Annotating and Sketching on 3D Web models

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Abstract
This paper reports on our progress and findings in building a Web annotation system for non-immersive 3D virtual environments. Over the last two years, we developed and tested two systems for collaborating designers to comment on virtual 3D models. Our first system, Redliner [12] lets design team members browse and leave text annotations on surfaces in three-dimensional models. Experience with Redliner, including two user evaluations in different settings, led us to develop Space Pen [13], a second annotation system with improved interaction capabilities. It goes beyond the post-it note metaphor, allowing users to draw in and on the virtual environment.

Keywords
Annotation, Collaboration, 3D models, VRML, sketch in 3D, pen-based interface, gesture recognition, Java 3D

INTRODUCTION
Collaborating with remote users on a specific work task can be facilitated by web applications for sharing and annotating documents. Architects, among other kinds of designers, produce three dimensional artifacts and work for each project with new partners (clients, contractors, etc). Specifically, web collaboration tools focusing on design activities must facilitate discussion about three-dimensional designs and must be easily navigated by all participants.

Two years ago we began work to address this need. We first created Redliner, a web-based system that enables users to post text annotations on a 3D model. After testing Redliner in design settings we developed a more graphically oriented system called Space Pen for drawing annotations on 3D virtual environments.

Motivations
As architects, we know that design involves more than merely conceiving and drawing a building. Architects work in teams with other participants who review and discuss a design to improve it until all parties are satisfied that it can and should be built. In this process, architects and their teammates exchange a large number of documents and spend a great deal of time meeting to resolve specific design issues. This becomes challenging when a firm, its contractors, and its clients are distributed around the world. The Guggenheim Museum in Bilbao designed by Frank Gehry is perhaps the best known project out of thousands each year that involve foreign architects on foreign sites. On these jobs much time and money is spent to enable all participants to meet and communicate their ideas. Architects and their clients already take advantage of fax, electronic mail and some capabilities of the Internet. However, tools to communicate design decisions effectively through that network are still immature. The discipline lacks an appropriate way for participants to discuss and record three dimensional design decisions.

Why 3D?
Like practitioners in other disciplines such as chemistry and medicine, architects use 3D artifacts to communicate complex concepts. Architects build 3D physical models at an early stage to clarify their concepts, and at a more advanced stage, to communicate design ideas to other parties. However, physical models are often large, heavy, difficult to modify and they usually present only a building's exterior appearance. Three dimensional computer graphic models are replacing physical models in many aspects of professional practice; therefore, we set out to use these models to support collaborative work and specifically the discussion of artifact-centered design issues.

The rest of the paper is organized as follows. The next section reviews related work on collaborative virtual environments, 3D sketching and annotation. The third section introduces Redliner, our first system for annotating 3D virtual environments by embedding digital post-it notes. The next two sections present two studies using Redliner, which led to Space Pen, presented in the final section, a system in which users can draw proposed changes directly onto the model on their Web browser.

RELATED WORK
Work on Collaborative Virtual Environments (CVEs), has applied technologies originally oriented toward entertainment and social interaction (e.g., MUDs and MOOs) to develop tools to facilitate work tasks. Emphasis has been on synchronous collaboration. Typical are ToolSpace [9] and DDRIVE [7] (Distributed Design Review In Virtual Environment), which both aim to support synchronous communication and collaboration in specific work tasks. DDRIVE, developed to support collaboration on car design,

supports web audio discussions for review of 2D and 3D artifacts. ToolSpace offers a 3D VRML (Virtual Reality Modeling Language) workspace for collaborative work, interaction and discussion through text messaging. In contrast, our Redliner and Space Pen systems support asynchronous discussion through annotation. Asynchronous collaboration avoids scheduling work sessions and also generates a valuable history of discussion and decisions. This asynchronous approach is similar to the voice annotation system in the Virtual Book project [23] or to the V Anno project [13], where users leave annotation markers in the 3D model and record voice annotations for future retrieval. However, the Redliner system supports text annotations stored on a server as plain text so that semantic search, indexing, or threaded thematic sorting of the text can later be achieved.

Much research has recently focused on digital annotation of text documents. Cadiz and Brush have developed and tested systems for asynchronous collaboration around text documents [3][5]. They conclude that systems for collaborative work should "be unobtrusive but accessible, inform without overwhelming, separate higher and lower priority information for different actors at different times" The Annotea project [27] proposes a new standard for annotating html pages.. Marshall underlined the difference between several types of annotations in textbooks and digital libraries [20]. Although Redliner allows only one annotation type (leaving text notes in the model) its successor, Space Pen introduces a second way of commenting on a virtual model by drawing on plane surfaces in the 3D environment.

Loughlin and Hughes [19] introduced the post-it note metaphor to annotate 3D fluid models. Markers associated with text are embedded in a virtual environment and reviewed later by other users. A magic lens filter allows hiding or highlighting markers in a selected area. Adriano and others [1] argued that annotation systems to support learning should take place in 3D virtual space to provide a richer context. Their prototype system proposes allowing users to place grocery shopping lists on a VRML refrigerator door (post-it style) so that relations between annotation and places can be more easily recognized, based on the objects they are attached to. Models shared in Space Pen and Redliner are ordinary VRML models, and our annotation interface is available on any web browser. Craig and Zimring's IDT (Immersive Discussion Tool) [6] is an aysnchronous system to annotate architectural 3D models. IDT allows users to leave arrows to designate specific points of the design, circles to annotate larger areas, or geometric constructions made of connected cylinders and spheres for representing 3D artifacts or gestures. Text can be attached to any mark left in the model. However IDT lacks a multiple user interface and wasn't developed to the point where users could save and retrieve comments.

Products such as Autodesk's Voloview [24] or DrDWG [8] aim at CAD drafters and engineers. They offer reviewing and redlining DWG format files produced with AutoCAD.

However, their complex editing interfaces are intended only for professional use and mostly for 2D documents such as floor plans or engineering drawings. Finally, Silicon Graphics' Iris Annotator [14] lets users annotate 3D models using several media types -- text, audio, video or other 3D models. However, there is no central server where annotated models are saved, and consequently no history or record of design changes.

In our test of the Redliner system (outlined below), navigation in virtual space with a VRML browser emerged as a significant problem. Disorientation is a common effect of navigating 3D virtual environments. In studies on the ease of use of VRML2.0 [4] most users felt lost in the 3D environment and often needed to refer to maps or viewpoint lists to reorient themselves. Several studies examined new ways of navigating into 3D virtual spaces [2][12][21], but as Burton, Kilgour and Taylor [4] observed, the what navigation interface is best depends on what kind of 3D virtual space one is browsing and on what kind of task is required.

REDLINER : LEAVING POST-IT® NOTES
We began by implementing Redliner [15], a system to annotate 3D models by leaving annotation marks (represented as colored spheres) directly in the 3D representation of a building. Any member of the design team can log on the Redliner Web site, identify a login name and choose an annotation color. The system first presents the history of previously annotated projects as well as any new versions of the design posted by the design team.

Figure 1. The Redliner interface: Left: Annotation window lists sorted comments. Right: The 3D inter-action window includes four (mode) buttons and the CosmoPlayer navigation bar.

The Redliner interface (figure 1) is simple. It can be described in a few sentences and intuitively understood even by novice users. It contains a window with two frames: one containing users' text annotations and the other for 3D interaction with the design model. Comments listed on the left side of the Redliner window are sorted by time and by author. The right side displays the 3D model. (Screen resolution issues discouraged us from embedding the comment text directly into the 3D model.)

Typically, one member of the design team is responsible for producing the design model for review by others. This person also sets up a list of viewpoints in the 3D model window to help visitors to navigate. When a visitor leaves an annotation mark on the model, the virtual location and orientation is saved as a new viewpoint so that future visitors can retrieve and view the comment in the design context in which it was made. After a user finishes annotating the model the system emails other participants to inform them about the new notes.

The three mode buttons in the 3D interaction window (Figure 1 right) control different Redliner modes: Annotate, Measure and Navigate. They modify or change mouse events in the 3D window to have different effects on the model. In 'Annotation' mode, mouse clicks leave a colored sphere on the virtual model and open a text-input window. In 'Measure' mode, two consecutive clicks reveal the distance between two selected points. (We added this feature after users complained about difficulties understanding dimensions in the model.) In 'Navigation' mode, clicks and drags inside the 3D view window move the user around the model. The 'Exit' button indicates the session end.

Implementation
Redliner uses the capabilities of certain VRML browsers (CosmoPlayer, Cortona, etc.) to communicate with Java applets via the VRML External Authoring Interface. The Redliner applets watch for events from the 3D window or the mode buttons and respectively activate the **callback** or **actionPerformed** method. The **callback** method displays a new sphere at the location of the click, opens the "measure dialog" or displays an existing comment according to which mode was selected and where the click occurred. The **actionPerfomed** method responds to the mode change or exits the system.

When the visitor clicks on a surface to annotate the model, the system generates a VRML description for the annotation sphere while the applet gathers the text comment in a pop-up window. Once the visitor saves the comment, Java sends the VRML description and the associated text to a server Perl script. The Perl script adds the sphere to the existing VRML model.

TESTING REDLINER
We tested Redliner in two different settings. In the first test, we asked users to annotate a model of their workplace. The annotation took place within the workplace itself, so they could easily relate the virtual and the physical space. The second test involved an architectural project for remodeling an apartment building. There, the space the users were annotating did not yet exist, so they had to rely entirely on the virtual model.

Test 1: The L3D Laboratory
Our first test took place at the University of Colorado. Students and faculty members at the Center for Lifelong Learning and Design (L3D) had recently moved into a new laboratory space and were actively discussing how best to inhabit this space. We set up a Redliner workstation inside the L3D lab and asked the group members to annotate a model of their new laboratory space, commenting on the arrangement of workspaces and furniture.

Method
The test was divided into two parts. In the first part, we videotaped sessions of eleven participants using Redliner (working alone or in teams of two) to annotate the model. We explained to participants how to move around the model using preset viewpoints or the walking mode of CosmoPlayer and how to view and leave comments. We also gave them a floor plan indicating the location of each preset viewpoint. We provided full technical support during the experiment and each user or team was given as much time as they wanted to annotate the model. Two cameras recorded users' reactions and discussion. A third view showing the Redliner web window allowed us to observe how users were navigating through our system (figure 2). Once they were done reviewing the virtual space, we asked them to comment on the system concepts and usability.
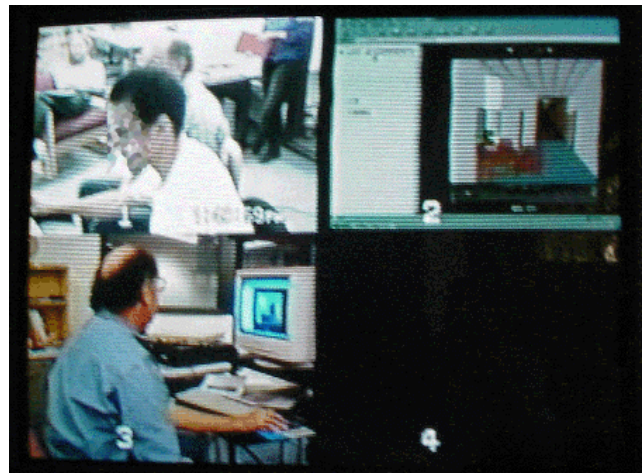

Figure 2. The video setup. Participants were observed (channels 1, 3) while their annotations were recorded in real time (channel 2).

In the second part, conducted several weeks later, we printed all the comments that users had left on Redliner and stuck them on their real locations in the lab. We invited the same participants (as well as other members of the group) to walk around the room and this time to leave physical post-it notes on the walls and furniture. Sixteen people participated. We tried that way to identify the limitations of our system by comparing our computerized system to its physical analog. Similarly Whittaker and Schwarz [25] identified several limitations of MS-Project™ compared to paper based scheduling of work tasks, such as failure to promote face-to-face communication, decreased awareness of other people's actions and lack of visibility and permanence.
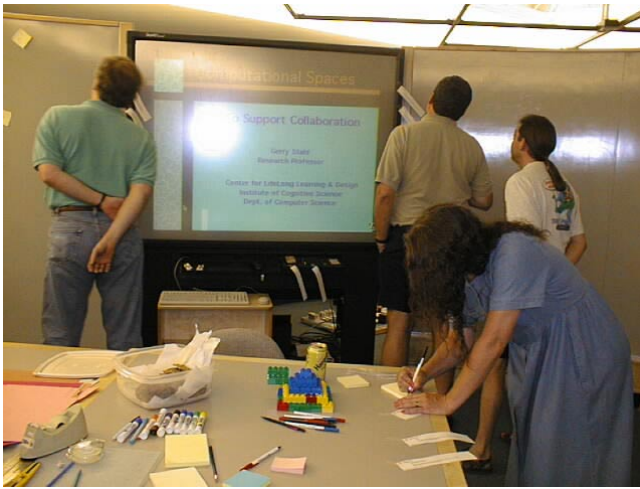
Figure 3. Annotation in the physical space. Participants wrote and left real post-it notes on walls and furniture.

Figure 3 shows several participants reading post-it notes left on the wall while another writes a comment to be placed on the table she is writing on. Both in the physical and virtual parts of the experiment, some elements of the space generated more discussion than others. For example, a dozen comments were left to discuss the shape and the use of a dividing wall element (figure 4).

Figure 4. Comments left on a dividing wall element. Long strip notes at the top are printed from Redliner; the smaller rectangular ones were posted later in the physical space.

Observations

More than 70 comments were posted in Redliner during the week of the experiment. Each user or team had a different way to use the system. Some started by browsing the list of previous teams' comments and clicked on those that looked interesting to find them in the space and then possibly respond. However, the most common way people used

Redliner was to move around the virtual space clicking on the notes in highly commented area of the model, recognized as the most conflicting arrangements.

We observed the same behavior during the physical annotation experiment. People walked around the room toward places they wanted to change, read the comments related to that part of the room and often left a note describing their opinion. Comments were left more quickly in the second part of the test where users walked around the physical space. In one hour a total of 53 comments were posted on walls and furniture.

Often during the first part users stood up and walked around to gain a better understanding of the physical space before returning to the virtual environment to leave a note. Most participants made extensive use of the 2D floor plan to orient themselves in the virtual environment, and connect their understanding of the virtual space with the physical space.

Navigating through the space from one viewpoint to another obliged the users to discuss and react to every part of the room. In the two-user teams almost every preset viewpoint initiated a discussion, which usually led the team to drop a comment summarizing their observations.

Some users had difficulty navigating the different Redliner functions. Users often did not understand how to relate the text of a comment to its location in the virtual world. Some felt inhibited moving from the text display of a comment to its location and they quit before exploring the whole model. At the end of the test, though, the L3D lab model was covered with colored notes (figure 5).
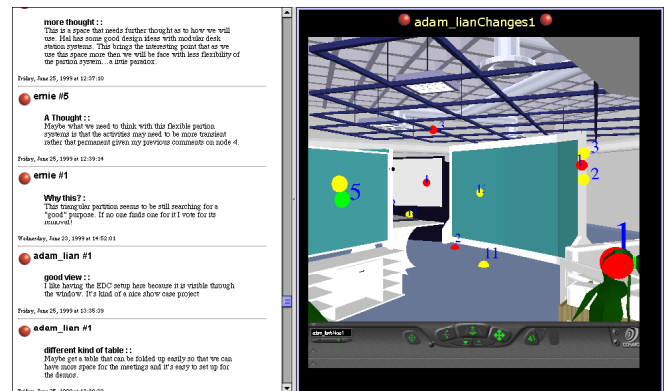

Figure 5. The L3D lab model annotated by several users (right). The list of text comments associated with the spheres in the model (left).

Results

The experiment took place in the space itself. Users annotated a virtual model of the place they were physically inhabiting. Comments like "*we lived in the space long enough already, so the 3D representation is not necessary. 2D would be enough*" were common. Most believed that knowing the physical space was a big advantage. However, they also acknowledged that viewing a digital 3D model of a

design proposal is comparable to a "model house" that used by real estate agents to help people understand a proposed space.

Some users requested the ability to arrange the space themselves and move objects around, or at least to indicate a desired move by making arrows or sketches. They viewed localized text annotations as a limited way to annotate a space. Some also felt confused when they wanted to comment on an area of the room (rather than an object), on a general characteristic (e.g., the quality of light), or on the absence of something. "*Where should I put the note?*" was repeatedly asked. Comments such as "*We would like to float over the space and see it as a whole to sketch and comment on general concerns*" led to our later Space Pen implementation to facilitate 'virtual graffiti' on any place in the model.

Some would like to view several interchangeable space arrangement alternatives in the same model. Therefore we added "layers" functions to Redliner in the next (Strasbourg apartment building) experiment to enable a user to switch on and off different foci or options in the design. Some users said they would like the system to automatically label the annotations with keywords (Redliner supports user input of a title for each comment) and group them according to keywords as well (in addition to the current system's sorting by time and author)

Participants found that the ability to leave anonymous comments in the physical world and to relate comments with one another enticed them to leave different, often shorter, comments than in the virtual model. Comments such as "*Yes*", "*I agree*", or "*good idea*" were not left on Redliner, but appeared often in the physical space. However, users liked the fact that these virtual post-it notes don't fall off the wall and that the system keeps a good record of the history of discussion. Another insight about why we saw fewer notes in the digital world than the physical space (besides the complaint that it's hard to navigate in VRML unless one uses preset viewpoints) is that users were paired in the experiment and they all logged in with their real names. At least one user mentioned that subtle peer pressure was a reason that people took longer to format more coherent and elaborate notes than the spontaneous annotation that we saw in the real world when note-writers remained anonymous. Therefore encouraging anonymous annotation might foster more input. Anonymous users, however won't get the benefits of notification when new annotations are made to the model. Users suggested that annotation markers could also indicate whether the comment was positive, negative, or neutral.

Some comments left in the physical space also contain drawings describing furniture arrangement. Users wrote in capital letters, bold, or underlined words to add emphasis. Redliner did not offer these options.

Test 2: Apartment building in Strasbourg
From April to June 1999 we conducted another test using Redliner in the design of an actual architectural project. An architectural team (including Jung) was chosen to remodel an apartment building in the center of Strasbourg. We decided to try using Redliner to support the team in remodeling the top floor apartments. The client possessed a computer at home but had little experience using it. We installed Redliner on the client's computer and showed him how to use the system. We also added several buttons (Figure 6) to the 3D interaction windows to facilitate turning on or off the display of optional layers showing different design alternatives, or different components of the building (i.e., structure, partitions, wiring, furniture, etc).

Figure 6. First stage of the design: Users could display or hide optional layers in a global representation of the project. (Text annotation frame is not shown).

This test aimed to evaluate the use of Redliner in an ordinary architectural process. To facilitate design decisions, we offered several new features; in particular the possibility for each participant to present and view several design alternatives. Figure 6 shows an example. Participants could view and annotate the design project as a whole in a "semi-3D" format (consisting of floor plans viewed in space related by their positions and some structural elements common to all floors), where they could view the project, but also relate the different floors in 3D.

Findings
As the design progressed, we posted models of the project at different stages. The client and two other participants of the architectural team then annotated the models. These two users visited and annotated the model more frequently than the client. The client did attempt to use the system but felt intimidated and finally didn't use it as much as we hoped. The most difficult part to understand was how to operate the CosmoPlayer browser. The basic idea of the Internet and running a program over the network was also a disrupting new concept for the client.

However, the client felt compelled by seeing and walking virtually around his future home. As we demonstrated the system the client began to comment on design issues. Later, although the client did not use Redliner extensively to annotate and communicate with the architectural team, still many questions the client raised during the face-to-face meetings (that we still scheduled) related to perceptions gained by viewing the model in 3D.

Lessons learned

Overall, users were excited about reviewing and annotating a design project in a 3D environment over the Web. Being able to access and comment on the model anytime, anywhere was seen as a great advantage of the Redliner system. One apparent benefit was that the 3D model draws one's attention to details that might elude one in a 2D representation. A simpler means to navigate the model was also clearly needed: CosmoPlayer was a significant obstacle to using Redliner.

Many users wanted to comment on the general space rather than a local design issue and wondered where to place this annotation. Text annotation was considered limited; users wanted to interact more directly with the space (such as to quickly sketch over a problem area in the model to suggest improvements or additions), and Redliner only offered dropping annotation markers. In the first test, users perceived the system as an interesting collaborating tool but maybe not for design purposes. In the second test, users appreciated the ability to view alternative design options, but still felt frustrated with using just text to propose a design change. Design collaboration requires more than text comments.

In summary, users wanted:

A simpler means to navigate the model.

Threaded discussions & better organization of comments.

A way to apply annotations not only to individual objects, but also to regions of space.

Interaction with the model beyond text comments – that is, the ability to mark or draw right on the space where you want it.

The ability to edit or add to the model directly.

We took these findings seriously in our research. Much of the above functionality has since been added to the Redliner interface and is currently addressed by other projects in our research group. Here, we focus on addressing the users' requests to 'draw in 3D' and describe a system we implemented called Space Pen.

SPACE PEN: DRAWING ON SURFACES

Based on lessons learned from Redliner, we are developing Space Pen [16]. It serves the same goals as Redliner: to give designers better tools to annotate 3D models. As in Redliner, users can tag the model with notes associated with text comments. Space Pen users can also mark up the surfaces of the 3D model (like writing graffiti) and save those drawing annotations for others to review.

The Space Pen annotation system also builds on work on freehand drawing ('calligraphic') interfaces such as [10], [17] and [18]. We share the position taken by these efforts that the uses of drawing and diagramming should not merely produce graphic imagery like in [11], but also can communicate symbolic and spatial information to knowledge based design systems.

Space Pen's support for sketching in 3D relates to other 3D sketching systems that have been principally developed to support the creation of models. For example, Sketch [26] interprets strokes to create 3D forms. Stilton [22] uses an existing model or photograph as a background and transforms the user's line drawings into geometric 3D objects such as boxes or pyramids. By contrast, in Space Pen, 3D sketching mainly supports annotation rather than modeling. Although our interface could allow users to create new 3D objects, we are more interested in developing a commenting interface for drawing on existing 3D models. Space Pen takes advantage of previous work in 3D annotation, 3D drawing and Collaborative Work in Virtual Environments and integrates all of them in a new 3D collaborative annotation system based on sketching.

Navigating in a VRML browser was a persistent problem with Redliner. To avoid this, we wrote our own 3D browsing interface in Java3D. We adopted a simpler way of walking through the model using keyboard arrow keys, familiar to users of popular 3D games like Doom or Quake. Space Pen still employs the VRML format for describing 3D scenes, which allows users to create a model using off the shelf modeling software. Space Pen imports the model using the Java 3D library and the vrml97 Java archive. It can import any VRML model and analyze its geometry, enabling users to annotate and draw on its surfaces later on. The Space Pen interface (shown in Figure 7) employs a minimum of graphical user interface widgets: the color selection circles (left) and the 'save' button are currently the only screen widgets used. Other Space Pen functionality is invoked using pen gestures.

Figure 7. Adding a door on a wall. A rectangle drawn on a surface is recognized (echoed in the bottom left text field) and rectified (right).

The ability to draw directly on model surfaces addresses users' desires to annotate the model with more than text comments, and to propose physical design changes in the

model space itself. A user can, for example, indicate a new position, dimension, or shape for a window or door just by drawing it on the wall surface (figure 7, left). The drawing mark can—but need not—also be associated with an explanatory text comment.

To address users' needs to post more general comments about a space or a larger part of the model (in addition to commenting on a specific object), we added a "draw in space" feature. A quickly drawn straight line gesture generates a temporary drawing surface directly in front of the user's point of view (figure 8). Drawing marks made on this surface remain as new elements of the model.

Following the work on diagram recognition in two dimensions [10], Space Pen can also recognize drawings that the designer makes on model surfaces. Presently, it's limited to recognizing simple symbols: rectangles, circles, triangles and arrows. Once a symbol is recognized, the system can interpret it in different ways. For example, Space Pen can rectify a crudely drawn figure, or execute a command based on the graphical symbol. In figure 7 (right) the rectangle drawn on a wall to indicate a door has been automatically rectified and filled with another color, giving a more realistic appearance of a door.

Space Pen could—in a future version—augment interaction by providing predefined object behavior from sketches like moving a sketchy widget on an interface design in the SILK system [17]. The current version of Space Pen already performs recognition of freehand sketches in the 3D space and can use this recognition to trigger actions on the drawn object. We saw that the user can draw a rectangle to annotate the model with a door. Space Pen also recognizes the surface the rectangle has been drawn on. We are working on getting Space Pen to make a further inference beyond simply creating the door geometry, for example, linking the newly created object to a product database and adding additional behaviors for it to perform (e.g., a 3D door that opens and closes). In the same way, the system could interpret an arrow as a command and we are working on interactively uploading and downloading the object models and managing version control on the server.
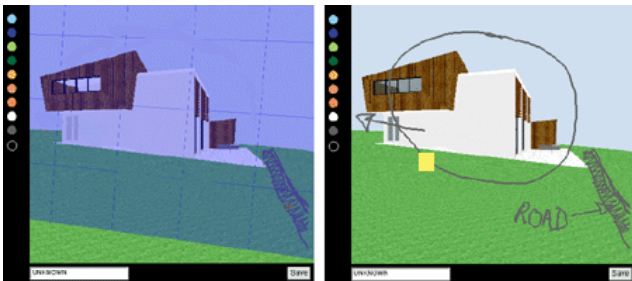

Figure 8. Drawing annotations in space. Drawing a quick straight line on an existing surface generates a temporary grid plane (left) for a user to draw general comments about the whole space. The bright square below the house indicates a text note left to complement the drawing annotations.

In our last implementation of the system, we added a 2D "you are here" map and we are working on adding a viewpoint lists to Space Pen. The viewpoint list was valuable and notably was used by all participants in the Redliner experiment. It is still the best way to retrieve comments that are dispersed around a large model. In addition, we plan to add more sophisticated means to search and manage the text comments; e.g., support for a threaded discussion that references specific locations in the model, and indications of positive and negative comments.

CONCLUSION

This paper described our efforts to create an intuitive collaborative system for annotating and sketching on 3D models on the Internet. We aim to develop a system that anybody can use, architects as well as non-designers, computer experts as well as novices. Space Pen, at its early stage of development, already improves annotation in 3D environments over Redliner by allowing different kind of annotations.

Although our research has focused on designers and architects' work, we believe that other disciplines that reference physical structures, such as chemistry, engineering, mathematics, and especially education, could benefit from web based 3D drawing annotation.

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