USING VIDEO FOR ANALYZING DAYLIGHT SIMULATION TOOLS

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ABSTRACT

This paper describes how socio-technical techniques can be employed to analyze video data of people using daylight simulation tools. We present and compare two different studies: the first is a classroom exercise using a heliodon, a classic daylighting analysis tool; and in the second a lighting professional is asked to use a new data visualization plot. We believe video is a powerful asset for interpreting the usability and effectiveness of these tools.

INTRODUCTION

Understanding how users conceptualize and interact with simulation tools has been of intense interest to the building performance community (Augenbroe 2001). Survey research (Donn 1997; Mahdavi, Feurer et al 2003) has established baseline practices as well as user requirements for tools. Others have taken a participatory approach in investigating the relationships between practice and simulation tools (McElroy, Elrick et al 2003). This paper presents studies of designers working *in situ* with daylight analysis tools.

To assess the effectiveness and performance of a lighting tool, and determine whether the designer has considered relevant factors like climate, seasonal variance and location, we must consider two things. First are the designer's characteristics: How did the designer behave physically and interact with the tool? Is she confident? Is she open to looking at the actual conditions as opposed to accepting universal standards that deny the situation-specific needs of lighting?

Second, we look at the history and process of designing. What were the conditions under which the designer worked with the tool, such as the setting, the factors considered, and the data used? Were the commands entered correctly and the did the designer enter the right data? Did she use more realistic assumptions or experiment with lighting conditions other than the standard approach. Lastly, how was she introduced, trained, and supported for using the tool?

Existing lighting design tools such as the traditional heliodon or new software and other *tools for energy efficient lighting tend to be used and analyzed as though they were unmediated sources of information* – that is, speaking truth in their own right**.** But tools are always combined with users: their effectiveness depends on the user and her skills, individual styles, training, and organizational beliefs. Very few analyses consider these issues and therefore treat tool use as a “black box”. Given the wide-ranging skills, confidences, training, and backgrounds of building designers, these differences can significantly affect the operation and impact of how the tool works.

Video can illuminate the process of how people interact and comprehend simulation programs. In human-computer interaction and cognitive science research, video is the primary vehicle for detailed analysis of human-behavior (Suchman 1987, Goodwin 1996, Brum-Cottan and P. Wall 1995). Practically speaking, dense information on video can be examined and appraised for defining user-requirements, to coordinate between design and development teams, and to evaluate how the tool performs under a variety of conditions. The process for making work visible is not automatic--contextual, interpretative, and ethical considerations need to be made.

In the case of lighting design, it is becoming increasingly important to study how people incorporate energy efficiency and conservation goals. Designers increasingly must factor energy use into their work. Currently the focus of energy is often reduced to more efficient or add-on technologies that are outside the “real” control of people. Nevertheless, studying all aspects of agency is needed as part of researching energy and lighting.

Overview

The format of the paper describes a socio-technical approach of using video for understanding user activity. It first discusses excerpts from a 5 hour session observing an undergraduate building science lab with physical models and the heliodon. Although the heliodon may be considered "obsolete" to current software simulation programs, we believe they are relevant since they are compatible today with ubiquitous foam-core and machined models. Furthermore, they are also interoperable with current and future software technologies such as digital controllers, photography, and projection systems. For example, Underkoffler and Ishii (1999) demonstrated a projection and imaging system to project shadows on a landscape. Although this was a "toy" problem, other more mature technologies can involve similar components.

With physical models, we will discuss how video can be used with simple usability and more complex socio-technical methods. We will also discuss how video can be used to analyze new software under the socio-technical framework. A rich variety of information that can be gathered on simulation tool use via socio-technical video methods. It relies on screen, voice, and gesture data recorded on a digital camcorder. Many hours of data were recorded for this test, resulting in many pages of transcripts. Small, but exemplary, portions are excerpted for this paper which identifies usability, learning, and professional adoption issues. Using the excerpt, the paper develops a set of video-based metrics to enhance reviews of lighting design activities.

PHYSICAL MODELS

We have conducted a preliminary analysis of a lab session for an undergraduate building science class. We first observed a half-hour training session where a teaching assistant introduced students to the equipment and the assignment. Students were expected to use a digital camera and notepad to record simulation results from a heliodon to simulate clear skies (Hopkinson 1966). For the heliodon, students were assigned to photograph their model at 12 discrete points in time (3 times of day during 4 seasons) within a 15 minute session. Later they would use these photographs in a lighting analysis presentation.

During the training session, we determined that two video camera positions would be useful to record activity in the solar lab. The first camera was positioned in a loft area focusing on the heliodon. This allowed for constant recording of the platform, model, and nearby users. A second camera was used at ground level to both focus in on specific interactions as well as to capture activity throughout the entire lab where multiple students and instructors would gather.

During class, the teaching assistant wrote the names of each month on a piece of masking tape and placed all twelve of them on a wall. Students were encouraged to stick the appropriate tape with the name of the month they are investigating onto their model to include in the photograph. Students also were told to use a small sun path diagram with a peg in it to calibrate the heliodon with the artificial light source. This diagram was necessary since the labels on the heliodon were superfluous as the machine was no longer bolted to the floor in a known position relative to the fake sun.

STANDARD USABILITY METRICS

Usability studies efficiency, accuracy, and satisfaction of people completing tasks (Neilson 1998). In this case, we measure two of the most common usability metrics-- time to complete a task and errors.

Figure 1 illustrates a basic usability metric, picture taking time, that is quantifiable by reviewing video-tape. Coded are the times of JP, 1 of 7 students that we recorded and observed during the laboratory session. On average, it took him 16 seconds to get the camera position ready and take a picture (*JP_picture*= 0:16). JP also took 36 images in total-- many more than the 12 required . Often at a single time point he would take multiple photographs from different vantage points. The outlier point in the histogram, which took over a minute, was due to an interruption by the instructor. Other values coded for this first student were the time to setup (*JP_setup* = 1:48), the average for changing the reference tape and rotating the heliodon (*JP_move* = 0:29, σ = 0:14), and finishing time removing the model (*JP_finishing* = 0:18). The average for the other 6 students were as follows: picture taking time (*others_picture* = 0:17), setup (*others_setup* = 1:22), changing tape and month (*others_move* = 0:23), and finishing (*others_finishing* = 0:20).

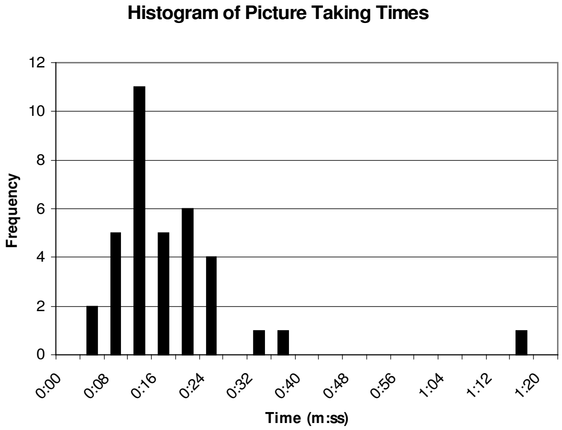


Figure 1. Histogram of picture taking time for JP taking 36 photographs of his models. Note the outlier point near the 1:20 mark was due to an interruption.

This timing information can be useful for developing baseline metrics for new daylight simulation tools. If these results were robust across a population (including more experienced users) under realistic design conditions, a few direct comparisons can be made with either new physical, software or hybrid tools. First, if a person P can operate a new computer program which generates and timestamps accurate images in less than 16 seconds (*P_picture*< 0:16), it would be considered more efficient than using the heliodon. Similar comparisons can be made for *P_setup*, *P_move*, *P_finishing*. We could also compare times for model creation (physical versus digital for example) and other variables. Lastly, there are other metrics that can be quantified such as remembering camera position, effect of having real time feedback for moving and watching the model during rotation, and examining facial expressions.

Figure 2. A critical event is captured on tape. Here the heliodon table erroneously falls onto the floor.

Figure 2 shows that this table can fall onto the floor, possibly endangering the user, entering an "invalid" state, and losing operational capacity since it no longer can move freely across its rotational axes. To recover, we observed cases where up to three people had to lift the table into an operational position. This is considered a severe usability flaw due to errors that can result in injuries, lack of mechanical precautions from making the error and difficult recovery from errors when they do occur.

Note, it is not automatic that a computer program can fix the problem identified in Figure 2. For example, if the computer program allows the user to enter an invalid latitude or time it may also result in an invalid reading.

SOCIOTECHNICAL METHODS

The previous usability studies illustrate measurable performance of a user completing a task, or problems they encounter while doing so. Nevertheless, there is a larger activity system involved when people use tools. Hollan et al. 2000 describe how pilots use of navigational instruments is much more complex than reducing the process to the few variables the instrument reads. When traditional instruments were removed from modern digital cockpits, there were usability problems which only were corrected only by digitally reproducing the old display, with no major technological advance.

We may find a similar situation to be true for daylighting. There is a classroom environment where professors, teaching assistants, and students with different histories all interact around a “simple” instrument. In the software section, constructs of division of labor and community beliefs also are particularly relevant. Similar to Miyake (1986), we use conversation between people completing a task as a natural way for investigating, in fine detail, what people are thinking.

Teaching Investigation Skills

A student 'TS' tests the shading controls for the east and west side of his building. After he puts his model on the platform, he rotates it mostly near solar noon. An instructor asks him how his analysis is going, and he responds that he does not believe that the sun penetration "actually goes east and west as much as I thought it would go" since "because now it [the sun] is at noon on june 21st". But the instructor points out that "noon is the point where the sun is really straight" (Figure 3). She is pointing above her head where the actual sun would be at noon in the summer, instead of the fake sun attached to the corner of the laboratory. This reflects her understanding of the mechanics of solar increase of the mechanics

Figure 3. The instructor points to solar noon suggesting lower angles may be better for investigating how light enters the sides of the model.

She then suggests to "to think about the east and west exposure, which is going to be 3-4 o'clock in the afternoon for the west, and for the east its going to be about 10 o'clock". With overlapping talk, the student repeats what she says and is in agreement. When she leaves him to do his work again, he exclaims "wow, that's really bright inside!" and knows that he has to fix something with his shades.

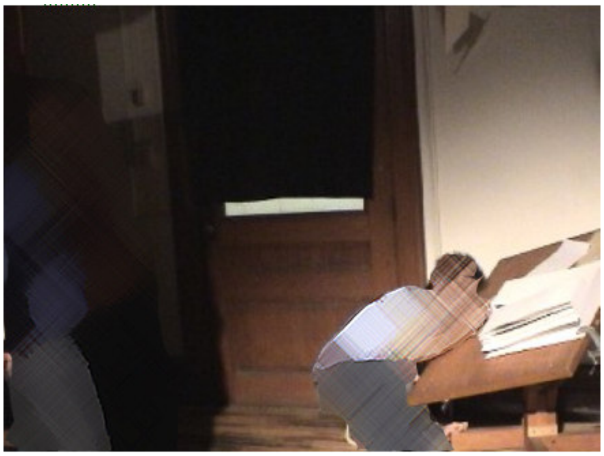


Figure 4. The student examines early morning times and exclaims "wow, that's really bright inside!".

Canonical Instruction

Another student 'JP' investigates how light enters ribbon-like apertures created by carving into a landscape of undulating hills. The apertures are created by cutting slits to expose a below-ground living area. Due to its irregular geometry, its solar performance is not immediately clear. The teaching assistant 'TA' notices that JP has a piece of tape labeled "October" on his model and challenges his mode of inquiry.

[TA] The professor wants you to be doing four different times of year and three different times of day-- morning, noon, evening, but not too evening.

[TA] So why are you doing October? Think about what times are most useful for you

[JP] <inaudible> [hurriedly gets tape with new month on it, changes table position]

In this case, the instructor circumvents the exploratory and interpretive aspect of using models. The canonical dates she recommends may not be the most interesting for this model. For example, a photograph taken during "too evening" hours which were discouraged by the TA may be interesting times for examination. In fact, one of the calendar days of the canonical times (the second equinox) has a redundant solar angle, and provides an opportunity for the student to select a special time of their own to investigate and record.

Figure 5: (left) The teaching assistant asks JP why he is using October, a non-standard month. (right) without responding, he hurriedly changes his date selection.

PHYSICAL MODEL SUMMARY

Usability studies with video can identify and capture performance metrics such as time to take a photograph, move the table, and errors. These metrics can be used as benchmarks for assessing new tools. Socio-technical methods illustrate how training can significantly affect tool use. In later interviews, TS told us that, on his own initiative, he frequently brought new designs back to the solar lab for testing. JP, on the other hand, believed he put in too much work for the information he got out of it and did not return.

SOFTWARE

This section uses socio-technical theory for analyzing an experimental daylighting tool. A lighting designer 'Brina' offered to test the tool described in (Glaser 2001). She "Brina" had 13 years of industry experience as a lighting designer. Glaser and Brina met in a neutral third party location to test the tool. The session started by Glaser training her in scenarios of use and asked how she could incorporate them into a hypothetical design scenario. Specifically, Brina was asked how she would use the tools for designing a lighting system for a pentagonal office with three windows. She was shown an overall daylight distribution plot as shown in (Figure 6).

Figure 6 shows the plot titled "AVERAGE". It maps, with color, the *average* daylight distribution across the pentagonal room across most of the year (Jan 1 to Dec 26, 4am to 9pm) under clear sky conditions. It shows, on average, some parts of the room will receive very high amounts of illumination (hundreds of footcandles), while others are relatively dim (in particular the east side of the room).

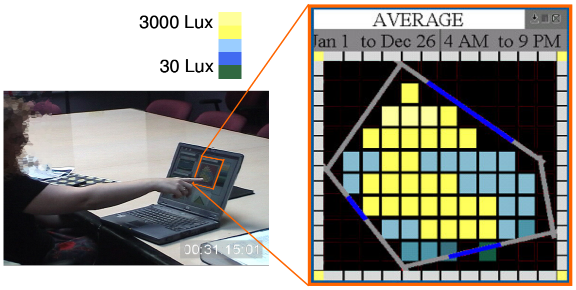


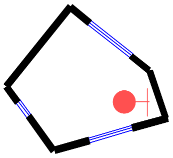
Figure 6 (left) A screen capture of the user study "Brina" and (right) close-up view of the panel she is pointing at.

The conversation for this study is broken into multiple subsections ("Initial Use of Daylight Plot", Organizational Breakdown and Individual Recovery", Integrated Design", and "Final Refinement") and seen as figures 7-10 respectively. These sections are excerpts from a larger corpus of data spanning over 90 minutes. Figures 6-9 occur sequentially during the study, while the discussion in Figure 10 occurs about 12 minutes later. Each line of text is numbered sequentially except to indicate the break in time from Figures 9 and 10.

Initial Use of Daylight Plot

Brina begins by describing requirements for achieving a "good balance" (lines 1-2) in the space. Balance may be interpreted as having uniform electric lighting throughout the space-- something which older lighting requirements recommend (versus separating task and ambient lighting). In lines 3-5, she begins to read the graph ("we are looking kind of dim over there", referring to daylight availability), and starts a design consisting of a single sconce (lines 3-5). Sconces are light fixtures that adjoin walls and wash light above them. At this point, she stops and reflects upon the peculiarity of using a daylighting chart in planning the electric lighting system.

1 [B] =uhm, there we are always trying to get a balance with
2 that type of lighting, so even though you get a lot of
3 daylight, in this pattern, and we are looking kind of
4 dim over here so we want to get a wall sconce or
5 something happening,



Points out a wall sconce to highlight a dim area

Figure 7. The designer initially places a sconce in a dark area of the space.

Organizational Breakdown and Individual Recovery

In Figure 8, Lines 6-9 illustrates that Brina questions the relevance of designing with daylight. She says that it is unrealistic to design for the sun since it has a high degree of variability (e.g. “cloudy day” “evening” lines 7-13) and is still concerned with the “balance” (line 7) of electric light. This is not surprising since it is consistent the division of labor in lighting design offices—namely that daylight is delegated to the architect and others to manage. The utterances, “we are assuming” (line 8) and “there is this sort of general assumption” (lines 13-14) reflects that *it is not she, alone, who is making this assumption.* In other words, her design method of ignoring daylight in planning electric lighting systems is shaped by her community of lighting designers.

Nevertheless, *Brina individually realizes* that planning “[electric] lighting for when it is dark” is “not a very good idea” (lines 14-16). This realization has direct implications to a new design she proposes.

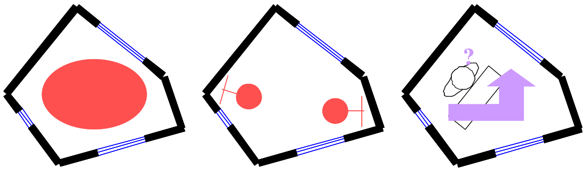
6 [B] uh- there, we are always trying to design for a good
7 balance, uhm and and good work light, no matter what’s
8 happening with daylight, because we are assuming a
9 cloudy day or
10 ok, [aha]
11 [or bad] circumstances ((short laughter))
12 =ok [great]
13 [or ev] evening circumstances- so ther there is this
14 sort of general assumption that which is probably not a
15 very good idea, that, you know, lighting is for when it is
16 dark and=
17 [D] =aha
18 [B] when you don’t have a lot of daylight,

Figure 8. Brina identifies professional bias to not rely on daylight

Integrated Design

By using the average daylight plot, Brina develops a new solution which factors windows, electric lights, and sensors (Figure 9). At lines 19-20, she gains confidence in the interface’s representation. She describes a general lighting system that can be turned off (lines 21-22). The specification of a general lighting system is significant since it differs from a uniform balance of light approach that she may have discussed before. She proceeds to add wall sconces again (lines 22-23) to brighten only areas of the room that receive low amounts of sunlight, on average. Lines 24-25 she explicitly talks about the building occupant as part of her dynamic model. She has concerns about occupant comfort and believes sensors can remedy the situation (27-28).

19 [B] so, uhm but I think, I think it would be a useful tool to
20 know where the daylight is coming in,
21 so that maybe, maybe there is a general lighting
22 system that can be turned off and we add wall sconce
23 over here and wall sconce over here
24 then we have the person at the desk, be willing to get
25 up, which is [the whole problem]
26 [D] [Right]
27 [B] =with those sensors, so that people don’t have to get up
28 from their desks to change the light,
29 [D] aha



Discusses general lighting system that can be switched off during daylight hours

Points out 2 wall sconces to help in dim areas

Some confusion on how the occupant controls the lighting.

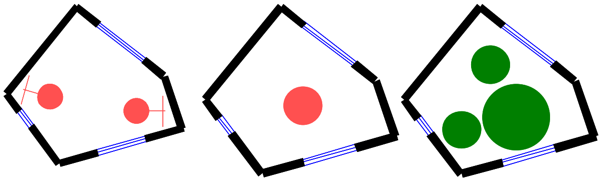
Figure 9. Designing an electric lighting system sympathetic to daylight and the occupant.

Final Refinement

About 12 minutes later in the user study, Brina suddenly revisits the design problem (Figure 10). In lines 101-107, Brina discusses the necessity of adopting information that is pertinent to her job. She is able to quickly revise her solution (108-114) to accommodate the concerns she had about the occupant in the second design intervention. Specifically she recommends daylight sensors to switch the lights (to mitigate the number of times the occupant has to interact with the controls throughout the day). Although this particular control strategy may not be favorable to all occupants, Brina is now satisfied with her solution (lines 117-120).

100 [B] you have to figure out, you have to get enough
101 information to do the job properly. You have to get
102 sort of the least amount of information to do that job=
103 [D] ok
104 [B] to the best of your ability. So as soon as you understand

105 where you're going, =
106 [D] [uh huh]
108 [B] [like] I now understand that this side of this room
109 could be the wall sconce and this side of the room,=
110 [D] =ok.
111 [uh huh.]
112 [B] [ok] and that, you know, if I put a fixture in
113 the middle, and I give the daylight
114 sensor here and there, near the, you know,
115 ok, I've [got it]
116 [D] [uh huh]
117 [B] sort of solved in my mind, and
118 [D] [aha]
119 [B] [so I] can move onto the next [thing].
120 [D] [aha]



Points out again the sconces for dim areas

More precisely specifies the general lighting system to be turned off when daylight is available

Initial sensor specification

Figure 10. Revised solution that better takes into account daylight, electric light, and the occupant.

Software Analysis Summary

The study shows how 'Brina' a lighting designer uses new daylight software. Initially, professional assumptions for quick specification of electric light inhibit her understanding of time-dependent daylight graphs. In a span of about fifteen minutes, though, the designer reorganizes her design strategy. Her new approach employs upon her to think about energy efficiency and the occupant.

Each part of Brina's user test (Figures 6-10) show an increased mastery of using the simulation tool. When she started to propose a solution that integrated both daylight and electric light, she interrupted herself due to a division of labor in practice which boxes daylight. Nevertheless, she was able to critically reflect on these assumptions and tentatively sketch an integrated solution. Over ten minutes later, Brina refines her design showing that she can integrate the multivariate information presented to her.

From the perspective of building performance, Brina improved both the lighting quality and energy consumption in her proposed design. The lighting quality was improved due to her balancing daylight with electric light. Specifically, by designing two electric lighting systems (a general system, with wall sconces for highlighting) the occupant (or sensor) can chose to turn on or off one or both to make the lighting more even during daylight hours. This flexibility also has significant energy benefits since daylight can work autonomously.

There were a couple noteworthy of limitations to this study. First, this study was conducted by a single designer working on an abstract hypothetical problem. Secondly, the conversation focused around the average daylight plot even though the tool had more features for examining daylight distributions.

CONCLUSIONS

This paper presents methodologies for understanding how people interact with building simulation tools. It illustrates how user interaction can be captured, codified, and analyzed using a video camera. The benefits for doing so range from practical benchmarking of new tools, to understanding the complex social-technical system surrounding their use. Simulation innovations cannot be realized until they are embodied and tested with people.

The results of the studies presented in this paper have implications to both physical and computer tools. Building science laboratory teaching methods should encourage investigation where the student, model, and issues are at the center, not the testing apparatus and best practices. In addition, some of its operations are costly and prone to errors, suggesting there is room for improvement by new technologies. The study of software use shows that designers have great capacity to go beyond their standard practice. This questions many of the task-based assumptions of building performance tools, and hints at designing tools for better collaboration.

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