Data for Reflection: Monitoring the Use of Web-Based Design Aids

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Abstract
Web technology provides a new way of generating information about design processes. By monitoring student use of Web-based design aids, it is possible to collect empirical, quantitative evidence regarding the time and sequence of activities in design.

The research team has undertaken several software development projects to explore these concepts. In one project, students can use a Web browser running alongside CAD software to access a cost database and evaluate their designs. In a second project, students use a browser to record their time expenditures. They can better document, plan and predict their time needs for a project and better manage their efforts. In a third project, students record the rationale supporting their design decisions. The information is stored in databases and HTML files and is hyperlinked into the CAD software.

Each tool provides facilities to record key information about transactions. Interactions are documented with student identification, time of activity, and kind of activity. The databases of empirical information tracking student activity are a unique substantiation of design process that can feed back into teaching and the creation of ever better design tools.

Keywords
Design Methods, Empirical, Web, Cost Estimating, Time Management

1 Introduction

As design studios move relentlessly toward reliance upon networked computers, Web-based information technology provides unparalleled opportunities for conducting research in design methods. Not only can the Web be used to deliver static, “textbook” information, but also the use of scripting can provide active calculation abilities and engineering advice. Even more revolutionary is the use of “data-driven” Web sites to monitor and audit students’ efforts and develop quantitative evidence regarding design process.

This research is predicated upon an assumption that computing is inextricably integrated into the design studios. Computers are available at any time and to any student for any studio task. Predesign is conducted by not only reviewing literature in the library and interviewing future building users, but also searching the Web for relevant information and precedents. Programs are compiled using desktop publishing software to combine media such as scanned sketches, spreadsheet-generated tables and charts, and written text. Conceptual design is conducted with pencil and paper, cardboard and glue, digital compositing of photographs, 3D CAD modeling and digital whiteboard sketching for desk crits and collaborative discussions. Schematic design and design development is done using more 3D CAD, rendering, 2D CAD, and computer-aided mathematical modeling of engineering systems. Construction documents are prepared using CAD, word processors and hypertext authoring tools. Presentation boards are composed using image editing and presentation software, and produced using large format color plotters.

While this scenario of computer usage is not yet prevalent in schools of architecture, it is foreseeable as the situation of the near future. Costs of data storage have reached the point of being inconsequential, while processing power far outstrips our ability to use it. Prices for computers amount to the equivalent of merely beer money for many students. One researcher suggests that there are no technological or financial impediments to storing in digital form *all* of the information that one collects in a lifetime, including newspaper articles, magazine and journal articles, correspondence, conversations, and video clips of significant events (Bell 2001).

Our investigations anticipate ubiquitous computing in support of architectural design. If the network switch controlling information flow to the student is always on, how can we improve designed artifacts and design processes? The answer hypothesized by this research has two prongs: 1) we can provide expertise far beyond that available in the old model of a studio master; 2) we can monitor students’ efforts and apply a continuous improvement approach to the design process.

The second prong in this research is actually the more important. A reflective attitude about performance and process is a hallmark of professional activity among architects, planners, lawyers and doctors (Schön 1983). The principles of quality assurance in production and services promulgated by W. Edwards Deming depend upon statistical analysis of processes (Walton 1986). Architectural design processes can benefit from Total Quality Management that applies Deming’s methods (Solomon 1992). The application of principles of quality assurance to improving the design process has clear benefits to the profession, practitioners, and students.

If designers use Web-based tools and their transactions and queries are logged, then it will be possible to collect data about the design process. The frequency of use of a tool by an individual, the pattern of use in terms of time of day or stage of the project, and even the change of the design itself may be recorded for later retrospection. It is also possible to test the knowledge of students before introduction of a tool and again after a period of use to determine how that knowledge has changed. Such tests may be implemented as Web-based surveys that feed database tables and provide for further analysis. The statistical data that can be collected from design support Web sites provide a quantitative and objective basis for reflective thought about design process.

This paper reports ongoing efforts to implement these strategies for design process improvement. A review of empirical studies of design methods sets the stage for the research. A short primer on the technology of data-driven Web sites provides the concepts and vocabulary for discussion of examples. The paper presents a description of several coordinated research projects that address cost estimating services for design studios, records of design rationale, and management of design activities. Built into these tools are capabilities of recording who initiated an interaction, when the action took place, and for what reason it was initiated. Future work will include statistical analysis of these records, providing an accurate portrayal of design process and helping to identify how the process may be improved. Finally some preliminary conclusions are drawn and further research is outlined.

2 Previous Empirical Research in Design Methods

Much design methods research and commentary has been speculative and based upon tacit knowledge gained through practical experience. The well-known model of design that portrays the process as consisting of a cycle of analysis, synthesis and evaluation was put forward largely based on the authority of personal experience (Asimow 1962). Optimization approaches have been proposed as a model of what design process should be, rather than what it is (Alexander 1964). The argument for the pattern language approach has been based upon an appeal to historical evidence in folk architecture and contemporary examples of its use in real projects (Alexander et al. 1975).

Nevertheless, precedents exist for learning about design methods and design process using rigorous empirical methods. Ethnographic approaches involving observation of design educators interacting with students have documented characteristics of design process such as sketching, projecting forward to consequences, and reflecting back upon procedural steps (Schön 1983). In the early days of computer-aided design research, experiments were devised to determine the efficiency and value of computer methods in comparison to traditional manual methods by conducting trials in which participants used each of the two methods (Cross 1977). More recently, trials each of a manual method and a computer-based method have revealed the advantages and disadvantages of each method (Clayton et al. 1999). Protocol studies in which the activities of designers are videotaped and then analyzed are providing empirical elaboration of design process models (Gero 1995). Analysis of time records produced by architecture design students is another technique for collecting empirical data on design process (Clayton 2000). Design processes have also been compared by studying the products produced by each of computer methods and manual methods (Ataman 2001). Videotapes of collaborative design sessions using Internet-based communications tools such as Microsoft NetMeeting provide extensive data for analysis that can produce an empirical model of design (Al-Qawasmi and Clayton 2000).

Another trajectory of research has taken advantage of the use of "virtual design studios" to create data images of collaborative architectural design processes. In a virtual design studio, members of a collaborative design team are distributed geographically and tied together through information and communication technology (ICT). Because all of the interactions can be recorded, a virtual design studio provides a wealth of data regarding design process. Researchers have observed the evolution of design ideas that are shared and adopted in a collective, participatory design process (Engeli and Mueller 1999). Only very recently have researchers begun to record interactions as transactions on the Web that can be analyzed to reach a better understanding of process (Fischer, Herr and Ceccato 2001).

Architectural collaboration software imposes structure upon parts of the design process. The interactions recorded in the software, such as "chat" communications, are a document of the process that can be used to better understand design (Jabi 2001, Jung and Do 2001).

3 Information and Communications Technology

Web and Internet technology plays a part in many of the research efforts listed above. However, the data collection capabilities of the Web are only just beginning to be tapped. A short introduction to client –server computing and Web technologies will help to make further discussion more clear.

From the end-user perspective, the technology of e-commerce Web sites is familiar to anyone who has used Amazon.com®, an automated Web-based help site, or even a Web-enabled library catalog. A customer is presented with information and forms on a Web site. The customer types information into fields in the forms. Upon selecting a "Submit" button or a "Buy" button, the information disappears into some data processing system at the other end of the Web. Some tangible action subsequently shows up to the customer, such as a book arrives in the mail or perhaps a charge shows up on the next credit card bill. The conceptual model for the customer interaction is simple to the point of transparency for millions of Web users.

The fundamental computing concept for such sites is "client-server" computing. In the case of Web applications, there is a powerful centralized computer that has large amounts of disk storage, fast data processing capabilities and fast communications lines. This "server" can provide Web pages to any networked computer that requests the pages. The requesting computers are called "clients" and make use of standard client software, known as "Web browsers." The best-known browsers are, of course, Microsoft® Internet Explorer and Netscape® Navigator Web browsers. The client-server concept applies to other kinds of computing services, such as printing, file storage, and databases. Contemporary networks integrate all of these into a seamless whole of Web services, printing services, file services and database services.

Beyond the basic concept of client-server computing, the underlying infrastructure for e-commerce Web sites is a combination of three easy to use and accessible technologies: markup languages and browsers, database management systems, and Web scripting that can accommodate queries to the database. A particular combination of these is HTML, Microsoft Access, and Active Server Pages (ASP) using Microsoft Visual Basic® Script. With these tools it is easy to build Web pages that are composed dynamically on the fly using data retrieved from a database. User interaction is collected by HTML forms and then forwarded to the Web server. The server uses the information to perform queries on a database, format the retrieved data into new Web pages, and deliver them back to the user's browser. Forms can also collect new data that is submitted to the database on the server and stored for future retrieval. A diligent student can reach novice-level skill within a few weeks that allows practical results to be achieved. A student or faculty researcher can set up a test bed using low-cost software, such as Microsoft Office, Microsoft Personal Web Server and Open Database Connectivity (ODBC) for database serving.

By exploiting the inherent low degree of privacy of the Web, empirical usage data may be collected. Any activity on the Web server can be recorded in a log with information identifying the Internet Protocol (IP) address of the client computer, the time, and the nature of the activity. User names and passwords can further identify the person initiating the activity. Every request for information or submittal of information to the database server can be logged as a record in a database table, recording the time of the activity, who initiated the transaction, and the context around the transaction. In the context of design tools, this data provides an empirical characterization of aspects of the design process.

The research team has undertaken several projects that illustrate the breadth of possibilities.

4 Example: Cost estimating on the Web

An understanding of cost and construction implications of design decisions is crucial to achieving client satisfaction in the real world. Nevertheless, the average graduate of an architecture school has very little awareness or ability to make judgments about construction and cost (Gutman 1996). Cost considerations are touched upon at many points in a curriculum, such as materials and construction courses and professional practice courses, but are often missing from the design studios that are the heart of architectural education. By making use of data-driven Web sites, cost considerations can sneak into the design process.

A challenge to incorporating cost considerations into the design process is the shear quantity of data that is relevant. The number of items that must be considered as alternatives overwhelms an individual. Database management systems have long been the choice of construction cost experts. Software such as Timberline® Precision Estimating has long been a market leader. Yet even so, the collection of historical cost data can only be undertaken by large organizations with large amounts of resources and specialized market focus, such as Dodge, R.S. Means and construction firms. A cost estimating project for even a modest-sized building requires much more tedious effort than a single student can devote in a semester.

This research project addresses these concerns by employing a cost database that is fielded on a Web server. An easy to use Web-based interface allows students collectively to maintain the data. For any project, only a few new pieces of information need to be collected and put into the database. The data is easily accessible from the digital design environment; as a student models ideas using AutoCAD® or another CAD system, the cost database is close by in a browser window. The cost data can even be linked to an AutoCAD model by taking advantage of hyperlinks that can be attached to any AutoCAD entity. One can retrieve the cost data for particular items in the CAD model into a browser window and total the cost for the entire project.

The software consists of the same conceptual parts described earlier: a browser interface using HTML forms; an Access database residing on a Web server; and ASP files that use Visual Basic scripts to create new records and retrieve existing ones. Figure 1 illustrates the components of the software.

The database is organized into five primary tables: the historical cost data, the component quantity data, project identity data, user information and transaction log. The historical cost data provides the unit cost for each assembly, such as a metal stud wall, a concrete slab, or a built-up roof. It is organized using the UniFormat classification system. The component quantity table provides the quantities of each assembly for a specific cost estimate for a specific project. A record in this table represents a "take-off" quantity of a component in the building being designed and points to an assembly record in the historical cost data table and also a record in the project identity data table. The project identity data table stores historical inflation indexes and location indexes, add-on factors such as tax, fees and contingency funds, as well as ownership information to identify to which student the data belongs. The user table manages login information by providing first name, last name, password, course and other identity information. The transaction log stores timestamps and identity stamps for the transactions that are tracked, such as login, logout, creation of records for projects, and requests for cost estimate reports. Additional tables provide lists of values for historical and location adjustments and that make user input easier.

Figure 2 illustrates the opening screen, which allows a user to login to the system. Different user categories provide different permissions and different levels of access. All users, including guests, may retrieve cost data and various reports. Users who are given "estimator" status may store records in the project database to identify a studio assignment and records in the component database to represent a quantity take-off of the design. Users who are given "chief estimator" status are allowed also to input new records into the historical cost

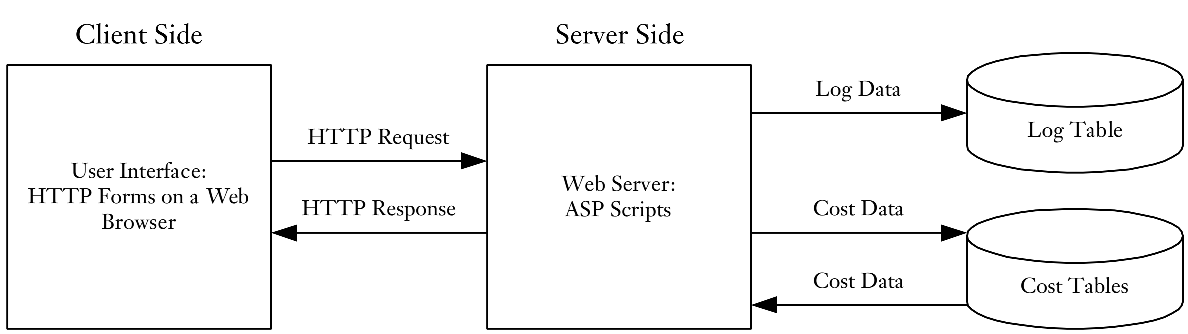

Figure 1. Software components of the Web-based cost estimating tool.

data. Users who are given "administrator" status may manipulate any value in the database, such as the table of location data, the table of historical indexes, and others.

Figure 3 displays the screen that allows a user to pick assemblies that will be used in the project. By navigating the hierarchical menu on the left, the user can designate a UniFormat division, section, and subsection. The UniFormat line items are picked from the pane on the right.

Inputting the quantity of an assembly is achieved using the screen in Figure 4. A designer can click on the assembly item and then change the quantity value. A running total of cost of the project is visible at the bottom of the screen.

Each record is stamped with the identity of the user who put in the data. This allows the data to be audited to achieve high confidence levels. As the data is checked periodically, it is possible to judge the reliability of data put in by each individual. It is easy to purge all data put in by users who frequently put in inaccurate data. It will be possible to identify which users need more training to improve the quality of data that they provide.

The identity stamps also contribute to the auditing of software usage that is crucial to continuous improvement of the design process. An instructor can check how much data has been provided by each student, giving an objective measurement of diligence. The accuracy of the data can be studied for each student.

The auditing data will show which students use the software and at what stages in the design process. Numerous questions can be answered from the data collected. Do students conduct cost estimates of alternative designs or do they merely produce a number as documentation of the completed design? Do they use the data at early stages or only at the end of a project? How widely do design alternatives vary in terms of construction materials and methods?

The research includes a survey of students' attitudes toward cost as a factor in design. Before fielding the software, a survey will be conducted to establish a baseline of typical student awareness of cost issues and to what extent they currently incorporate cost into their design processes. After one year of availability, the survey will be repeated to see to what extent student awareness has changed.

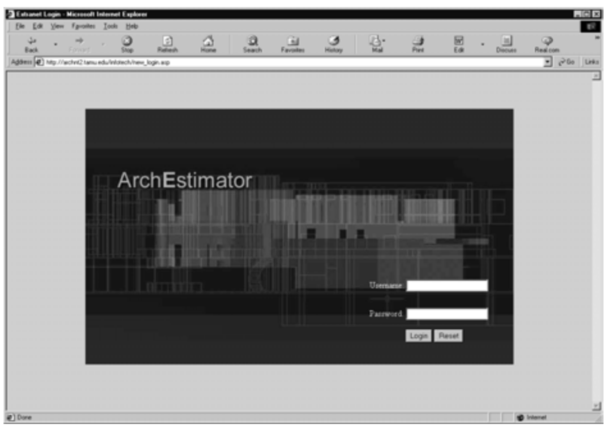

Figure 2. Web-based cost estimating software login.

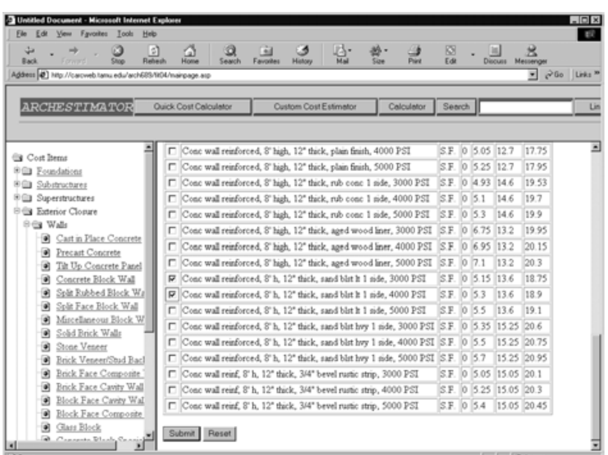

Figure 3. Selection of assemblies.

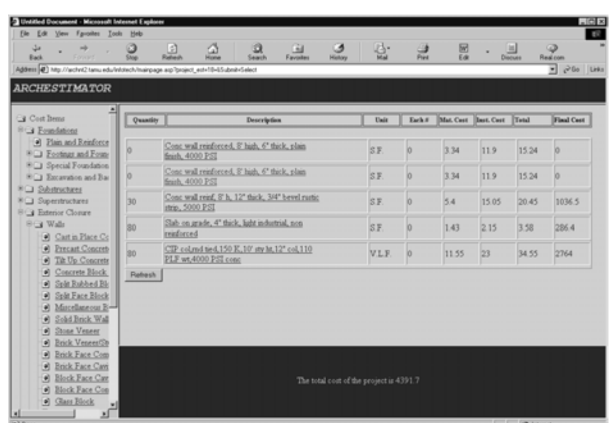

Figure 4. Entry of quantity values for items in the cost estimate.

The software has been tested as a ½ hour exercise in a design studio supplementing a lecture on cost control. Although the test was informal, students appeared to manage the software very easily and to appreciate the value it could provide to their design decision process.

Some of the theoretical benefits of the software are:

- Students can quickly perform cost estimates without leaving the CAD environment that they use for their design. They have access to the same information from wherever they are located on the Internet. This may encourage students to incorporate cost considerations more completely into the design process.
- The software helps students track their changes in design with the change in cost and gain a better understanding of their design processes and greater confidence in their results.
- The software provides an opportunity for students to observe the varying cost of the same building if built in various cities. This helps in fostering a connection between academia and practice.
- The software helps instructors to study students' design process and determine to what extent students' consider cost as a design factor. Information learned from analysis of the data can be applied to development of future course plans.

5 Example: Timesheets on the Web

Time management is a skill that is crucial in the professional world but notoriously ignored by students. To successfully complete a building design and construction project, each of architects, engineers and constructors must meet high levels of performance with regard to productivity, timeliness, quality and others (Oglesby 1989). Time and cost constraints on the design process have been identified as an important area for research (Savage et al. 1998). Due to the shortcoming of validity and reliability in performance management, designers have difficulties in estimating time and expenses, schedules, tracking production, and other managerial tasks (Williams 1996).

Previous studies have collected empirical evidence that confirms widespread impressions: many students in design studios procrastinate and delay doing their work until very near the deadline (Clayton 2000). The "all-nighters" and stereotype of excessive workloads may not actually be a consequence of excessive demands upon students but may be a symptom of dysfunctional time management. Some researchers suggest that the poor habits that students develop in school then translate into poor habits by professionals (Anthony 1991). Feedback from professionals to new graduates then contributes to a culture of inadequacy and poor management ability that diminishes the ability and image of the entire profession.

Web-based software may be able to give students a way to reflect more accurately upon their process and cultivate time management skills. Students will employ a browser to fill out forms for weekly timesheets. The time data will be recorded into database tables. Queries of the time database may then be used to study time expenditures, project toward completion of a project and compare time expenditures to those of other students. After sufficient examples are recorded in the database, it will even serve as a resource for using historical data to allow forecasting of time demands at the beginning of projects.

The software is a simple re-implementation of the spreadsheet-based process used in the previous research. Students record activities attributable to their design studios. Each activity has a date, a time, an associated project, a description, a category, and duration rounded to the nearest fifteen minutes. The categories are based upon a well-established model of the design process (Asimow 1962). They are as follows:

- Research. Activities that are not attributable to the specific design project, such as general reading about architecture, learning software, or buying textbooks and supplies.
- Analysis. Investigation of the requirements that must be satisfied by the project.
- Synthesis. Invention of a possible solution that satisfies requirements.
- Evaluation. Assessment of whether a solution has met requirements.
- Documentation. Preparation of illustrations, reports and posters that portray the designs.
- Presentation. Communication of design information to a client or class.

The activities are represented as records in a table. Other tables represent the list of people using the database, the list of projects assigned in design studio courses, a list of categories of activities, and a list of courses, as illustrated in Figure 5. A final table logs all transactions by type, time, date, and username.

The user interface requires input of a login name that protects the identity of each student. A user can fill out a form to record one or more activities and submit the activities to the database, shown in Figure 6. A user can also retrieve his or her records as shown in Figure 7. Analysis of records can be performed by the instructor using spreadsheets. Future enhancements will permit online comparison of time records to various benchmarks, such as average time devoted by classmates, historical time expenditures across a semester, and an ideal load-balanced time budget.

Surveys before students are exposed to the time management software and at the end of a semester of use will measure the knowledge obtained by incorporating the tool into the course. Study of the data collected from long-term use will indicate how well students learn to balance loads and even out time expenditures across a project.

Future work may compare student time management patterns to professional ones.

6 Example: Documenting design rationale

Similar technology can be used for documenting design rationale. The decision sequence that leads to a final design is itself a valuable record. It can be reused in a future project of similar scope and context. It can be used after commissioning of a building to assure proper actions during maintenance and operations. It can be used to reflect upon design process as an exemplar for students and apprentices or as part of a continuous improvement strategy. Documentation of design rationale as a hypermedia, hypertext resource has focused upon a model of argumentation (McCall, Bennett and Johnson 1994). The reasons behind illustrative design cases of building structures have been formulated in terms of structure, function and behavior (Maher and Gómez de Silva Garza 1996).

In an initial prototype, the researchers produced a Visual Basic program that runs within AutoCAD, shown in Figure 8. Using the program, one can record text notes describing intentions with regard to form, function and behavior. These

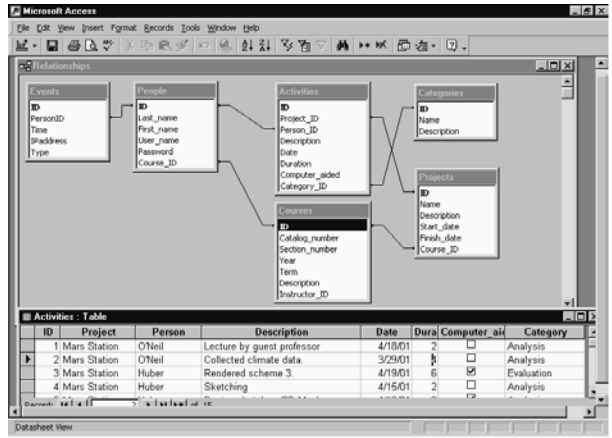

Figure 5. Time sheet application database showing tables and example records from the Activities table.

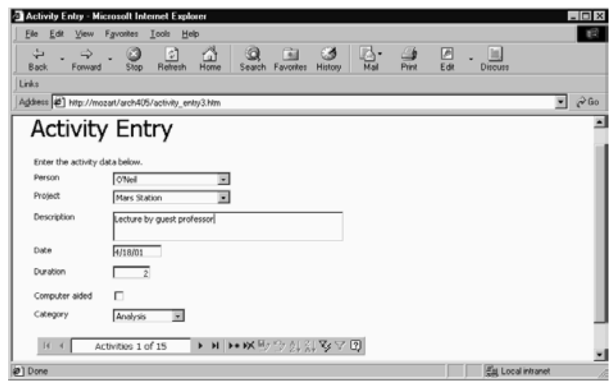

Figure 6. Entry of data describing an activity.

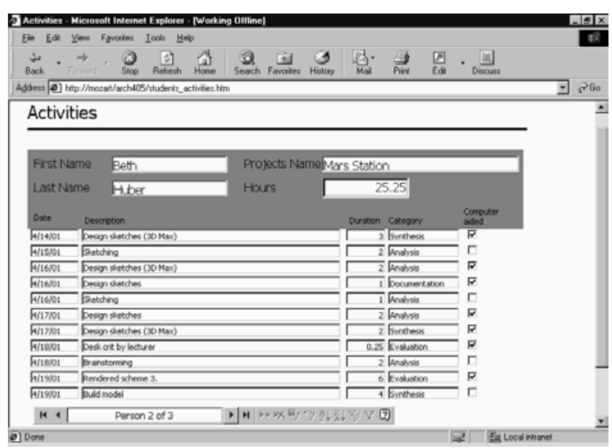

Figure 7. Online time records retrieval. The total hours expended is shown in the upper panel.

notes are associated with entities in AutoCAD. The tool writes the notes out in an HTML file that is hyperlinked to the AutoCAD entities. The value of the tool is in structuring the note taking into the form, function and behavior paradigm and associating the text with the graphics. Once structured, the notes can be aggregated by function to approximate a building program, by form to approximate the specifications section of construction documents, and by behavior to describe the expected performance of the building.

The next version will substitute a database running on the server and provide a Web interface. Students will be able to record design notes in the database and link them into their AutoCAD drawings. The combination of the AutoCAD plans and the Web notes will aid in presenting the work, as well as in the design phase as the design is modified.

Examination of the rationale notes will enable the researchers to better understand the students' design processes. It will be possible to identify which domains of knowledge were considered, how frequently and in what patterns. Through time, the researchers will obtain an extensive body of data recording design processes that will itself become the source data for new research.

7 Conclusions

All three of these tools are practical and valuable assistants to design studio students. The tools require very little training and little effort beyond good practice. Yet they should provide discernible and measurable improvements to the accuracy and credibility of students' design work. As a way to increase student design quality they can easily be justified.

However, the main point of this paper is not that design products can be improved through application of Web-based computer technology. The argument supported by these example software applications is that Web-based software based upon e-commerce techniques can be used as a data collection device for understanding the design process. The lack of privacy of Web-based transactions and their susceptibility to data mining can be turned to a legitimate pedagogical and research resource. The patterns of student behavior that can be recalled from the data collected by these tools can inform educators and enable application of continuous improvement principles to design education. The frequency of events of each transaction type, the pattern of their occurrence within daily or weekly timeframes, or the relation of the events to the stage of the project may be characterized. Individual patterns may be compared to grades or performance on a design project to determine if there is a correlation. The design processes of multiple students may be generalized and evaluated to give the instructor an evaluation of his or her effectiveness. Design methodology can be moved onto an empirical plane of objective observations of phenomena that can be analyzed with quantitative statistics as well as qualitative characterizations.

By using data-driven Web sites to support the design process, it is possible to provide the feedback that is necessary for continuous improvement and the reflective activities that are a hallmark of professional behavior. This research is generating empirical, quantitative evidence regarding the time and sequence of activities in design. The significance of tools like these to architectural education and design methodology is immense. While unaided design stagnates due to lack of documentation of process, computer-aided design just gets better and better by using objective data for reflection.

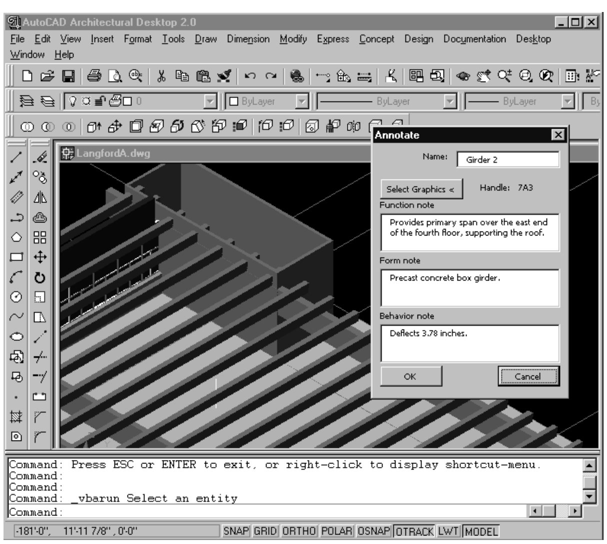

Figure 8. Documenting design rationale.

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