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Virtual Reality Models for Location-Based Facilities Management systems

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ABSTRACT: Large-scale Facilities Management Information Systems (FMIS) require integrating a great amount of information about each building, and the ability to easily locate these buildings and their components, especially when considering the potential of using the FMIS in a mobile Location-Based Computing (LBC) setting. The interoperability of these systems is of paramount importance because of the need to develop and use them by a large number of groups in a distributed fashion. Available interoperability product models, such as Industrial Foundation Classes (IFC), have several limitations with respect to the requirements of these systems. In this paper, we describe innovative methods for integrating and visualizing information for large scale FMIS and discuss the computational issues needed for creating and deploying the 3D models used in these systems. CAD models, maps and images are integrated to create the 3D model of a facility, and then the resulting model is integrated with cost and scheduling information and used to collect inspection data using mobile computers equipped with tracking devices and wireless communications. In order to realize the proposed FMIS, several standards for Geographic Information Systems (GIS), LBC and other de-facto standards are introduced for the purpose of complementing IFC in fulfilling the additional requirements of integration, visualization, and tracking. The proposed approach is demonstrated through a case study about a FMIS for a university campus.

1. INTRODUCTION

Research and practice in Facilities Management (FM) have seen a considerable growth in the last 20 years. Managers realized that efficient systems for tracking and storing facility information as well as support systems for planning and management were necessary. Many organizations began implementing new information technologies in their FM departments to help reduce costs and improve the performance of building systems through optimizing the return on their investments in assets (Dennis, 2003; Johnston, 2001). A survey about the usefulness of different information technologies for efficient asset management identified the following "very useful" information technology solutions: E-mail: (83%), Computer-Aided Design (CAD) (68%), Computer-Aided FM (CAFM) (49%), CAD Standards (46%) and shared databases (46%) (Johnson et al., 1999). In recent years, space management using 3D modeling and communication networks for on-line Facilities Management Information Systems (FMIS) is gaining more interest because of the expected benefits of reducing costs and improving the performance of building systems. In particular, integrated FMIS are required so that all users of the system could potentially share all data from one data source, i.e., the 3D model of the facilities. In addition, the resulting FMIS can be used in mobile

computers to collect inspection data and automatically link these data to the FM models. However, a large-scale location-based FMIS requires integrating a great amount of information about each building, and the ability to easily locate these buildings and their components, especially when considering the potential of using the FMIS in a mobile setting. The interoperability of these systems is of paramount importance because of the need to develop and use them by a large number of groups in a spatially and temporally distributed fashion.

In this paper, innovative methods for integrating and visualizing information for large scale FMIS are described and the computational issues needed for creating and deploying 3D models used in these systems are discussed. CAD models, maps and images are spatially integrated to create the 3D model of a facility, and the resulting model is integrated with cost and scheduling information and used to collect inspection data using mobile computers equipped with tracking devices and wireless communications. In order to realize the proposed FMIS, several Geographic Information Systems (GIS), LBC and other de-facto standards are introduced for the purpose of complementing IFC model in fulfilling the additional requirements of integration, visualization, and tracking. The proposed approach is demonstrated through a case study about a FMIS for the downtown campus of Concordia University in Montreal.

2. Short Review of FMIS and Motivations of the Present Research

A conceptual model of an integrated FMIS was proposed by Dennis (2003) including the following modules: (1) IT infrastructure consisting of the Intranet for the organization, a local area network in the FM department, Internet access and related hardware; (2) CAD system for drawing management; (2) Electronic Document Management System (EDMS) for accessing and managing records information in an electronic format; (3) Computerized Maintenance Management System (CMMS) for tracking maintenance and repair activities through generating work orders where a help desk is used to deploy the work order activities; (4) Computer-Aided Facilities Management (CAFM) system for tracking and reorganization of occupied spaces; (5) Capital Planning and Management System (CPMS) for tracking capital renewal and deferred maintenance requirements; (6) Web-based Service Request System (SRS) for on-line submissions of service requests and status queries by customers; and (7) An interface to the core business systems of the organization. The CAD and EDMS are mainly used for managing the electronic records information that is developed during the initial construction and renovation of facilities. The Enterprise Asset Management (EAM) component systems are used for the ongoing operation and maintenance of the facilities. Therefore, the FMIS is comprised of the records management and EAM component systems, plus the links to the core business system. However, only loose integration is proposed between the CAD, EDMS and the other components of the FMIS.

Vanier (2001) discussed a number of applications that are available for strategic asset management support systems and concluded that only partial solutions exist, such as condition assessment surveys. He investigated an integration model of CMMS, administration databases, and financial information management systems using an approach similar to that of the popular computer game SimCity (www.simcity.com) as a decision-support tool for municipal infrastructure planning. Ultimately, the model must be accessible to technical, administrative, and financial staff and supply data to everyone in the organization as well as other computer applications and databases.

The above research efforts, among others, clearly demonstrate the need for integrating much information within FMIS and the need for linking the resulting systems to the end users and to other systems over the Web. However, little work has been done on how to integrate and visualize the information for large scale FMIS. The progress in mobile computing, tracking techniques and wireless communications is creating new opportunities for deploying large 3D models of the facilities to be managed on small mobile computers that would make it possible to answer the following questions: How can we find a particular room in a 20-floor building or the equipment in this building that needs repair? Where were the cracks found on a certain wall during previous inspection? This research proposes a new type of FMIS that could help in answering such questions. The proposed approach presented in this paper is the first attempt to integrate 3D models with FMIS and to make the resulting information accessible to mobile on-site workers.

3. Creating Virtual 3D Models for Integrating and Visualizing Large-Scale FMIS

3.1 The Concept and Benefits of Virtual 3D Models for FMIS

A virtual reality FM model is proposed as an interface metaphor to information and services on the World-Wide Web. This approach can be considered as an extension to using GIS for FM (Kyong-Ho et al., 2002). Much work has been done to implement GIS in FM applications for linear infrastructure systems, such as electrical distribution systems, highways and sewer systems (McCormick and Wissler, 1999; Schmitz, 2002). An interface between the virtual reality model and FMIS would provide an efficient tool to manage building space information. For example, Schürle (1999) developed a virtual reality model of Stuttgart University combining CAD data and photogrammetry techniques to manage a large university campus resulting in transparent data management and a unique data source for all users of the FMIS. The following benefits are expected from using virtual reality based FMIS: (1) Significant cost savings related to eliminating duplicated data entry and providing FM personnel with tools to answer questions quickly and more accurately. These tools would allow the users to access data and visualize inspection and maintenance information through a 3D graphical interface; (2) Tracking assets by geographic location in 3D; (3) Enhancing maintenance planning using spatial analysis functionality to identify where work has taken place and determine patterns; and (3) Assessing facilities conditions and critical failures in order to prioritize rehabilitation efforts and preventative maintenance programs.

Shiode (2001) proposes three factors that can be used when selecting the method of construction of the virtual models: (1) the degree of reality and accuracy used, (2) the data input types and the degree of functionality required, and (3) the required degree to conduct analyses. The input data which allow the capturing of height and facade information affect the virtual 3D model. These include terrestrial images, panoramic photos, aerial photos and range imaging. Because FMIS need analytical features, full volumetric CAD models should be used in building the virtual model. However, in order to add as much reality as possible to the surrounding virtual environment, block modeling with image-based texture mapping can also be used to extrude building footprints from a 2D GIS dataset. The implementation of this approach should optimize the 3D models that are made up of many extruded polygons representing various buildings without compromising the realistic modeling and visualization aspects of the model (Tamada et al., 1995).

It should be noted that creating virtual 3D models could be expensive. However, in addition to FMIS, these models could be of particular interest to a wide range of applications including planning and design, commercial sector and marketing, tourists, etc. (Dodge et al., 1997). The user interface and the levels of details (LoD) of information presented should be customized to meet the requirements of the end user, with the possibility of handling huge quantities of data.

3.2 Proposed Integration and Visualization Approach

The 3D virtual model is created by 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 the facilities. For the buildings managed by the FMIS, two representations are created for each building with different 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. In large-scale virtual models for FMIS, several buildings should be added to complete the virtual model of the area surrounding the buildings considered in the FMIS, but the details of these buildings are not needed. In this case, only the exterior shapes of the buildings (LoD_e) are created.

The details of the method for creating the 3D model for FMIS are beyond the scope of this paper and are explained in Hammad et al. (1999). However, in order to understand the interoperability issues in the integration process, the steps used in this method are briefly explained (Figure 1).

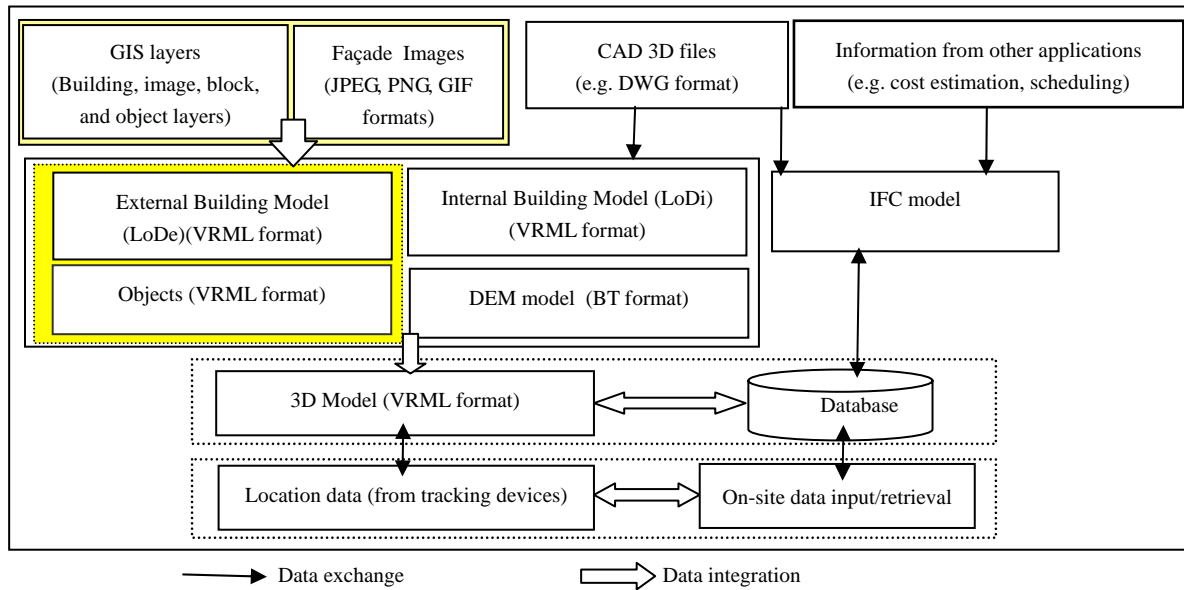


Figure 1. Data Exchange and Integration Model

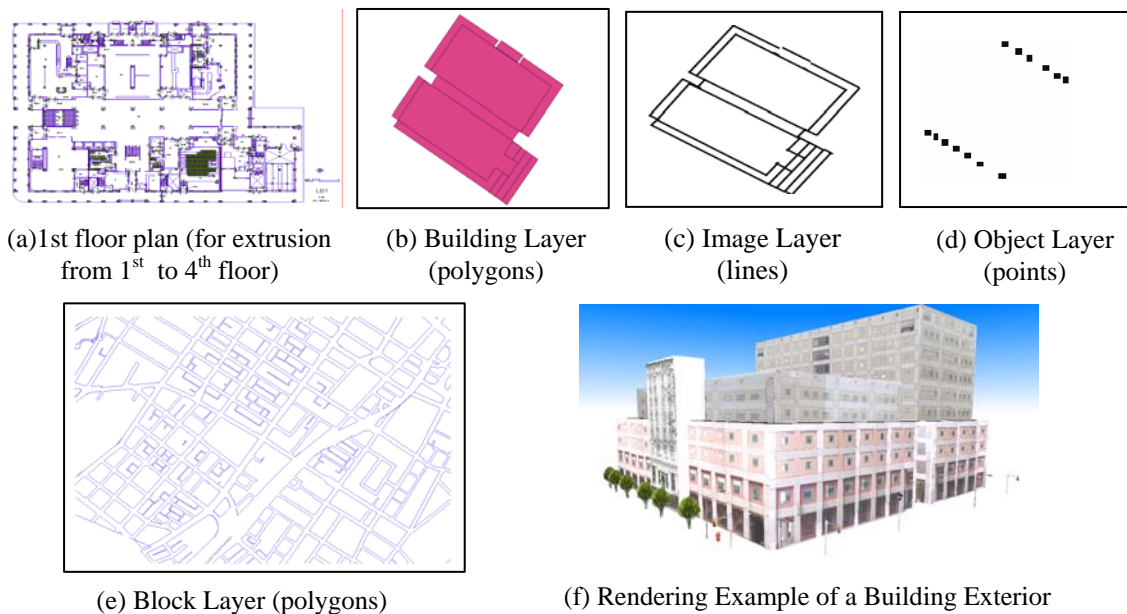


Figure 2. Example of Data Used in Creating 3D Models

- (1) For the exterior representation of a building (LoD_e), the footprint of the building is constructed and added to a building layer in the GIS (polygon layer). In case the building has changes in its perimeter with the height, additional polygons are added to capture these changes. Figure 2(a) shows an example of the CAD data used to create the footprints of one building. The base level and the height of each polygon are added as attributes of that polygon.
- (2) The images of the facades are collected and processed to create orthogonal images. These images are applied on the surfaces of the buildings' models by applying texture mapping techniques. For this purpose, the locations of the surfaces corresponding to these images are represented by an image layer in the GIS (line layer). Figure 2(c) shows an example of the image layer for one building. The base level, height, and file name of each image are added as attributes of that image.
- (3) For the interior representation of a building (LoD_i), the 3D CAD model of the building is prepared and translated to VRML. In order to locate the model of the building in the virtual 3D model, two points are

identified in both models (e.g., two points on one edge of the building) and their coordinates are used to calculate the transformation matrix, including rotation, scaling and translation, from the local coordinate system of the CAD model to that of the virtual model. Another issue to be considered is the orientation of the coordinate axes used in different visualization software. For example, the axis in the height direction in Java 3D (the 3D API of Java language) is the Y-axis while in 3D Studio Max is the Z-axis.

- (4) A block layer is also added in the GIS (polygon layer) to represent the pedestrian areas surrounding buildings as shown in Figure 2(e). A nominal height is added as an attribute to all polygons to represent the height of the pedestrian areas above the pavement level of the roads.
- (5) Other objects of interest, e.g., traffic lights, street lights and street furniture, may be added to the 3D model as part of the scope of the FMIS. These objects are added to an object layer in the GIS (point layer) (see Figure 2(d)). It can be assumed that all objects of the same type have the same shape, and therefore a standard library of 3D shapes can be created and used to generate a specific object.
- (6) The above layers (building, image, block and object layers) are used to automatically extrude the 2D shapes into 3D shapes, add the texture mapping, and insert the 3D objects into the virtual 3D model. An example of the result of this synthesis is shown in Figure 2(f).
- (7) In addition to the geometry, each element of a building (or other objects) in the virtual model is linked through a unique identification number to a database where the attributes extracted from the IFC files related to that building are saved. The database will serve as a lifecycle database for cost and scheduling information of maintenance and inspection activities. IFC is used to export/import data about both the product and process models between engineering applications.
- (8) When using the FMIS on site to collect data, tracking devices can be used to add the location of the collected data to the 3D model. More details about this step are given in Section 4.

4. Mobile and Location-Based Issues in FMIS

LBC is based on tracking the location of the user and providing him/her with information based on this location in a distributed mobile computing environment (Satyanarayanan, 2001; Davies et al., 2001). Data collection for FMIS could be accomplished using a laptop equipped with a tracking device so that dispatchers of work orders could view where workers are located in real-time and determine the closest to handle an emergency repair. In addition, the virtual FM model acts as a guide for the inspectors to locate a building, every part of that building, and services within it. Using this approach enables users to interact with the environment, which significantly enhances their understanding of the environment. An important component of LBC is the mobile computing platforms. These platforms, such as Tablet PCs and Personal Digital Assistants (PDAs) are being developed with integrated barcode technology and wireless communications.

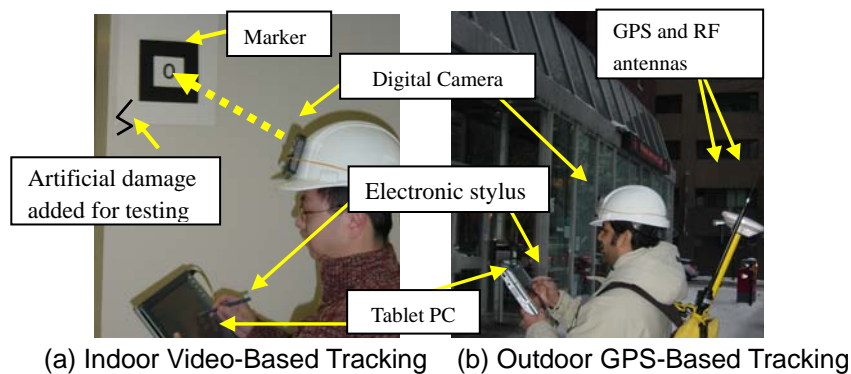


Figure 3. Examples of Tracking Methods

Asset meter readings with instantaneous updates to the asset record and maintenance tasks that are contained in the FMIS are possible (Willard and Fowler, 2004). Voice-on-Terminal is also being embedded

into these specialized PDAs. This allows for the connection of the wireless data device providing the user with anytime, anywhere voice and data communication in a single unit. Advanced data collection terminals will allow individuals to download, view, and update schedules, update work orders, issue and receive inventory items, track product movements, and communicate with personnel in operations, maintenance, or corporate.

Several sensor-based positioning systems can be used indoors, such as video, electromagnetic, infrared or ultrasonic systems (Karimi and Hammad, 2002). Video tracking is used to track visual markers by means of a video camera (Kato, 2000). This method is comparatively inexpensive; however, it has many limitations on the accuracy of tracking and the range for recognizing a marker, which varies with the marker size. The satellite-based Global Positioning System (GPS) is one of the major positioning systems for outdoor use. GPS does not need any infrastructure and support users to identify their locations with high accuracy. However, GPS can be used only under the condition of having direct line of sight to at least four GPS satellites. Differential GPS (DGPS) is based on correcting the effects of the pseudo-range errors caused by the ionosphere, troposphere, and satellite orbital and clock errors by placing a GPS receiver at a precisely known location (base station). The pseudo-range errors are considered common to all GPS receivers within some range. DGPS has a typical 3D accuracy of better than 3 m and an update rate of 0.1-1 Hz. Real-time kinematic GPS (RTK-GPS) receivers with carrier-phase ambiguity resolution can achieve accuracies better than 3 cm (Kaplan, 1996). Figures 3 (a) and (b) show the video-based and GPS tracking methods investigated in this research for indoor and outdoor tracking, respectively. In both cases, the user of the FMIS is equipped with a tablet PC, an electronic stylus, and a digital camera fixed on the hardhat for recording images and video clips. However, in Figure 3(a), the video camera has an additional role of recognizing markers attached to the walls at known locations.

5. How Interoperability Standards Are Used in Building and Deploying Virtual FM Models?

5.1 Product Models

There is a drive to standardize the exchange of information of products and processes of buildings and other structures. According to the International Alliance for Interoperability (IAI), the mission of the organization is “to provide a universal basis for process improvement and information sharing in the construction and facilities management industry, using IFC’s” (IAI, 2004). IFC data model is becoming more and more popular in the Architecture/Engineering/Construction and FM (AEC/FM) industry applications and more software vendors are supporting this model. However, IFC is still under development and many extensions are necessary to fulfill the many requirements of the AEC/FM industry. Furthermore, IFC is basically a standard for data exchange between engineering applications and it is not yet ready to be used as the native format for those applications. Therefore, it was found that IFC alone is not adequate for building the virtual FM models proposed in this research.

With respect to the specific support for FMIS, the research group at British Columbia University has worked within the IAI on the development of IFC-based data model for integrated FM (Hassanain et al., 2000; Hassanain et al., 2003). The IFCFacilitiesMgmtDomain schema provides a set of models that can be used to exchange information for managing the movement of people and equipment, capturing information concerning the condition of components and assets, capturing requests for action to be carried out, etc. However, these models do not support the requirements for describing damages relative to the 3D model of the facilities.

5.2 GIS Standards

Geography Markup Language (GML) is an extension of XML (eXtended Markup Language) for encoding the geographic information, including both the geometry and properties of geographic features. GML is designed to support interoperability through the provision of basic geometry tags, a common data model, and a mechanism for creating and sharing application schemas. A geographic feature is a named list of properties. Some or all of these properties may be geospatial, describing the position and shape of the

feature. Each feature has a type (class) that prescribes the properties that a particular feature is required to have. The properties are modeled as attributes of the feature class. An example of a GML feature is Road with such properties as name and width.

A special category of GIS data is the DEM. DEM is a digital representation of the continuous variation of a relief over space. Elevation data can be represented digitally in many ways, including a grid model where elevation is estimated for each cell based on a regular grid, a triangular irregular network, or contour lines. There are different DEM file formats, such as DEM, SDTS DEM, GTOPO30, SRTM, DTED, BT, etc. A common format of DEM files is from the USGS (U.S. Geological Survey) but it is only suited to the distribution of fixed-size standard elevation products. In addition to being inflexible, DEM can consume much disk space and therefore slowdown input/output tasks. The Binary Terrain (BT) format is a standard format to represent DEM in binary files and is fast for input/output tasks (Discoe, 2004). The BT format was designed to be simple, compact, easy to read and write, and flexible with respect to size and coordinate representation.

5.3 Image Standards

When virtual 3D models are used over the Web, the downloading time should be considered. Therefore, choosing the right image format is of vital importance to keep the balance between image quality and file size. There are three image formats that are widely used in 3D models (Shannon, 2004): Graphics Interchange Format (GIF), Joint Photographic Experts Group (JPG) and Portable Network Graphics (PNG). GIF has small size and is ideal for images with large blocks of a single color. JPG uses a complex compression algorithm. JPG files are also small and can be compressed by up to 80% or more. However, JPG uses lossy compression that causes some quality reduction. PNG, with 24-bit color support, allows ranges of color akin to a high quality JPG, but PNG file size can be rather big in comparison with a similar JPG image. PNG allows creating an image that can be placed on top of any background, with the background showing through the pixels that are not opaque using alpha-channel for a variable transparency mask (Shannon, 2004). Compression in PNG incorporates special preprocessing filters that can greatly improve the loss-less compression efficiency. This filter preprocessing causes PNG to be a little slower than other formats when reading or writing the file.

5.4 Virtual Reality Visualization Models

The most popular interoperability standard for virtual reality models is the Virtual Reality Modeling Language (VRML). VRML is an open standard for describing interactive 3D objects and virtual worlds delivered across the Internet.

5.5 Location-Based Computing Standards

5.5.1 National Marine Electronics Association (NMEA) Standard

NMEA (NMEA, 2004) has created a standard format for data reading from GPS receivers. In addition to the location information (latitude, longitude, and altitude), NMEA sentences give information regarding the quality of data that is being received. An example of the NMEA sentences is the GGA (Global Positioning System Fix Data) sentence, which gives information regarding the attributes of a particular location, DOP, number of satellites used and so on.

5.5.2 Mobile Location Protocol (MLP)

MLP is an application-level protocol for getting the position of mobile stations (mobile phones, wireless PDAs, etc.) independent of the underlying network technology and the positioning method (MLP

Specifications, 2001). MLP serves as the interface between a location server and location service clients. Possible MLP transport protocols include HTTP, WSP, SOAP, etc.

5.5.3 Wireless Application Protocol (WAP) Forum

The scope for the WAP Forum is to define a set of specifications to be used by service applications. The framework supports both applications executing on application servers and applications executing in terminals. The WAP Location Query provides three basic services: (1) Immediate Query Service allows an application to query for the location of a WAP client, with an immediate response. An example application that could use this service is a tracking application (e.g., for fleet management) that wants to track WAP clients by request; (2) Deferred Query Service allows an application to query for the location of a WAP client, with possibly multiple deferred responses. In the previous example of fleet management tracking, the application may require to track WAP clients periodically; (3) Location Attachment Service attaches location information to a WAP client request and personalize the response with respect to the user location, e.g., to find the nearest defect in a structure from the inspection database. Both the request and the response are encapsulated in XML messages. It is also possible to request the location of several clients at the same time, or to request different kinds of location information in the same query. The quality of position allows applications to request information of a certain accuracy or maximum age.

6. Prototype System and Case Study

To demonstrate the feasibility and usefulness of the proposed approach, a prototype FMIS is developed. This prototype is part of a more comprehensive system for infrastructure management (Hu et al., 2005; Zhang and Hammad, 2005). In order to allow information sharing on the Internet, Java programming language is used to build the system. Java is a platform-independent and versatile language, enabling developers to create applets that can be downloaded and run within a Web browser while interacting with server-side applications. Java 3D is used to implement the 3D graphics of the system (Walesh and Gehinger, 2001). The system integrates a 3D model with object-relational database, GIS and tracking components to develop a FMIS that can be used on site for retrieving and updating information of a certain element by directly interacting with the 3D model. The system is designed to provide a user-friendly interface that can be used in mobile situations with access control to FMIS databases including inspection and maintenance records. Users can query the database through the GUI or by picking a specific element, and get the results as visual feedback in the 3D model. Users can easily navigate in the 3D space using the navigation tools provided in the system. Two tracking technologies are investigated: RTK-GPS for exterior applications using Trimble 5700 RTK-GPS receiver, and video tracking using ARToolKit for interior applications (Kato, 2000).

Concordia University downtown campus is used as a case study to validate the proposed approach. The 3D virtual model was developed using the following data: (1) 2D CAD drawings of the buildings obtained from the FM department of the university; (2) A digital map of the city of Montreal obtained from the municipality of Montreal; (3) DEM of the city obtained from USGS website; (4) Small VRML object library 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 main image editing activities were to adjust the size, skew, scale, and to cut and merge selected areas of the images. The digital map and the DEM data of Montreal were acquired to generate 2D and 3D maps using the Modified Transverse Mercator Projection (MTM). Eurostep Toolbox (Eurostep Group, 2004) was used for accessing IFC files that have been created using ArchiCAD and Timberline software.

The GIS layers, Images and 3D objects described above were combined together and translated to VRML following the steps explained in Section 3.2. The translator application developed in Visual Basic uses a GIS library (ESRI, 2004) for extruding the GIS shapefiles and crating a number of VRML files that constitute the virtual 3D model loaded into Java 3D scene graph of the prototype FMIS. It should be noted that the entire downtown campus area should be modeled to have a complete model of the existing

building stock; however, at this stage, only the buildings of the university are added to the model (22 buildings).

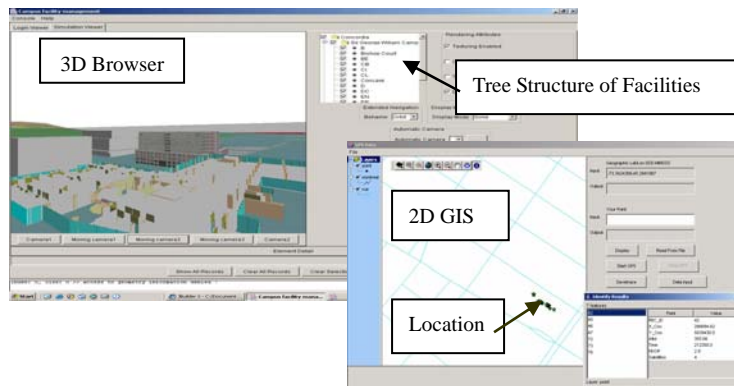


Figure 4. Screenshot of the User Interface of the Developed Prototype System

As a basic example of a user interface for collecting data, an inspection routine of building envelopes was linked to the 3D model (Figure 4). The 3D Model can also link to all necessary specifications, drawings, procedures and inspection and maintenance records, so that the users 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 FM, such as mechanical/electrical equipment, emergency evacuation plans, etc. This can help the users to easily understand the entire facilities configuration and access the related information.

7. Concluding Remarks

The paper discussed the requirements for future large scale Facilities Management Information Systems (FMIS) that can be used in mobile and location-aware situations. These systems will require integrating a great amount of information about each building, and the ability to easily locate these buildings and their components. It was emphasized that the interoperability of these systems is of paramount importance because they will be developed and used by a large number of groups. The paper described a new approach for integrating and visualizing information for large scale FMIS and discussed some of the basic computational issues needed for creating and deploying the 3D models used in these systems. CAD models, maps and images were integrated to create the 3D model of a facility, and then the resulting model was integrated with cost and scheduling information and used to collect inspection data using mobile computers equipped with tracking devices and wireless communications. Several standards and formats were identified for the purpose of complementing IFC for realizing the requirements of integration, visualization, and tracking in future FMIS. These standards/formats include GML for GIS, BT format for DEM, JPEG and PNG for texture mapping images, VRML for virtual reality, and NMEA, MLP and WAP for LBC. Java and Java 3D were proposed as the programming tools for developing the integrated FMIS. The proposed approach was successfully demonstrated through a case study about a FMIS for a university campus. Future work will include a usability study of the system in practical situations and investigating collaboration scenarios among a team of on-site workers using the proposed approach.

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