Knowledge-based model generalization for truly virtual cities

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SUMMARY

In this paper, we present a model generalization for truly virtual cities by using the city residents' urban image. Topological analysis of city residents' urban image provides the knowledge base for scale-dependent and context-dependent generalization. The generalization model uses this topological structure to decide which geographic objects will be presented when new scale or perspective emerges during "flying–based" navigation mode of the virtual city user, according to the geographical context and to the user's real time log navigation parameters. The proposed model generalization was implemented by rule-based system on the desk-top virtual model of Tel Aviv city.

KEYWORDS: *virtual cities, 3D visualization, urban image, model generalization*

INTRODUCTION

A truly virtual city is a virtual or simulation model of a real city. The construction of such models has been applied recently for many cities, e.g. Los Angeles, London, Barcelona, Glasgow and Tokyo, thanks to the improvement in geovisualization technology. Currently, the research in this field tends to concentrate on the models' technological dimensions and their implementations for supporting urban planning (Fisher and Unwin 2001; Brail and Klosterman , 2001; Geertman and Stillwell, 2003; El Araby & Okeil, 2004), with little attention being paid to the wayfinding difficulties that characterize these models and their design implications (Bourdakis, 1998; Omer et. el., forthcoming). Truly virtual cities are unique geographical representations, and with regards to their real time movement, varying geographical scales and 3D perspectives could entail non-intuitive behaviour and visual distortions, resulting in wayfinding difficulties. In addition, users of a truly virtual city experience difficulties of orientation just as the users of every virtual environment (VE). These difficulties can be related to the lack of "presence," restricted fields of view, and the use of input devices that might reduce performance during navigation (Darken & Sibert, 1996; Sutcliffe & Gault, 2004).

Designing truly virtual cities with the aim of enhancing wayfinding means enabling the users to move from a current location to another desired one. Numerous studies deal with the principles and techniques for improving navigation within VE, mostly according to the cartographic intuition of the designer e.g. adding or highlighting local and global landmarks and using navigational tools. However, in the case of truly virtual cites there are two advantages. First, the possibility of using generalization methods, especially those developed for GIS and 3D visualization, which are mainly driven by communication requirements, such as legibility, graphical clarity and understandability (Muller et al., 1995) as a basis for appropriate applications for virtual geographical environment The second advantage is the possibility of creating a generalization knowledge and rule-based system by using real city experiences. Such knowledge can be acquired from several sources: written information, mapping agency guidelines, analysis of existing maps series, human cartographic experts and a specific empiric research on the intended use of the spatial representation (Weibel, 1995; Kilpelainen, 2000).

Lynch's urban image theory (Lynch, 1960) is one of the best known ways of dealing with city design and its visual representation (Al-Kodmany, 2001) by providing methodological framework for understanding how the city residents perceive their city. In this paper, we present a knowledge-based model generalization for truly virtual cities by using the city residents' urban image. The proposed generalization process was implemented with the '.net environment' on the desk-top virtual model of Tel Aviv city, an area of about 50 square km. The model is based on Skyline® software and is constructed from a DTM in a resolution of 50m grid, digital orthophoto at a resolution of 0.25m pixel, 3D objects and GIS layers of building height, street network and areas.

The knowledge for the model generalization was acquired from the Tel Aviv residents' urban image by using their city sketch maps. For constructing the knowledge base, we used the Q-Analysis method to identify the topological structure between the elements in these sketch maps. The generalization model uses this topological structure to decide which elements would be presented to the virtual city user, according to the geographical context and to the user's real time log navigation parameters.

URBAN IMAGE AS A SOURCE OF KNOWLEDGE

From a methodological viewpoint, the urban image is actually a sort of collective cognitive map or an aggregative indirect cognitive representation obtained from an aggregation of individual sketch maps of the city (see figure 1). The Urban image provides knowledge on the more imageable elements of the city and on the way in which they interrelate. In order to design a legible simulated environment this knowledge allows us to decide which geographic objects will be presented when new scale or perspective emerges during "flying–based" navigation mode in large geographical areas. The selection of these geographical objects should be related to the scale of the observed area i.e. to use different levels of detail (LOD) according to the size of the area (Frigioni and Tarntino, 2003) and to the contextual relations between objects. In frame of cartographic generalization, the latter can refer to: being part of a significant group, being in particular area and being in relation with "same level" surrounding objects (Mustiere and Moulin, 2002). In the text that follows, we present how the residents' urban image can be used for constructing a knowledge-based model generalization that integrates two components: scale-dependency and context-dependency. Considering the nature of the simulated environment in virtual city, both generalization components are restricted to a selection of objects without manipulating the form of the objects.

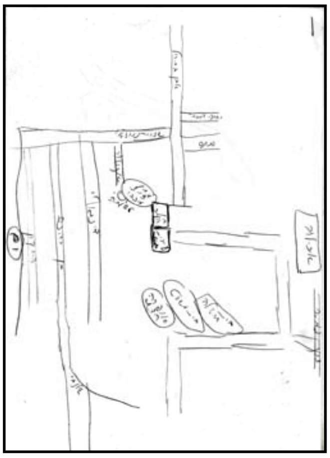


Figure 1: an example of an individual sketch map of Tel Aviv city.

Scale-dependency: Which elements should be displayed or highlighted in a given scale? The basic assumption of the urban image concept is that the urban elements that appear in residents' aggregative map represents the imageable elements of the city that are important for enhancing legibility. In this respect, the imageablity degree of an object is determined according to its frequency in the aggregative map, i.e. an object that appears in many individual sketch maps is considered as an imageable element.

Context-dependency: Which elements should be displayed in the context of the reference object i.e. the object that the user focused on? Since a context is by definition a common appearance in the cognitive representation, the context objects that should be included in the context of the reference object could be determined according to their common appearance with the reference objects in the individual sketch maps.

Operatively, we can infer these two kinds of knowledge by examining the topological structure of the urban image to find out how the residents organize the relations between the urban elements. For that purpose we applied the multidimensional scaling method of Q-analysis (Atkin, 1974). The basic concepts that underlie Q-analysis are sets of objects and the relation between these sets. In terms of our context, let C be the set of m urban objects (i=1..m) so that $C= \{c_1, c_2, \dots, c_m\}$, and P a set of n sketch maps (j=1..n) so that $P= \{p_1,p_2,\dots, p_n\}$. Let μ indicate that a pair of elements (c_i, p_j) are related. If an object c_i is drawn in sketch map p_j, then c_i is related to p_j by the relation μ: $(c_i, p_j) \in \mu$. This relation defines the dimension of an object denoted by q.

On the basis of presence/absence of relations between pairs of elements from sets C and P (incidence matrix) a simplical complex $KC(P; \mu)$ was constructed that represents the topological structure. The simplical complex allows us to identify the direct connectivity between objects in each dimension (q-near) e.g. 3-near denotes that the objects appear together in q+1 (4) sketch maps, and their indirect connectivity between objects (q-connectivity) connected transitively by different q+1 sketch maps. The topological structure $KC(P;\mu)$ enables us to acquire from the urban image the necessary knowledge for generalization. First, using the dimension level q of the objects and their q-connectivity to determine which objects will be displayed at a given scale, and second, using the q-near relation of the reference object to determine which objects will be displayed in the context of the reference object. That is, the context of an object is composed of the urban image elements which have q-near relation with the reference objects.

MODEL GENERALIZATION BY RULE-BASED SYSTEM

Implementing a generalization model in virtual cities must take into account their 3D visualization during a real-time movement by using the user's real-time log navigation parameters. There are several display parameters discussed in VE studies (Barfield et al, 1995; Tan et al, 2001; Nash et al, 2000). The geographic field of view (GFOV) is the projected screen dimension on the terrain and is trapezoid shaped i.e. the actual visible landscape. The GFOV changes according to three parameters (figure 2): the eyepoint elevation angle (EPEA), or tilt, the field of view (FOV) and the viewing perspective height (VPH). The EPEA is the angle between the VPH and the center of projection (COP). The FOV defines the virtual eyepoint spectrum. Since it is mostly constant, we need to consider how changes in VPH and EPEA affect the GFOV. When the VPH is high, or when a large positive EPEA is used (up to 90^0, producing a top-down view), the user sees a relatively small area (small GFOV). Note that small positive EPEA causes smaller scale far from the center of projection (COP) due to a compression of the horizontal and vertical dimensions i.e. elements located far from COP appear smaller. Due to this 3D visualization distortion effect, the geographical scale of each object in the area that the user sees (GFOV) is determined by the 3D Aerial Distance – the distance between the observer eyepoint and the location of this object.

Locating these display parameters by using the user's real-time log navigation parameters enables the implementation of the generalization process, which aims to display urban objects according to the observer's geographical area. The generalization process comprises three steps: an initialization step for identifying and locating objects, "scale-dependent generalization" and "context-dependent generalization."

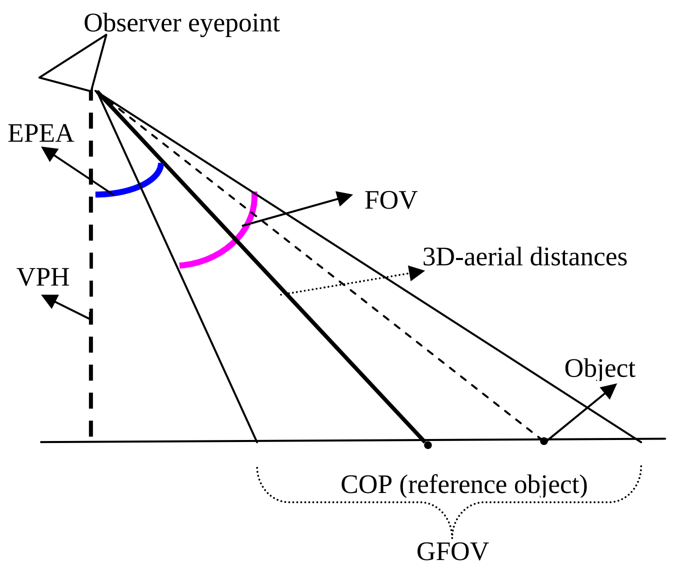


Figure 2: Illustration of the parameters used in the context of a 3D virtual environment.

Step 1: Identifying and locating objects (initialization)

The system enables the users a flying-based navigation mode, offering them the possibility of reaching any desired location. Once the user indicates that he or she has reached the location, the system calculates, as a prerequisite step, the GFOV, according to the EPEA and VPH as set by the user and the FOV (which is constant at 53^0). Next, the system checks the coordinates of each urban image element from the list. Those elements that are not enclosed within the GFOV borders won't be selected, while those elements that correspond with the GFOV will go through the next phase (figure 3a). The second step is the search for a relevant urban element from the list of urban images that will serve as "reference object" for the desired location the user has chosen. The identification process of the reference object is carried out by implementing the "nearest element" method, in which the system finds the urban image element that is located nearest to the desired location, and identifies the urban image element as the reference object (This phase is displayed in figure 3a, step 1).

In order to decide which other urban image elements that are included within the GFOV should be displayed, in addition to the reference object, each element undergoes a procedure that includes two components (figure 3a): scale-dependent generalization component and context-dependent generalization component.

Step 2: Scale-dependent generalization component

Assuming the user has reached a desired location (represented by a referenced object), the system performs two calculations: The 3D-aerial distance between the observer eyepoint and each of the urban image elements (that are within the GFOV) identifying their *dimension (q)* according to the topological structure. On the basis of this calculation, the system checks whether the element suits the scales' conditions as described below.

The issue of LOD in a cartographic generalization refers to the density and types of objects that should be presented in each scale. In the current application we decided intuitively on different six scales Li (i=1…6) in a range between a 3D-aerial distance of 250-10,000m. The scales are defined according to the relation between 3D-aerial distance and the dimensions of the topological structure (*dimension*) as follows: Let L_{local} (q_1, 200-300m) indicate the local-scale spatial structure and L_{global} ($q_{>11,}$ >10,000 m) indicate the global spatial structure. An Element that is located at a 3D-aerial distance of 250 m from the observer eyepoint and is included in the topological structure (its *dimension q* is at least 1) is defined as being in "local scale" and will be displayed (see figure 3b*)*. Furthermore, viewing the virtual environment in a 3D-aerial distance greater than 10,000 m is defined as being in "global scale,", and an element which has a *dimension (q)* greater than 11 is defined as a "global spatial element". Displaying several global elements results in a global structure, independent of perspective or a reference geographic object (figure 3b).

Since increasing the 3D-aerial distance above local scale would likely result in high density of objects, a generalization method is needed to produce optimal visual complexity. For that purpose, four intermediate hierarchic scales were defined (figure 3b), each containing a combination of the *minimum-q* and the 3D-aerial distance: L1($q_{1-2,}$ 300-1,000 m); L_2 (q_{3-4}, 1,000-2,500 m); L3 (q_{5-6}, 2,500-5,000 m) L4 (q_{7-10}, 5,000-10,000 m). Each scale defines a *minimum-q* that is the minimal dimension above which an element can be displayed. The aim is to display those elements that are part of the urban image taking into consideration the 3D visualization distortion effect. Hence, in the scale- dependent generalization component, as the scale (Lc) is bigger, indicating that the 3D aerial distance is greater, the elements that will be displayed are those with a higher *dimension (q)*.

Step 3: Context-dependent generalization component

In order to connect the reference object to the spatial structure of Lc, additional elements are needed to create a hierarchical spatial structure. These elements are chosen according to their *q-near* dimension with the reference object (see figure 3b). The q-near is set according to the *dimension (q)* of the reference object. In order to ensure sufficient amount of elements we defined the parameter k. The parameter k denotes the minimum amount of elements from the adjacent hierarchical q-near level that are needed to be displayed, which for this application was set to k=3. Trying to take into account the geographic limitation of the 3D virtual environment, in case that there are several elements with the same *q-near* dimension, the elements with the shortest 3D-aerial distance will be displayed.

The context-dependent generalization component sets a higher priority to the topological connectivity aspect of the elements rather than to their *dimension (q).* By doing so, it enables the selection of additional elements that establish the context of a given reference object. Namely, displaying the urban image elements that are mostly direct connected to the reference object in the residents' representation of the city.

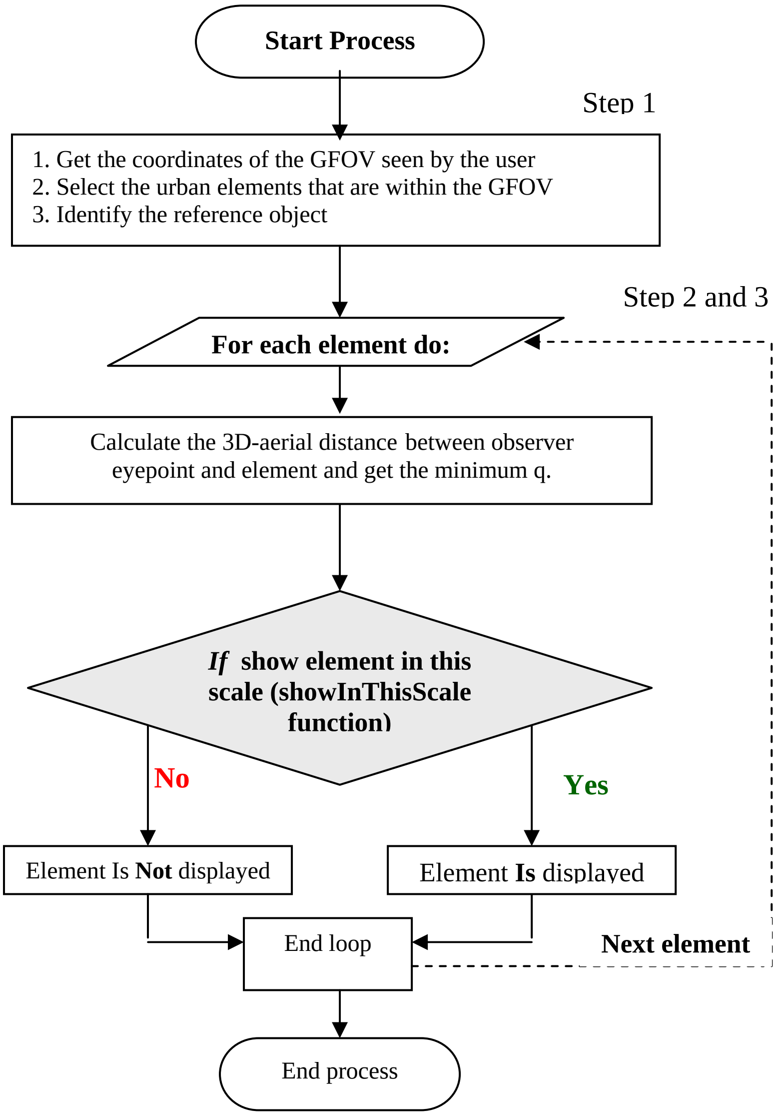


Figure 3a: the overall (algorithm) procedure applied in the system.

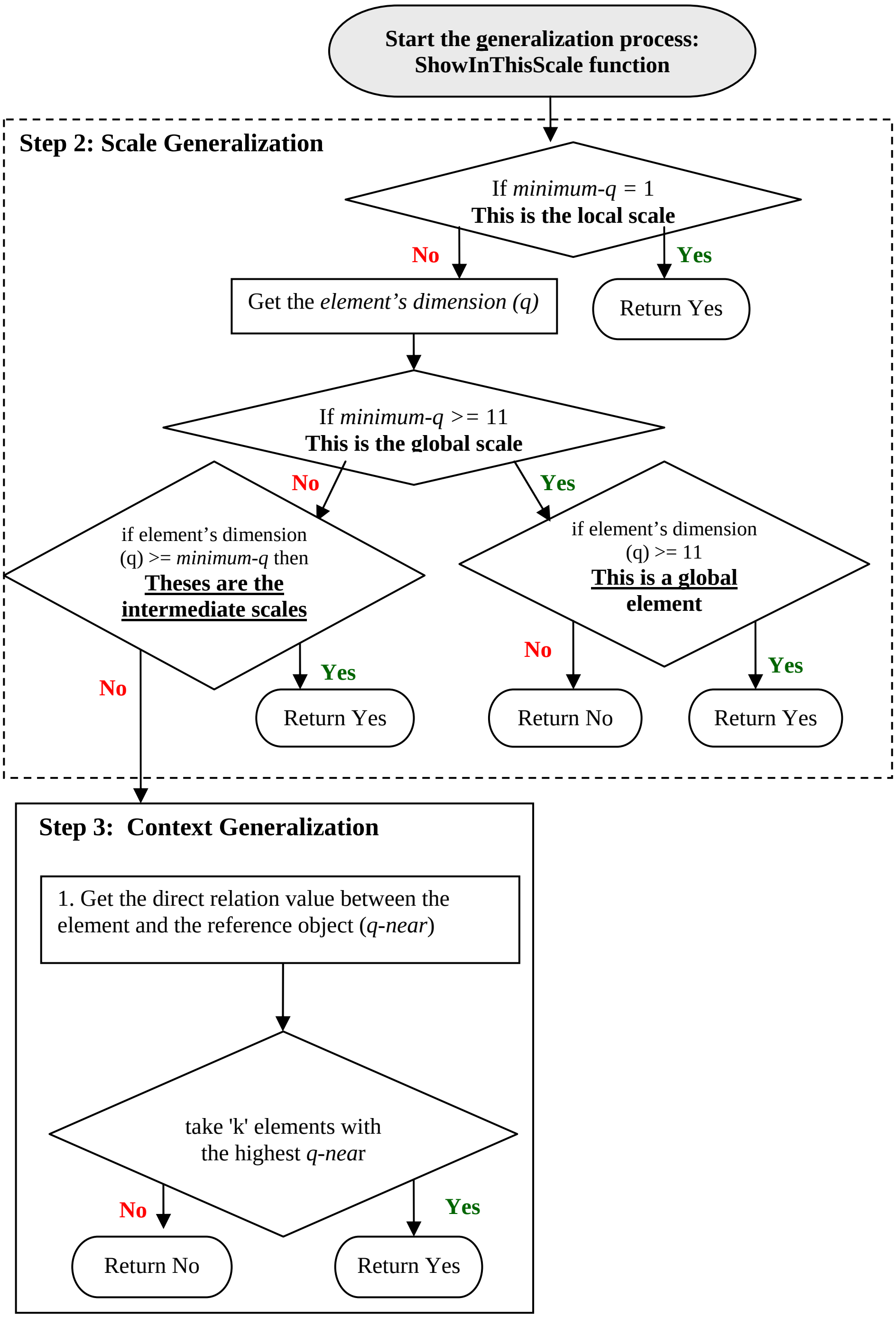


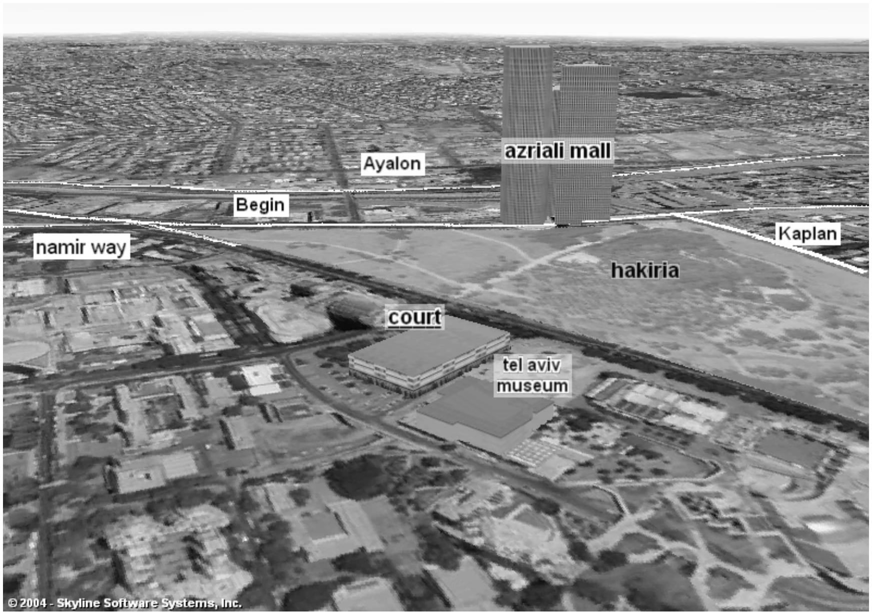
Figure 3b: the generalization process applied in the system including scale generalization process and context generalization process.

Illustration of the knowledge-based model generalization implementation

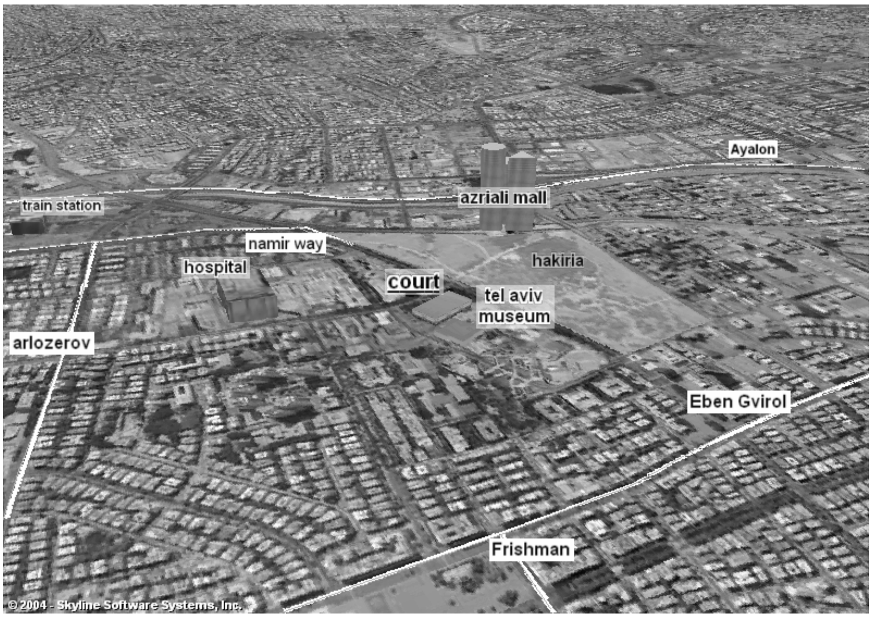
In order to facilitate the identification and legibility of the simulated environment of Tel Aviv city during a flying-based navigation mode, a distinction has been made between three types of urban image elements landmarks, paths and districts, following the urban image concept, with an aim to emphasize the different attributes characterizing each type. Hence, landmarks are displayed as 3D models imported to the environment, paths are displayed as polylines and districts as polygons. In addition, we add text labels above each element.

Figures 4a-b illustrates the operation of the generalization process. In both figures, the reference object is the court building, indicated by the underlined label. Each element is evaluated according to its 3D-aerial distance from the observer eyepoint. These snapshots clearly illustrate the implementation of the scale-dependent component in the generalization model, according to the changes in the 3D-aerial distance: when the distance is greater, some elements that appeared in figure 4a and have a low-dimension (q) are switched off in figure 4b because they don't have the *minimum-q* required in the new intermediate scale due to the increase in 3D aerial distance (i.e.Kaplan Street), those that do have a *minimum-q* remain (Hakiria area Azriali mall) and other new elements both landmarks and paths are added (Arlozorov St).

The context-dependent component is also illustrated in figure 4b, where in order to maintain a hierarchical topological connection between the court building and its surroundings, the elements with the highest connectivity to the reference object are switched on, even if they don't have the highest *dimension (q)*. For example, Frishman St., which has a lower *dimension (q)* but higher *q-near* than Begin St. is switched on while Begin St. is turned off.



a



b

***Figure 4*:** The reference object (the court) viewed from two different 3D aerial distances.

CONCLUSIONS AND FUTURE WORK

Topological analysis of city residents' urban image provides the basis for integration between two components of knowledge generalization: scale-dependent and context-dependent. The model generalization proposed in this paper considers these components using a rule-based system, when a new scale or perspective emerges during flying-based navigation mode. The uniqueness of this approach is its contextual character: using empiric spatial knowledge for design of the simulated environment and the ability to change this environment according to the observed geographical area and the real time display parameters. Further study, mainly empirical, is needed to examine the efficiency of this kind of generalization for supporting wayfinding in truly virtual cities. More specifically, such study is needed for two aims: first, for evaluating the potential of urban image framework to support the virtual city design by the selection of the urban objects to be presented by 3D models. This decision also has an economic aspect since constructing 3D models, mostly with the photos of the facade textures, involves vast amounts of money and time. Second, the working assumptions of the proposed model mainly regarding the context-dependent component i.e. the context is defined on the basis of a common appearance of objects in the individual sketch maps, should be proved empirically.

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