Context Aware Paper-Based Review Instrument

A Tangible User Interface for Architecture Design Review

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Abstract

We describe the design and implementation of a prototype computer-supported collaborative work (CSCW) environment for review of architectural construction documents. This environment utilizes a novel plain-paper tangible interface that supports shared activity such as review of construction documents using an "over the shoulder" computational assistant called CAPRI.

*Despite the increasing use of computers, work in most architecture firms still largely revolves around paper drawings. Architects structure their work around paper instead of digital representations for reasons of legal liability and tradition, as well as technical limitations. While hardcopy is intuitive, dense, and easy to access, it lacks direct connection to the wide range of design knowledge increasingly available in interactive design environments. This lack is felt most acutely during design review processes, when the designer or reviewer is often called upon to consult and consider holistically a variety of supporting (**backing**) documents, a task which requires focused attention and a good memory, if errors are to be avoided.*

Our prototype system enables multiple reviewers to interact equally with a paper construction document using a tangible interface to query detail and backing data from a project knowledge base. We believe this will decrease the reviewer's cognitive load by bringing design data to them in a contextual and timely way. In doing so, we believe errors will be caught sooner and mistakes reduced.

Overview

We begin with a visionary scenario describing the full feature-set of CAPRI (Context Aware Paper-based Review Instrument), our prototype application for design review. We follow with a review of related work and brief descriptions of concerns that motivate the present project regarding design review process in architecture. We describe how CAPRI can help users decrease cognitive load. Lastly, we describe certain implementation issues, including how to use pre-existing design documents in the context of design process.

Design Review using CAPRI – our vision

Three architects, charged with reviewing construction documents for an elementary school design in an architecture firm, are having a meeting to review a portion of the project. They select one of the drawing sheets and place it on a work-table, around which they take seats. Each member of the team has several sheets of plain paper at his or her elbow, and each can raise questions or contribute information at any time. CAPRI plays the role of an assistant by providing context aware reference material to the reviewers during the design review session when they want it. Above the table, directed downward, are a video projector and camera. When a reviewer places a blank piece of paper (a "query page") near one of the doors on the hardcopy plot, a menu of options relevant to the door projects onto the blank page. A different menu projects onto the page if it is moved next to a different door. In this case, the menu includes *Program*, indicating the existence of text regarding doors in the architectural program. One of reviewers touches the *Program* button on the menu. A paragraph of text appears regarding classroom doors. After reading, she makes a gesture over the page and the menu returns. This time she touches the *Image* button on the menu. A picture of a metal door is displayed on the page. Placing her finger on one corner of the page, she drags the page to one side. The projected image follows. Another reviewer places a new page on the drawing, next to a window, and makes a simple *check (V)* gesture above the paper. Specifications for the classroom windows appear. Finally, reviewers position a query close to the room number and summon a reflected ceiling plan. The three architects begin to compare the drawings and check design consistency among them. They decide to modify one of the cabinets shown in the plan. One architect sketches the desired change on the relevant query page. CAPRI issues a slight "click" to indicate that the sketch has been captured. The review continues…

Background & Related Work

Paper-based Review

In architectural practice, drawings, whether produced as graphite on paper or through the use of 2D, 3D or BIM computer aided design (CAD) systems, remain the critical graphical medium for developing and communicating ideas throughout the design process. That is, although most workers have personal-computer workstations, hardcopy print-outs are used as the centerpiece of design review meetings. Several factors may explain this, including the fact that the information density achievable on paper still significantly exceeds that of even the largest computer displays, reducing reliance on short-term memory. In addition, paper is relatively egalitarian in terms of control and access (no-one "owns" the mouse), and paper presents a straight-forward interface (Johnson et al. 1993). However, paper documents are obviously deficient in terms of accessing supporting design information from the project—information such as reference drawings, photographic images, program, meeting minutes, catalogues, building codes, drawing specifications, etc. Increasingly, this backing information is available in digital form, but lack of access to it during reviews forces designers to rely on their memory or to take time to access secondary supporting (*backing*) documents. Such retrieval increases the chance that the reviewer will either be distracted before completing the task or abandon it entirely. Incomplete information review, in turn, increases the likelihood of errors.

The existence of digital backing data raises the prospect of direct access during design review. One goal of the CAPRI prototype described here is to develop an interface for accessing such information.

Cognitive Challenge of Design Review

Design review is cognitively challenging. When reviewers work on a design, they have to consciously (re)consider multiple design entities and associated information, holding details in their working memory, which is limited in duration and size. To function smoothly and accurately, reviewers have to develop schemas that help incorporate the many elements in short-term design reference memory into long-term memory (Mackay and Fayard, 1997). In this way a transformation in performance occurs. Interruptions and distractions make this process harder.

Most questions that arise during design review are specific to features of, or locations within, the building. That is, they are contextual. For example, we might know what generic hardware goes on doors in the building, but might not recall what hardware was specified for a particular door. Even if a drawing provides that information via key symbols or hardware schedules, it does not provide the rationale for the hardware (the "why" behind the choice). However, during design review sessions, reviewers may need this information, and the ready availability of it reduces the reviewers' cognitive challenge.

Contextualized capture and review of design rationale and automated design critique has been developed before in closed systems such as JANUS (McCall, et al., 1990). However, the CAPRI environment, the prototype system we developed, differs in that it combines paper documents with a tangible user interface to access context-specific information during the design review process. CAPRI augments information available on the paper document, the tangible interface enabling designers to access relevant information during design review and decision-making, without losing focus.

Organizational Hierarchy

Often, especially in hierarchical organizations, the designer/reviewer, the project manager, and the drafting staff communicate through construction documents. Several interactions may occur in the review process between a reviewer and project manager, on one hand, and between the project manager and the drafting staff, on the other. Interactions are discontinuous, which adds coordinating and scheduling overhead to the project.

Interestingly, the ease with which information can be acquired through the above process varies. In addition, due to the cyclic character of most design process, it is not uncommon for "the same question" to be asked repeatedly in successive iterations. Moreover, this process disrupts the prompt query process when a reviewer occasionally needs to see the architecture information for the design review, because staff may have to reconstruct backing data that was discarded or lost due to staff changes, etc.

Most contemporary designers use CAAD (Computer Aided Architectural Design) systems for creating, reviewing, and referencing design, but such systems offer only one-way interaction from users. In addition, while these systems enable the designer to use an interactive editing environment, they provide only interaction between the designer and the computer program's design elements (lines, circles, walls, etc.), not the full background information supporting a particular design configuration.

In contrast to the design condition, review often happens with another's design. That is, reviewers examine not only their own design work but also that of others on the team. In order to access design knowledge and rationale during review, interaction with the existing design, created and edited by others, is essential. Figure 1 shows the typical flow of questions and design information in the traditional process, during which queries often pass through several individuals before being answered.

An alternative interaction between a reviewer and an existing design is an electronic retrieval from a digital design knowledge base. Such a database is likely to be quite amorphous, consisting of organized data and individual files in many formats. Increasingly, design rationale and decisions are stored in digital form, as is reference material. Desktop, network, and internet search for information, during review, will be increasingly common. In the future, through interaction with a

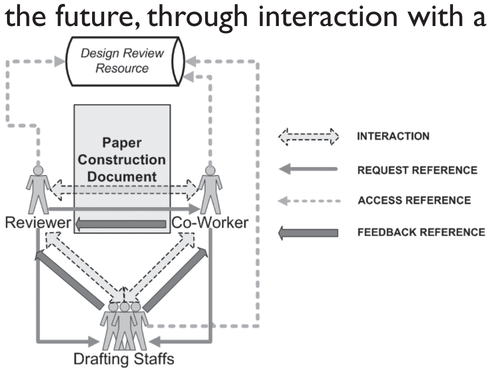

Figure 1. Flow of Design Information Feedback in Traditional Way

digital document and its connections to a digital design knowledge base, reviewers will be able to refer directly to review information. CAPRI explores one interface prototype.

Smart Workstations

Since the early 1990's several projects have used video and other sensors, coupled with data projectors, to create an interactive environment based on a desktop model. Previous research into interactive desks includes the MIT metaDesk and the UNC Office of the Future (Ishii and Ulmer 1997; Raskar et al. 1998). These projects have generally focused on creating complete workspaces with enhanced interaction or visualization abilities, though others, such as the EnhancedDesk, Marcel, and Digital Desk projects, sought to integrate paper documents and digital information through use of matrix codes and optical character recognition (Kobayashi and Koike 1998; Newman and Wellner 1992; Wellner 1993).

Tangible User Interface

Tangible user interfaces (TUIs) such as those developed by the Tangible Media Group at the MIT Media Lab, have been persuasive in spatial or geometric domains in human computer interaction (HCI) research such as architecture, landscape, and urban design (Ishii and Ullmer 1997; Underkoffler and Ishii 1998). TUIs can manipulate the physical layout of the objects to directly connect their informational meanings and responsive feedback in a tangible user interface (Camarata et al. 2002). TUIs employing paper allow users to take advantage of benefits of both physical and electronic documents (Kim et al. 2004).

Augmented Reality

Related to TUIs and Smart Desks, Augmented Reality (AR) is also an emerging platform for interacting with computers, connecting physical objects to a potent digital world that is growing rapidly in the HCI area. Examples include the Ariel project for engineering drawings and Live Paper (Mackay and Fayard 1999; Robertson and Robinson 1999). In contrast to these projects, CAPRI seeks to enable users to access appropriate information with existing paper documents without building an internal database. Blank sheets of paper are used to build ad-hoc queries and as surfaces for projecting information, which matches with a design object such as a window, door, or wall on the design document.

CAPRI

CAPRI is an augmented and tangible environment for facilitating review using design objects that are the fundamental computational elements. In the "vision" section we described the complete "1.0" implementation. The current implementation, written in Java, has most of those features, but not all.

Hardware

The system utilizes of a desk, a camera, a data projector, and a personal computer. A bracket located vertically above the desk supports both the camera and projector, pointing down at the desk. Interestingly, available consumer-quality video cameras

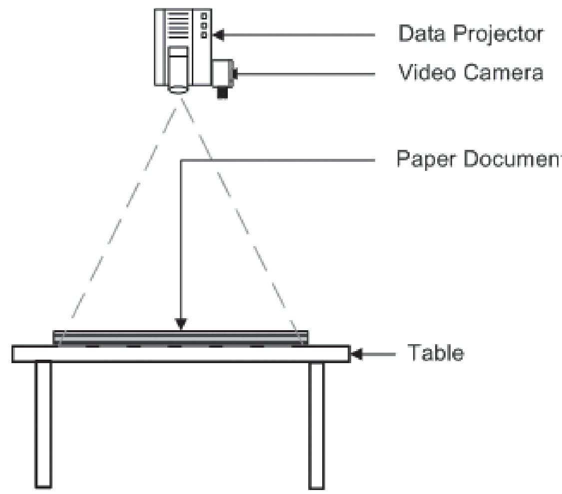

Figure 2. CAPRI Setup: Desk, Drawing, Query Pages, Webcam & Projector

("web cams") vary widely in terms of the angular width of their field of view. Pairing the projector with a suitable camera that "sees" roughly the same areas as the projector, so that they can be mounted at the same height, turned out to be a challenge. Figure 2 shows the physical configuration of the system.

CAD Work Requirements

For the information density and recall reasons presented above, we currently use paper documents as the primary referent for a review. It is assumed that these drawings are produced using a 2D CAD system, with the work conforming to some reasonable layering standard, such as those promoted by the American Institute of Architects (AIA), the International Organization for Standardization (ISO 13567), or the National CAD Standard. Plots are produced just as they would be for a traditional review.

Overall System Process

The system currently divides changes in the video feed into two types: changes to the paper medium state and changes representing hand motion—what we call the motion medium. The *medium detector* identifies the location and size of paper media, hand gestures, and characters on drawings. Through the process of the *context interpreter*, the system parses context information, which is location and attributes of design object in CAD files. It builds the metadata index to interact with design reference in databases. The *context interpreter* also analyzes detected images of paper medium and/or motion medium depending on event sequences. The *output interface* is the paper medium which is the same as one of the *input interfaces* in order to display a content navigator and to review information. Figure 3 illustrates the overall CAPRI system process.

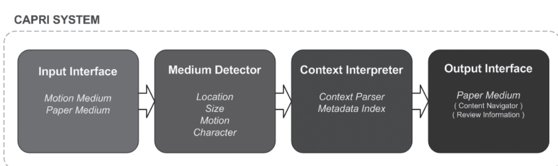

Figure 3. Overall System Process.

Sheet Initialization

When the system senses the placement of a drawing sheet on the desk surface (through analysis of the video stream), the first task is to identify the drawing sheet. With modest system configuration and a consistent title block (as in Figure 4), it is possible to locate the sheet number and identify it through OCR (Optical Character Recognition). Once identified, the system accesses the corresponding SVG drawing from its internal database.

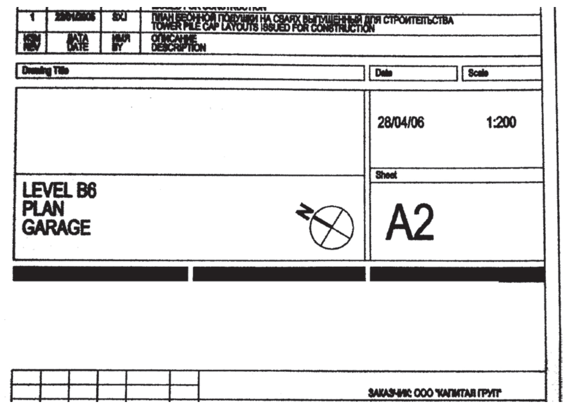

Figure 4. The Title Block of Construction Document

Metadata Indexing

Prior to use with CAPRI, the CAD drawings are converted to SVG files. SVG is a modularized language for describing two-dimensional vector and mixed vector/raster graphics in XML (W3C, 2003). SVG elements within the file have unique identifications and can be displayed and manipulated by stand-alone or web-browser applications. Design elements from the 2D CAD drawings are converted to SVG and simultaneously used to produce a metadata index that establishes the context for the document. File names and layer names are parsed and combined with user-supplied configuration data to provide SVG element information, which is subsequently used in developing semantic queries for further information. For example, blocks on the *int-door-stl* layer might be configured to be tagged as a steel door.

Figure 5 illustrates how the context metadata index might be built from a two-dimensional CAD drawing. Since the reference drawing is plotted, the reference SVG file is used as a database (not for display), though other SVG files are displayed in response to queries.

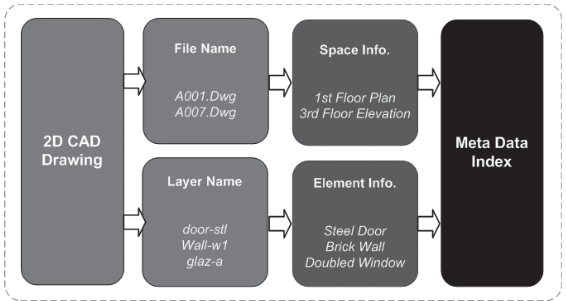

Figure 5. Derivation of Context Metadata

Figure 6. Query Initiated by Placing Blank Sheet Over Drawing

Of course, a project's construction documents only capture some of the design information, as they aree focused on material location and attributes. Information regarding design intent, tradeoffs, and alternatives is limited, since such information will be primarily non-visual, stored outside the drawing set. We assume the existence of related, non-CAD project data, in a searchable online format, but the capture and storage of that data is beyond the scope of the current project.

Establishing the Query

When a blank piece of paper (a "query page") is laid on the hardcopy document, CAPRI senses it through video analysis. The coordinates of the bounding rectangle are extracted and the upper-left corner of the page is used as the "location" of a query. Using the upper-left corner of the query page as a starting point, CAPRI searches the drawing for a corresponding element such as a door, window, wall and so forth. Figure 6 shows a query being initiated (the circle was added to indicate the query location).

Query Results: Content Navigator

After locating the closest element, CAPRI searches for related information using the element ID previously extracted from the conventional 2D CAD drawing. Results of this search are used to build a "Content Navigator" menu for the user (see Figure 7). If an element such as the previously mentioned door were queried, the menu would show options relevant to steel doors, such as *program, detail drawing*, *specifications*, *material report*, *current cost*, etc. Thus, the menu varies from one object to another depending on the contents in the metadata index and related database. The user makes a selection by pointing with a finger or pencil, or by making a gesture above the query page (see below).

Query Results: Review Information

Once the user has indicated the desired information, CAPRI presents the information within the query page's bounding rectangle, without need for page turning or shifting attention. The location

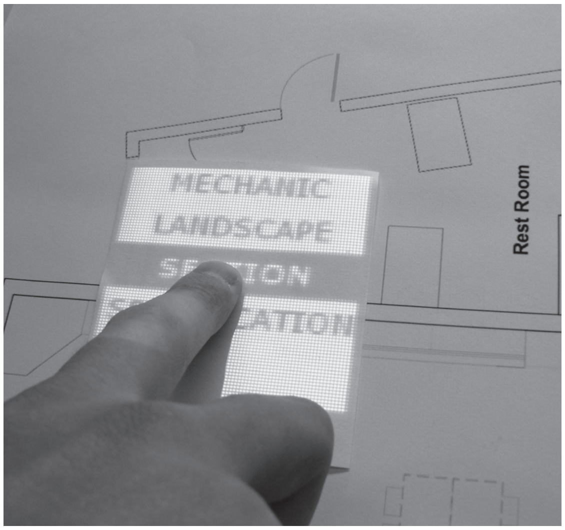

Figure 7. Pop-up Menu to Navigate Information.

of the query page can be changed during the review session without losing the query results so long as it remains in the camera's visual area, or it can be removed from the scene briefly to discard the query prior to making another, at which point the process begins again. Figure 8 illustrates review information on the query paper.

In the case where there is only one element of information for review, the review information would be directly delivered without requiring navigation . For example, information on the detail drawing is immediately displayed on the query paper when a query page is placed on the detail bubble in the document.

Gestural Input

As an alternative to selecting from the projected menu, the reviewer may make a simple gesture using their index finger to draw in the space above the query page. The system attempts to recognize the gesture from a set of gestures previously recorded. The system supports an initial

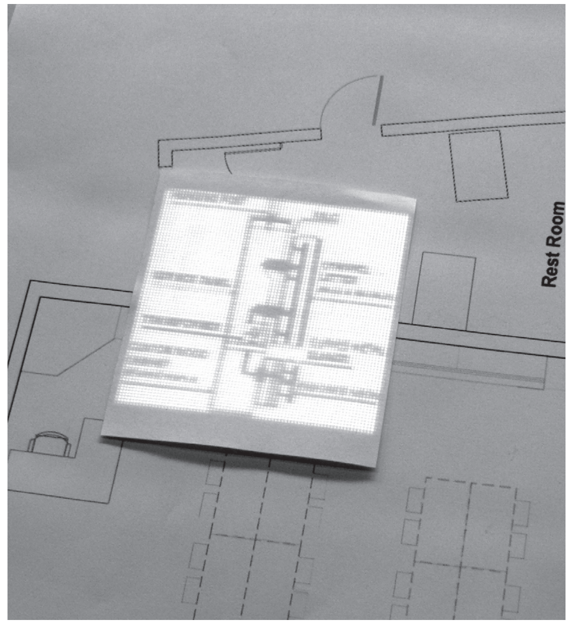

Figure 8. Review Information.

built-in set of gestures that includes triangle, check mark, rectangle and so forth. Table 1 shows the example list of gestures and the corresponding query.

DEFINITION	Detail Drawing	Visual Image	Building Code	Specification
GESTURE				

Table 1. Example of the List of Gesture and Definition.

Flexible Query Behaviors

Sometimes the query page is too small to display all the requested information. In this case, since CAPRI sizes results to the query-page boundary, users can simply use a larger piece of paper, or several pieces of paper, to "zoom in." The effect can be seen by examining the query pages shown on the right side of the images in Figure 8.

The system also enhances interaction by allowing multiple simultaneous queries, each made as described above and also illustrated in Figure 9. Once completed, a query can be repositioned for easier

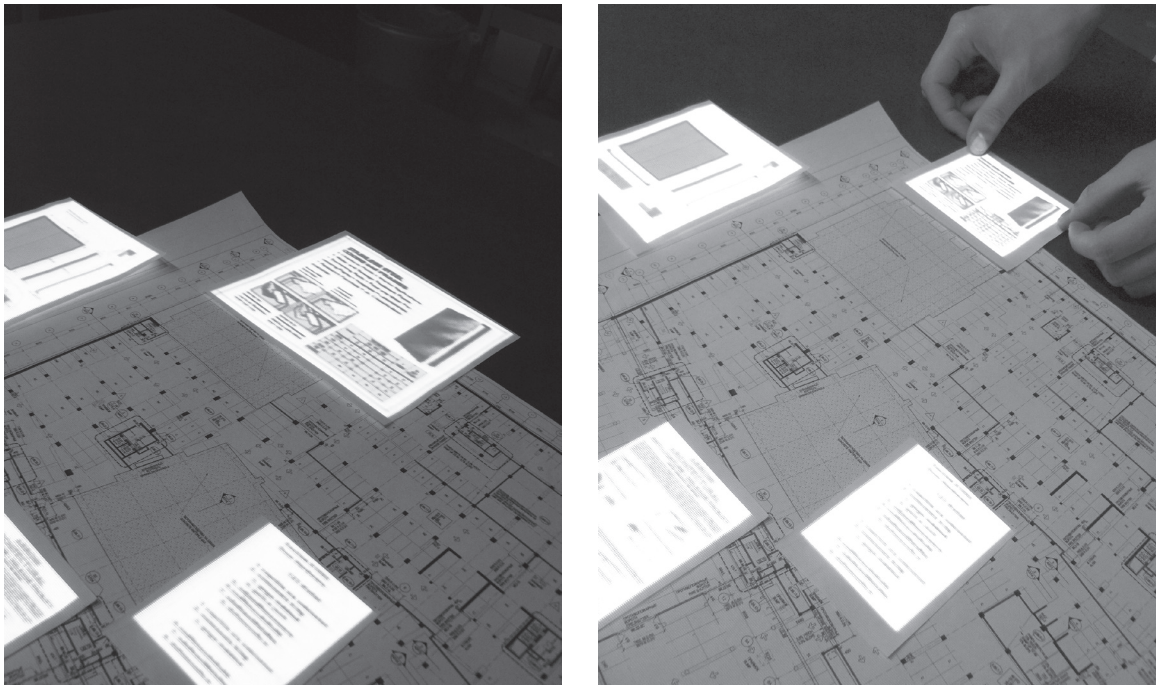

Figure 9. Positioning Multiple Queries (left) and Zooming (right).

viewing or for visual access to other portions of the underlying drawing.

For more flexible query-page positioning, other corners besides the upper-left ones can become query locations. For example, if some portion of the query paper extends beyond the bottom of the primary drawing, the system uses the relative coordination depending on where the portion is located. Taking advantage of flexibility, the CAPRI system provides a wide range of usages to improve communication between queries into data.

Next Steps

At this point CAPRI is a proof-of-concept prototype. The current version (CAPRI 06) adds the tangible interface features of the query-page interaction described here to a single-user, pen-based review application (CAPRI 05) developed by Lee as part of his M.S. thesis (Lee 2005). Several interesting directions remain to be explored. The utility of the system would be enhanced by developing the discovery and encoding of context data during drawing pre-processing and queries, and by extending the data-access framework to cover types of project data not recorded in CAD files (meeting minutes, phone logs, email, etc.). The interface should also permit data to be input as well as queried, whether in the form of spoken comments, written notes, or the capture of sketches done on top of query-page results.

Conclusion

In this paper we described the design and implementation of a tangible interface to an interactive desk system named CAPRI (Context Aware Paper-based

Review Instrument). After considering review processes in an architecture firm, we identified some issues and opportunities that relate to the design review process. To address these issues and take advantage of the opportunities, we adopted a strategy combining elements of machine vision and augmented reality with a web camera and data projector. CAPRI developed out of this desire to provide design reviewers with seamless integration of hardcopy and online information and to provide natural and intuitive interaction with both through a tangible interface.

In CAPRI we presented a novel way for realtime linking of the physical interface element (the query page) and digital information. Our method not only enables users to build a precise query simply by positioning a tangible object (the query page), but also presents a new paradigm for flexible realtime interaction with digital information (the menu/display interface). Using this method, we developed an interface prototype that retrieves design data and projects it onto the desk surface in response to user actions. The system allows multiple users to interact simultaneously and equally, using their hands and fingers, which enables them to make clear their design query during the review process.

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