NEXUS: THE DEVELOPMENT OF A PLATFORM FOR LOCATION AWARE APPLICATIONS

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This paper focuses on a research project called „NEXUS“ that is carried out by the Institute of Photogrammetry and the Institute of Parallel and Distributed High-Performance Systems of the University of Stuttgart.

The purpose of the project is the development of an infrastructure for spatially aware applications. The basis of this infrastructure consists of spatial object models that represent parts of the physical world and which are augmented by virtual objects. The virtual objects allow for the ability of the system to connect existing information systems like the WWW and interactive services to objects of the real world. The spatially aware applications which are using the computer models can be accessed by mobile users equipped with handheld computers that include components for mobile communication, positioning and control. Thus, the applications are not only aware of the location of the stationary objects within the model, but also of the user-locations. Queries on the information sources applied by the users of the system can therefore be structured spatially.

1. THE CONCEPT OF NEXUS

All objects of the world around us possess a spatial component, i.e. exist in a geographical context. To analyze and interpret spatial phenomena by means of computer aided methods, Geographic Information Systems (GIS) have been developed.

Nowadays, many applications have to offer capabilities for the examination of spatial relations and so the services of GIS have to be reimplemented into them. In order to avoid this, NEXUS is aimed at providing a generic platform for spatially aware applications that supports different GIS-functionalities like navigation tasks or spatial queries. With respect to Computer Aided Facility Management Systems (CAFM), not only the ability to perform geographical queries should be supported, but the interactive control of processes has to be realized, too. Therefore, an important objective comprises the implementation of active functionalities into the system in a way that objects of the real world can be controlled by their corresponding representations in the computer models and vice versa.

The infrastructure is designed to be a scalable Middleware Layer that can be accessed by multiple users and that is capable of managing cooperation processes between different applications. The environment of NEXUS will be composed of small mobile computers, the so-called NEXUS-stations, which include components for wireless data transmission as well as positioning and control sensors. But the platform can be used from any other computer, too (*Hohl et al.* 1999).

The platform is based on object models that represent the NEXUS-world (see Fig. 1). They store the geographical properties and semantics of stationary objects, e.g. buildings, streets, etc. and also objects of indoor areas like museums or shopping malls. Not only the real world is reflected in those computer models: in order to extend the capacities of the system, the concept of virtual objects was introduced. They allow a connection to already existing information systems, especially the World Wide Web, so that the users of the platform are not only limited to the information stored in the NEXUS-models but can receive current spatially structured information from other sources. Moreover, the virtual objects can also act as brokers for services like online-banking, etc. Taking into consideration that the users might want to interact with their environment, virtual objects could have the function of post-its or black boards, too, so that the NEXUS-participants can either communicate with each other via messages or add notes to virtual objects.

Due to the fact that the object models of the project include virtual representations, they are called Augmented Area Models. Each Augmented Area Model describes only a part of the whole NEXUS- or Augmented World respectively, e.g. an area of a City or only the detailed interior of a room. It is necessary that the interchangeability and compatibility of the various models that might overlap or include each other will be guaranteed. A homogeneous structure of the NEXUS-models enables an easy integration of new Augmented Area Models similar to the connection of a new WWW-Server to the Web, which is an important factor concerning the fast expansion and acceptance of the system. Since all models are accessible through the NEXUS application interface, switches between the different models can easily be realized.

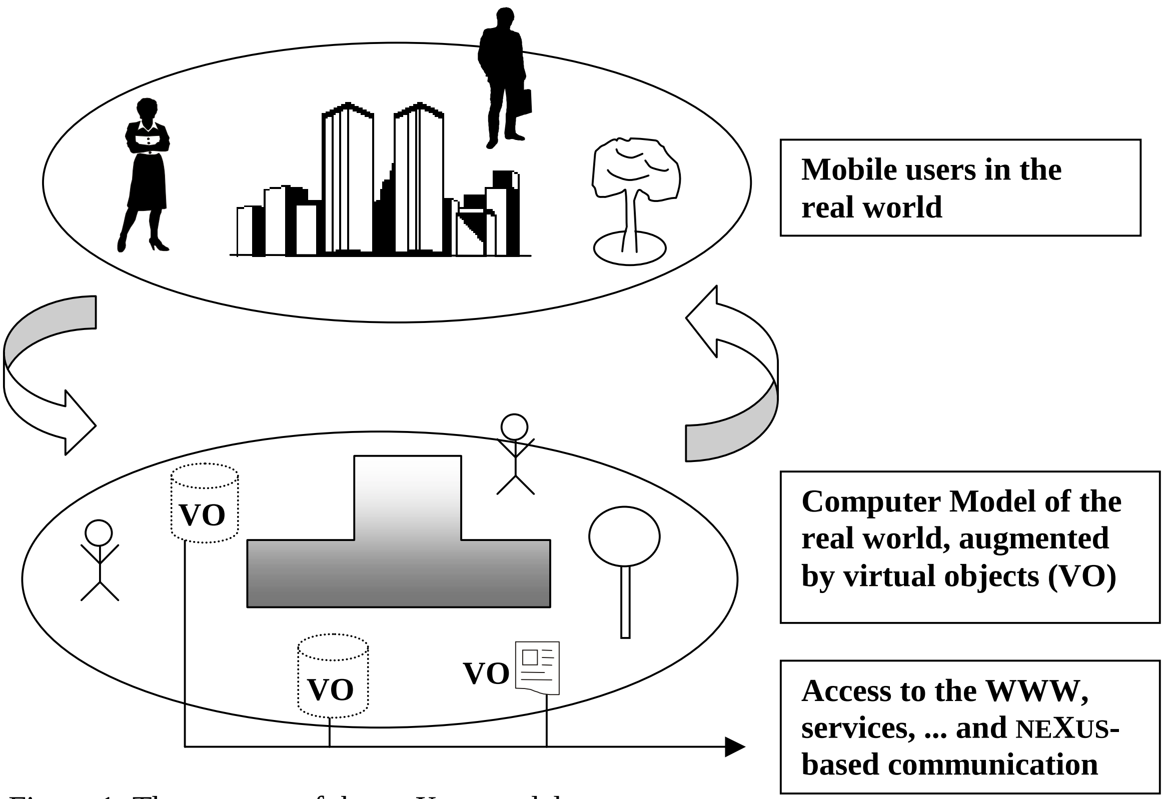

Figure 1: The concept of the NEXUS-models

Beyond the incorporation of either real or virtual stationary objects into the NEXUS-models, the system also takes account of the mobility of the users. As already mentioned, their end device, e.g. a handheld computer like a Personal Digital Assistant (PDA), is not only equipped with facilities for mobile communication, but also with positioning sensors. In outdoor areas it is intended to use the Global Positioning System (GPS) [Thang 96] in combination with several supporting sensors (see 5.1) to determine the positions of the NEXUS-users. Indoor-positioning requires different methods based on infrared signals (e.g. Active Badges by Olivetti, see [Want et al. 91]), radio networks or indirect positioning techniques like map matching or image interpretation. Having calculated the positions of the users, they can be managed within special databases for mobile objects which are administered by a global location service. Thus, the NEXUS-users can also be seen as objects acting in the Augmented World.

Due to the enormous amounts of data and calculations that have to be handled by the platform, the object models must be distributed on various end-nodes which are managed by a global federation service.

2. AN APPLICATION SCENARIO

To illustrate the idea of the NEXUS-platform, this chapter shall give the reader an impression of the goals to be achieved by the system. In the first place these objectives concern the access and exchange of information as well as the provision of functionalities for spatial and semantical queries and for the control of physical processes.

As an application scenario for the NEXUS-platform, it is planned to establish a City Information System for Stuttgart. Imagine that a user who has never been to the town before arrives at the Central Station. He is away on business to attend a conference but has also got some free time that he can spend in Stuttgart. To find his way in the unknown environment, he is carrying his little computer device that enables him to access NEXUS.

Leaving the train, a Virtual Information Tower (VIT) is displayed on the screen of the user‘s NEXUS-station. VITs are virtual objects which are located at all places of interest. If a VIT becomes „visible“, i.e. a NEXUS-user gets close to it, the information attached to the VIT can be accessed through a mobile NEXUS-station. In our example, the VIT administers - among other things - all the accomodation facilities in town and handles the connection to their Web pages. Our user is looking for a mid-price hotel located in a perimeter of 1 kilometre around the City Centre. With an easy query on the platform he receives all the opportunities he has, is shown some pictures of the sites, is informed about the vacant places, the room prices, included services, etc. and can book according to his choice right away.

To get rid of his luggage, he decides to go to his hotel first and so he asks the system about the fastest way to get there. On a map delivered to him by the platform he can exactly see where he is situated because of the positioning sensors included in the NEXUS-station. Since the position of the user is known, a network analysis can be performed to guide him to his accomodation. He wants to go by public transport and so the system passes to him the subway-lines he can take and also the points of transfer. Having checked in at his hotel, the user is heading for the meeting place. As the weather is fine and the location where the conference is taking place is not too far, he decides to walk. In order to find his way, the user again utilizes the target guidance functionality of the NEXUS-platform and so navigation signs on his NEXUS-map lead him to his destination. Let us assume that our NEXUS-participant wants to meet a colleague who is also taking part in the conference but doesn't know where he can find him, the system will help him in case that his aquaintance made himself „visible" for others. If he didn't - perhaps because he hasn't arrived yet - our user could post a message at the virtual black board located in the entrance hall of the meeting place that is automatically routed to the colleague when he enters the building.

One can also imagine that the technical devices used during the event could be controlled by the NEXUS-platform. Authorized personnel might have access to a virtual control board with which e.g. the volume of the speakers or the brightness within a conference room can be changed by sending control signals to physical devices. Thus, interactions between the real world and the NEXUS object models can be established by propagating changes from the virtual to the physical representation and vice versa.

After having finished the business affairs our NEXUS-participant wants to have a look at the City Centre of Stuttgart. As he passes a historical monument, he just points at the building with the telepointing device integrated in the NEXUS-station and directly is forwarded all the historical and architectural facts available (in the NEXUS-models, the WWW or other sources). He is proceeding along the pedestrian zone and after a while, an audio signal calls the attention of the user to an incoming message: a department store informs all the people going by and having declared their acceptance to receive external informations about the latest bargains. He is interested in one of them, because he intends to bring some presents for his family. Therefore, the user enters the building and the NEXUS-station automatically switches to the Department Store Information System that leads him to the desired product.

By and by the user has become hungry and so he invokes a spatial query about all the restaurants in the area around him, looks for the prices and the offered food. He chooses an Italian restaurant and while sitting there, he feels like going to the theatre after dinner to conclude his trip to Stuttgart. Via his NEXUS-station he informs himself about what is played and finally orders tickets for his favourite performance.

3. REQUIREMENTS AND ARCHITECTURE OF THE SYSTEM

Now that the idea of NEXUS has been presented, the demands on the platform for the realization of the concept can be deduced. These requirements lead to the design of an architecture for the NEXUS-platform.

3.1 Requirements for the NEXUS-platform

The requirements especially concern the integration of the following aspects into the NEXUS-infrastructure:

Mobility: support for mobile communication and positioning systems.

Scalability: management of numerous Augmented Area Models and administration of a multiplicity of users/mobile objects in distributed databases.

Application services: support for control processes, for the functionality to perform queries or identify features and for the connection to external information sources.

Internal communication: provision of communication facilities between the different NEXUS-based applications and between the components of the platform.

Data safety: Protection of unauthorized data manipulation and guarantee of confidentiality of personal data.

Adaptivity: support for the dynamical adaption of the system if parameters, e.g. the bandwidth for the data transmission, change.

3.2 Description of the architecture

The architecture of the NEXUS-infrastructure consists of different components that have to work together in order to enable the realization of the demands that have been posed on the platform (see Fig. 2).

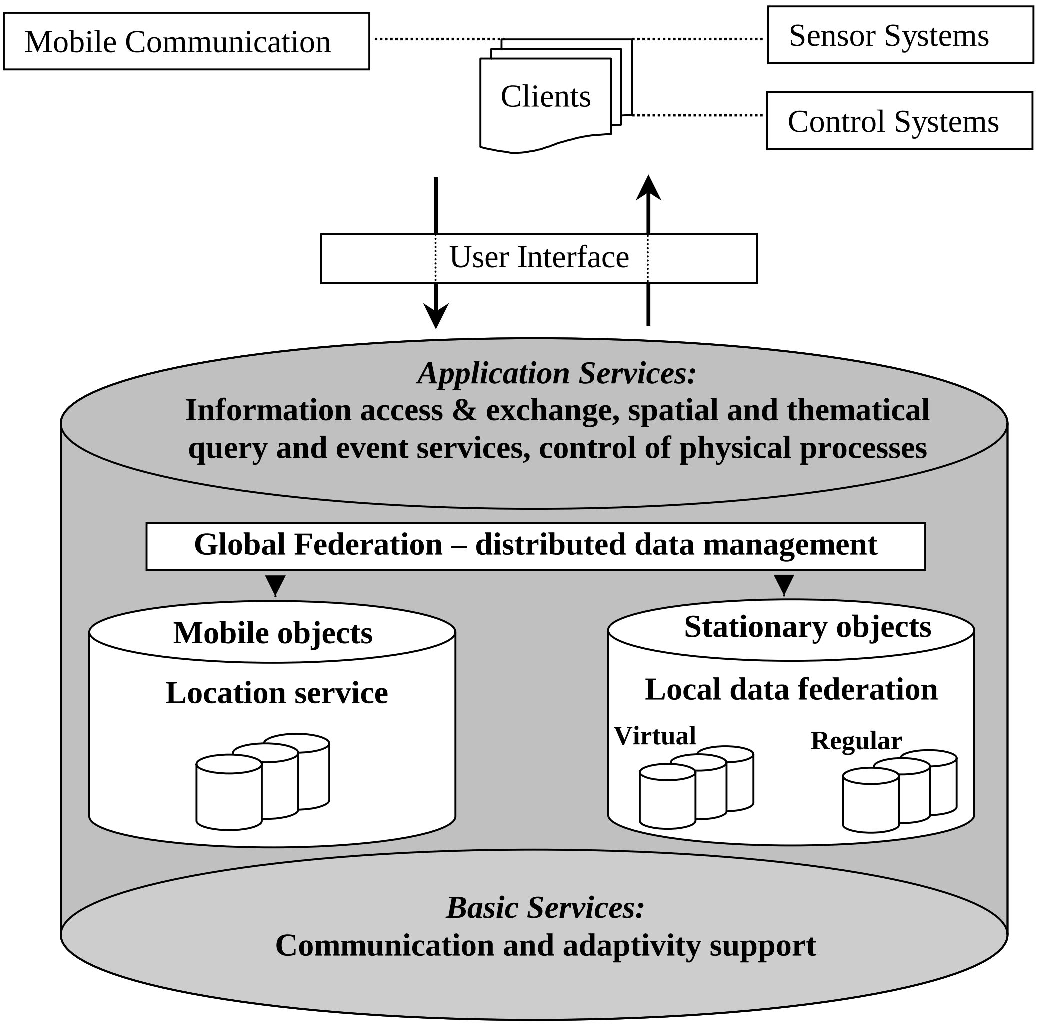

Figure 2: The architecture of the NEXUS-platform

External components: the *Clients* or spatially aware applications can access the NEXUS-platform by *mobile communication* means via a standardized user interface. The *positioning systems* allow for a detection of the user within the real world respectively within the Augmented Area Model, so that he is able to perform spatial queries on his environment which are related to his position. By means of the *control systems*, the user can influence the real world by triggering control processes via his NEXUS-station.

Application services: the application services include all the functionalities of the platform that a NEXUS-participant can access. Beyond spatial queries and navigation tasks, a user could also subscribe to event services that transfer information to him if a predefined (spatial) situation occurs, e.g. each time a culturally interested user is located within the perimeter of a museum, he receives an audio signal that calls his attention. A user also might be able to control physical processes of the real world via his NEXUS-station in case he is authorized to do so (e.g. adjust the heating of a building if he is the caretaker).

Global Federation: the global federation manages all the NEXUS-data that has to be distributed in numerous end-nodes, i.e. local servers, to ensure scalability. The component can be divided into two parts: the *location service* for the mobile objects that stores the information about the positions of the users and the *local data federation* that is responsible for the storage of the Augmented Area Models. The latter is again divided into two elements. The first one administers the virtual objects and their connection to the external services and information sources, the second one manages all the regular stationary objects.

Basic services: the basic services concern the support for *communication* and *adaptivity of applications* and are necessary for all other components. The communication between the different elements of the NEXUS-platform allows for an efficient and transparent exchange of information with objects on mobile as well as on stationary computers. Adaptivity support is needed in order to manage the available resources and thus guarantee a quality-of-service for the NEXUS-applications.

4. OUR RESEARCH TOPICS

Some of the problems which have to be solved within the scope of the project are especially concerning the Institute of Photogrammetry. In fact, four topics can be determined which have a special priority. They shall be discussed in detail in the following sections.

5.1 The integration of different positioning sensors

As the positioning-system for NEXUS has to supply information about the location of the users both in indoor and outdoor areas, different positioning techniques have to be applied. Generally, our approach is based on primary sensors for outdoor (GPS) and indoor (presumably Active Badges) areas. In order to enhance the accuracy with which the position of a user can be detected, secondary sensors like digital compasses, step counters, inertial systems, map matching procedures and image analysis methods must complete the system [*Drane & Rizos* 1998]. The integration of multiple positioning sensors also aims at providing a continuously available and reliable positioning system that is avoiding interruptions in case one or more sensors break down. The positioning system has to be connected to the NEXUS-infrastructure by defined interfaces.

Two important tasks are to be solved to realize a positioning system for NEXUS. The first one is related to the integration of all the different positioning informations of the included sensors into one uniform protocol and to the management of sensor interruptions. The second one deals with the handover of the positioning information from outdoor to indoor areas and vice versa.

Until now, some investigations on the reliability of a low-cost GARMIN DGPS-receiver have been carried out that have showed positive results with positioning accuracies of 2 to 5 m. Although the density of buildings (predominantly with three or more floors) in the test area is very high and the streets are mostly quite narrow, there were relatively few positions where there was no signal available (see Fig. 3).

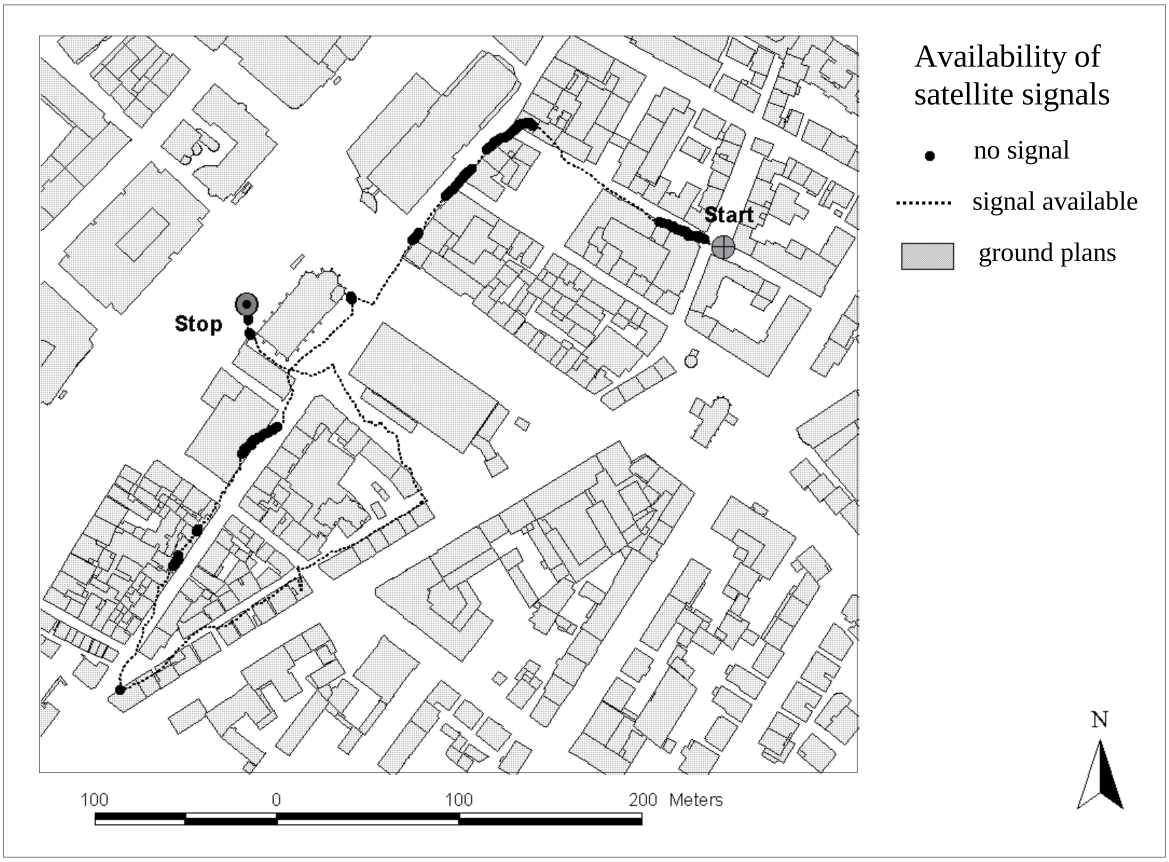

Figure 3: DGPS-Test Stuttgart: walk through the „Bohnenviertel“

5.2 The integration of GIS-components into the platform

The integration of GIS-components into the NEXUS-platform is another task that has to be worked on by the IfP. Beside the implementation of GIS-functionality into the system, a major problem comprises the preparation of different levels of detail for the analysis and visualization of data stored in the NEXUS-models. Another field of investigation deals with the implementation of active object functionalities in order to enable control processes.

In times of increasing amounts of digital spatial data, new structures have to be found to manage and process them. As it is expected that the NEXUS-platform must be able to handle huge data sets, the concept of multiple representations has to be introduced. Therefore, the main research topic focuses on the generation of multiple representations both semantically and geometrically for the virtual and stationary objects stored in the Augmented Area Models. The purpose of this approach is the provision of the adequate levels of detail for the NEXUS-objects used by the NEXUS-based applications, so that data analysis and visualization processes can be optimized. E.g. if a user performs a network analysis that shall guide him to a desired location, the system must automatically access the representations of all involved objects that lead to the shortest processing time for the calculation of the result. In order to generate the various levels of detail, different techniques can be applied depending on the geometric type of the NEXUS-objects. For 3D-TINs, triangulation methods ([*De Floriani & Puppo* 1995], [*Schmalstieg* 1997]) are suitable. Explicitly modelled objects, however, have to be generalized by knowledge-based systems ([*Anders & Sester* 1997], [*Mackaness et al.* 97]) and machine learning techniques [*Sester* 1998]. *Van Oosterom* [1995] suggests a treelike structure that stores the most general information in the root, whereas details are filed in the leaves. To connect the different representations, conflation techniques are employed [*Walter* 1997].

For the acquisition of an Augmented Area Model, a 3D data set has been derived from the building information system of the city of Stuttgart in a first step (see Fig. 4). In order to capture the actual, more detailed building geometry, laser scanner data have already been recorded that will be processed in combination with ground plans. Texture will be taken from terrestrial photographs [*Haala & Brenner* 1999].

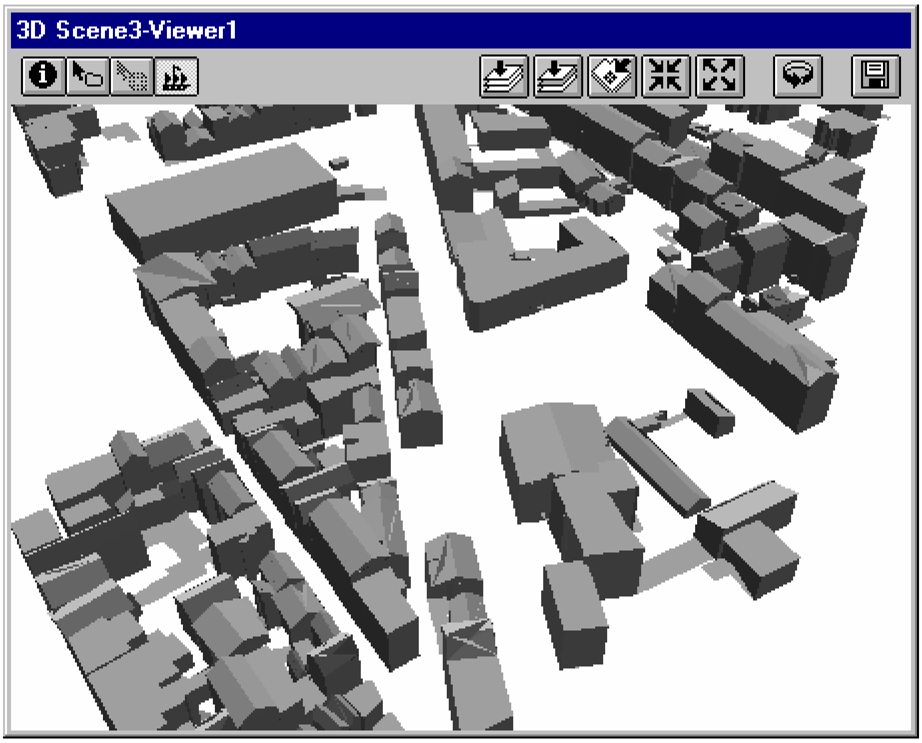

Figure 4: A part of the Virtual City Model of Stuttgart.

eographic Information Systems concerns the implementation of active object functionalities. Provided that our environment will be ubiquitously equipped with intelligent (computer-)objects in the near future [*Weiser* 1993], processes of the physical world could be controlled by the NEXUS-station via their representations in the object models and vice versa. The challenge consists of the extension of usual GIS-objects with active functionalities and the examination of the communication and interaction between objects of the virtual and the physical world.

As a further point of interest, the provision of real GIS capabilities for the NEXUS-platform has to be realized, taking account of a multi-user environment and the data exchange via network protocols. Therefore, the necessary spatial operators have to be defined and optimized according to the users' needs. Especially the mobility and time-dependent aspects (e.g. current situations like traffic jams) have to be reflected by spatial queries. In order to minimize the network load, the optimal configuration for the distribution of processes on client and server has to be analyzed. Consequently, GIS-functionality must be provided by the client-machine to a certain degree as well [*Fitzke et al.* 1997].

5.3 The visualization of data for the user

An important factor with regard to the acceptance of the system is the appropriate and fast visualization of the data for the user on his NEXUS-station. Therefore, visualization methods have to be implemented that complete the level of detail-concept. To enhance the graphical performance, culling procedures which only process the objects that are inside of the user's view frustum, progressive rendering techniques that continuously improve the quality of visualization if a user stops moving, or dynamic loading methods that allow a fast loading of all visible objects into the random access memory, have to be integrated into the system [*Kofler* 1998].

5.4 Object identification through image analysis

Another research topic examines the development of techniques that allow the identification of real world objects by means of image analysis. The main objective concerns the interpretation of visual information that can be extracted from the digital images. In a first step, it is intended to identify objects through labels or bar codes that are attached to interesting objects [*Ahn & Schultes* 1997]. On a further level, objects of the users' environment like buildings or doors which serve as tags and on which the users can point must be identified as representations of the NEXUS-objects as well. Since the visibility of objects is limited by the user's position, the area that has to be analyzed is already reduced and thus the connection of the objects within the image and the corresponding representation in the object model can be generated easily. Consequently, the detection of spaces within the Augmented Area Model resulting from current changes in the real world can be achieved by the comparison of images and the GIS-models of NEXUS. This leads to a steady update and therefore to a correctness and consistency of the system.

5. CONCLUSION AND FUTURE WORK

On the basis of the presented ideas about an infrastructure for spatially aware applications, a first prototype is being developed within the ongoing research project to evaluate the NEXUS-concept and to identify the problems that have to be focused on. This prototype deals with a few exemplary applications and as it was shown, some preliminary steps have already been taken. Currently, different approaches to integrate GIS-functionalities into the platform are being analyzed.

Further research is necessary in all the fields that are connected to NEXUS. For this reason, it is intended to extend the scope of the project and to involve partners who have experience concerning databases and mobile communications.

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