

FRAMEWORK FOR MIXED REALITY APPLICATIONS IN CIVIL ENGINEERING

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ABSTRACT

Mixed reality interaction methods can provide better understanding of 3D virtual models of infrastructures. These methods can be used to accommodate different civil engineering applications, such as facilities management, construction progress monitoring and bridge inspection. Properly designed navigation methods are critical for using these applications efficiently. This paper investigates a framework for mixed reality applications in civil engineering. The framework includes a practical method for creating virtual models for location-based services and several interaction and navigation methods suitable for mixed reality applications in civil engineering.

KEY WORDS

Mixed reality, framework, navigation, tracking, interaction, visualization, civil engineering

INTRODUCTION

Future infrastructure management systems have several requirements, such as integrating lifecycle data and supporting 3D visualization and interaction models. Using these systems in mobile situations will allow on-site infrastructure field workers, such as construction superintendents and facilities and bridge inspectors, to use mobile and wearable computers to interact with geo-referenced spatial models of the structures. They can also automatically retrieve the necessary information in real time based on their location, orientation, and the specific task context using Virtual Reality (VR) or Mixed Reality (MR) techniques (Hammad et al. 2004). MR allows interaction with 3D virtual objects and other types of information (e.g., text) superimposed over 3D real objects in real time. In these systems, field workers will be able to access and update information related to their tasks in the field with minimum efforts spent on the interaction with the system, which results in increasing their efficiency and potentially their safety. Augmented Reality (AR) and Augmented Virtuality (AV) are two cases of MR where different combinations of the virtual and real components are possible along a virtuality continuum (Milgram et al. 1994).

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3D models of urban and infrastructure environments can be used as virtual models or added as augmentation to the real environment in order to accommodate different applications, such as facilities management (FM), construction progress monitoring, or urban planning. In order to realize the virtual components, information about the objects' shapes and locations is organized in a database using a geospatial model so that the augmentation of the 3D real scene with data extracted from the database is possible. Moreover, new types of interaction models should be developed specifically for VR and MR applications in order to support the users in accomplishing their tasks.

It is difficult to navigate large virtual environments. To accomplish their tasks in these environments, they need to be able to navigate either to accomplish specific tasks or to become more familiar with the virtual environments. Properly designed user interfaces for navigation can make that experience successful and enjoyable (Chittaro et al. 2003). A large number of studies have been carried out on the general principles of 3D navigation and wayfinding in virtual environments (Spence 1999, Nash et al. 2000, Dijk et al. 2003). However, little work has been done about providing navigation support in engineering MR applications involving large scale urban environments (Aspin et al. 2001, Whyte 2003).

This paper has the following objectives: (1) To investigate a general framework for mobile location-based civil engineering applications; (2) To investigate a new taxonomy of interaction models and navigation methods for MR applications in civil engineering; and (3) To investigate tracking algorithms that can be used in these mobile applications. The requirements of the new framework, called LBC-Infra, are discussed and a general structure is proposed focusing on mobility and interaction aspects.

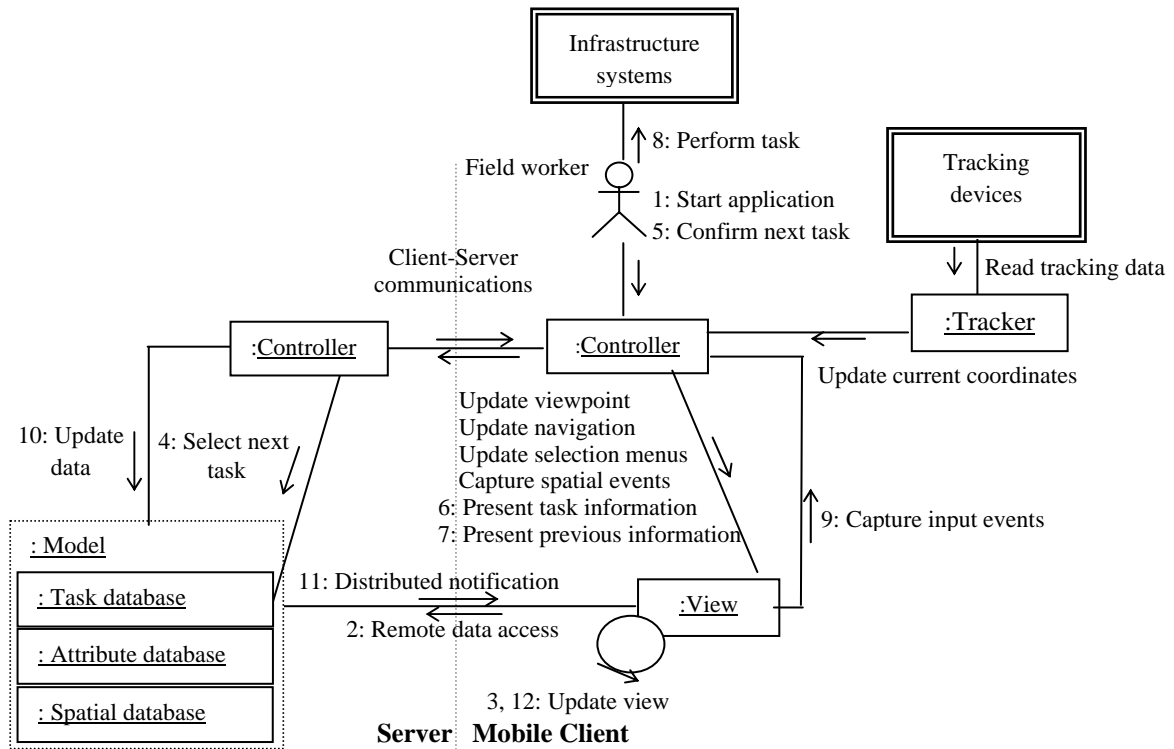


Figure 1. Collaboration diagram between the entities of the framework

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The proposed framework is based on a collection of high-level reusable software objects and their relationships. The generic structure of this framework embodies the general functionalities of LBC-Infra so that it can be extended and customized to create more specific applications. Figure 1 shows the relationship between the high-level objects of LBC-Infra using a Unified Modelling Language (UML) collaboration diagram, where objects interact with each other by sending messages. The numbers in the diagram refer to the order of execution of the messages. Messages that are not numbered are threads that are executed at the beginning of the application and run continuously and concurrently with other messages, or they are event-driven messages that may occur at any time.

DATA INTEGRATION FOR CREATING THE VIRTUAL MODEL

One of the important issues in developing MR applications for building engineering is to use a systematic method in creating the virtual model. Large-scale virtual models of urban environments (e.g., a university campus) can be created using commercial Geographic Information Systems (GIS) software (Gross and Kennelly 2005). However, these models focus only on the exterior shapes of buildings and do not include all the details necessary in building engineering applications (e.g., design and scheduling information).

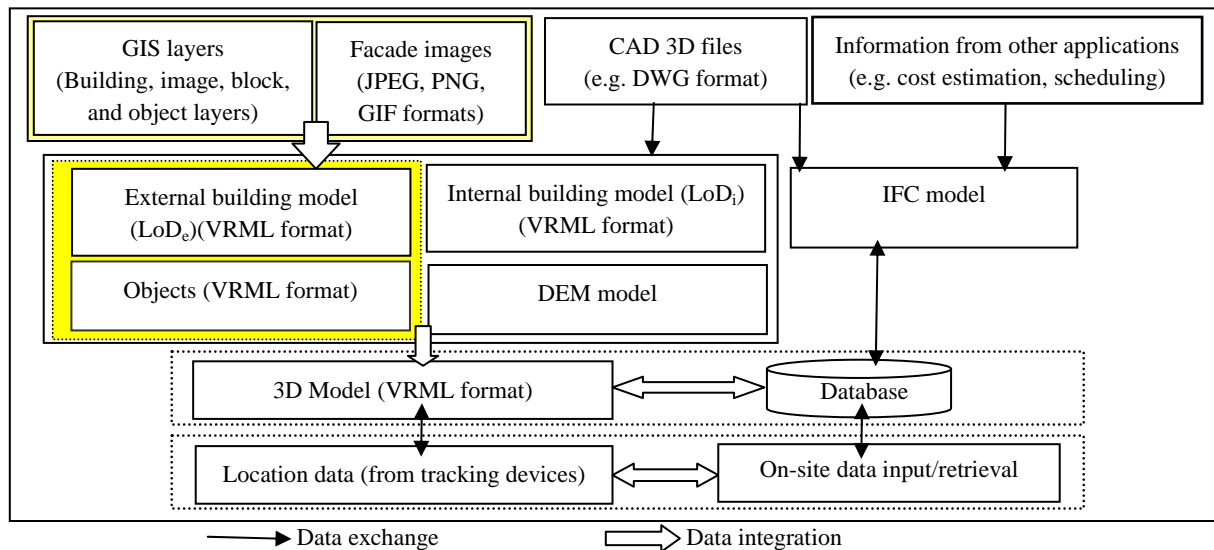


Figure 2. Data exchange and integration model

The proposed data integration method for creating the virtual building model is based on synthesizing information from GIS maps, CAD models, images of building facades, and databases of the cost, scheduling, and other data generated during the lifecycle of buildings (Figure 2). Two representations are created for each building with different Levels of Details (LoD): one is for the exterior of a building (LoD_e) and the other is for the detailed 3D model of the interior of the same building (LoD_i). Images are applied as texture mapping on the facades of the buildings' models to make the buildings more realistic and easier to recognize.

INTERACTION COMPONENTS AND NAVIGATION TAXONOMY

The proposed framework provides the following main interaction components in an application: (1) Visualization and feedback: The application can display graphical and non-graphical information; (2) Control: The application interprets the user input differently depending on the selected feature and the context; (3) Access: Accessing data can be achieved based on location tracking. The user just needs to walk towards an object of interest and then click on it or stand in front of it for a short period of time. The application tracks his/her location and updates the viewpoint accordingly. Based on the location, relevant data are retrieved from the database and displayed; (4) Navigation: As an extension to conventional navigation systems based on 2D maps, the system can also present navigation information in 3D; (5) Manipulation: Objects related to buildings can be interactively added to or moved within the virtual environment; and (6) Collaboration: The framework facilitates wireless communications among a team of field workers, geographically separated at the project site, by establishing a common spatial reference with respect to the site of the project. Because of the space limitations of the present paper, we focus only on the visualization and navigation components that are suitable and practical for building engineering applications. Based on our experience with similar systems and our review of previous research, we have defined a taxonomy of navigation methods and tools for those applications.

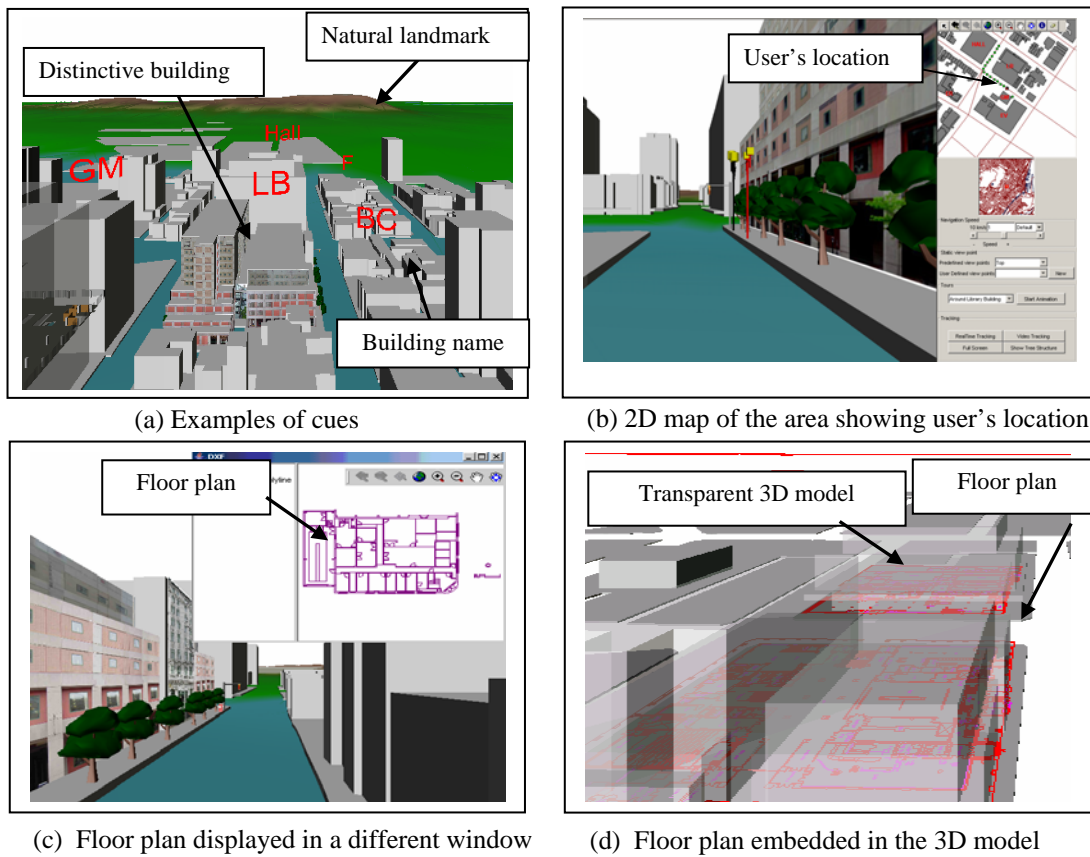


Figure 3. Examples of navigation supports

The navigation tasks are classified into three categories (Darken et al. 1996): (1) Naive search, in which the navigator has no a priori knowledge about the location of the target; (2) Primed search, in which the navigator knows the location of the target; and (3) Exploration: Way-finding task in which there is no specific target. The navigation in the 3D model can be realized by using tracking devices, such as GPS tracking or video-based tracking, or pointing devices, such as a digital stylus.

Four types of navigation behavior can be used: drive, fly, orbit, and examine behavior. These types of behavior use the pointing device to control the view platform motion. Each button on the pointing device generates a different type of motion while the button is pressed. As an example of the navigation behavior, the drive behavior allows the user to move to any point in the 3D space, with pointer controls for translations along the X, Y, and Z axes and rotation around the Y axis. Furthermore, the navigation speed can be controlled manually or automatically. In the manual mode, the user can change the speed of navigation using a slider. In the automatic mode, the speed of navigation can be changed according to the distance from the present location to the target. The navigation slows down when the user approaches the target and speeds up when he/she moves away from it. This method is more suitable for building engineering applications than are other more sophisticated approaches, such as the speed-coupled flying with orbiting technique (Tan et al. 2000).

Navigation support can be classified into six categories:

- **Cues:** Three types of cues are considered: landmarks, building names and the depth cue. Figure 3(a) shows examples of cues which are used in our applications (to be explained in detail in the case studies). The Digital Elevation Map (DEM) is integrated with the VR model of the built environment to display natural landmarks (e.g., mountains and rivers). Furthermore, the distinctiveness of some buildings is enhanced by adding texture mapping in order to increase the memorability of those buildings and their locations (Vinson 1999). In addition, building names can be shown on top of the buildings. To improve the realism of the virtual environment, the stereoscopic effect can be used, which provides a depth cue for the user; as a result, the distances and dimensions can be better perceived.
- **Animated arrows:** Navigation guidance can be provided with animated 3D arrows showing the user the path to the object of interest. The arrow moves from the current users' location towards the object.
- **2D maps and floor plans:** Electronic maps are good navigation aids that help users exploring and learning about the space and orienting themselves (Chittaro and Scagnetto 2001). Figure 3(b) shows how an electronic map of the area can be shown beside the 3D model with the present location of the user. In addition, 2D floor plans can be displayed in a different window beside the 3D model or embedded in it to ease the wayfinding process inside a building (Figures 3(c, d)).
- **Terrain following and collision detection:** Constraining the movement of the user in the 3D space can facilitate the navigation by preventing the user from going below the ground or colliding with buildings. Terrain following is particularly important in navigation within terrestrial style environments.
- **Viewpoints:** Static viewpoints provide a link to a familiar place with a known position. If the user gets lost, the viewpoints can help him/her to get back to a safe and familiar point.

There are two types of static viewpoints: predefined viewpoints that are already defined in the application and user defined viewpoints that are created by the user during the navigation in the virtual environment. The tours provide a set of viewpoints (a path) through which the user can cycle to visit the world in a certain order.

- Tree structure: The tree structure is another method for managing the interaction with the components of the virtual environment. It acts as an index by showing the hierarchy of the environment. Users can look for an element in the tree such as a building (or a floor within a building) and select it. Consequently, the selected building will be highlighted, and the viewpoint will change to navigate to it.

AUTOMATIC PICKING

The automatic picking feature allows a field worker to pick an element in the virtual environment just by looking at it continuously for a certain short time (e.g., 2 sec.). Once an element is picked, relevant information about it is retrieved from the database and displayed.

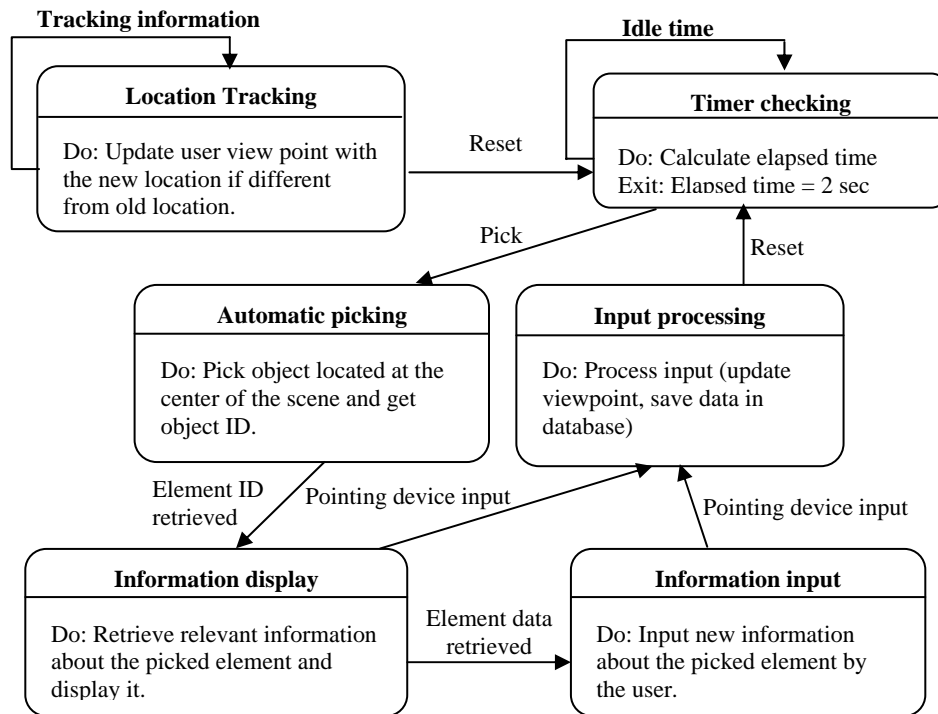


Figure 4. Automatic picking state machine model

The automatic picking process consists of six main operations as shown in Figure 4. (1) Tracking user location: the user location is continuously tracked using the GPS or video tracking for outdoor or indoor tracking, respectively; (2) Tracking user interaction: The user interaction is tracked to find out if the system has entered an idle state. Whenever the user moves or generates an event (e.g., using the pointing device), a trigger is automatically launched to reset the idle time; (3) Computing idle time: The idle time is calculated by comparing the current system time with the last system time when the idle timer was reset. If the idle time is two seconds, then the automatic picking gets launched; (4) Automatic

picking: The element that lies at the center of the scene is the one that will be automatically picked. The picking consists of creating a picking tool, selecting a picking mode, creating a picking shape, picking the closest element, calculating the intersection point, and retrieving the picked element; (5) Displaying relevant information: Based on the ID of the picked element, a query is generated and executed. The returned data is displayed as a tool-tip text (e.g., the inspection and maintenance history); and (6) Input information: Based on the displayed data about the picked element, the user is able to input new information; for instance, he/she can specify the location of a defect on the picked element itself, thereby automatically creating a 3D symbol depicting the defect type on the surface of the element. The newly entered information is saved in the database for future reference.

CASE STUDIES

Concordia University downtown campus is used in the case studies to demonstrate the proposed framework. The 3D virtual model of the university campus was developed using the following data: (1) 2D CAD drawings of the buildings obtained from the Facilities Management Department of the university; (2) A digital map of the city of Montreal obtained from the municipality of Montreal; (3) A DEM of the city obtained from USGS website; (4) VRML library of small objects developed by the authors for objects to be embedded in the 3D model, such as traffic lights, fire hydrants and street furniture; and (5) Orthogonal digital images of the facades of the buildings collected using a digital camera. The digital map and the DEM data of Montreal are used to generate 2D and 3D maps using the Modified Transverse Mercator (MTM) projection.

The 3D model can link to all necessary specifications, drawings, procedures, and inspection and maintenance records, so that the user can access the information needed for a specific task from the model through a customized user interface. At this stage, the 3D model contains only the structural elements of the buildings. Future work will consider adding other information related to mechanical/electrical equipment, emergency evacuation plans, etc. This integrative approach can help the user to easily understand the entire facilities configuration and access the related information.

CASE STUDY 1: NON-IMMERSIVE VIRTUAL REALITY FOR FACILITIES MANGEMENT

In the first case study, we developed a prototype system using Java with a non-immersive VR user interface that can be used to collect inspection data in a Facilities Management Information System (FMIS). As a basic example, an inspection routine of a building was linked to the 3D model (Figure 5). In addition to the building structure model, more details have been considered such as the HVAC system model. The necessity of documenting the HVAC data along with all other building information (e.g., geometric and process data) is essential in FMIS. Using the user interface allows the inspector to interact with the 3D model and retrieve related data instantly by picking an element. Defected elements can be tagged with colored spheres to represent the location and the severity of the defects. The visualization of this information improves data sharing between the inspector and the management office.

The application provides all the navigation supports that are discussed in the taxonomy. The tree structure of the campus is created automatically by reading the structure data from the database. The navigation paths for the tours are defined in GIS and used in the system by applying an interpolation algorithm between their vertices.

We conducted a usability test to evaluate the efficiency of the navigation support techniques developed in this application. The subjects who participated in the test (23 engineering graduate students) were asked to navigate from one location within the campus to the main library building under three different types of navigation support: (1) without any support, (2) with visual cues (landmarks and the names of buildings), and (3) with animated arrows. The average test times for the three types of navigation support were 19.78, 13.63, and 11.47 seconds, respectively. The independent groups Analysis of Variance (ANOVA) was performed on the test time data. The effect of using the navigation supports was observed, $F(2, 23)=8.88, p<0.01$. This analysis proves that the new navigation support techniques significantly improve the efficiency of navigation in the virtual environment.

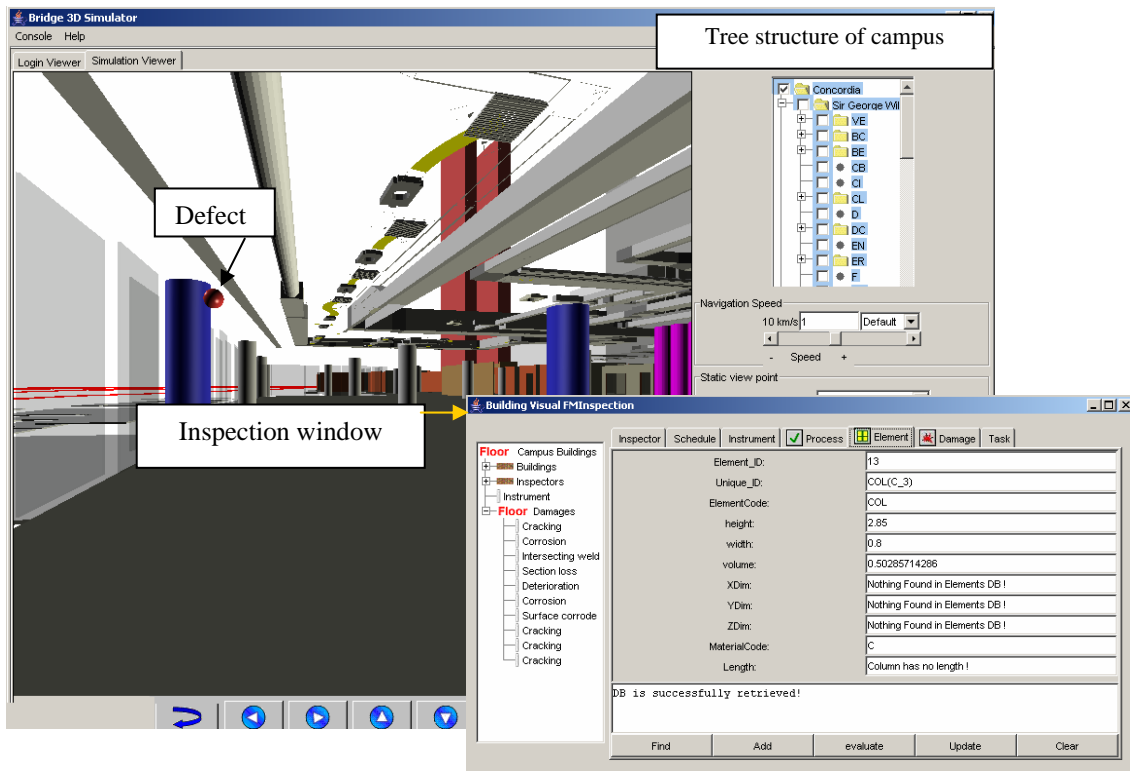


Figure 5. Non-immersive VR user interface

CASE STUDY 2: AUGMENTED REALITY FOR CONSTRUCTION PROGRESS MONITORING

The same model of the campus is used as a test bed for indoor and outdoor mobile AR applications. Two tracking technologies are investigated: RTK-GPS for exterior applications using a Trimble 5700 RTK-GPS receiver and video tracking using ARToolKit for interior applications (Kato et al. 2004). Because of space limitations in this paper, only the indoor case is discussed. The automatic picking algorithm was implemented and tested using the same virtual model discussed in the first case study.

Figure 6 shows an example of the results of the AR application used in a building construction project on the campus. This figure shows a column on the fifth floor with a marker attached to it. The marker has an edge length of 20 cm. Figure 6(a) simulates the view that the user sees when the real structure of the column is augmented with the virtual workspace and the ID of the column. Figure 6(b) shows a construction superintendent equipped with the AR devices. He is checking the workspace by viewing it through the head-mounted displays (HMD). User position and orientation are tracked and used to update the 3D view.



(a) Augmentation of the column as seen by the superintendent (b) Construction superintendent equipped with AR devices

Figure 6. Example of AR application in building construction

Two types of HMDs were tested: Microvision Nomad ND2000 (2005) and MicroOptical SV-6 (2005). Microvision Nomad ND2000 has a rugged, monochrome red display (32 gray levels) readable in all lighting conditions with automatic brightness adjustment. MicroOptical SV-6 is smaller, less rugged and has a color display. Both displays support the resolution of 800x600 pixels. After testing these displays under different conditions, it was found that the MicroOptical SV-6 is more suitable for this application because of its overall superior visibility using colors. In the partial testing of the prototype system using the above hardware and software, several problems were identified, e.g., the field of view is too narrow, reading the HMD in the outdoors is rather difficult, etc. As for the size of the text displayed with the above resolution, it was found that a minimum font size of 25 points is required for comfortable readability.

CONCLUSIONS

In the present paper, we have discussed a new framework for mixed reality applications in civil engineering. We have presented a practical method for building 3D models of an urban area and a new taxonomy of navigation methods and support tools suitable for engineering applications in urban virtual environments. Furthermore, we have demonstrated the validity of the proposed framework by examining two case studies using virtual reality and augmented reality environments. The result of our initial usability study showed that using navigation supports allow users to navigate more efficiently in the virtual environment.

Future work will focus on further development and testing of the prototype applications, which considers both hardware and software issues, and on investigating the usage of the proposed framework as a collaborative environment for field workers.

REFERENCES

- Aspin, R., DaDalto, L., Fernando, T., Gobbetti, E., Marache, M., Shelbourn, M., and Soubra, S. (2001). A conceptual framework for multi-modal interactive virtual workspace, *ITcon Vol. 6, Special Issue Information and Communication Technology Advances in the European Construction Industry*, pages 149-162.
- Chittaro, L., Ranon, R. and Ieronutti, L. (2003). Guiding Visitors of Web3D Worlds through Automatically Generated Tours. *Proceedings of Web3D 2003: 8th International Conference on 3D Web Technology*, ACM Press, pages 27-38.
- Chittaro, L., Scagnetto, I. (2001). Is Semitransparency Useful for Navigating Virtual Environments?, *Proceedings of VRST-2001: 8th ACM Symposium on Virtual Reality Software & Technology*, ACM Press, pages 159-166.
- Darken, R., Rudolph, P., and Sibert, J.L. (1996). Wayfinding Strategies and Behaviors in Large Virtual Worlds, *Proceedings of CHI'96 Human Factors in Computing Systems*, pages 142-149.
- Dijk, B., Akker, R., and Zwiers, J. (2003). Navigation Assistance in Virtual Worlds, *Informing Science Journal*, Volume 6, pages 115-125.
- Gross, Z., and Kennelly, P.J. (2005). A Primer for Creating 3D Models in ArcScene, *ESRI Journal*, April-June 2005, pages 26-29.
- Hammad, A., Zhang, C., Hu, Y. and Mozaffari, E. (2004). Mobile Model-Based Bridge Lifecycle Management Systems. Proc., *Conference on Construction Application of Virtual Reality*, ADETTI/ISCTE, Lisbon, pages 109-120
- Kato, H., Billingham, M., and Poupayev, I. (2004). ARToolKit version 2.33: A Software Library for AR Applications, <<http://www.hitl.washington.edu/artoolkit/>>
- MicroOptical web site (2005). <<http://www.microopticalcorp.com/>>
- Milgram, P. and Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays, *IEICE Transactions on Information Systems*, Vol E77-D, pages 1321-9.
- Nash, E.B., Edwards, G.W., Thompson, J.A. and Barfield, W. (2000). A Review of Presence and Performance in Virtual Environments, *International Journal of Human-Computer Interaction*, pages 1-41.
- Nomad Display Systems (2005). Microvision web site. <<http://www.microvision.com>>
- Spence, R. (1999). A Framework for Navigation, *International Journal of Human-Computer Studies*, Volume 51, pages 919-945.
- Tan, D.S., Robertson, G.G., and Czerwinski, M. (2000). Exploring 3D Navigation: Combining Speed-coupled Flying with Orbiting, *CHI 2001 Conference on Human Factors in Computing Systems*, pages 418-425.
- Vinson, N. (1999). Design Guidelines for Landmarks to Support Navigation in Virtual Environments. In *Proceedings of CHI '99*, pages 278-85.
- Whyte, J. (2003). Industrial applications of virtual reality in architecture and construction, *ITcon Vol. 8, Special Issue Virtual Reality Technology in Architecture and Construction*, pages 43-50.