to understand the city and its complex system of relationships we defined a city ontology sub-divided into thematic sub-ontologies or systems. In this paper we show a sub-domain of the "Networks" top-level class, the street system, and some of its internal relationships. The other sub-ontologies are defined according to similar principles, but the external relationships between the systems are still to be detailed in such a way that they will represent the real complexity of cities without conflicting with their internal logic.

Finally, it is important to stress that the ontology was developed to encode the features within a designing system, that is, they are supposed to encode urban structures for designing and not to describe the urban environment which can sometimes be inconsistent with the embedded qualitative definitions. However, existent entities are accepted has existent representations with their specific parameters and relationships, while designs, that is new representations, are constrained by the embedded pre-defined qualitative definitions although still opened to a wide range of parameter options. It is the role of the formulation and evaluation to find the values that fit the context' needs minimizing the effect of pre-existing mal-adjustments.

Acknowledgments

The City Induction project is funded by FCT, Portugal (PTDC/AUR/64384/2006), hosted by ICIST at TU Lisbon, and coordinated by José Duarte. Beirão, Gil and Montenegro are funded by FCT grants SFRH/BD/39034/2007, SFRH/BD/46709/2008 and SFRH/BD/45520/2008 respectively. Acknowledgments to Henco Bekkering, Sevil Sariyildiz and Frank van der Hoeven for their comments.

References

Beirão, J, Duarte, J and Stouffs, R, 2008, Structuring a Generative Model for Urban Design: Linking GIS to Shape Grammars, 26th eCAADe Conference Proceedings, Antwerpen, pp. 929-938.
Duarte, J.P.: 2001, Customizing mass housing: a discursive grammar for Siza's Malagueira houses. PhD Dissertation, MIT.
Gruber, T. B.: 1993, A translation approach to portable ontology specifications, Knowledge Acquisition, 5(2), pp. 257-267.
Marshall, S.: 2005, Streets and Patterns: The Structure of Urban Geometry, Ed. Taylor & Francis.
Marshall, S.: 2002, A First Theoretical Approach to Classification of Arterial Streets, ARTISTS Delieverable D1.1. London: University of Westminster.
Montenegro, N. and Duarte, J.: 2009, Computational Ontology of Urban Planning. Towards a City Information Model, Proceedings for 27th eCAADe Conference, Istanbul (forthcomming).
Pedro, J.B.: 2002, Programa Habitacional, vol.4 – Vizinhança Próxima, (Housing program, vol.4 – Close neighbourhood), LNEC, Lisboa.
Steiner, F. and Butler, K.: 2007, Planning and Urban Design Standards, Ed. John Wiley & Sons, Inc.
Stiny, G. and Gips J: 1972, Shape Grammars and the Generative Specification of Painting and Sculpture, Information Processing, 71: 1460-1465.
Stiny, G.: 1981, A note on the description of designs, Environment and Planning B: Planning and Design, 8, pp. 257-267.