Can VR be Useful and Usable in Real-World Contexts? Observations from the Application and Evaluation of VR in Realistic Usage Conditions

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Abstract

This paper presents our observations from the use of high-end projection-based VR in different real-world settings, with practitioners but also novice users that do not normally use VR in their everyday practice. We developed two applications for two different content domains and present case studies of actual experiences with professionals and students who used these as part of their work or during their museum visit. Emphasis is given on usability issues and evaluation of effectiveness, as well as on our thoughts on the efficacy of the long term deployment of VR under realistic usage conditions, especially when the technology becomes mundane and the content takes precedence over the display medium. We will present an overall assessment of our experience, on issues relating to usability and user satisfaction with VR in real-world contexts.

1 Introduction

The majority of Virtual Reality (VR) applications developed today consists of research products that are either industrial prototypes created within very specific contexts or are used for presentation purposes. Despite the promise and the development activity of over two decades, there has been a considerable lack of real-world applications. The issues regarding the deployment of VR in everyday work contexts have been discussed many times and continue to revolve around the familiar practical difficulties: setting up special and costly hardware within facilities that are not easily transportable, requiring special teams of developers and maintenance staff, but also providing the high-level tools that will support users in their complex tasks (Neale, Cobb, & Wilson, 2002) and can succeed in establishing a collaborative VR work environment amongst individuals of different disciplines (Mackay & Fayard, 1997).

Experienced practitioners in the field of VR have indicated that to work effectively in a Virtual Environment (VE), the application content must include the ability to access or change environmental/system/meta parameters, create and manipulate particular objects, perform analyses, and export changes to permanent storage (Sowizral et al., 1995). While the current state of VE development has advanced its techniques to support these tasks, rarely does one find complete VEs that achieve both a high-quality photorealistic real-time environment and the level of interactivity required to carry out sufficiently complex real-world tasks.

Our goal was to create a VE infrastructure supporting both audio and visual realism and a high level of interactivity, and to situate and evaluate its utility in an appropriate *real-world application* context. We chose two different yet, in many ways, interrelated domains of application: the world of architectural design and urban planning (UP), where realism and interactivity are inherent requirements of the work process, and the domain of archaeological reconstruction, especially when this is used to educate on cultural heritage topics. A detailed user requirements analysis with the different end-users, that is architects, urban planners, archaeologists, educators, and children (Roussou, Sideris et al., 2004), confirmed the suitability of our choices and led to a detailed study of the existing workflow in these domains. A key element of this work has been our close collaboration throughout the entire project with the end-users of real-world projects in the two domains. The architectural and urban planning project involves the redesign of public spaces as part of the construction of a new Tramway in the city of Nice in France. The archaeological project involves the reconstruction of the ancient Doric temple of Messene in Greece.

Following our initial user needs analysis that guided our choices and design, we proceeded with the development of a complete VE for each case, which was continuously informed by the participation of the end-users of the real projects. Additionally, development and evaluation advanced together in order to determine the elements required to make the VEs useful in the context of the real-world project we were fortunate to connect to. The resulting VEs provide, in the one case, a design and brainstorming tool for architects and decision makers that also serves as a consensus building tool and as a presentation tool for the project; and in the other case, a multi-modal and engaging learning environment for archaeologists, educators and students.

In addition to the design approach, our work included in-depth formative and preliminary summative evaluation. Evaluation was performed based on observation, questionnaires and interviews with architects that took place both in a controlled lab experiment setting as well as in the ``field'', i.e. the actual work environment where the VE was used in decision-making meetings of the urban planning project. Similarly, observation, questionnaires and interviews were used with the archaeologists, educators and the children users of the cultural heritage production.

2 Related Work

Virtual reality development for architectural design and urban planning applications can be roughly grouped into two categories: applications that display detailed 3D CAD models of architectural spaces/structures and rapid prototyping systems. In the first case, the challenge has been to visualize large data sets in as photorealistic a fashion as possible. These environments are mostly used for presentation, recreation, and educational purposes (e.g. review of architecture before it is actually built, cultural heritage reconstructions, 3D entertainment rides, etc.) where complex 3D spaces are constructed so they can be explored in walk-throughs (Brooks, 1986); (Houston, Niederauer, Agrawala, & Humphreys, 2004). The majority of these projects allow for little interactivity beyond the user's ability to freely navigate about the environment.

On the other hand, the virtual prototyping environments allow immersive VR to be used in earlier phases of a design process and are thus designed to incorporate a higher level of interactivity and object manipulability. In most cases, these capabilities are implemented at the expense of visual realism, as they have been developed by computer scientists in order to further advance research in VR tools. Furthermore, most of these environments support only trivial user tasks and thus cannot be used in real-world situations yet. Nevertheless, many interesting ideas have been introduced by architectural prototyping projects that we can draw from. The CALVIN project (Leigh, Johnson, Vasilakis, & DeFanti, 1996), for example, introduced the idea of different perspectives, the mortal (ground-level) viewpoint and the deity (global above-ground) viewpoint, either of which users can assume to interact collaboratively in designing a space in VR. Other projects, such as ARTHUR (Broll et al., 2004) or BUILD-IT (Rautenberg et al., 1998), have developed novel interfaces to support and augment the collaborative workspace or to provide rapid sketching tools that facilitate the understanding of spatial features in urban design and consultation (Seichter, 2003).

The core idea from the beginning of our project has been to combine the strengths of the above two categories of virtual environments, namely to achieve the realistic visualization/auralization of a large space coupled with the ability to use it early on in the design process as an interactive work tool. Essentially, our goal is to create a virtual space that can complement and enrich people's day-to-day work practice in a useful and meaningful way, an application that would allow both design and review to take place in a VE. In order to achieve this we chose two ongoing real-world projects which formed the case studies described next.

3 Case Study #1: VR in a Real-World Urban Planning Context

The city of Nice and the Greater Nice-Cote d'Azur Urban Community (CANCA) recently decided to build a Tramway. The Mission Tramway project involves 8 km of rail in the densest parts of the city, requiring the re-design of several open spaces such as the main city squares, “Place Garibaldi” and “Place Massena”. We established a working relationship with the officials and the company of architects in charge of the project.

The basic premise of our VE design approach has been to engage the users from the first steps of the design. Putting such an approach into practice requires collecting and analyzing as much information about our users as possible, through a detailed user requirements process and a deep understanding of how they work. Hence, a preliminary survey was first undertaken with architects, chief engineers and decision makers of the project, followed by a study of the traditional workflow employed (Drettakis et al., 2005). We then determined the elements required to make the

VE useful in the real-world setting, choosing appropriate elements to develop a rich and audio visually realistic VE (Roussou, Drettakis, Tsingos, Reche, & Gallo, 2004). This preliminary work also guided the development of an appropriate interface and an evaluation methodology to test the overall usability of the system.

The result of our working relationship led to a closer collaboration with the architects on the re-design of "Place Garibaldi" (a central square in the city of Nice), and enabled us to gain access to all the project data. The architectural design of this square was of major importance to the city, since it is considered a historic landmark. As such, many stakeholders participated in the decision making process, including the mayor, the officials of the city council in charge of open spaces and public works, and other authorities at a national level who generally have a definitive say in any modification of a historical space. There is also a public hearing which occurred at the beginning and continued throughout the design process. Our collaboration was founded on the principle of mutual benefit. We were interested in studying and understanding the workflow to allow us to design novel VE tools that combine realism and interactivity, and to apply them in a real-world setting. The architects and decision makers of the Mission Tramway were interested in using the resulting interactive VE as an aid in decision making and brainstorming, as well as an impressive means for presentation of the project.

The VE that was finally developed included the ability to experience the reconstructed square from multiple different views (top-down, perspective or "balcony" view, and ground-view) and work within all these views. The user activities allowed included selecting, resizing, and positioning different types of trees, benches, umbrellas, and other elements, as well as different transport modeling scenarios that aided in visualizing the overall effect that the tram would have on the square. Finally, the visualization elements included image-based textures for facades, realistic vegetation, shadows, 3D sound, crowds, and, of course, the representation of the tramway and traffic (Drettakis, Roussou, Tsingos, Reche, & Gallo, 2004).

4 Case Study #2: VR in Support of Archaeological Research and Education

The second case study concerns the archaeological site of ancient Messene in Greece, specifically the study of the excavated Doric temple of the site. The temple is preserved in poor state, but there are a considerable number of architectural members found in the adjacent area, all of them well documented and interpreted by the Society for Messenian Studies, the archaeologists responsible for the excavation of the site.

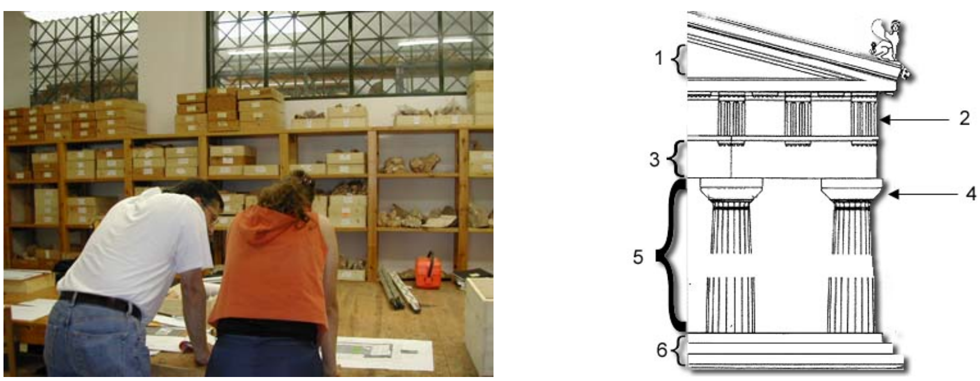

Figure 1: Working with archaeologists to define the virtual reconstruction task (left). Cross section of a temple, indicating the different members that the user manipulates in the VE (right).

We worked with the archaeologists of the Society in order to identify their needs and also to identify the users who would benefit from a VE that will visualize the process of an archaeological reconstruction (Figure 1). As a result, restoration architects and archaeologists (especially archaeology students) were identified as the domain experts, who would use the VE as a tool for the exploration and validation of varied reconstruction hypotheses. To date, the tools available for this purpose are usually low-tech, low-accuracy models that cannot give the correct impression of scale and context. We also worked with the museum educators of the Foundation of the Hellenic World, a cultural heritage center in Athens with a CAVE-like display open to the public, who expressed the need for a similar VE that could be used in the context of a museum learning activity. In this case, adult and younger museum visitors, attracted by the interactive learning aspects of VR, would use a highly realistic interactive environment to learn more about history and archaeology.

The VE that was developed accurately represents a representative section of the temple, which the user must reconstruct. The user's activity in this VE resembles creative child's play with a construction kit: users of the environment must select the correct architectural members and position them appropriately. The process of virtually "building" parts of the temple provides the opportunity to actively experiment with different possibilities and solutions during the virtual reconstruction and to explore alternative scenarios. The environment also includes an instructional component, which provides novice users with information and the terminology used for each part of the reconstruction. Due to the tactile nature of the task, we decided to use a Haptic Interface, designed by PERCRO, as the main interface of interaction between the user and the VE.

5 Evaluation

Our evaluation methodology draws from the structured framework proposed by (Gabbard, Hix, & SwanII, 1999); (Bowman, Gabbard, & Hix, 2002) for the design and evaluation of user activity in VEs. This includes the combination of user needs analysis, user task scenarios, usability evaluation and formative evaluation, and preliminary summative evaluation.

The user needs analysis was carried out at the very beginning of the project and led to the definition of the user task scenarios that were used in the evaluation sessions. Usability evaluation forms a central tenet of our evaluation methodology, as it involves observing the users of the VE in order to determine if the VE aids or hinders them in reaching their intended goals. Given the nature of our project, we chose to limit our testing to a small number of users and follow an in-depth qualitative approach. One of the reasons for this is the obvious practical difficulty in evaluations within real-world situations, i.e., getting busy, highly qualified professionals to agree in participating in experimentation, which requires a significant investment in time. Other reasons include the highly experimental nature of the prototypes and the use of innovative and relatively inaccessible equipment (tracked immersive VR displays). We believe that for this project, case studies, where small groups of users are studied in depth, are more useful for gaining insights into the effectiveness and efficiency of our system, and come as a natural continuation to the design process that preceded the evaluation.

Figure 2: View of the urban planning VE on a curved presentation display (left) and an architect using it on an immersive workbench (right).

The methods used in our evaluation included direct observation, a post-experiment questionnaire and post-experiment interviews.

Direct observation. Users performed the various tasks whilst being observed by a facilitator. Users were encouraged to use a think-aloud protocol (Ericsson & Simon, 1985) to explain what they are doing, to ask questions and to give information. The facilitator used an interactive style, asking users to expand upon comments and activities. Sessions were also videotaped for further analysis.

Questionnaire. A usability questionnaire was developed to identify the user's perception of the effectiveness and efficiency of the system and their level of satisfaction with the interaction. Our questionnaire was constructed by merging a number of standard user satisfaction questionnaires, such as the approaches provided by Perlman (Perlman, 2004) and others (Davis, 1989). The questionnaires include questions that require answers on a 1-7 Likert scale (Likert, 1967).

Interviews. An informal interview following the experience was used to help identify the various issues that occurred during the experience and that could not be captured by the questionnaire. The interview was particularly important for understanding the issues involved in the in situ usage of the system, where the use of a questionnaire does not make sense.

5.1 Evaluation of Case Study #1

5.1.1 Controlled Evaluation and Situated Use

The “Place Garibaldi” VE was evaluated both in the laboratory (controlled) and in the users' natural work environments (situated). Usability testing was conducted in the controlled setting of our laboratory with three of the collaborating professional architects, all directly implicated in the Nice Tramway project, and specifically in the design of the new Garibaldi square. Prior to the sessions with the architects, we ran pilot studies with engineers who had no previous VR or computer graphics experience. The main experiment was preceded by a simple training environment in order to allow the user to learn the interface. The experiment took place on a Barco Baron workbench. Each subject was head-tracked, wore active stereo glasses, and used a tracked game controller for interaction (Figure 2).

The users were asked to carry out a set of predefined tasks. The tasks used for the usability evaluation accurately represented the intended actual use of the application and occurred within a realistic scenario. The overall goal in using the VR tool, as defined by the users themselves from the beginning of the project, was to “create, define the appropriate size and position of design elements (different umbrellas and benches), and to evaluate the occupation of space and overall aesthetic effect on the new design of the square”.

The main experiment VE included the entire environment of the new design of Place Garibaldi. The task was to place, size and arrange the umbrellas and stone benches in regions close to the orange trees. The user was asked to first position the elements, then determine the size (height and size) of the umbrellas and the placement of the benches, and finally to evaluate the “presence” and “occupation” of the square.

Each user was presented with the top-view at the outset, and was told to create and place umbrellas and benches, starting with the lower right corner. The user would insert a primitive (umbrella or bench), and typically position it in top-view. The users were reminded that they could switch freely between views. In a typical session, the user would place a set of umbrellas, either aligned or not, to populate the space. They would then switch to perspective view to correct or adjust placement, and to resize the width and height of the umbrellas. Balcony view was often used to judge the design.

In addition to the controlled lab experiments, the system has been used at several different occasions in the context of the real project. This was part of the agreement, in which the authorities provided us access to the architects and the data in exchange for their use of our system. We visited the authorities and the architectural offices at several occasions. One of these meetings concerned the discussion of a planned proposal for the choice of the type of trees to be used in the square. The choices included either the 3 meter-high orange trees or the 8-meter high oak. The working group was comprised of 3 high-ranking city officials, in charge of public spaces and urban planning, 4 city middle-level managers who were mainly architects concerned with the overall view of the project, 2 officials from the Mission Tramway, and the architect in charge of the overall project. The two scenarios (orange trees and oak trees) were mapped onto two different buttons on the handheld device. The members of the working group used the tool to explore the different views and locations provided for the virtual square and to make different choices. They chose one or another type of tree in different places in the square in order to test spatial relationships, the placement of objects, but also the different effect of shadows etc.

Another instance of field deployment involved the use of the full VE system (tracked stereo-vision workbench) for a brainstorming session. Two of the main architects and the designer of the project participated in this session and used the system as an opportunity to discuss issues concerning the design of the square, most notably the choice of trees and ground elements.

5.1.2 Observations

After completing the controlled lab experiment, each of the three architects was asked to complete the questionnaire and participated in the post-experiment interview that followed. We studied the videotaped sessions in order to better reflect on the important issues and difficulties that were expressed by the users during their interaction with the system. Similarly, we studied the data we had collected from our observation of the city officials and architects that used the VE as part of the in situ experience.

In terms of learnability and ease of use, all participants ranked the system as easy to learn (6 or 7 on the Likert scale) and stated that they were able to use the tool without difficulty. We were particularly pleased with this result, since the majority our subjects had no prior experience with interactive 3D systems or video games.

In terms of effectiveness and efficiency, there was a uniform approval (6 or 7 on the Likert scale) of the utility of the tool and the fact that the system would improve productivity in the workplace. The top view, although familiar to the users through the use of conventional paper renderings, was judged moderately useful in its VR version (3-5 on the Likert scale). From observing the videos and the interviews it became clear that the precision of manipulation when using this view was insufficient. In retrospect this was to be expected, since the distance from the object being manipulated is too large. Clearly, the best solution to this is a mixed 2D-3D interface, where a “pen-like” interface could be used to directly place objects onto the top-view, as is currently done in existing CAD tools. In fact, the need to have the same interface as CAD tools for these tasks was explicitly mentioned by one user who also asked to have menus present in the other views (balcony view and ground view). On the other hand, another user stated that one of the main values of the system was that it removes the “break” which exists between traditional 3D CAD systems and the resulting design. Additionally, one participant stated that the perception of ambience and scale were extremely useful and important for an architect in the evaluation of an urban planning project, and found that the tool had great potential for brainstorming and interactively trying out different alternatives.

In terms of VE interface features, the “balcony” view was used extensively and was greatly appreciated by all participants. All users agreed that this was a particularly useful view of the environment, and that it helped in their judgment of the resulting design, but also during the design. This is attributed to the fact that the VE environment followed the real design process, since the choice and successful design of these views was based on our observation and understanding of how the users actually work, and their continuous input throughout the design-development-evaluation cycles. Finally, in terms of satisfaction, all users stated both in the questionnaire and in the interviews that they liked the tool.

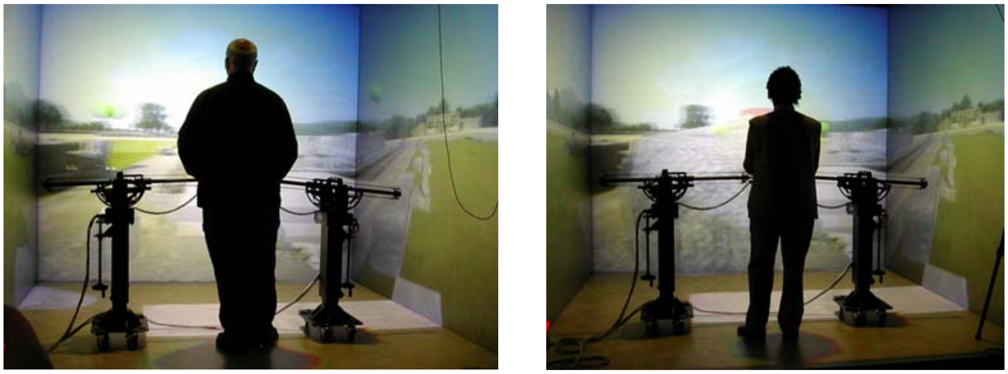

Figure 3: Archaeologists and educators participate in the evaluation of the virtual reconstruction tool, using a haptic Interface device designed by PERCRO (http://www.percro.org/).

5.2 Evaluation of Case Study #2

5.2.1 Sessions with Content Experts and Museum Visitors

We tested the archaeological activity environment with expert and novice users in the context of a museum, with three different categories of users: adult novice users (museum visitors), young novice users (museum visitors between 9 and 14), and adult domain experts (archaeologists and educators). All studies took place in the Foundation of the Hellenic World's cubic immersive (CAVE®-like) display, during or after normal museum hours. All novice users (adults and children) were family visitors who spent their day at the museum.

Overall, we ran complete sessions with a total of 14 adults, 7 of which were novice users and 7 content domain experts (Figure 3), and with 7 children between 9 and 14 years of age (Figure 4). In addition, we collected opinion questionnaires concerning the haptic interface from 25 more museum visitors after their experience with the environment, particularly the use of the haptic interface.

The instruments used were questionnaires and informal interviews. A usability and presence questionnaire was used after the experience for all users. Additionally, for the non-expert users, a pre-test questionnaire was used to test prior knowledge and then a similar post-test questionnaire to see if there was a change in their knowledge, as a result of the virtual experience. We also collected general visitor opinions about the Haptic Interface with visitors of the museum who used it during normal museum hours.

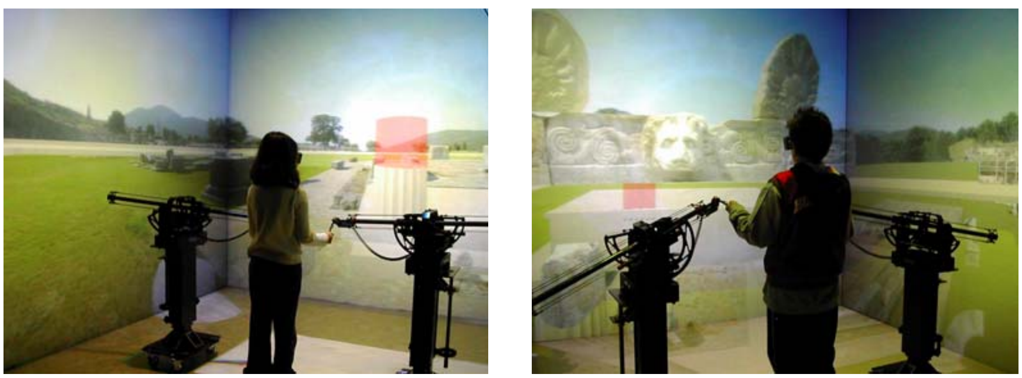

Figure 4: Young users, between 9 and 14 years of age, use the Haptic Interface to interact with a virtual reconstruction environment during their museum visit.

5.2.2 Observations

The evaluation of the virtual reconstruction case study with the content experts (archaeologists and educators) involved primarily the usability of the system and its potential as an educational work tool. The archaeologists we worked with and the majority of the archaeologists we evaluated the VE with, were very positive about the environment and its potential in educating restoration trainees, mostly because of its ability to present the content in a photorealistic and accurate manner and, most importantly, in the correct natural dimensions. However, most users pointed out that in order for the environment to be used in a real-world workspace (provided that all other practical issues were resolved), the representation of much more detail would be required, as well as the ability to simulate specific restoration techniques, such as filling in missing parts with plaster or treating aging. Many comments concerning the potential of the haptic interface and suggestions for improvement were also collected.

The evaluation of the case study with novice users aimed at determining whether interaction within the VE helps the user to gain a better sense of the process of archaeological research and learn about the positions, dimensions, and interrelationships between architectural members. The focus of the investigation has been on the potential for cognitive change, involving the measurement of the interaction effects on the user's understanding of the somewhat abstract concepts eluded by the task. However, an important aspect which cannot be separated from the evaluation of learning, especially when working with children, is the measure of affect (fun, engagement), as well as the potential pedagogical value of the system. Within this evaluation framework (cognitive, affective, pedagogical), we also looked at usability issues, involving mostly the learnability and ease of use of the system. The analysis of these studies is currently underway.

6 Conclusions

The above are preliminary observations derived from different types of experimental sessions and focus groups, with unavoidably small user sets. Although preliminary, with thorough analysis not yet completed, we consider these to be rich results because they provide insights and involve an in-depth observation of how actual non-IT expert users may be able to use Virtual Reality as a central tool in their work processes (for example, the in situ use of a VE in the decision making process of a real project).

Conclusions at this point can only be general, the main one being that by using a user-centered design approach and a focused evaluation process we were able to tailor the development of the VEs to the real needs of our end-users and to increase the validity of our environments as practical yet rich work tools. In terms of usability "engineering", the active involvement of the users in our projects confirmed once again that an informed human-computer interaction approach to application development is central in ensuring that the VE will meet the practical need for useful, usable, and successful multi-modal systems.

Many problems remain, of course. Firstly, these case studies are still far from proving that VR can be used in a real-world context with non-expert users on a long-term basis. To date, there are examples of VR practice in industries, such as the automotive or oil and gas industry, where immersive systems are used in the workplace. However, these workplaces still need to employ special laboratories and scientists in order to support the use of VR. When we talk about VR systems used in the workplace, in an educational setting, in a leisure-based context, or for any other kind of widespread public use, we envision use that resembles (in terms of its simplicity and straightforwardness) that of a home or office PC. For this to happen, the practical difficulties of VE development for real applications cited in the introduction, as well as issues of cost, distribution, space, and maintenance still hold and must be resolved. Secondly, our involvement in a real-world project clearly demonstrated the need for significant acceleration and streamlining of the capture process for real-world content (buildings etc.). Also, the frequently changing directions and needs in such projects underlined the need for better authoring tools for the creation of interactive scenarios. Both of these improvements would allow a faster turnaround time, enabling an improved response of the development team to the users and thus better user involvement in the process. Thirdly, in the cases described, there are still particular interface details that must be added, modified, and improved in order to make the environments more usable, easy to learn, and efficient. Although none of these interface improvements are particularly hard to resolve, they do require further software development which means specialized scientists and artists who will develop specifically for each case. VR hardware, software, and authoring tools have evolved greatly thus making the process of developing a VE much simpler than before. However, this still requires special programming skills, experience, time and effort, all of which can not be predicted and depend on the complexity of each application and case.

Overall, although the approach we followed of engaging users in the design is time and resource intensive, we consider it to be worthwhile and will continue to explore the application of HCI models into the design of VEs. We believe that this approach provides a flexible way to deal with the variety of situations presented within real world projects and, thus, provides promise for the development of environments and meaningful tools that can be of real value to their users and can advance the widespread use of VR.

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