

A 3D COLLABORATIVE GEOSPATIAL AUGMENTED REALITY SYSTEM FOR URBAN DESIGN AND PLANNING PURPOSES

B. St-Aubin^a, M. Mostafavi^a, S. Roche^a, N. Dedual^b

^a Département des sciences géomatiques, Université Laval, Pavillon Louis Jacques Casault, Québec, Québec, G1K 7P4, Canada - (Bruno.St-Aubin.1@Ulaval.ca)

^b Department of Computer Science, Columbia University, 450 Computer Science Building, 1214 Amsterdam avenue, New York, New York, United States of America

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ABSTRACT:

In typical urban planning and design scenarios, good collaboration between implicated participants is fundamental but not necessarily easy to achieve. This can be due to a variety of factors ranging from the different backgrounds of the people involved to the complexity of the tools used by the experts. Furthermore, the collaborative aspect of urban planning and design is often limited to the meetings where designs and plans are assembled and discussed. This paper presents a system we designed to resolve those problems through a collaborative geospatial augmented reality application acting as an intuitive multi-user interactive scale model aiming to facilitate decision-making in urban planning and design projects. The proposed system integrates innovative technologies of geospatial augmented reality with tools for 3D modelling and spatial analysis in order to establish a collaborative augmented reality based urban planning and design system. Early results from our experimentations demonstrate the interesting potential of such a system for interactive and collaborative urban planning and design. The paper presents a comparison of the proposed approach with the existing ones and proposes further development as future work.

1. INTRODUCTION

Urban design and planning are complex and elaborate disciplines that involve concepts of economy, engineering, arts, architecture and much more [LYNCH 1984]. As such, it is only natural that decisional processes related to these fields involve participants from various domains of expertise. More often than not, this leads to a multitude of obstacles ranging from the complexity of the software and data involved to difficulties in communication due to the backgrounds of the participants implicated in the processes. These obstacles can severely hinder decision making in urban D&P, especially when the time comes for promoters to present scenario options to clients. This particular step in the decisional process usually involves a restricted numbers of participants that discuss and ultimately choose the option that best suits their needs.

The integration of the processes with geospatial technologies, mainly geographic information systems (GIS), has already shown that it can facilitate the processes in multiple ways. Many authors have demonstrated that conventional methods of integrating two-dimensional (2D) GIS technologies to urban D&P scenarios facilitate the decision making processes by allowing a deeper understanding of the underlying geospatial data [HANZL 2007, BATTY 1998]. Unconventional GIS solutions have also been proposed to address specific needs in urban D&P scenarios such as the need to document the decision making process for public participation review [CIOBANU 2006] or to follow the urban land use change through a temporal GIS [RAZA 1998]. A web-based multi-user GIS that allows voting, e-mail communication, and exhibition of points of conflicts is one example of a well developed collaborative GIS for use in urban D&P [VOSS 2004].

While the solutions proposed have undeniable advantages, they still contain significant obstacles to successful public participation. Mainly, they are rigid solutions that are difficult to adapt to different scenarios that may arise during public consultation meetings. These applications are also very limited in their user base since they still require an important degree of familiarity to operate. Finally, their technical limits keep them from capitalizing on the full spectrum of increasingly available, high resolution three dimensional (3D) data. Augmented reality (AR), the process of overlaying computer-generated images spatially registered to the real world, is an increasingly popular technology that can overcome these obstacles.

The motivation behind this research was to explore the potential of AR as a tool facilitating decisional processes in the context of urban D&P. In order to facilitate these decisional processes, the solution we designed addresses three specific problems in conventional geomatics tools, their inability to manage 3D geospatial data, their complexity of use and their inability to provide multi-user working environments. The goal of this paper is to put forth the result of our research which took the form of a complete working geospatial AR system. Our contribution consists in an integration of AR technology to basic 3D GIS functionalities that is intended to show that AR, coupled with 3D GIS is a possible solution to the previously identified obstacles. This solution allows the quick and simple creation of a 3D geospatial scene and implements intuitive methods of interaction by means of marker-based AR. It also allows collaborative participation to some degree and proposes avenues to make it a fully collaborative AR solution.

The remainder of this paper goes as follows: Section 2 presents a brief literature review on AR and its potentials. Section 3 describes the methodology used for the development of the

proposed collaborative system. The results are then presented and discussed in section 4 and we conclude in section 5.

2. LITERARY REVIEW

AR enables users to visualize three-dimensional virtual objects that are registered to the physical reality and allows interaction with them through physical means. Through the use of a head-worn display, we are able to replace the user's view of the real world by an augmented world [AZUMA 1997]. A basic AR system is composed of three components, a computational unit, a tracking system and display system (see figure 1).

Augmented reality has had many uses in improving various types of decision-making process. For example, an AR system was conceived to generate and display a volumetric rendering of Computed Tomography (CT) images, as well as radiation dosage treatment plans, which could be used by physicians to determine the effectiveness of a potential treatment may have on a patient [WANG C]. AR systems have also been put to use to quickly assess a disaster area and provide a decision support system in such a situation [HAYASHI K 2004].

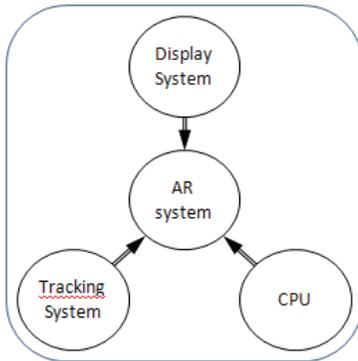


Figure 1 : The basic components of an AR system

Furthermore, there has been some work in incorporating AR technologies into GIS systems for various purposes in outdoor environments. ARVino is a system that allowed users to project viticulture information onto the real-world environment, in order to grant viticulturists access to GIS data as they visually examined their vineyards [KING G 2005]. Studies have also been conducted to validate that outdoor AR systems conform to the geospatial cognition system inherent in human beings [WU X 2008]. Finally, AR systems have also been designed for collaborative design and task planning tools. An application was designed to facilitate collaborative planning of production lines by modeling machines as virtual blocks, which were then positioned by the user through a visually-tracked paddle [GAUSEMEIER 2002]. ARTHUR is another AR system that utilizes a round tabletop interface to track users and project virtual models. It also allows 3D computer aided design of virtual models in order to facilitate complex design and planning decisions by architects [BROLL 2004]. However, these solutions have limited capabilities in terms of spatial data management. The next section presents our proposed system integrating AR with 3D GIS capabilities that address some of these limitations.

3. METHODOLOGY

3.1 General approach

The overall methodology adopted over the course of this project was based on the Unified Process (UP) approach since we had a vague idea of the system we wanted to create at first [BEDARD 2009]. Although we did follow all the regular steps of the UP approach, we will not discuss the inception phase since it was mostly done informally through meetings with experts. These meetings helped us identify specific functionalities needed to answer the needs of urban designers and confirmed that collaborative AR tools possessed the capacities to facilitate decisional processes in urban D&P. The transition phase will also be left aside since it is ongoing at the moment of writing this paper. This last phase will entail usability testing with users from different backgrounds.

3.2 Elaboration phase

The elaboration phase of the project consisted in establishing a simple, cost-effective and functional hardware setup for a collaborative indoor AR application. This first phase was conducted following an exploratory approach in order to study the feasibility of different possibilities regarding the various components of a collaborative AR system. Implementation tests were conducted in order to determine the most appropriate configuration for the helmet worn display and the tracking system. Since the objective was to develop an indoor system, computer hardware was not as much an issue as it can be in mobile AR systems for example.

Over the course of this phase, optical see-through AR displays were evaluated against video see through displays, the criteria for selection being the simplicity of their implementation, their cost, and degree of possible immersion. Different tracking systems based on fiducial markers, colour recognition and infrared sensors were evaluated according to their portability, simplicity of implementation and accuracy of tracking. The expected result of this phase was a working system architecture on which to build or geospatial AR system (see figure 2).

3.3 Construction phase

The aim of the construction phase of our project was two-fold. The first goal was the conception of a flexible, reusable and simple geospatial collaborative augmented reality framework to allow the creation of complex 3D geospatial augmented reality system (3DGARS). Once settled on a library for our augmented reality needs, we built the geospatial framework around it. The second goal was to create a concrete application allowing the use of the framework conceived. An evolutionary prototyping method was followed throughout the course of construction phase. The evolutionary cycles of this method comprised three steps, a conceptual effort, framework development and rapid prototyping of a solution.

A conceptual effort was conducted in order to provide insight in the classes and the behaviour needed to answer the users' needs, specifically in the context of urban D&P. This involved regular round-tables with architects and professors in architecture, which helped us identify their specific needs in a 3DGARS. They also allowed us to obtain feedback on the various prototypes conceived during the last stage of this evolutionary process.

The second step of the cycle was the development of the framework considering the comments received during previously mentioned meetings. This implied creating new classes, modifying existing ones and creating functions to address specific needs. A strongly object-oriented approach was adopted instead of relational approaches used in traditional spatial databases. This approach was chosen in order to favour the reusability of the classes developed and even more interestingly, to allow abstraction mechanisms for the natural representation of spatial objects [ABDUL-RAHMAN, 2007].

The final step of the cycle was to develop or modify the prototypes following the changes in the framework made in the previous stage. The focus of this step was to conceive intuitive user interfaces that would allow the creation and managing of 3D geospatial scenes as well as intuitive user interaction with the data represented in the scene, through AR technologies. The prototypes produced at this point were usually demonstrated, discussed and briefly tested during regular meetings, thus completing a cycle of the evolutionary process. The various prototypes produced during this step eventually became the complete application that we used to test our framework.

4. RESULTS

4.1 The components of the AR system

After studying and testing infrared, colour and marker-based indoor tracking systems according to the criteria mentioned previously, it was determined that marker-based tracking systems offered the best option for our needs. It offers robust tracking, excellent portability and is the easiest to implement due to abundant documentation and examples available.

	Marker	Colour	Infrared
Simplicity	2	3	1
Portability	3	3	1
Accuracy	3	1	2

Table 1 : Comparison of tracking systems (1 is lowest, 3 is highest)

Colour tracking, while very easy to implement, is inadequate because it is simply not a stable method of tracking, it is highly susceptible to light and camera changes. It also poses the obvious problem of interference with objects of the same colour as the tracking colour chosen which means the environment of operation must be controlled to avoid the presence of the chosen tracking colour. Infrared tracking also poses certain prohibitive limits. It requires that the objects to be tracked be able to emit or receive infrared emissions, which means adding infrared reflective identifiers to the objects to be tracked. Furthermore, to achieve true 3D tracking by infrared requires the use of multiple cameras fixed in the environment of operation, hence its unviable portability. Marker based tracking proved to be the most robust way of registering the real world to the virtual world. This is due to the fact that the markers are of known shapes that can be recognized through computer vision algorithms. This allows the use of distortion models to calculate the orientation and position of the virtual objects to register to the real world. In light of this, marker based tracking was the option retained.

The marker tracking library we chose, GoblinXNA, proved particularly easy to implement compared to others. GoblinXNA is an extensive framework for research on augmented and

virtual reality [ODA 2009]. It is based on Microsoft XNA Game Studio 3.0, and written in C#. The framework supports 6DOF (six degrees of freedom) position and orientation tracking using optical marker-based tracking, in addition to providing a 3D scene graph, rigid body physics simulation, networking for multi-user environments, shaders, particle systems, and 2D user interface primitives. The fact that GoblinXNA has an integrated 3D engine also greatly facilitated the development of our framework and application.

The choice of the type of helmet worn display to use was rather straightforward since optical see through displays have prohibitive price tags compared to video see-through displays. However, we have still conducted a study of the other criteria mentioned, and have found that video see-through provides the least immersive but easiest to implement solution of both technologies. With optical see-through device, it is much harder to achieve a complete registration of the virtual objects to the physical world due to the latency in the registration process. In video see-through displays, the video shown to the user is the same one that is used to calculate orientation and position, by not showing the video frame until the image processing is done, accurate registration is achieved. On the other hand, optical displays cannot allow the delay of what is shown to the user since he is looking directly at the real world. This introduces latency in the registration of the virtual objects, especially when movement of the head is fast or when the object that the virtual object is attached to, moves [ARTOOLWORKS 2007].

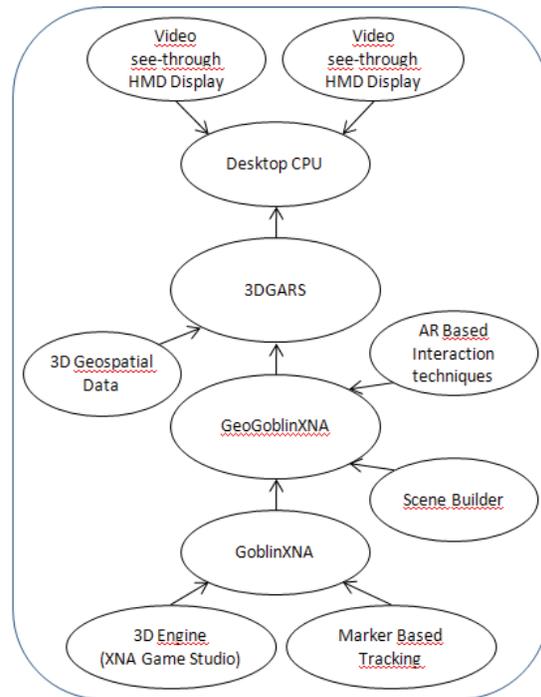


Figure 2 : Our 3DGARS system architecture

4.2 GeoGoblinXNA, a geospatial AR framework

The geospatial augmented reality framework that was conceived, baptized GeoGoblinXNA, was built around the previously mentioned library, GoblinXNA. Briefly put, GeoGoblinXNA's goal is to simplify everything related to managing 3D Graphics and the AR technologies in order to prioritize the spatial and thematic aspect of the data involved.

The basic data structure offered by GoblinXNA is based upon conventional scene graph data structures like Open Scene Graph [OSG COMMUNITY 2007]. Therefore, it is not suited to stock and manage thematic data. As a solution to this problem, a geospatial scene graph data structure was developed to allow the managing of thematic data. This modification integrates the spatial and thematic object in

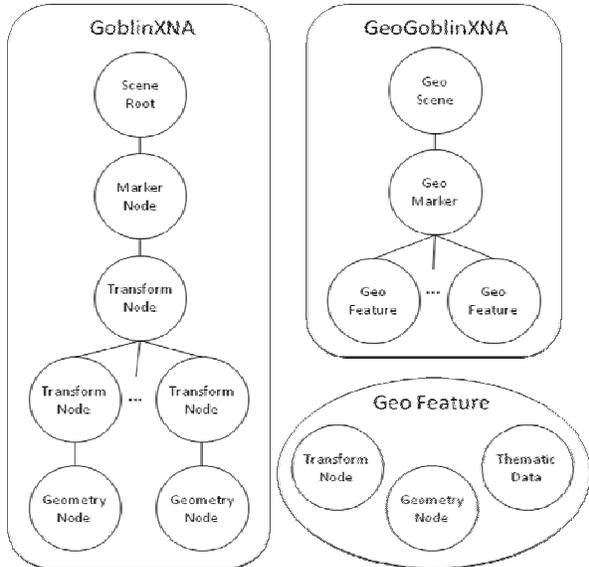


Figure 3 : A standard GoblinXNA data structure (left) compared to a standard GeoGoblinXNA data Structure (top right). The GeoFeature class is also shown (lower right), note the added thematic data object.

Besides the addition of thematic data managing, the simplicity of GeoGoblinXNA has obvious benefits when developing a 3DGARS. For example, the original process of adding a spatial feature in a scene graph, is changed from creating the geometry node, then the parent transform node, then individually initializing each of them and finally linking them together, to simply creating and adding an object of the type *GeoFeature*. Of course, functions have also been developed to just as simply remove an item from the scene, be it a marker or a feature. These functions allow for greater flexibility as well as more intuitive development of a complete application. Other functionalities include basic thematic query handling, input and output functions, adding of geometric shapes to the scene and transferring features between markers. In our 3DGARS these functionalities are available through a windows form interface accordingly named, the Scene Builder (see figure 4).

GeoGoblinXNA also implements novel methods of interaction with the augmented environment that are designed to be used by the public at large. To this end, a virtual-hand pointer, which is a combination of the image plane, pointing and virtual hand selection techniques [BOLT 1980, PIERCE 1997] was conceived. We chose an amalgam of these techniques, instead of relying on a single one, as each technique has faults which we wanted to overcome. For example, a typical pointing technique would require that we project a ray from our toolbar location onto the model space. Since our model space is large, this would mean that faraway objects cannot be reliably selected, due to the amplified hand jitter motion. Alternatively, image plane based selection techniques would have provided us with the ability to select objects based on their position on the

image plane, thereby easing our ability to select further objects that are visible to the user, but selecting objects located close to one another becomes quite confusing. Finally, a virtual hand selection technique would allow us to select objects that may be obstructed by other virtual objects, but this is only possible within a limited range. By combining the strengths of each technique, GeoGoblinXNA defines an interaction technique that is able to select both nearby and faraway virtual objects while providing a seamless transition between our projected environment and our notebook.

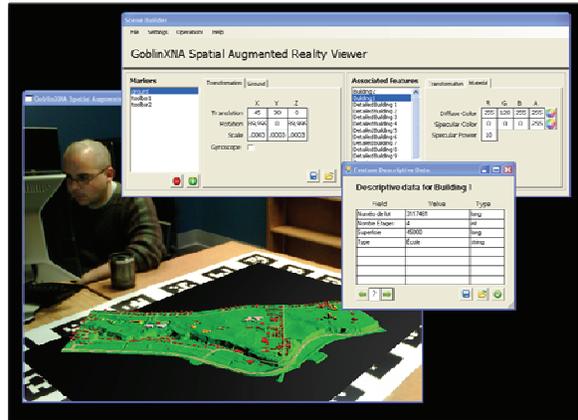


Figure 4 : A user in the process of creating and managing a 3D geospatial scene with the aid of the Scene Builder interface

Once a virtual environment is present, the user is able to select a virtual feature of interest by moving his or her virtual hand pointer to the image plane location of the model. This will automatically colour the building model light blue, indicating that the user has selected a building and the system is awaiting confirmation of said selection. The user then confirms their selection by pressing the left mouse button. GeoGoblinXNA uses a toolbar-laden mouse instead of other techniques and devices such as gestures with toolbars because the mouse is a device that almost everyone is familiar with, requires little training to use, allows for easy integration with our virtual-hand pointer, and enables us to design a simple, streamlined interface, since the mouse/toolbar combo allows for both continuous pointer manipulation and discrete trigger activation. Once a building has been selected, the building moves to the notebook focus area. Clicking on the building model while it is selected will deselect the building.

In order to display a selected feature's information, a virtual notebook object has also been created. The notebook environment allows the manipulation and extraction of specific thematic information about the feature selected. The model of the selected feature is displayed on the left-hand side while a series of textboxes on the right-hand side is used to display thematic information related to the selected feature. It is then possible for the user to rotate the selected feature model along the vertical axis. To rotate the model, the virtual-hand pointer must be placed over one of the two arrowheads that are on each side of the model. Depending on the hovered arrowhead, the model will rotate either clockwise or counter clockwise. Finally, a button has also been added to show results of a query prepared using the Scene Builder object.

GeoGoblinXNA currently supports a server-client type of collaborative work within its augmented environment. In other words, a server-side user can create and manage a 3D geospatial scene and client-side users can connect to the server-side application. Upon connection, and whenever changes to the 3D scene are made by the server-side user, the updated scene is sent to each of the clients through a network connection. More precisely, when the server user alters the 3D scene, the modifications are sent through the network to the client users. Each client then processes these edits, whereupon they alter their respective views of the scene accordingly. Given that these modifications are made relative to the set of markers used, the position and orientation from which each user is viewing the set of markers is inconsequential. The end effect is that each user sees the corresponding modification correctly executed from their perspective. The server-client connection also allows for users to visualize thematic queries that can be prepared by the server user through the Scene Builder interface. Once the queries have been prepared by the server user, the clients can highlight the queried objects by clicking on a specific button in the virtual notebook. This functionality was specifically developed in order to facilitate group decisional processes by highlighting objects of interest in the 3D scene. The collaborative environment is intended to be used in a way that a master user can direct discussion between client users.

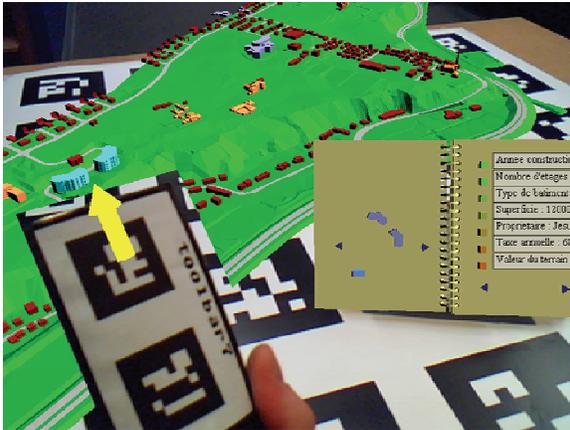


Figure 5 : A user in the process of interacting with a 3D geospatial scene by AR means

5. DISCUSSION

The geospatial AR framework put forth in this paper allows the creation of geospatial AR systems that could bring a viable solution to the inherent problems of public participation in urban D&P decision making process. It proposes concrete answers to the obstacles identified in the beginning of this paper. On the contrary to the unconventional and conventional GIS solutions conceived by Ciobanu, Raza, Hanzl or Batty, our solution allows the use of high resolution 3D geospatial data and provides intuitive interaction methods for a non-expert user-base. Due to its strongly object oriented approach, it is also a highly flexible solution which could be adapted to any given scenarios, unlike many other applications where the code is written in accordance to the scenario. It also accommodates any types of feature (buildings, roads, fire hydrants, etc.) since the feature object and his attributes are of generic types. This class could be made into an abstract class from which other specialized classes could be created. This was not integrated to our solution since it is very time-consuming, however it is easy

to implement and should be implemented since it would facilitate query and descriptive data manipulation.

While the AR technologies put to use by our solution are not particularly ground-breaking, their integration to GIS concepts is innovative. Most of the AR projects cited in this paper were designed to be used in rigid conditions, for very specific scenarios [WANG 2009, GAUSEMEIER 2002] and as such are not adapted to GIS technology. In a GIS, it is important to allow an indefinite number of features to be represented. Flexible thematic data structure in the features is also primordial since multiple types of features may be present in any given region. The system proposed by King, though very impressive, takes in account that only GIS data related to viticulture is needed. The graphic user interface used also has some limits, it does not allow for easy input of information by the user.

However, our solution still possesses some issues that were unforeseen due to our mostly geospatial approach to the problem. For example, we hoped in the beginning to be able to drape satellite imagery over our topography model, which is easy to achieve with standard GIS like Esri's ArcGIS. However this proved impossible for us since the 3D engine used requires for strictly power of two textures (size $2^n \times 2^n$). Furthermore, 3D engines are not conceived to work with spatial reference like 2D GIS are. Some more work would be required in order to incorporate this aspect within the cascading transformation principles of scene graph data structure. Lastly, we have found that integrating spatial analysis in our solution, a crucial aspect of conventional GIS, was very difficult due to the 3D nature of the data. 3D spatial analysis would definitely warrant another research project of its own.

The AR interaction aspect of our proposed solution also contains some limits due to the nature of the tracking system chosen. Of course, to work with marker based tracking systems, the markers need to be visible at all time in order to see their associated information. In the case of the notebook and pointer interaction method, it can become difficult to point on the notebook since the pointer marker can occlude the notebook marker. This difficulty could be alleviated by migrating to an AR library that permits the creation of custom markers like ALVAR for example [VTT 2008].

Issues related to the spatial database of the solution are also present. While a strongly object-oriented approach for the development of the system simplifies coding, it greatly hinders the spatial query process. Had this problem been foreseen, a hybrid between object oriented and relational databases approach could have been conceived. Furthermore, it would be very beneficial for our application to migrate to an external database as it would simplify the input and output process, improve networking capabilities and greatly simplify the querying process by allowing access to regular SQL queries.

Finally, the collaborative capabilities of our solution were, regrettably, not as advanced as we had hoped. While it does allow limited collaborative work in the form of multiple users extracting information from the scene, it does not allow for communication by other means than the natural voice of the users nor does it allow multiple users affecting the 3D scene simultaneously. However, the framework upon which GeoGoblinXNA is built supports client to client networking. Therefore, it would be possible to implement such a mode of collaboration between users in GeoGoblinXNA. The ARTHUR

system is a good example of the collaborative capabilities we had hoped to achieve with our 3DGARS.

6. CONCLUSION

In this paper, we proposed a 3D geospatial augmented reality system based on a framework we developed called GeoGoblinXNA. The framework created allows for developers to simply and quickly create a 3D geospatial augmented reality system applied to a desired scenario. The 3DGARS we conceived to answer particular needs in urban D&P is an example of the type of application that can be conceived using our geospatial augmented reality framework. Our application allows the quick creation of a 3D geospatial scene, with descriptive data and also permits user interaction by AR through a virtual notebook and 3D pointer.

The development of this system was intended to show that the integration of collaborative AR technology to 3D GIS is a solution that could answer problems that stem from collaborative urban D&P scenarios. Preliminary tests we have conducted show that user interaction is very intuitive, more so than regular GIS interfaces. Although advantages of using 3DGARS have been demonstrated, there are still many problems limiting the usefulness of this solution. Given enough time, most of the problems identified could be addressed. The problems related to the rendering of 3D graphics would require the intervention of developers specialized in that field.

Although multiple avenues could be considered for future work on this framework, our priorities are focused on the expansion of its collaborative capabilities as well as the migration to a hybrid object-oriented and relational database data structure.

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