A Real-Time Visualization System for Managing Emergency Response in Large Scale Urban Environments

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After a decade of evolution of multimedia systems, spatial DBMS, visualization tools, virtual reality applications, and problem solving environments, a new generation of information system is emerging. Advances in processor, display, and storage technology now make it possible to combine aspects of these various systems into information managers that, for the first time, truly exploit human information processing abilities. For example, it is now possible to render photo-realistic 3D interactive animations in real-time. A great deal rides on understanding what sorts of information systems can be built to take advantage of this qualitatively different world. One type of system that we believe will prevail is one that allows user clients to navigate vast 3D or 4D data bases, and query associated information, in real time. Such a system is in use today allowing interactive exploration of Los Angeles. With it one can fly (or drive) through various neighborhoods, inspect realistic architectural models of buildings, make queries about aspects of the buildings, etc. The system has a number of compelling applications including emergency response, tourism, community involvement in planning, in-car navigation, training, etc. Taken as a whole, these and other applications will become economical to deploy as the cost of the core model of the city is amortized over many applications and as technological advances reduce costs. This paper explores potential applications for the Virtual Los Angeles database/system and discusses the key technical challenges that need to be addressed to bring the full potential of the project to realization.

APPLICATIONS

Virtual Los Angeles

Virtual Los Angeles is a real-time scene graph based visual simulation database, which can be interactively navigated and queried using an application that we call the Urban Simulation System. Virtual L.A. consists of a 320 square mile digital terrain model of the Los Angeles basin that has been constructed using USGS one-degree Digital Elevation Model (DEM) data. The digital terrain model has then been textured (image mapped) with geo-referenced aerial photographs. The database has been built using real world coordinates and works within a global coordinate system (GPS or California State Plane). Into this three-dimensional large area context model we place our high-

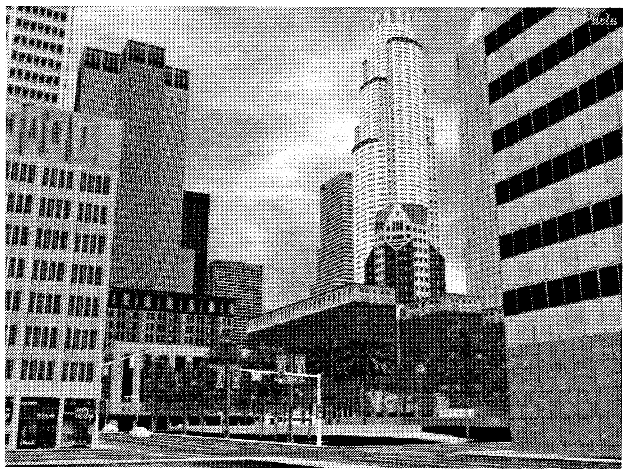


Fig. 1. Downtown Los Angeles

resolution urban simulation models. To date we have completed more than fifteen different projects covering about twenty square miles of dense urban fabric. One could envision a very large checkerboard where we are defining one square at a time. Where two models are contiguous they are also seamless. These models are both dimensionally (in Z as well as X & Y) and visually accurate. Our objective is to create models that are accurate to the level where the graffiti on the walls and the signs in the windows are legible.

Scarcely a week goes by without at least one new application being suggested for the Virtual Los Angeles database and Urban Simulation System. Currently, a team of researchers is working on several projects, with both public and private organizations, which are looking at future development in the Los Angeles region. The system we have developed has been found to be extremely valuable at placing new development into the existing built environment so that it can be evaluated in its actual urban context. Los Angeles has, at best, a spotty record when it comes to new development being sensitive to the needs of the surrounding community. The system enables virtually everyone to be included in the planning process, expert and layman alike. We have found that designers, architects, developers and consultants are able to identify real problems (which they were completely unaware of) and remedy those problems long before the first hole on a new development is excavated.

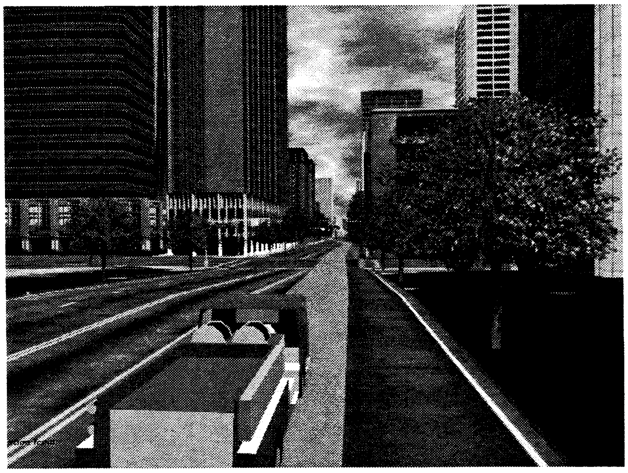


Fig. 2. Navigating through Downtown Los Angeles - Street Level View

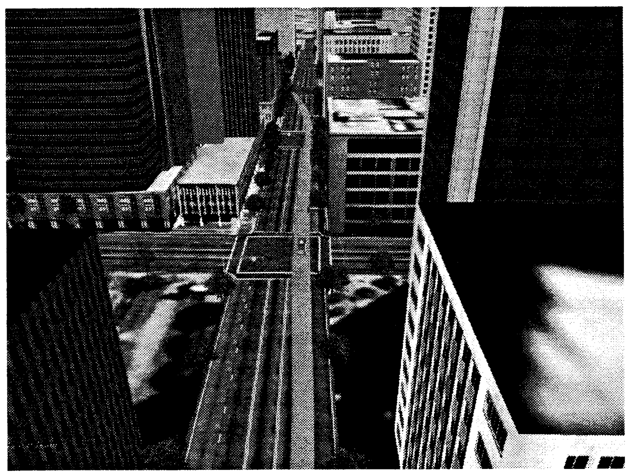


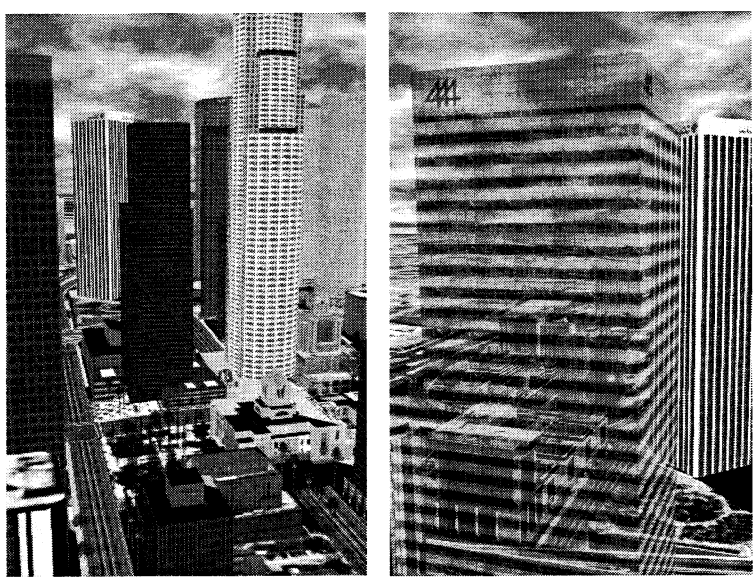
Fig. 3. Navigating through Downtown Los Angeles - Aerial View

Three Dimensional Navigation System

One application that we have successfully demonstrated is a prototype for a 3D in-car navigation system using the Virtual Los Angeles database and urban simulator. This system was successfully demonstrated in August, 1997. The team created a system which can be placed in a vehicle and through the utilization of Global Positioning System (GPS) Coordinates is capable of tracking the vehicles position in the City of Los Angeles in real-time. On an LCD panel mounted on the vehicles dashboard, we are able to display the same view that one sees when looking out the windshield of the vehicle, or we can fly up and track the vehicle from above. Additionally, onto this scene we can superimpose navigation or way-finding aids, such as a red-carpet depicting the optimal route to follow to a specified destination. The great win here is that the occupants of the vehicle can, at a glance immediately identify where they are and where they need to go by using immediately identifiable visual landmarks (see figures 2 & 3). Further enhancements to this system will allow (perhaps via cellular telephone) a variety of dynamic options including the capability to track other vehicles in real-time, to point and click on a store-front to access its WWW page or the ability to highlight a desired building and/or route in response to queries from within the vehicle.

Emergency Response Management

An allied application of the three dimensional navigation system which has shown great promise is in the area of emergency response management. Using this capability an emergency response center (police, fire, ambulance, etc.) commander will be able to locate all of his/her vehicles and/or people in real-time and be able to provide more effective command and control instructions using visual cues from the Virtual Los Angeles database as the basis for verbal directions. Additionally in the field, the response personnel will be able to accurately locate the position of beacons such as fire alarms identifying first the building and then the floor and exact location on the floor (e.g. main corridor) visually in three dimensions. The system also allows the response personnel to dynamically access WWW databases (maintained by the building owner and occupants), showing plans of the floor plates and the locations of all "interesting" features, such as fire hydrants, hose bibs and toxic chemical storage areas. With the advent of personal GPS systems the units will be able to dynamically track all personnel during an emergency in order to take every precaution to safe-guard the lives of these public servants (sadly in a recent incident in Los Angeles, a fire fighter was lost when it was incorrectly thought



Figs. 4 & 5. Fire Alarm Activation Far and Near that he had safely exited a burning building).

In Los Angeles disasters seem to be a way of life. Whether it is large fires, earthquakes, floods, civil disturbances, etc., the necessity for sharing information between disparate departments is critical. It is not hard to imagine a large-scale fire in the hills of the city with hundreds of units (police, fire, ambulance, etc.) from forty or more different municipalities simultaneously engaged across tens of thousands of acres. Command and control of such a conflagration is of course difficult. However, it is entirely conceivable that with a system, such as the one which we are proposing, all of these resources could be tracked and commanded from designated centers scattered across much of the City, all of which are independently viewing at the same current three-dimensional real-time picture. We feel the combination of a real-time three dimensional model/system which allows unrestricted movement around an area in question (in order to obtain the best vantage point) coupled with the ability to dynamically communicate and collaborate will provide an environment that will revolutionize the way that emergencies are handled.

Dynamic Database Updates

One enabling technology which we are developing as a part of this system will allow the underlying 3-dimensional databases to be updated in real-time. This capability would include the ability to update both imagery and geometry, to insert attribute information and the ability to annotate the information in a user friendly way. For instance, in the event of an earthquake or hurricane a system installed in a helicopter could be used to assess damage and update emergency response center databases and command centers across the stricken areas. While in flight the helicopter will track itself using the aforementioned high resolution GPS system. An instrumented video camera on board would be used to photograph areas which have been damaged. Knowing the parameters of the camera (lens, zoom, etc.), the accurate location of the helicopter (lat., long., alt.) and the relative orientation of the camera (heading, pitch, roll), the system will be able to superimpose images of damaged areas onto the existing 3-dimensional urban database model. The personnel in the helicopter could then add annotations to the database, such as tree or power line down across road, bridge collapsed, fire, etc.. This data would be relayed via cellular communications to the appropriate command centers (police, fire, street bureau, department of water and power, etc.), where the databases would be updated in real-time and the information displayed (as appropriate) on the large command center projection screen. In the same way the progress of a large brush fire could be tracked by just updating the imagery (black smoking areas are burning).

We are also looking at developing a system which will facilitate training in a multitude of areas. For example, the Los Angeles Police Department has recently been tasked with providing security for the Metropolitan Transit Authority (MTA). As a part of this requirement the Department is interested in using such a system to both familiarize their personnel with the miles of tunnels (which are very difficult to explore while the trains are running) and to conduct training scenarios where different problems are simulated and the officers are tasked with developing the appropriate response.

The Three Dimensional Information System

Ultimately we see this system not simply as a 3D graphics/database or real-time simulation system, but as an intuitive interface/index to the world of three-dimensional spatially distributed information.

For example, as a result of the 1994 Northridge Earthquake, several hospitals in the Los Angeles region will need to be rebuilt. One hospital, that we are working on a replacement for, has been described as the second largest interconnected building in the U.S. after the Pentagon. This labyrinthine hospital complex has 3.1 million sq. ft. of space and 25 miles of corridors. Our plan is to use the system not only to plan and design the new hospital, but to manage it throughout its useful life as well. We have begun a dialogue with various construction contractors (e.g. Dinwiddie) which would allow the association of the as-built drawings, which the contractors are required to provide, with each wall or surface in the building. Using this interface one could virtually walk into any space, click on the wall or ceiling and pull up the appropriate as-built drawing(s). In addition we would have the contractor photograph each wall before the wall is closed up. These photos (locating the conduits, etc. within the walls) will be indexed to the appropriate wall/ceiling/floor object, so they can be retrieved using the same point and click interface described above. This would provide a much more accurate record of the actual placement of the ob-

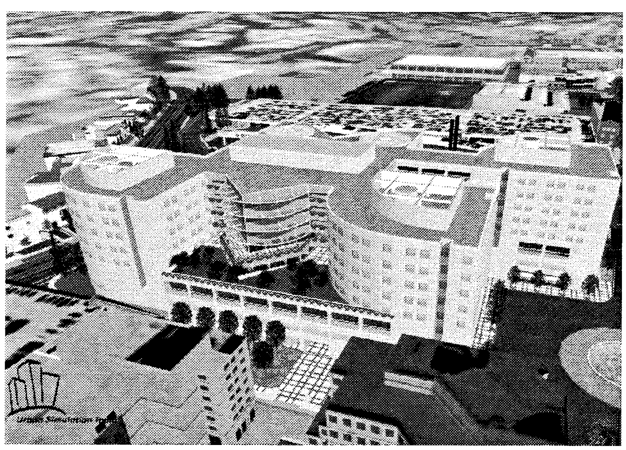


Fig. 6. New Hospital

jects (conduit, pipes, etc.) within the wall at a much lower cost than the standard approach used today.

Transit Planning, Training and Management

There are numerous transit related applications for such a system. They include: driver training, helicopter flight training (in a dense urban environment), traffic management and prediction, and other types of simulations. We have already created an interface for the new Los Angeles Metro (subway) that allows virtual visitors to walk around the area surrounding a Metro station, enter the station and board the subway train, travel to another station, get out of the train, leave the station and walk around the new area. When the train pulls into the station the doors open and the visitor can get onto the train. While on the train the rider can walk about inside the car, but cannot exit until the next station.

Historic Reconstruction

Working with university based subject experts with funding from a major Museum, the we have created a model of the Forum of Trajan, a building from ancient (circa 100 BC to 400 AD) Rome. This project could be expanded to create a cross section of Roman life which encompasses all facets of the ancient City. We are considering adding the capability to allow the insertion of virtual actors and street life into the model. This would allow the visitor to experience a typical day in Rome at selected times in the history of the City. Because we have incorporated the concept of time (other than real-time) into the system, we can create a history of Rome, by adding attributes to the graphic objects (static or animated), which comprise the virtual city of ancient Rome, specifying creation and dissolution dates. When loaded the system recognizes the time dependent nature of the database and adds a time slider to the simulation controls. The user can then interactively select (in addition to a starting location) a time or date (which can be changed at any point) to begin the simulation.

Fig. 7. Forum of Trajan

It is our intention to allow the subject experts to self document their reconstructions using a point and click Web interface which is incorporated into the system. Since the system also allows multiple alternative graphic objects to be interactively selected from a context sensitive menu, subject experts are able to create and document their own alternative reconstructions and add them to the master database. Ultimately faculty will be able to conduct their office hours, not in their offices, but in ancient Rome at a time of their own choosing. The students will (from their own homes) join the faculty in ancient Rome on a pre-selected date in time and as avatars they will experience Rome as it was in the days of Augustus (or Trajan, or Julius Caesar). During these sessions it will be possible for those proximally located to see and speak to each other, as well as see and hear the virtual actors (Augustus, Julius Caesar?) as they make their way through the virtual environment. Perhaps they will be joined by a subject expert on the Forum of Trajan, from his office at a remote university, while they explore the Forum of Trajan.

GENERAL FEATURES AND ENABLING INFRASTRUCTURE OF THE VW DATABASE

An important feature of the Urban Simulator is its support for temporal or diachronic data. This feature can be used in many ways. A building project may have several construction phases that the client may wish to visualize. In this case alternative models are built for each phase and the phase number is inserted into the attribute field for that version of the project. When loaded the Simulator parses the attribute field, finds the phase numbers and builds a "phase" slider. During the simulation the user simply pushes the phase slider to transition from phase 1 through n.

This temporal feature can be used to illustrate dynamic changes that may occur to an urban environment over time. For instance, we have created a tree library that contains trees that grow at realistic rates. We have a master model of each tree that has numerous incarnations each of that are of an accurate size and breadth for that tree type for each year of its life span. These trees may be planted in our models by simply inserting an external reference to the master tree model with a creation date and tree age (say date 1974, age 3 years) inserted into the referencing node attribute field. Multiple references of this type may be made, each with its own unique date and age. When the master slider is activated we can watch the trees as they are planted (at various times) and then as they grow at realistic rates. This capability can also be combined with our switch capability and at any point the oak trees can be switched for palms, or elms, or pines, etc.

The crucial idea here is to create a tool set that is, from the modelers perspective, both easy to use and empowering. Because the system has been designed specifically to enhance the productivity of the urban modelers, we are able to create tools, methodologies and technologies that complement each other.

Enabling Different Levels of Interaction

The simulation interface includes fly/drive controls, enabling the user to travel anywhere and view any part of the model from a digitally accurate perspective. We have designed an intuitive mouse and menu driven interface that most people are able to master in a manner of minutes. The scene may include dynamic objects, for example cars or pedestrians. The user can attach to any of these as they move through the model, so that chosen paths can be followed and evaluated.

Another mode of interaction allows 3D selection, or picking of objects in the scene. The user can exercise several options:

1 Removing the selected object, such as a building, from the scene
1 Highlighting a particular area
2 Substituting alternative models
3 Accessing attribute data associated with the object

This third option is significant for designers assessing different stages of a development. For example, it means different design options can be easily compared and contrasted by a simple click of the mouse. It also enables temporal changes to be studied, such as the potential development of a site over time, or how new highway construction might affect a location.

Finally, using pick mode enables the user to identify and query an associated database for object attributes. This option makes possible dynamic query and display of information from federated databases (such as a GIS) in a real-time 3D format. Additionally, World Wide Web addresses (URL's) can be inserted into the attribute field for any element. When such a node is "picked" a World Wide Web browser is dynamically activated with the appropriate WWW address. This approach allows the use of what is now becoming a ubiquitous database interface standard to associate a rich (and virtually infinite) assemblage of information with the 3D graphic entities located within the visual database.

For example, this interface is being used to annotate the Virtual Los Angeles database. In our models of the Hollywood and MacArthur Park areas of the city every parcel and storefront has its own unique URL. Where feasible these addresses point to a Web page maintained by the individual business. If such a Web page does not exist the Urban Simulation team creates a place holder page which is updated as warranted. Additionally, a reverse indexing scheme has been developed to allow attribute queries to locate graphic entities within the real-time simulation.

TECHNICAL CHALLENGES

We look forward to a day when there will be a basic level of 3D world model data maintained as a resource for the public. The geographic extent and the level of detail, may depend on government boundaries, different project areas, costs, etc. but it is predicted that the number and the value of derived services and applications will make the argument compelling. In effect the basic models will include satellite and aerial images combined with DEM data to form terrain 3D models. In addition, basic 3D models of building exteriors may be included perhaps at first in special areas of particular public interest such as tourist attractions, commercial areas, new developments, public buildings, etc. but eventually encompassing more and more of the urban landscape. This infrastructure, to the extent that it is of widespread public value, will be maintained by various organizations, perhaps both public and private (local for building models, county for aerial, state/federal for satellite imagery).

What will happen as this infrastructure begins to take form? To reach its maximum impact two things need to happen. First, we need to enhance as much as possible the ability to easily create new applications that capitalize on the base 3D model infrastructure. For example, the initial investment may only support limited areas with specialized applications that are important enough to warrant the cost of development. At this point other applications can piggyback on the content already developed and add incrementally to the content. In the long run the cost of maintaining the infrastructure and content is amortized over an ever larger number of applications and another cycle starts. This "snowball" like growth is reminiscent of the Internet growth in recent years.

To encourage the kind of synergistic growth as described above, we must enhance the ability of potential users to (a) access the database, (b) develop new applications and (c) add to the content base. The project is targeted at exactly these goals. We already have a system containing satellite and aerial imagery for the LA basin and 20 square miles of street level models of LA urban areas. There is a multi-user real-time delivery system that is in place. Access to this database is currently via ATM lines to individual clients but in the future the delivery mechanism is expected to be the next generation Internet. Our analysis/simulations have shown that this system can run comfortably within the bandwidth/Quality of Service requirements needed to support video on demand and/or teleconferencing applications. In order to accomplish this objective a new client, which is predicated on commodity level personal computer hardware and software will need to be developed. Additionally, the system design will need to address the issue of protection of intellectual property rights and security concerns for the distribution of the content. We intend to address all of these points in the design of the system.

A Distributed Database System

In addition there are challenging system architecture issues. It seems clear that there will be a distributed system of 3D database servers; in order for the system to scale but also because local governmental bodies and commercial organizations will want to control their own databases and users will want access to "certified" model data. There are obviously issues of providing a "seamless" view of the world model even though the implementation is segmented. Other issues include support for controlled sharing and security, such as allowing others selected access to your application and/or content and denying them access to other areas. For example, we wouldn't want criminals to be able to track the location of the police in real-time. However we would want people to be able to be able to track the location of the bus they take to and from work. The division of responsibilities between clients and servers is another issue, which could significantly effect performance.

Applications will have two basic types of functionality. One is the ability to include application specific data from external sources and control its display. In addition, there is the need to allow users to more easily create new content. The first capability, in conventional databases corresponds to the query and presentation of query response. The second corresponds to authoring new content. Authoring tools depend on the type of content. Building high quality 3D urban simulations will not easily move into the hands of the unspecialized user (this may change as the research on automatic generation of 3D models from multiple images begins to mature. We assume that models will continue, for the time being, to be built as infrastructure for multiple applications and it will be a task for a specialist. However, beyond this, we expect that users trained in the applications with less specialized knowledge will be able, quickly and inexpensively, to develop applications if the 3D model data and external sources are available. The ability to dynamically update and/or modify the model in real-time will be come an important feature for the emergency response and other applications. Other types of authoring are concerned with modifying or augmenting the existing database; for example, the ability to add an annotation on some building or other entity in a 3D model. Such additions could be permanent, as when the database becomes a knowledge repository. Another type of authoring is for collaboration purposes and the modifications made could be transitory and only needed during the collaboration; on the other hand a record of such a collaboration could be used in many ways, e.g., postmortem analysis of the collaboration.

We see as enabling technology for the genesis of the digital earth both "vertical" and "horizontal" database integration. By vertical integration we mean the incorporation of disparate data sources into the 3D terrain and urban core model.

The data types will include:

1 Real-time Sensor Data

   Examples include GPS sensor data for location of mobile entities and real-time update of wind currents and pollution plumes across a city

   Applications include tracking of emergency vehicles, identification and annotation of observed problem areas, etc.

1 External Databases

   GIS databases of various kinds are a natural input to this type of system. The gas company might for example want to include gas pipeline network data in such a way that the pipes can be seen below the street surface or the electric or telephone company might want to annotate the contents of a street vault or the location of a sewer line.

6 Video External Feeds

   Video feeds could be at surface level or aerial. Could be with or without range data per pixel. Aerial video or photos could be used after a hurricane or earthquake to update street level models with data indicating blocked streets, collapsed houses or washed out bridges. Could be real-time or not.

7 Simulation Output

   Simulation output of fires, toxic plumes, traffic, epidemic spread, etc. could be input to the model for superposition on the more static world model.

Other technical challenges that need to be addressed include:

8 cost effective performance; quality of service issues.

9 Sharing: security (gaining, revoking), information discovery, views (shared, individual), forms of communication, interactions

The goal is to develop a flexible and extensible infrastructure for domain independent collaborative information visualization and exchange. The challenge is to discover what a base level of functionality is in order to provide an expressive and extensible system. Expressiveness can be considered from two points of view, programmable extensibility and compositional flexibility. These two elements provide an ability to develop domain specific solutions. The philosophy of the system is to provide a seamless view of the data and visualization environment to the user and developer. Subject to global system security users are able to interact and or extract information published into the information space. Additionally, they can add or publish their own data into the space as well.

CONCLUSION

The Urban Simulation Team has successfully implemented a system which combines custom simulation software and real-time database technologies with efficient modeling methodologies. This system is being used for a wide variety of "real world" projects including that of creating a virtual model of the entire Los Angeles Basin. The system has proven to be an extremely useful tool for identifying potential problems and quickly exploring a large number of alternative design solutions. The Urban Simulation System is also being re-purposed to support a diverse set of alternative applications such as in-car 3D navigation, historic reconstruction and the study and support of virtual learning environments. In all of these capacities the combination of a dimensionally and visually accurate real-time database and an intuitive and easy to use interactive browser have proven that this approach is one that will persist and flourish in the near future.

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