A Collaborative Framework for Virtual Globe Based 3D City Modeling

Christos P. Yiakoumettis, Georgios Bardis, Georgios Miaoulis,
Dimitri Plemenos, and Djamchid Ghazanfarpour

Abstract. Urban planning and city modeling have gradually shifted, during the last decade, from highly demanding, in terms of required skills and supporting information, to tasks now supported by efficient, widely available applications, thus becoming popular and largely accessible. There are many GIS systems nowadays that offer a freely navigable three dimensional environment. This evolution of GIS systems has, in turn, led to the requirement for and creation of virtual 3D models of the ground and buildings. Online communities have created and distributed over the Internet libraries of georeferenced 3D models. The public is encouraged to participate in the design of 3D scenes and many companies offer free tools to facilitate the design of 3D models, specialized in buildings. In this paper, we present a collaborative approach for the construction of a city model, and its implementation through a prototype environment, employing freely available design tools. The prototype system comprises a collaborative database, supported by a web-based interface. Users are able to create and upload their models to the common database over the web, thus constructing a realistic 3D city model in a given area in a collaborative manner.

Keywords: virtual globe, GIS systems, collaborative city modelling, visualisation, public participation, scene modelling, urban planning.

1 Introduction

A number of Geographic Information Systems (GIS) applications have been released during the last years, one of the first Geographic Information Systems

Christos P. Yiakoumettis Dimitri Plemenos · Djamchid Ghazanfarpour
Université de Limoges,Laboratoire XLIM, CNRS, UMR 6172
83, rue d'Isle, 87000 Limoges France
e-mail: {djamchid.ghazanfarpour@unilim.fr}

Christos P. Yiakoumettis · Georgios Bardis · Georgios Miaoulis
Technological Education Institute of Athens
Department of Informatics
Ag.Spyridonos St., 122 10 Egaleo, Greece
Tel.: (+30) 2 10 53 85 826; Fax: (+30) 2 10 59 10 975
e-mail: {chgiak@teiath.gr, gbardis@teiath.gr, gmiaoul@teiath.gr}

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being the one introduced by Microsoft in 1998 (Wikipedia, Virtual Globes) and included in the Encarta digital encyclopedia. Nevertheless, the first three dimensional geographic information system to become widely known was released by Google in 2004. It was the commencement of a series of applications, also known as *virtual globe* applications, that would follow in the subsequent years. All these GIS applications have tried to simulate real world based on a three dimensional virtual environment. Three dimensional scenes in such an environment are typically enriched with multimedia data which can be three dimensional models of buildings, photographs taken from an airplane or at street level, real time video, and more.

2 Virtual Globes

2.1 Simple Two Dimensional GIS System Architecture

Google Earth, released in 2004, was the first virtual globe application to break the limits of the experts' community and become widely known to the general public. It comprises a three dimensional virtual environment, freely navigable and explorable by the user. It is based on a server-client GIS system architecture where the typical scenario is initiated by the client requesting data, based on the user's current position in the virtual scene. In turn, the client retrieves the requested data either from a temporary cache memory or from the remote GIS database. Subsequently, the retrieved data are visualized on the client's side with the aid of a specialized application. The first applications which served this purpose were limited to two dimensional environments (Wikipedia, Google Maps), (Wikipedia, Virtual Globes). Google Earth started with publishing static maps, evolved to static web mapping applications and then to GIS distributed systems (Sriphaisal & Pujari). Satellite or aerial photographs have been used to provide the necessary database content (Zhang, et al., 2007). Besides the images, systems of this category contain information about ground elevation, roads, points of interest as well as three dimensional building models (Jones, 2007). The global positioning system is used to integrate and calibrate the georeferenced content.

2.2 Evolution of the Architecture

The evolution of the GIS systems has led to the improvement of the services and the amount of available information. In the beginning, additional information was added to the database, mainly based on aerial photographs. Names for the streets and roads network were among the first data to enhance the database content. Afterwards, metadata such as text, external links, hypertext and placemarks also found their place the database.

Despite this evolution through additional material, the fundamental functional block diagram has remained practically the same (figure 1). All data is imported to databases and calibrated over the same geographical positioning system.

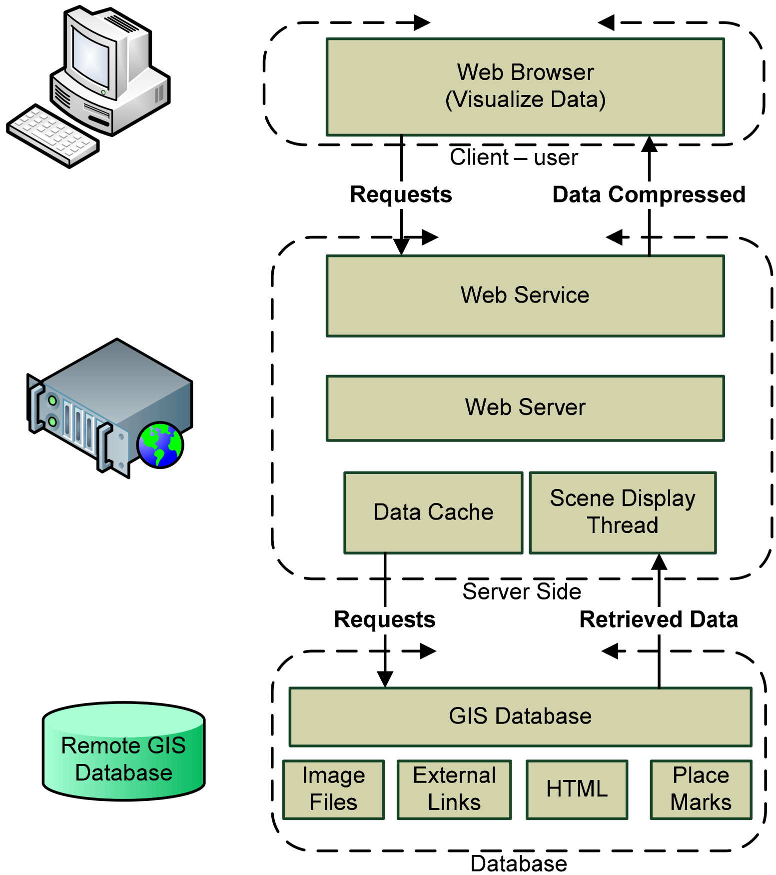

Fig. 1 Block Diagram of improved GIS system

In this case the data repository of the system is comprised of four different resources, each of them potentially forming a separate database. Nevertheless, all databases have to use the geographic positioning system. This architecture allows for system flexibility and easy content distribution to the extent that, for example, each database may be hosted by a different provider in physically remote locations from the others. Moreover, there is no theoretical limit on the number of physical databases that may constitute even one of the aforementioned resources. The end-user may choose which information to retrieve from the GIS system through the client application, which is presenting the data organized in intuitive layers, completely transparent with respect to the actual data organization. Each layer typically contains data from one or more different databases. When all the data are being presented, a synthesized image is created from the projection of the superimposed layers on the same geographic area.

Evolution led to three dimensional GIS platforms. Evolved platforms offer browsers with 3D capabilities and freely exploration of the scene. Beyond the images and hypertext, new browser can visualize the morphology of the ground. Moreover 3D models of buildings are also included in some browsers. (figure 2). The result is a synthesized three dimensional scene that can represent a three dimensional model of an area or city with realistic or reality-enhancing attributes. Initially, models of buildings were limited and only specific cities were modeled.

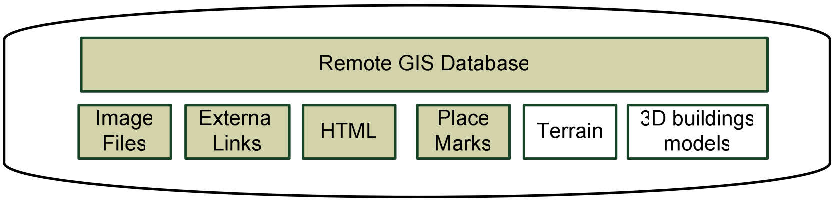

Fig. 2

3D models were designed and built in a 3D object description language called COLLAborative Design Activity (COLLADA). It has a language with XML schema and it has been adapted by many software and hardware developing companies.

On the user's side a standalone application or web browser with visualizing capabilities of COLLADA is required. Components have been developed by distributors for this purpose using OpenGL or DirectX graphics languages.

Today, there are numerous databases that can provide information and data for such a GIS system. The popularity of such systems and the advancements in computing and telecommunications have made possible the creation of powerful three dimensional GIS systems, based on the aforementioned architecture. Information about the altitude and the morphology of the ground has been incorporated to them whereas 3D models of buildings are also being gradually added. The goal is to create a virtual world that closely simulates the real one. Recently, many 3D models of buildings have started to appear on most popular capitals and cities around the world on the virtual globe systems. Each virtual globe application typically features its own independent database and is usually supported by its own developing team. Many cities have been modeled but most of them are still incomplete or not modeled at all.

2.3 Server – Client Functional Model

The virtual globe applications of interest in the context of this work are internet based and implement the server – client model. They are using a client application which is responsible for requesting data according to user criteria and location. A web server is submitting the required data. The communication between server and client is achieved by web services. Real time data transmission can be accomplished by AJAX and SOAP technology (Huayi, et al, 2010). Many users can request the same data or different ones, but all of them are accessing the same database. The latency between the retrieved models and data and the real-world information mainly depends on the update rate of the database but may also represent different levels of accessibility offered by the data provider where high latency characterizes free access but almost real-time access is only commercially available.

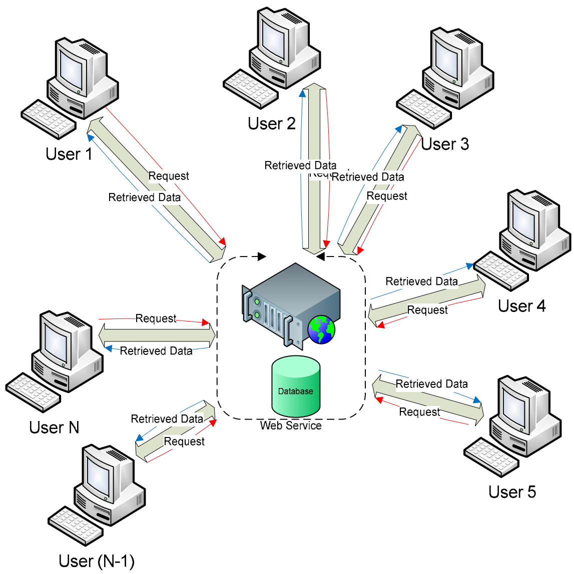

Fig. 3 Server – Client model of virtual globe systems

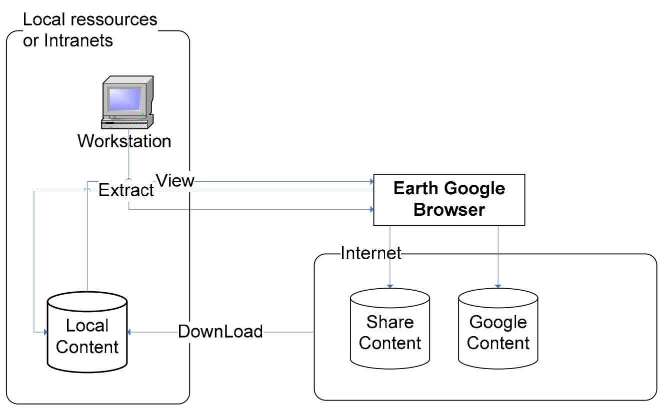

Fig. 4 Functional Block of a virtual globe (Google Earth)

According to the above functional block, the path of the information is only from the server to the clients, the latter only submitting requests for data to be retrieved from the server.

The latest versions of user's side client application have the ability to cache data, or even to load external data, locally stored on user's system. The local data offer the ability to create and maintain a local database thus enhancing through customization the experience of the virtual globe system. However, this local database can neither be shared nor it can be used to update the public database. Each user's client can only visualize his/her own data in combination with the publicly available data.

2.4 3D City Modeling

The modeling of the majority of cities of the world is incomplete or not available at all. The update of the GIS databases is taking place continuously but at low rate, considering the vast amount of information and the considerable computation power that is required to reconstruct a three dimensional model of the whole scene of a city. In this work we propose an alternative model of a collaborative GIS system, based on data distribution and gathering from multiple users, taking advantage of internet technologies and communication.

3 Collaborative Systems

3.1 *Principles of Web-Based Collaborative Platforms*

Collaboration is a process that two or more people work together in a project or to achieve a common goal. There are tasks that can't be accomplished individually. Nevertheless collaboration can help to carry out the task faster and more efficient (Dragonas & Doulamis, 2007).

Several methodologies have been presented in the literature. According to the most popular methodologies the main requirements of a collaborative platform can be reviewed on the followings topics:

- Information Systems of georeferenced scenes. Google Earth has been chosen for this purpose.
- Communication Tools. It is allowed communication between group members.
- Geometrical Representations. A software application that facilitates the visualization of a 3D building model among all the group members.
- Knowledge Representation Methods. Generic rules that are stored in an information database and describes conceptual 3D models.

Considering the above typical principles of a collaborative platform, a web based platform will be presented in the next sections.

4 State of the Art

In the field of geo-referenced systems and three dimensional modeling several approaches have been presented.

4.1 Geo-referenced Systems

The steep increase in processing capabilities of modern day computers has made possible the efficient manipulation of huge amounts of data in the form of pictures, videos and three dimensional models. It is beyond any doubt that, the internet has made widely known a great number of new applications and services. The last decade many geo-referenced systems have been introduced. In the beginning, the GIS applications were two dimensional, the first being included in the 1998 version of Microsoft Encarta. Afterwards, three dimensional data were added to GIS systems. In 1999 Chen introduced a three dimensional urban planning system for Los Angeles (Chen, 1999) which was a combination of VR technology and GIS systems. Web services have also been part of with GIS systems for urban planning in (Drummond & French, 2008).

In 2003, a generic framework for dynamic environment of three dimensional modeling was presented using java (Huang, 2003). An interactive framework for public participation in urban planning was presented by Huayi, Zhengwei and Jianya (Huayi, et al. 2010). Their approach is based on AJAX and XML technology. In addition, several approaches have been introduced by commercial companies. Google presented in 2004 Google Earth, which became widely popular and, subsequently, other companies have followed, including Microsoft and others. Some of the applications were designed for public use. In the field of urban planning commercial applications have also been introduced but their use is targeting expert people. The reconstruction and modeling are based on variety of parameters, like height, map of street, aerial, satellite photos and more.

4.2 3D City Modeling Systems

Modeling a city or scene requires a lot of information to be gathered. Data for 3D reconstruction process can be gathered by the photogrammetry process, based on geo-referenced photos captured by cameras on the ground. A set of sensors are scanning the building and the scene (Koutsoudis, et al, 2007). The result of the process is very accurate but its main disadvantage is that it requires special equipment and numerous measurements.

An alternative methodology of 3D reconstruction is based on LIDAR (Light Detection And Ranging) (Lan, et al, 2009). It is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses (Wikipedia, LIDAR).

On the other hand the 3D model can be generated by an engine. A declarative engine for generating a 3D large scale scene was introduced by Larive & Gaildrat (Larive & Gaidrat, 2006) – (figure 5).

Fig. 5 3D Large Scale Scene of 17.362 buildings (Larive & Gaidrat, 2006)

In addition several commercial applications have been presented in 3D reconstruction of georeferenced scenes. They can generate the model based on rules and on image recognition of satellite and aerial photographs.

Georeference in the global positioning system is only one of many approaches used. Regardless of the georeference approach used, there are plenty of applications that can be used for urban planning. Most of them are stand-alone applications and have a visualizing browser. The user can build his/her own scene and navigate in it. These applications are using a visualizing module typically based on OpenGL. With the aid of such applications, the user can build an urban plan by selecting and modifying existing models, thus constructing virtual worlds with their own rules.

4.3 Wiki-Mapia Platforms

Besides the three dimensional GIS systems, there are vulnerable of collaborative GIS systems using two dimensional environment. These approaches are known as wiki-mapia platforms. They permit the user to interact with a two dimensional map. Consequently, all the users of the platform are using the same resources, i.e. the same map. The user can add georeferenced content on the map which is instantly shared to the whole community of the platform. Some examples which support these platforms can be multimedia, place markers, or hypertext content. The wiki-mapia platforms function over web services and typically use AJAX and XML technologies to communicate with the user. The majority of the most known platforms are using the API of known GIS systems for the visualizing process.

5 Large Scale 3D City Modelling Using Google Earth

Google Earth, introduced in 2004, was the first virtual globe based system and large amounts of multimedia data were added in a small period of time to its database. Other companies like Microsoft, followed by releasing their own applications. Each one of the prominent GIS systems created its own community and an online public library of georeferenced content. These libraries were containing mainly three dimensional models of buildings. The models were built by the users with appropriate software tools and subsequently placed on the GIS system. The inaccuracy of the model and the inability of massive generation of three dimensional models of real buildings made the reconstruction of scenes or cities a processing task with high overhead. During the end of 2009, Google introduced a new tool for reconstructing a 3D model of a building. It was the Google Building Maker, a simple web based tool that allowed the user to reconstruct the model of a building from multiple satellite and aerial images within minutes. In our approach, we adopt Google Building Maker as the initial tool to design and build the 3D model of a building.

5.1 Our Approach

The current work presents the proposal and implementation of a *collaborative web-based environment for georeferenced 3D city modeling*. Our approach is using Google Earth platform. The environment offers the following functionalities:

- Construction of custom 3D building models.
- Refinement of the custom 3D building models to improve realism.
- Placement of custom 3D building models in a georeferenced scene.
- Navigation among the building models as well as in the corresponding georeferenced 3D scene as a whole.
- Publication and sharing of the custom models and scenes with the other users of the environment.

In order to achieve the aforementioned functionalities a series of tasks had to be accomplished. In particular, initially, a custom GIS collaborative database had to be built to store and maintain all custom constructed models. Next, the database was populated by building models comprising 3D scenes. These constructed models were contributed by a team of student volunteers.

A working region was set and each student was assigned the construction of the model of a building within the region. Google Building Maker was used for the initial design of the models and Sketchup was used to correct possible errors with respect to the corresponding building.

Moreover, the texture of 3D models can be improved with higher quality photographs or aerial images from the area.

By the completion of each building model, it was uploaded to the collaborative database and all the community was able to access it, visualize it and navigate to it. For the navigation process the Google Earth plug-in component was used.

The communication between the local server and the clients but also between clients and Google's server was achieved by AJAX technology. Google Earth API was used in order to manage the collaborative database and filter the data. In the figure 6 the steps of the whole process are been presented.

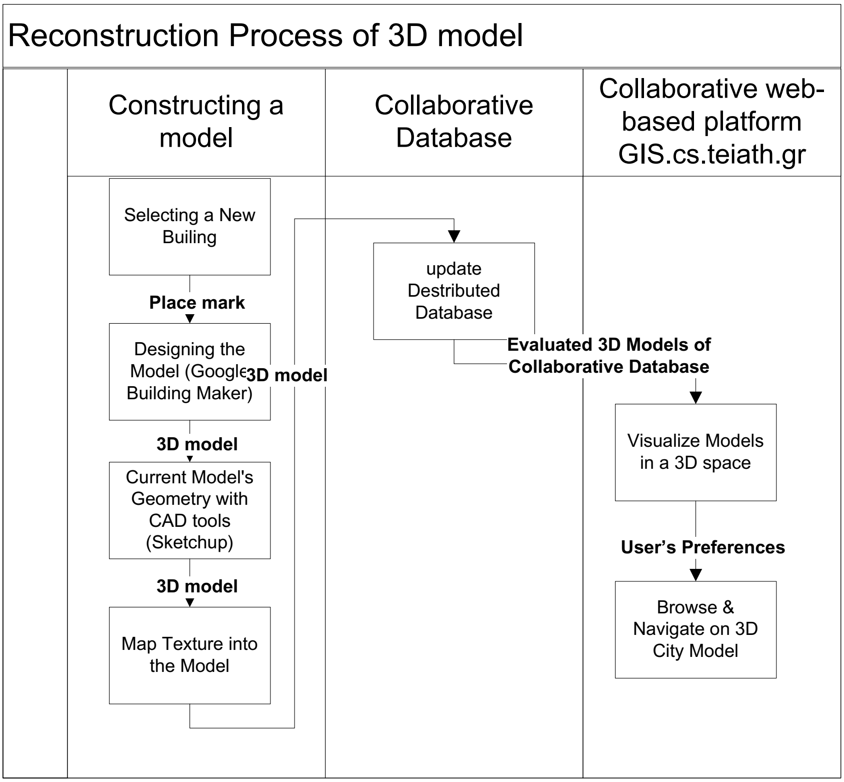

Fig. 6 Collaborative 3D city development process

Users were called to design 3D models of building in a desired specified area. Our web platform interface was visualizing the region in a 3D environment. All the available models were visible to all users. Users could freely navigate into the scene and select a desired free building to be constructed. Building was reserved by placing a placemark over the building. The placemark was announcing to the community that the building has been chosen for reconstruction. The model of building was reconstructed by Google Earth Building Maker. If it was necessary modifications and improvements was taking placing in order to improve realism. Afterwards the 3D model was uploaded on the collaborative web-platform and became visible to all the members of the community.

Our approach has been based on the server – client architecture, using a virtual globe system. On the side of the local server a collaborative database was built.

The users could access the collaborative database through a web based interface. A more detailed functional diagram is displayed below. Each module is presented in the figure 7.

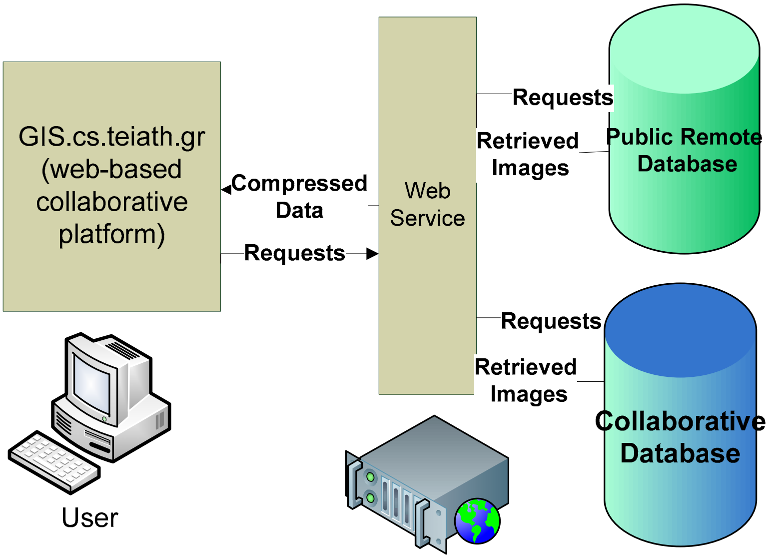

Fig. 7 Block Diagram

A collaborative local database was used. It was accessible by all the users of the platform. A programming component released by Google was used to browse and visualize the content of the GIS databases. The users were able to see their team's models and all the content of the public database through a web site. Any item that was added on the database was instantly visible by anyone.

For the reconstruction process of the city we have restricted the working area in a small region, by marking it on the database. The models and any other geo-referenced context had to be built on the user's side.

5.2 Reconstruction of 3D Building Model

Comparing all the existing tools for construction of a 3D building model, Google Building Maker was selected due to its user's interface and its reconstruction speed. With this tool a model can be designed within a few minutes. In addition texture can be added on the sides of the building model from the real satellite or aerial photographs. Other tools such as Sketchup or CAD tools present certain advantages but they lack the ability to automatically match the texture to each side of the building model.

Google Building Maker was not available for all regions in the world. In particular, it was available in cities with incomplete models or in ones having only a few 3D models. For our purpose we chose Athens (figure 8) and a particular region nearby Technological Educational Institute of Athens.

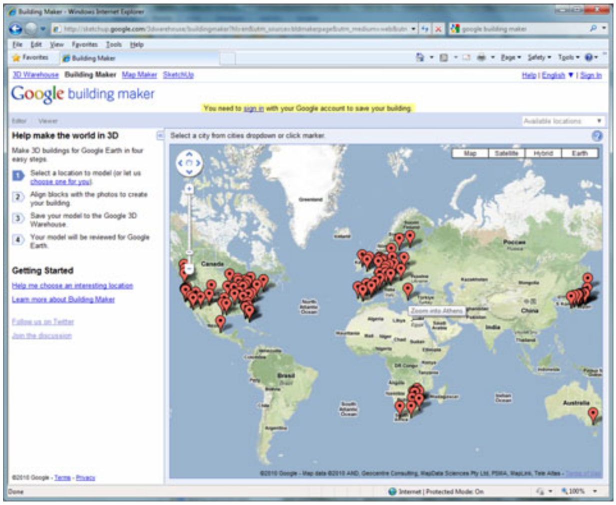

Fig. 8 Choosing a region

Users could choose a building to construct by placing a red placemark on it. With a blue circle existing models of public Google's Earth database buildings were marked (figure 9).

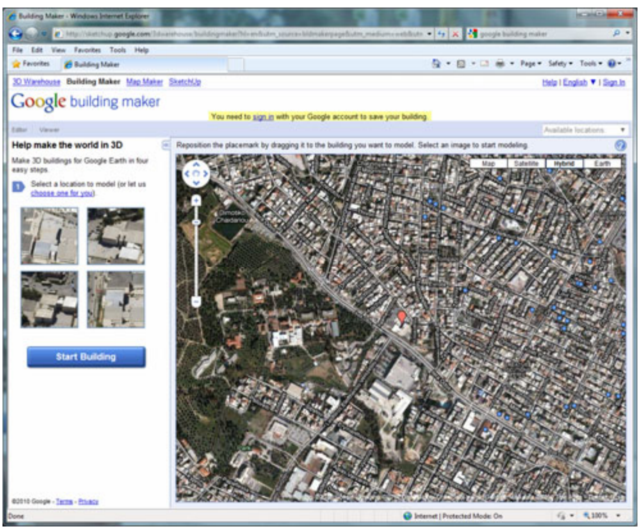

Fig. 9 Selecting a building for reconstruction

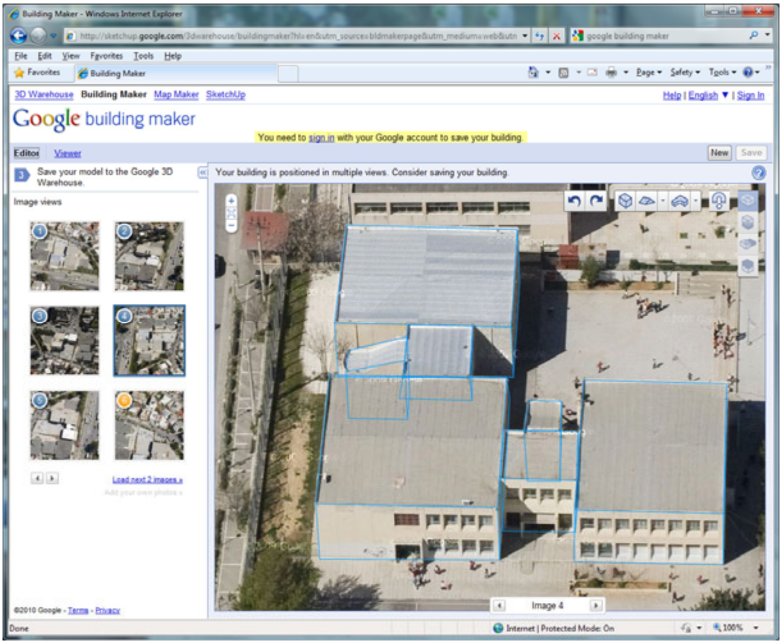

Fig. 10 Constructing a model with “Google Building Maker”

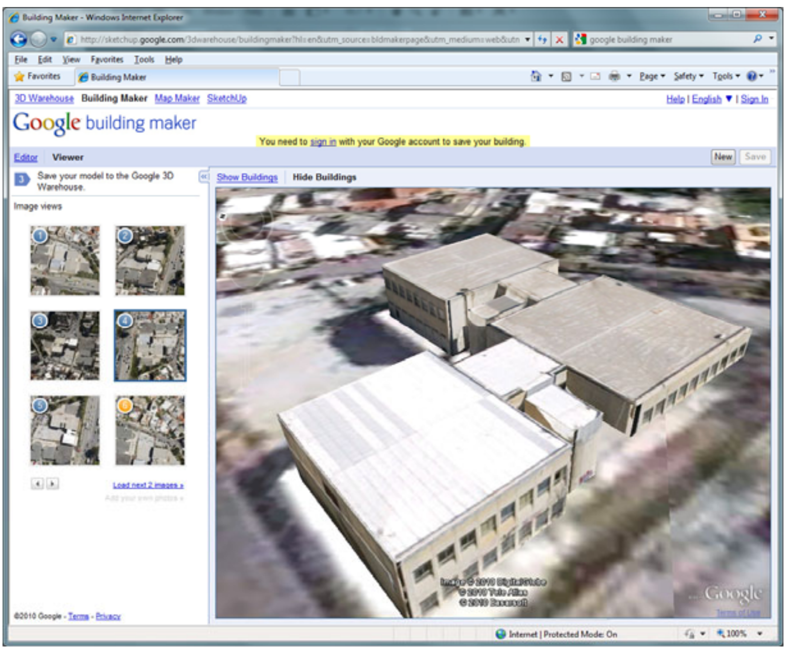

Fig. 11 3D model of building (“Building Maker” proccess)

The process of designing a model was based on bounding geometrical objects. Bounding boxes and bounding pyramids were used to construct the model. The bounding boxes had to cover and shape the building with best possible way. The GIS platform was providing the necessary photographs for a wide variety of points of view of the desired building. An arbitrary number of photos could be used for the design. An increased number of photos led to increased accuracy. The building was designed from the image of the first point of view and corrections were made by the next views. The 3D reconstruction process was done by the GIS system and a three dimensional geometrical model was created. Texture images were applied automatically on the sides of the model, from the satellite or aerial photographs. Each model that was created by the above process was placed on the public internet library of Google Earth and was accessible by anyone.

5.3 City modeling

Exploiting the possibilities of the above tool, a collaborative environment was created, based on an appropriate scene database, in order to gather many models of buildings and create a model of a localized scene or a whole city. The collaborative GIS system that was designed and used is shown and analyzed in processes in the diagram of figure 12.

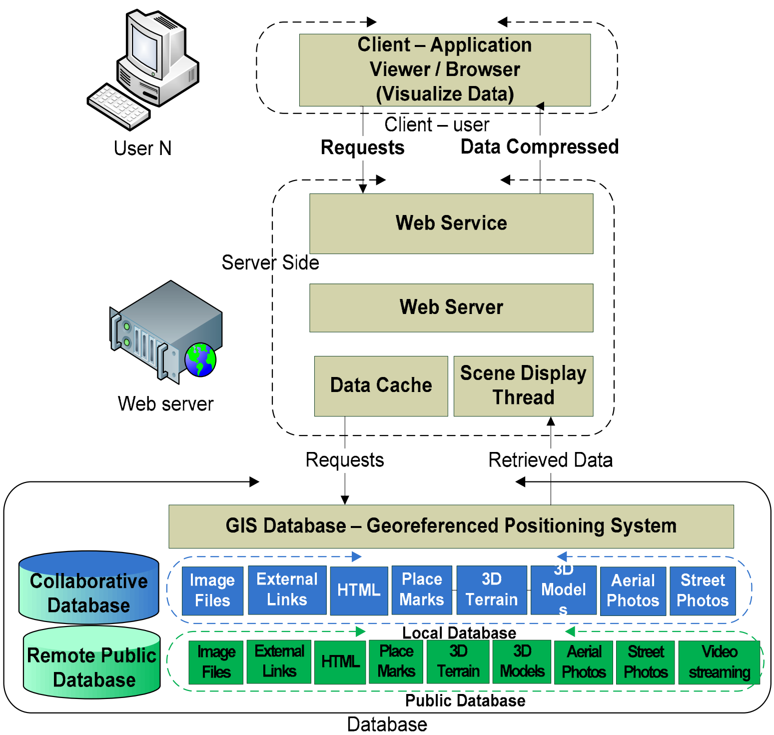

Fig. 12 “Gis.cs.teiath” Detailed Block Diagram

The remote access of the database and the distribution of data were achieved through http web service. In particular, a web site was built and the database was hosted in a SQL server. A Google Earth plug-in component was used to visualize the data and create a 3D dimensional world with OpenGL-DirectX. Google has made public an API for Google Earth use. Using AJAX technology and the Google Earth API, the public database was filtered and the shared database was loaded and visualized on Google Earth window.

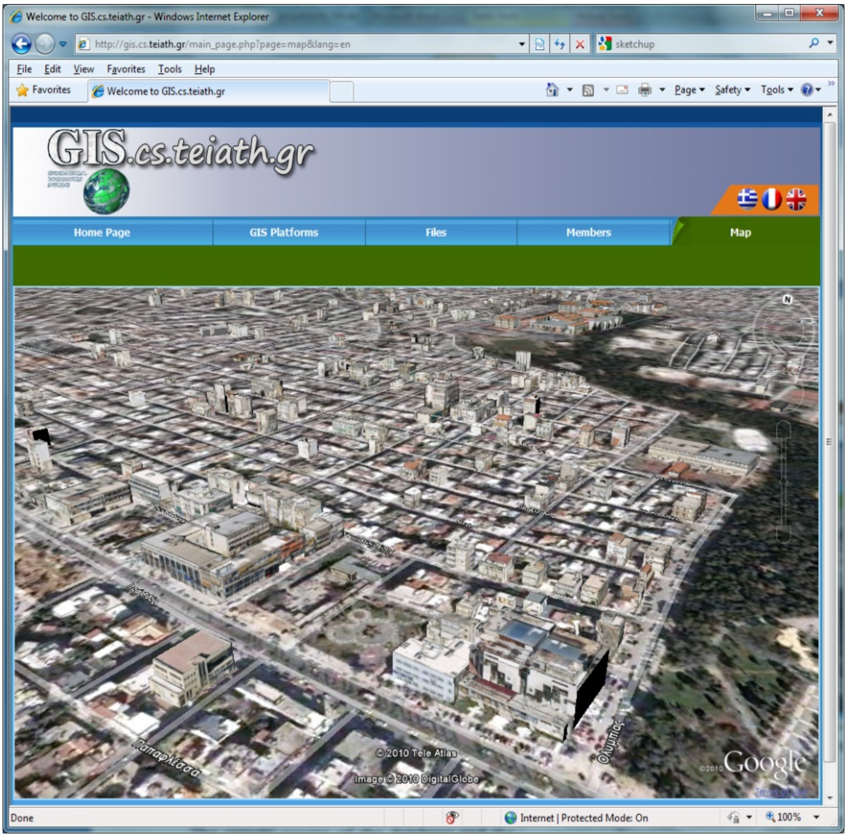

Fig. 13 "Gis.cs.teiath.gr" environment – 3D models of buildings in a collaborative

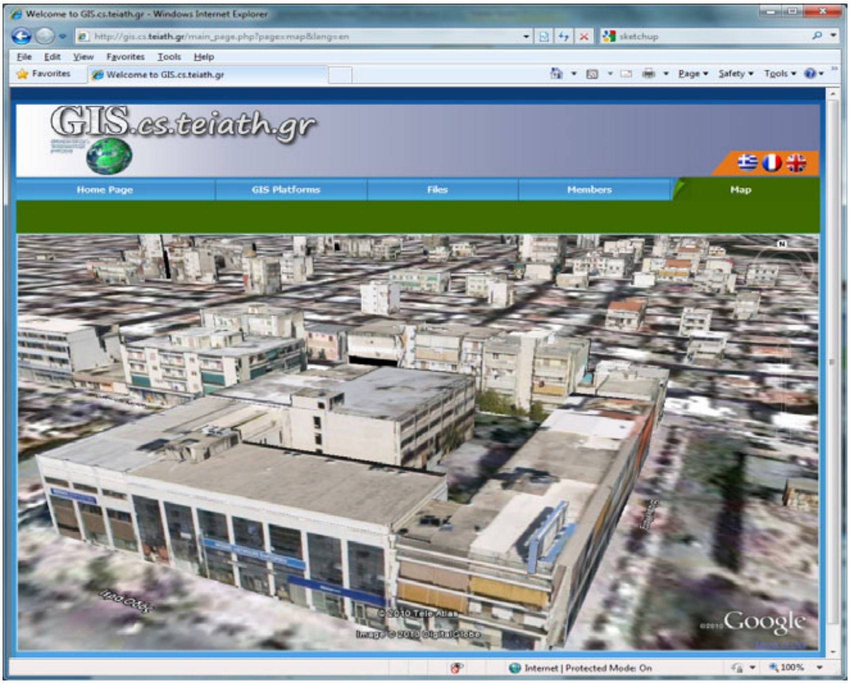

Fig. 14 Experimental set of 3D models of building

Each user could access other members' buildings. All members of the team were sharing the same map, working on the same region. They could navigate in a three dimensional space, by zooming in or out and by flying around the buildings. A mark could be placed on a building that was under construction, by the user, announcing that the specific building was in designing process. Each model was constructed using the Google Building Maker. All members of the team collaborated in order to create the 3D model of a scene like the one in figures 13-14.

5.4 Evaluating Process

As soon as a building model has been constructed, it was placed on the map using the global positioning system. Some building models were good copies of the original buildings whereas some others were poor or incomplete. Each building that was designed had to be evaluated before it was selected by the visualizing module.

Google Earth and Virtual Earth both have a public online library with multimedia content, including 3D models of buildings. Each user was free to build and upload models on these databases. However, each model had to be evaluated before it was placed on the virtual globes system. Only the detailed models and the ones that bear correct geo-reference was allowed to be visible on the GIS systems.

In our approach, each building could be evaluated in a scale from 0 to 10. The evaluation was taking place by a human expert, considering the satellite images of different point of views and 3D model of the buildings. In future versions of our platform, users will be able to evaluate the building of others. The buildings featuring correct outline and accurate placement were allowed to be visible in the Google Earth component.

6 Discussion

6.1 Our Approach

In this paper a collaborative web-based platform for city modelling was presented. Our initial requirements and goals were accomplished.

- A common working environment was designed. It was based on a custom GIS platform. All the members of team were using the same tools and share the same data. The working region had been specified and all the models of the scene were access by anyone.
- Common CAD tools and a Web-based application “building maker” was used from all the users to reconstruct the models
- A tree dimensional environment was freely available for navigation and exploration

The goal of the team was to develop the 3D models of a bordered area next to Technological Education Institute of Athens. In a small period of time about 440 models of building were reconstructed.

6.2 General Discussion

By 2004 and for a long period of time there were many regions around the world without any 3D building models or with only a few ones. Once the Google Building Maker was introduced by Google in the midst of October 2009, hundreds of three dimensional models of buildings appeared on the GIS system. Many of them have been evaluated by the team of Google and they appear on Google Earth too. A collaborative database of a GIS system, made possible the modeling of a georeferenced scene or a city. The participants of the experiment could choose a place to build, or add material hypertext, data or image on the map. The result of the collaboration was to build a three dimensional scene with about 440 buildings in a very short period of time. Each model was completed within minutes. The whole city could be modeled in this way distributing the work to all the participants of the team.

6.3 Buildings and Obstacles Overlapping

On the other hand, building a model with such a tool, although it is a relatively easy task, the result is not always the desired one. The accuracy of the model and the detail of the texture are not always the expected one. There are cases that the satellite or aerial photographs are not clean, or there are obstacles in front of the building. The obstacles can be anything, like trees, big cars, etc., the most common problem being the partial overlap of the buildings. This problem is very common in cities, where one building is close to the other. In the figure 14 there is a green part at the bottom of the image texture of some buildings. This occurred due to tall trees in front of the building.

If there is no spare space between the buildings, one solution is to create the 3D model of the whole complex of buildings. Hence, the whole building complex has to be modeled up to the point a clear area is reached. Likewise, if there is a small area between the buildings, then the texture among the nearby buildings will be erroneously applied on the sides of them.

Problems with low quality of images or texture images with noise (obstacles mapped on them) can only corrected by replacing the image with a real photograph from the proper aspect of view. All the models are written in COLLADA graphics language. It can be changed either manually or using a CAD tool compatible with COLLADA. Google Sketckup is one famous tool for that purpose. Moreover, a faulty model may occur if the bounding boxes or pyramids do not fit correctly on the satellite or aerial photographs. In that case the produced 3D model is poor in quality and typically rejected during the evaluation process.

7 Conclusions

In this paper we have proposed and implemented a prototype system for a collaborative GIS system. The data content comprised 3D models, hypertext and all the material supported by Geography Markup Language (GML) as it has been adapted by Google Earth. The initial content was constructed by volunteer students and was subsequently carried out and evaluated by the instructor. Despite the fact the refinement and evaluation process has revealed numerous discrepancies, the overall experiment has highlighted the value of collaborative model construction. The amount of effort required for the three dimensional modeling of the region that was covered by the experiment would be prohibitive for a single user. The implementation has shown the efficiency of the proposed design, under relatively demanding loads of concurrent access to the local database, as well as the more than adequate coverage of all desired functionalities. Last but not least, the prototype system and its use by the team of students have contributed a number of high quality 3D building models to the Google Earth community.

8 Future Work

Once the construction of a scene is completed, a question arises: how could we navigate or fly inside the scene, watching all interesting points while avoiding the rest of the information. The management and informative presentation of a large scale three dimensional scene is an issue which generates a great deal of heated debate one of the major problems of large city models. Beside the 3D models, if semantic knowledge is added on the scene, the user could be guided by the system to see only the desired information of the scene.

Moreover algorithms of best view can be applied on such a system to automatically guide navigation in the three dimensional environment, following a camera trajectory based on user's preferences.

Applications for a city 3D modeling system can be found in a variety of fields. Virtual tours can be achieved in places that one has not or cannot visit. In the field of tourism, a 3D city helps to develop and present a region to the rest of the world. Furthermore, simulations can be based on 3D city models, with respect to physical phenomena, evacuating processes, etc.

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