A design tool for analysis and visual quality control of urban environments supported by object databases

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ABSTRACT

In the paper, the main concepts about a design tool supported by an object database system will be described. The design tool should improve architectural design with respect to analysis and improving existing and planned urban environments regarding several quality criteria, especially those associated with visual aspects. Preconditions for defining the design tool's purpose are the determination of the "well-situated" urban elements, their impact on cognitive mapping, and the exploitation of this knowledge on cognitive mapping for the improvement of urban environments. Cognitive mapping is a kind of representation of schematic knowledge that a person has about familiar environments. A cognitive map is stored information or knowledge about the purpose and function of the environment. This leads to the conclusion that an urban environment design which takes of the process of cognitive mapping into consideration, will be experienced by most of the people in the same way. Investigations of this process result in a theoretical model of elements of urban environments, their relationships and their dependencies. The theoretical platform of the tool is based on design theory, cognitive science and computer science. Design theory and cognitive science will be used to develop the theoretical model. This theoretical model together with computer science will be the basis for tool development. The tool uses a schematic representation of urban environment, based partly on Lynch's theory of "urban form". Lynch's theory is crucial for the tool because it explains almost all elements of urban environments. Systematic investigation of urban environments and their characteristics are important for theoretical modeling as well as for the later computational modeling of the tool. The main computational support for the tool will be provided by an object database system, which helps to represent and to handle all the urban elements with their properties and relationships, with their natural semantics. The information represented in the database will be used to analyze urban environments as well as to improve and control their visual quality.

1 INTRODUCTION

The quality of urban environment has become important for present and future design and planning practice. A good analysis of the urban environment for future multifunctional planning is one of the priorities of Dutch policy[1]. Research presented in this paper focuses onndeveloping a design support instrument (tool) for cognitive mapping, analysis, controlling of visual environmental quality, designing and evaluating the urban environment.

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1 *Notitie over het beleid voor ruimtelijke kwaliteit* - Ministry VROM, RPD, The Hague, The Netherlands, 17 oktober 1995.

The general public, and specialist even more so, (planners, architects, urban designers) have always been concerned with the relationship between people and the land. The people-environment model is based on the hypothesis that a person responds to his environment as he perceives and interprets it in the light of his previous experience (Sprout & Sprout, 1965). Since the person's response in relation to the environment is assumed to depend on his perception of the environment, it becomes important to find out how this is perceived. This leads to the distinction between the 'real world', which is called the objective or geographic environment, and the 'subjective world' or subjective environment; the construction of a mental map, which depends on what is perceived by the person.

The purpose of this paper is to place a design tool supported by an object database system. At first we explain the theoretical platform for cognitive mapping and how to use cognitive mapping in design of urban environments. In the last part of the paper we present a basic object database and how to derive information from this database according to cognitive mapping.

2 BACKGROUND

In architectural and urban practice, analysis of the urban environment plays a significant role. The need for certain analysis to contain precise characteristics of urban elements is in the context of the analysis of city sites (for example: physical structure rather than street shapes or topography of terrain). There has been a continuous effort by architect and urban planner to understand and express those needs and desires. It is also important to understand at what point support will be necessary in architectural and urban design practice.

The architectural and urban planning process is a complex problem-solving activity. One of the ways of describing architectural or urban design is by means of graphical representation. The representation facilities must consider alternative options at particular levels of spatial organization. The architectural and urban design process have more specific characteristics. Some characteristics concern problems, the process of cognitive mapping of the urban environment. Graphical representation of city sites sometimes has limitations such as, differences in scales readability and details. These limitations can be a problem for correct analysis. The unification of representation is impossible for many reasons, but the characteristics to be analyzed, the criteria and finally the way (process) to do it, will be operational. This research formulates a typology of visual elements according to city sites focused on graphical representation. Typology is the main computational means for solving this problem.

2.1 **Theoretical platform**

The main focus of this research is environmental quality analysis of urban environment (city sites) according to computational cognitive mapping. Learning about and understanding the urban environment for the purpose of cognitive perception, facilitates many methods which have been developed recently in different domains such as psychology, engineering and planning.

This research focuses on the analysis of urban elements as an integral part of large scale city sites. The results of the analysis are correlated to produce quality criteria for the city sites. In the domain of urban designing and planning, we examine the problem of urban quality analysis through the implementation of its elements in the cognitive perception process. Urban design and planning define the process of the research by means of existing theories of design and cognitive science. These theories are a platform for creating a *conceptual model* of the tool. In schema below (Figure 1) different stages of the research are presented.

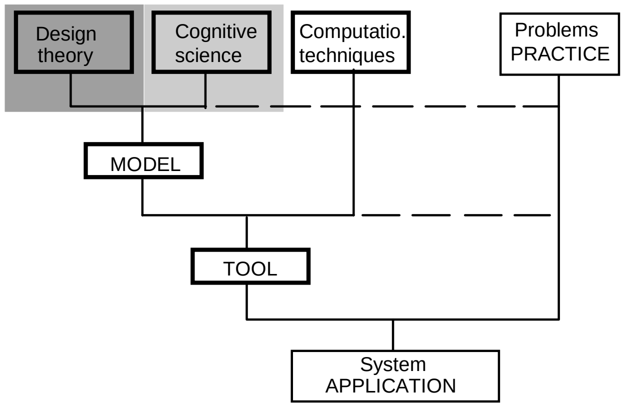


Figure 1: **The schematical presentation of the research**

Design *tool* is based on the theoretical model and different computational techniques, such as database systems, agent-based processing and intuitive interfaces.

The research is employs developed theories in design, cognitive science and computer science. It addresses aspects of knowledge of cognitive perception associated with analysis of urban design elements and design evaluation by computational processing. These three main theoretical levels of the research are:

(1) to define a new computational representation *model* of 'how people think' about the urban environment by quality analysis of its urban elements
(2) to create a computational *tool* as a representational instrument for the integration of qualitative analysis and cognitive mapping.

2.2 'Triangular' schema of urban environment

The simplified outline of the urban theory applied in this research is presented in Figure 2. The schema presents relationships between people and their environment. People are categorized in two groups: designers and users.

The schema indicates three main categories related to the urban environment: urban design, urban environment and urban use. The positioning of the sector belonging to the triangle represents the main part of the urban theory process.

The schema also presents the simplified model of the urban interaction process in their hierarchy. The process of interaction started with real world information and the process of creativity, as a physical/psychological phenomena in the design domain. Real world information, here called *object database systems* (OD), are sets of relevant information which aids the process of creativity (the design process). This information is the data which is transferred into the design process as *object-oriented database systems*. The result of using this design process is the improvement of existing environments, and improved new urban environments. This process considers not only urban purposes, but also the people for whom the environment is designed and built.

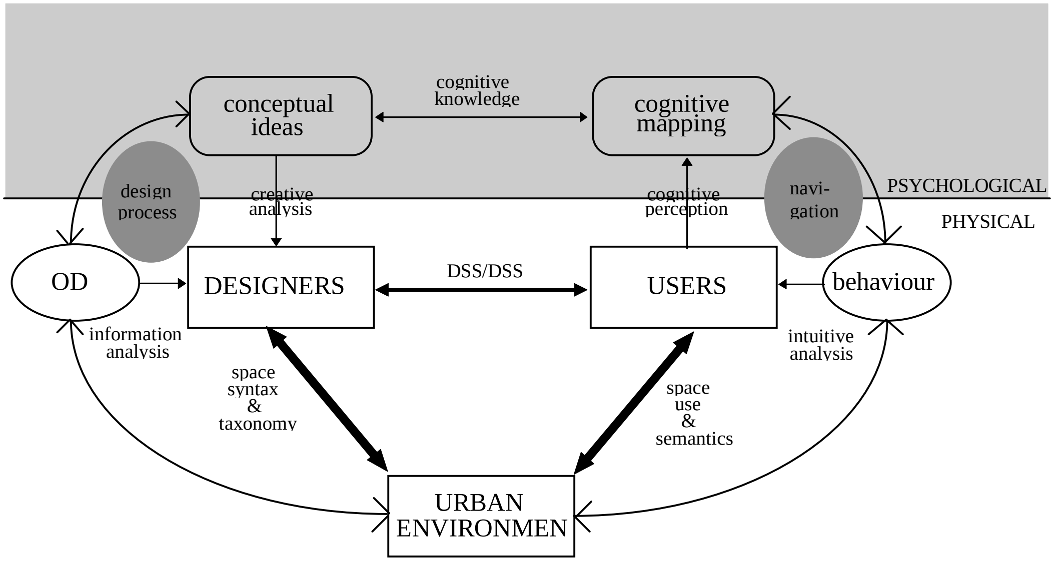


Figure 2: **Schematical outline of the urban theory approach**

Based on knowledge of the real world, and on the design process, urban designers can create a new final product realized in the urban environment. The new or improved urban environment has interactions with the users; people who pass through and use the facilities of the urban environment. People use the environment differently and their perception, or familiarity with it is a called *cognitive mapping*.

Indirectly, the process of perceiving the urban environment interacts with urban designers and their process of creativity. Directly, through the process of decision making, ordinary people will be able to contribute more actively to the process of urban designing.

2.3 **Lynch's theory of 'urban form'**

Lynch's theory of 'urban form' is located in the right-hand part of the schema. Lynch describes elements of urban environment and their interactions, and he defined the concept of *cognitive mapping* of how people behave within a particular urban environment.

Lynch defined things in his book "Image of the city" (1960), important for later explanation of the whole theory: first, physical elements of the city and second, psychological, perceptual senses. It is necessary to distinguish two forms of physical elements; natural i.e. air, sky, rivers, lakes, ponds, hills, etc. and man-made elements i.e. infrastructure, objects, vehicles, airplanes, etc. Natural and man- made elements, in fact, share some common characteristics, such as color, smell, noise, warmth, etc., which together help to build a perceptual form of the urban environment.

Lynch's theory defines two new important things for our knowledge about the urban environment. First, he defines a group of five elements of urban environment (physical characteristics of the real world) and secondly, he defines the concept of *cognitive mapping* (the psychological or subjective world).

The perception of the urban environment, is a product of the human mind and senses. People *recognize* a space, and urban space as well, by the reflection of light, shape and depth. People *orient* in a space by identifying it's elements and patterns . Five elements of urban environment (paths, edges, districts, nodes and landmarks) come from Lynch's analysis of effects of physical, perceptible objects. In our research we concentrate on the main aspects of types and characteristics of physical forms and their elements. The elements are perceived in a hierarchical by people. They make a '*mental interpretation of space*' by memorizing and retrieving elements of spaces and patterns in their brain. This process is defined as mental maps or 'cognitive mapping'.

Our research presents a extensive investigation of almost all urban elements, as well as elements for cognitive mapping, and makes a very precise systematization in a form understandable for *object-database* structuring and for computation processing.

3 DESIGN TOOL

The proposed design tool is capable of generating a computer-based urban elements and cognitive mapping method which identifies the problems and the information required to solve the problems of particular city sites. A computational model of the device in which the real properties of the urban sites are defined precisely and the appropriateness of the model for the task in hand are demonstrated. This tool provides explicit representations of the patterns as well as the urban elements during qualitative analysis of a particular urban site. The design tool aided by a multimedia object-database system and agent processing located in a computational system, provides professionals with the means to achieve more efficiently, reliable solutions through qualitative analysis of urban sites.

3.1 **Goal of design tool**

The goal of the design tool are: (1) to aid urban designers to analyze and test the quality of the urban environment by means of the cognitive mapping process, (2) to resolve visual-spatial conflicts and disfunctionality resulting from the increasing complexity and intensity of use of the urban environment, and (3) to help in the process of decision-making on the widest scale of interests.

The tool could also provide answers to the following:

- how to analyze the visual quality of the urban environment by using different multimedia representation sources
- how to reconstruct urban elements when they are in a difficult position for observers to 'read'
- how to find or predict which are 'well-situated' urban elements that will improve the cognitive mapping of the urban environment
- how to recognize 'what is what' in *confusing* urban patterns
- how to find and position landmarks in *dense* urban sites

and many other questions similar to these.

3.2 **Users of the tool**

This design support tool could be useful as a computational *platform* for several professional areas:

- *Architectural and urban planning offices:* as a knowledge-based design support system for quality analyzing, planning and decision-making of different city sites
- *Science:* for future research in the direction of spatial cognitive perception, design and urban theory, visual data analysis, agent processing and intuitive agent interfaces
- *Software development:* for creating market-based commercial application,
- *Educational activities:* as a system for effective and more practical educational processes as part of professional education

3.3 **Positioning in the design and planning process**

In the early stages of the designing and planning process this design support tool would be effective in the pre-testing of the new design or pre-testing of implementation of the new design for existing urban sites. The tool would be also useful in the final design testing phase.

In addition this tool would be helpful in the process of decision-making by presenting different variables for a particular urban environment using different decision-making criteria.

3.4 **Tool requirements**

The tool requirements should be as follows:

- 'open' for different characteristics of *u.e.* such as geo-political, cultural, natural, social, physical, etc.
- 'open' for all types of *u.e.* such as small, large, dense, distributed, etc.
- open for all types of input and output data (MMDB)
- both global and detailed in analysis
- able to include the surroundings of even the smallest unit for analysis
- orthogonal and vertical in projection as part of analysis
- able to analyze in different spatial scales and measurement systems
- able to make analysis of 'static' objects (maps, photos, drawings) and of dynamic objects (film, video, animation)

- able to present the results of analysis in graphical, numerical and textual form or in 2D, 2 1/2D or 4D visual forms
- able to do direct modeling/improvements in the existing data sources
- able to do modeling/improvements by various computer-based techniques (such as: CAD, VR, www)
- able to interact with the other parts of the system
- open for 'self learning'

The above requirements will be realized in different phases.

3.5 **Basic architecture of the tool**

The proposed basic level architecture of the tool presents three main modules:

- the object-database system, in this paper presented as a concept, is the 'real life' information about urban environments in different multimedia data forms
- the intelligent agent processing system, is based on recently developed computational techniques accessed by intelligent procedures, for query of data on the urban environments
- intuitive (agent-based) interfaces, for intuitive interacting within the self learning system/tool

3.6 **Operational criteria of the tool**

The proposed tool has to satisfy certain basic operational criteria:

- The handling of visual data efficiently, which must be coded in each element and summarized then as *figural patterns.*
- The use of *typology* of visual elements has to be accessed by intelligent procedures such as recognition of similarity or by analogy to previously selected elements and examples. Such procedures can help in the case of visually incomplete information.
- The tool must provide user-controlled links between all elements in process which might help in (1) describing all elements in a detailed manner, (2) interpreting a group of elements as a figural pattern, and (3) representing additional resulting information of the entire analysis.
- The tool is *situated* in a complex of information, structured in terms of prototypical conditions for the purpose of future analysis of other city sites. Therefore the system is self-learning and knowledge-based. The system is a problem-solving by memorizing architectural needs and knowledge as a *look back* system.
- The system will, on the first level edit visual data, on a second level, analyze visual data and on the third level, (a) describe, (b) explain, and (c) modify the visual data which have been analyzed.
- The tool is able to identify conflicts in cases where the use of the system produces contradictory results and can control them; identify results which disagree with common sense perceptions and modify in a restricted way assumptions and presumptions of the system.

4 THE OBJECT DATA BASE SYSTEM

4.1 **Added value of an object database system**

As aforementioned the core of the design system is an object database system (ODBS). The object database management system (ODBMS) provides generic features to the tools supporting the designer, e.g. for computation, reconstruction, representation, simulation and pattern recognition (see subchapter 3.4 and 3.6). All tools share the definition of the database by means of the data schema. It is a kind of common language, which the tools use to communicate with each other in order to serve the designer.
Each tool deals with a specific part of the information processing during the design process.
An ODBS combines the possibilities of database systems and object-oriented programming languages. We assume that these possibilities are known in principle.

Due to the characteristics of the design system, sketched in chapter 3, we have chosen an ODBS mainly for the following reasons:

- There are no restrictions or limitations with respect to the types of structure or behavior which can be represented; the structure reflects the natural structure of objects specifying information used by several tools and understood by the human designer as well. The behavior reflects the operations, which can be executed on the objects.
- Structure and behavior of objects can be updated or extended easily.
- Different layers of abstraction can be supported; that means, each object can be represented in several grades of detail (like zoom-in or zoom-out a certain object) and with different views on relationships between objects at various abstraction levels.
- Several representations (multi-media) of the same object can be supported naturally.
- An object can have several well-defined interfaces offering the needed information to a tool, hiding other information, and hiding implementation details.
- Building modular software is simplified through offering support for reuse of objects and system's functionality as well as the possibility of tailoring the generic system to the real needs of a particular organization.

4.2 **Applying object modeling concepts**

An object model is a set of generic concepts to describe certain characteristics of real or imaginary objects. The object model is used to produce the definition of the database by means of the data schema. Because we produce the definition in terms of objects we replace the term data schema with object schema. We use the object model of Perspective-DB (Perspective-DB, 1997). Here we give a short introduction to main concepts, which are necessary to understand the object schema described in the paper. A legend of the object model is sketched in the appendix. The legend originates from (Essenius et.al., 1998).

The basic concept is the object type. An object type is a characterization of objects through the definition of its members. A member is also an object type. All objects that are characterized by the same types of members belong to the same object type. Members can be attributes (properties), operations and relations. Relations when applied together with connectors form relationships. An object type is represented graphically by a rectangle. Members are represented by rectangles attached to the object type they characterize. Connectors are lines between object types. An object type may have a name written on the surface or beside the rectangle. Operations can be specific for a certain object type (they are represented attached to the sides of the rectangle) or they can be generic, meaning that they can be applied to each object type (they are represented on the surface of the rectangle). If a generic member does not suite a certain object type, it will not be visible. (We only represent the generic members which are important in the scope of the paper). Relationships may have attributes; they are represented attached to the connector.

A generalization object type is an abstraction of several specialization object types; it describes the common members of its specialization. Specialization inherit members of their generalization. A specialization can choose not to use a member it inherits. Generalization and specialization object types form a hierarchy; the generalization is positioned beneath the specialization.
The structure of an object type is often hidden. However, when required it can be popped up and the user can zoom-in its structure. In this way, we can reach different levels of detail of a certain information with the same generic operations and features Perspective-DB offers, e.g. querying and navigation.

In this paper, we only discuss those parts of the object schema used to describe the basic information necessary to "produce" and "use" conceptual urban design ideas during the design process. The examples give an impression how to describe physical information about urban environments, which support cognitive mapping. The following part of the paper is indicated in the left lower part of Figure 2.

4.3 The basic object schema

The basic object schema describes the generalization/specialization hierarchy of the object types needed to derive the information used to design taking cognitive mapping into consideration. We start with the object type "urban element" in Figure 3; it inherits its members from "virtual object" offered by Perspective-DB (is not represented here). "Urban element" has among other generic members: psychological precategorization of an urban element, and modal representation. "Modal representation" determines the media types that represent the urban element. An element can have several suitable media representations. Later we show how to work with such a member using "psychological precategorization" as an example.

Figure 4 shows a continuation of the generalization/specialization hierarchy of Figure 3. We choose "district" and "path" to give an idea. According to the inheritance rules, each of the shown specializations will inherit the members of its generalizations. They can add new members, which are in turn inherited from their specializations. In the example, all objects have a "code" as key, and "time" and “scale” as members. All districts as well as paths have “width” and “length” as members.

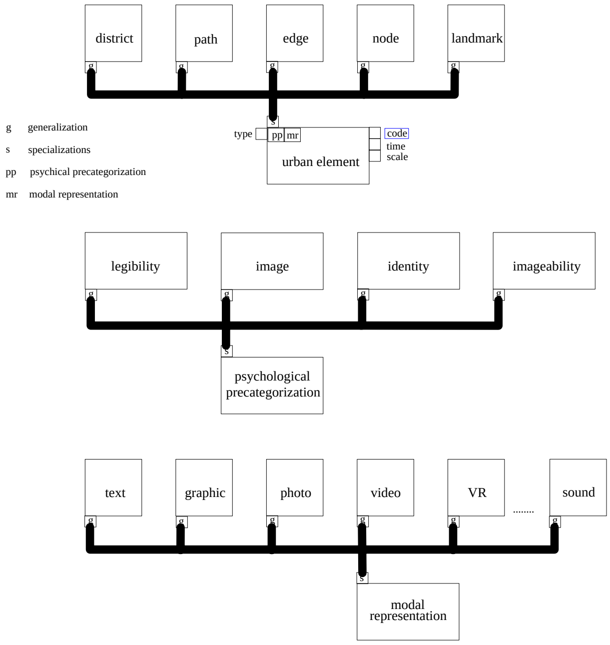


Figure 3: **Basic object types**

Figure 4 shows a continuation of the generalization/specialization hierarchy of Figure 3. We choose “district” and “path” to give an idea. According to the inheritance rules, each of the shown specializations will inherit the members of its generalizations. They can add new members, which are in turn inherited from their specializations. In the example, all objects have a “code” as key, and “time” and “scale” as members. All districts as well as paths have “width” and “length” as members.

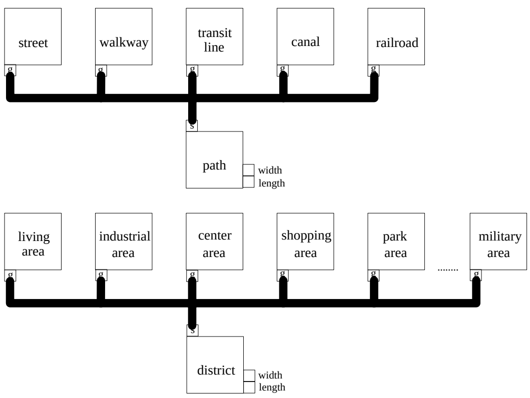


Figure 4. **Specializations of “district” and “path”**

4.4 **Example: Semantic categorization of “district”, “path” and “edge”**

<u>District:</u>

Figure 5 shows additional relationships between urban elements. The (sub) schema of Figure 5 uses the information coded in the generalization/specialization hierarchy. We have to imagine that the two schemes are coupled. In Figure 5 we show other aspects and another perspective of the same object types, represented in Figure 1 and 4.

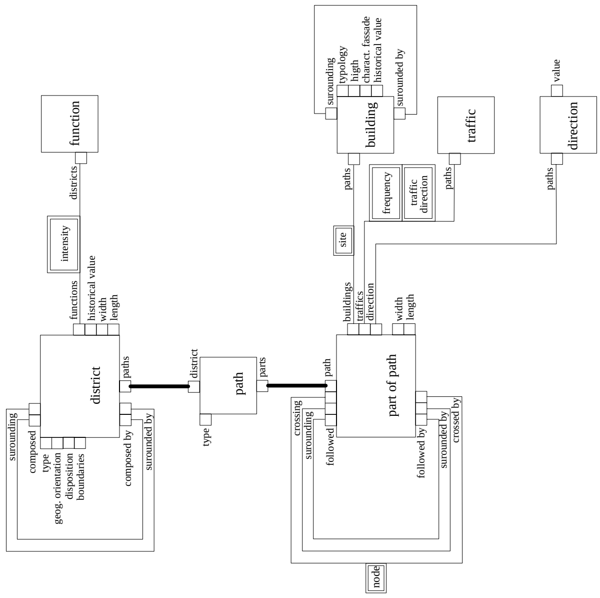


Figure 5. **Scheme of "district" and "path"**

In Figure 5, a district is represented by:

- A member "type" (inherited from "urban element") expresses the characterization of a district in terms such as introvert, extrovert, isolated etc.
- Further attributes are e.g. geographical orientation, disposition, kind of boundaries, the width and length (inherited) and a historical value to indicate memorials etc. inside the district.
- A district can be composed of subdistricts. A district can itself be a subdistrict.
- A district can own paths. These are the paths situated inside the district. That means, each path will be designed "out of" a district and each path will be identified inside its owning district.
- The subdistricts and the owned paths build the structure of a district.
- Other districts can surround a district. A district can be the surronder of another word district.
- A district has functions like living, culture, recreation and shopping function. Each function, which belongs to a district, can be characterized by its intensity.

<u>Path:</u>

A path is the owner of its parts. A path can be divided in as many parts as necessary. It can also be just one. The parts are partitions of a path with different characteristics of that path. The partitioning of a path, is a flexible means to describe a path as accurately as necessary. For these reasons we have modeled the characteristics of a path related to its parts.

In Figure 5 we describe a path (through its parts) as follows:

- If the path is a street the member "type" (inherited from "urban element") expresses its characteristics in terms of boulevard, avenue, passage, etc. If the path is a canal, "type" expresses its characteristics in terms of big, small, industrial etc. These domain of the value of a member depends on the specialization of the object type "path". Perspective-DB chooses the right domain automatically.
- Further attributes are width and length (inherited).
- A path part can follow a certain path part or can be followed by another part.
- A path part can cross or be crossed by another part. The relationship with the object type "node" specifies which node is placed at the crossing. This relationship "node" is another perspective on the object type "node", which is visible as specialization of "urban element" in Figure 3.
- A path part can be surrounded by other parts or can surround other paths. Surrounder paths, do not cross a path but are situated near a considered path.
- Other elements such as buildings can be situated beside a path. Here it is specified on which side of the path a building is situated.
- Traffic is ongoing on a path (part). Characteristics of the traffic can be specified, such as the direction and the frequency of the traffic.
- The geographical direction gives the compass-orientation.

"Building", "traffic" and "direction" are also object types, which are specialized from generalization objects not described in this paper.
The thin connectors between e.g. "part of a path" and "building", "traffic" and also "direction" specify relationships which are not "ownership". That means e.g. that a building can be created without needing to situate it on a path.

<u>Edge:</u>
Figure 6 shows a (reduced) description of "edge". The schema specifies that "edge" can form a border between each of the urban elements, including itself. It could be the border between objects of the same or different urban elements. For all the object types shown in this schema we have to imagine that a generalization can be overwritten by its specialization.

Comparable schemes specify also "node" and "landmark".

"Node", "edge" and "landmark" use the urban elements "district" and "path" to be explained and specified.

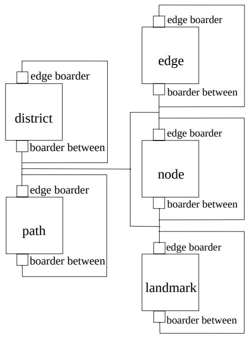
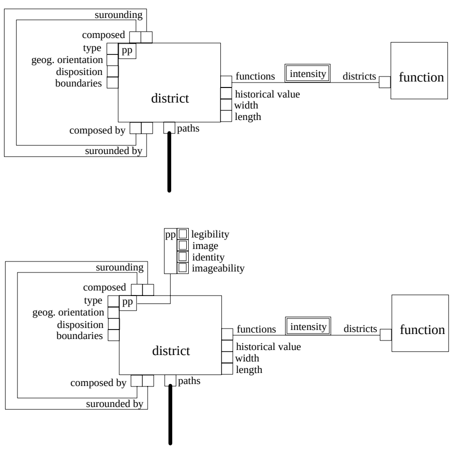


Figure 6. **Schema of the object type “edge”**

4.5 **Example: Relationships between urban elements and psychological precategorization**

A relationship between urban elements and psychological precategorization is described with the object type “district” as an example for an urban element, and the object type “identity” as an example for “psychological precategorization”. The object type “psychological precategorization” is a member of “district”, inherited from the generalization “urban element”, see Figure 7a.

When this member is activated, it pops-up its embedded objects, in this case “legiability”, “image”, “identity” and “imageability”, see Figure 7b. Perspective-DB supports an active object schema. All schema elements can be activated by clicking them. In this paper, we limit the discussion to “identity”. When we activate “identity”, the object type pops-up, showing its members. Here, we only represent the relationship “pattern” as a member of identity. This relationship represents, that identity is associated among others with a certain pattern in the human mind. The relationship between “identity” and “pattern” enables us to identify a district by a certain pattern, or to find the pattern which identifies a certain district. The pattern itself is composed of the object types “function”, “edge”, “node”, “landmark” and “structure”. The pattern, which contributes to identifying a district, is composed of certain functions, edges, nodes, landmarks and the structure of the district.



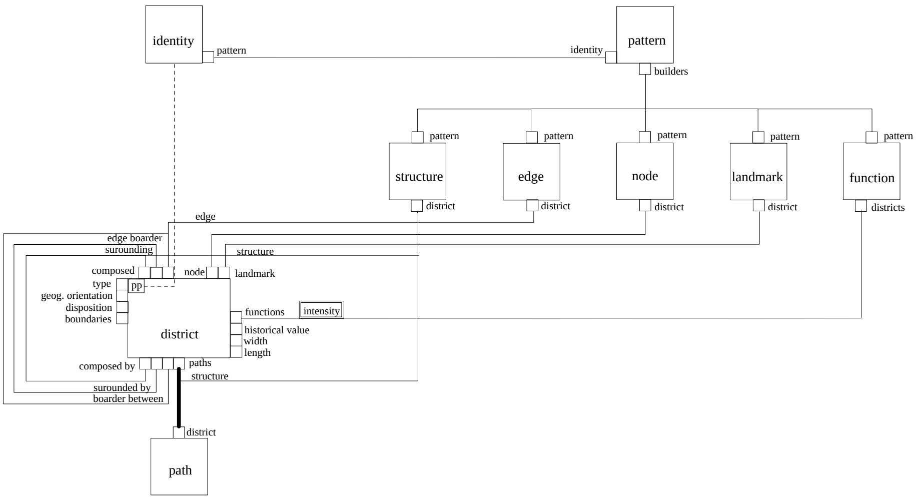


Figure 7. **Schema of the object type "district" to demonstrate the principle of relationships between urban elements and psychological precategorization**

The schema of Figure 7c looks complex because we did not filter the represented information. The system filters in order to give the user the facilities to see the needed information at a certain abstraction level and in a certain relation with other objects.

5 SUMMARY

In the paper, the main concepts about a design tool are described which will improve architectural design by taking cognitive mapping into consideration. We discussed how Lynch's theory of "urban form" provides the basis of an object database system. The database system is the kernel of the design tool. The tool supports the designer by explicit representations of the patterns as well as the urban elements during the qualitative analysis process of a particular urban site. We sketched the functionality of the system. Furthermore, we have shown that the elements of urban form can be modeled as the basic objects of our database, and how they can be specialized. We sketched the structure of the database how it is presented to the urban designer. We have shown how to model "psychological" aspects of cognitive mapping and how to derive design information through several abstraction levels from an object database. Up to now, the object model of Perspective-DB supported us with all the needed modeling constructs.

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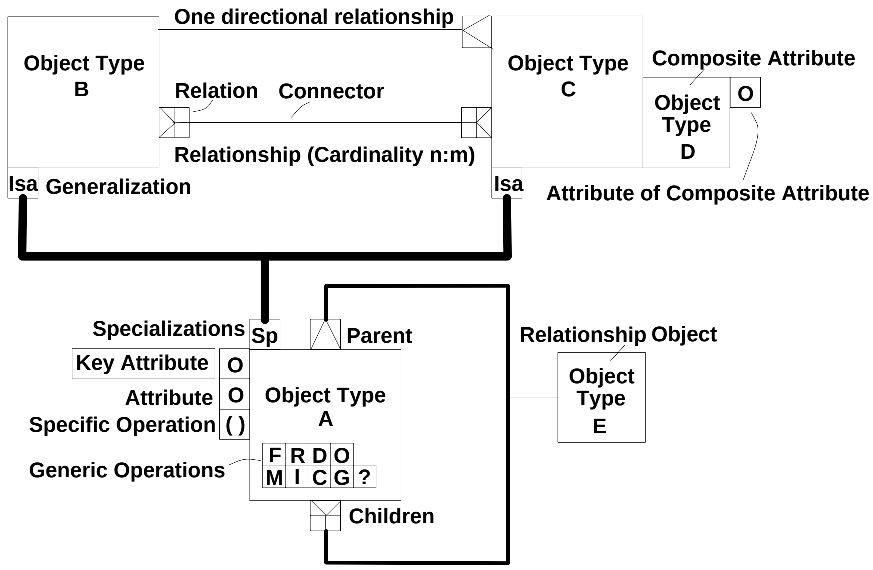

One directional relationship
Object Type
B
Object Type
C
Composite Attribute
Relation
Connector
Object
Type
D
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Relationship (Cardinality n:m)
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Generalization
Isa
Attribute of Composite Attribute
Specializations
Sp
Parent
Relationship Object
Key Attribute
O
Attribute
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Object Type
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