A DAYLIGHT DESIGN TOOL USING A *HYPERTEXT* FORMAT

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ABSTRACT

For over a decade research work in the Windows and Daylighting Group has focused on identifying and quantifying the architectural and energy impacts of daylighting. We have looked at the energy-saving potential of daylighting, its role as an enhancement or supplement for electric lighting systems, and its effect on the quality of interior spaces. Convinced that daylighting can have a beneficial impact in all of these aspects, we have over the last few years turned our attention to the application of daylighting design knowledge. Existing methods to facilitate better daylighting design appear to have had little impact in the built environment. We are therefore developing new design tools to encourage the use of daylighting by making the necessary technical information and design data more accessible and useful for designers than traditional reference materials and design tools.

Some recent advances in the computer world are helping us bridge the gap between the promises of research and the reality of design application. The "friendly" environment of current microcomputers and new software implementations of a concept in electronic information systems known as *hypertext* present new possibilities in the realm of technology transfer. Unlike traditional written information systems, hypertext has the ability to flexibly link data in a nonlinear fashion, allowing different users to move through the information differently. These new electronic systems may also include sound, animation and video as well as traditional text and images, expanding the hypertext concept to *hypermedia*. Part of the genesis of this software is in a recognized global need for the sharing of information; the parallel to architectural design is immediately seen, as ever-increasing demands on the profession highlight a growing need for accessible reference information.

The Windows and Daylighting Group is currently developing a daylight design tool using hypermedia tools. The intent is to first supplement, and eventually replace, written manuals and other references, whose size or structure are too cumbersome or otherwise forbidding to be used in a typical design process. The tool is intended to be a guide for both design and educational tasks. Currently in the early stages of development, the tool will ultimately take advantage of state-of-the-art multimedia hardware while the software will combine data and expert guidance into a fluid and dynamic design tool.

INTRODUCTION

After years of relative neglect, daylighting has emerged as an energy-conserving strategy in building design and a lost architectural art. Daylighting design decisions affect illumin-ation, aesthetics, the interior environment, energy use and peak electric loads. Daylighting is a design issue that can simultaneously support goals of good architectural design, quality of interior environment and reduction in energy use.

Responding to the pressure of the "energy crisis," the Windows and Daylighting Group has extensively researched the energy implications of daylight, and has developed a number of conventional design tools to promote its practice. While our daylighting research progress has been substantial, the resultant impact in the built environment is less than ideal. In rethinking contemporary technology transfer philosophies, we have concluded that most current approaches are fundamentally ineffective in influencing mainstream architecture.

Two recent trends have stimulated us to explore new avenues in the search for better computer-based daylighting design tools. One is the popularity of new hardware and software, especially among previously computer-phobic designers. The user-friendly environment of these computers is a big step towards more appropriate tools for the design community. The second is Apple's introduction of their *HyperCard* program. This is a flexible and widespread hypertext-like software environment. *Hypertext* is a term coined by Ted Nelson in the 1970s to describe electronic text that is not bound by the linear and sequential structure of the printed word. In our current "information age" it is also the state-of-the-art data transfer medium, allowing a user to work with linked information in an intuitive, interactive, fluid fashion. We see tremendous potential in this kind of software for producing computerized design tools that function effectively in the conceptual part of the design process.

The advantages of a hypertext document are many: 1. Size is not apparent to the user. Both the physical mass and the quantity of data in large reference books are intimidating. 2. The structure is dynamic, as opposed to the fixed organization of any written material. The user determines the flow of information, although it is along predetermined paths. 3. Information does not have to be absorbed sequentially, as implied by the nature of books. There are often no page numbers in a hypertext document. 4. The document can have "intelligence" in that links can be structured to best direct the user's actions. One click of the mouse button can take the user to the exact bit of related information, where a traditional document might require additional work with the index or footnotes to move around. The hypertext document can keep track of where the user is at all times, keeping him or her from becoming lost and facilitating the back-and-forth movements that make the document so flexible. Enhancing all of these features with the characteristics of an expert system could produce the ideal design tool that functions as an electronic design "consultant," an entirely new combination of data base, reference manual, design guide and expert system.

Addressing the multisensory nature of design, the tool is enriched further by adding features of hypermedia such as linking the data with pictures, sound, animation and video. Among the many possibilities: bringing concepts to life with animation, showing building case study examples and post-occupancy evaluations with video interviews, and allowing dynamic manipulation of high-resolution images in "what-if" design experimentation.

For several years we have been exploring the design and development of ideal computer-based building design tools, and the project described here is one experimental step toward that larger, long-range goal. We are examining the possibilities for better design tools using today's hardware and software while tracking developments towards more advanced software and affordable powerful computing workstations. This paper describes some limitations of existing design tools, the concepts we believe will contribute to the next generation of advanced design

tools, and our progress to date in the development of a prototype hypermedia daylight design guide.

DESIGNING WITH DAYLIGHT

Daylight as an architectural design strategy sits at the junction of key quantitative and qualitative building design issues and works well as an energy-conserving strategy when properly incorporated into building design early in the design process. Successful daylighting design requires the integrated efforts of all design team members since it influences so many other building design decisions. While not normally the dominant feature in a building, daylighting is one of the most important energy-related design issues.

Daylighting is a term with a number of definitions. For example: <u>Architecturally</u>, it is the interplay of natural light and building form, to provide a visually stimulating, healthful and productive interior environment. <u>For energy savings</u>, it replaces or augments indoor electric illumination needs, reducing annual electricity requirements for lighting and overall building energy requirements for heating and cooling. <u>For load management</u>, it is the dynamic control of fenestration and lighting systems to manage and control peak electric demand and load shape. <u>In terms of costs</u>, it is the use of all of the above strategies, to minimize operating and maintenance costs and to maximize occupant productivity.

Most people enjoy daylight, a preference stemming perhaps from a primal remembrance of the spectrum in which we evolved as organisms. Through contact with daylight we can tell time, know the weather and enjoy a view. The responsiveness of the biological systems of most animals to daylight has been widely demonstrated (Lam 1977). Daylight as an amenity is reflected in building market values, rental prices and vacancy rates (Selkowitz and Griffith 1986).

Daylit buildings are less sensitive to electrical power shortages, a benefit with respect to worker productivity in areas with unstable electrical power availability. The savings in productivity during a half-day blackout might pay for the entire added first cost of the daylighting system (Selkowitz and Griffith 1986). Daylighting strategies normally pay back their first cost over a number of years of annual energy use and demand charge savings, but the payback can happen much sooner when productivity is a factor. Daylit buildings are also less sensitive to fluctuations in energy prices.

While understanding these broader issues, the Windows and Daylighting Group has focused research efforts on the energy-saving aspects of daylighting. We believe that daylighting strategies could be employed as part of an overall integrated lighting and building design strategy to reduce building energy consumption fifty percent below today's levels in non-daylit buildings (Selkowitz and Griffith 1986). The interested reader is referred to a number of more detailed LBL technical documents listed at the end of this paper. A brief summary of our research as to the energy impacts of daylighting:

- Daylighting strategies can save a large fraction of lighting energy. With moderately sized windows or skylights, we have simulated and measured savings up to 75 percent in daylit spaces.
- Daylight design strategies admit solar gain that contributes to cooling loads. The added heat can be more or less than an electric lighting system would contribute, depending on the fenestration system and the electric lighting power density.
- Total building energy use drops sharply with daylight use over a range of small to moderate effective apertures. For larger effective apertures the benefit relative to opaque walls diminishes although total energy use is always significantly lower than with an equivalent non-daylit building (fig. 1).

• Daylighting can significantly reduce peak electric demand, which can be a considerable economic savings where utilities are concerned with load shape and demand management.

Daylighting in current architectural practice has experienced both success and failure. Many buildings, some of them award winners, are successfully using daylight to save energy and improve interior space quality. However, because daylighting design is a difficult multidisciplinary task that has impact on many other building issues, some applications have failed to meet design goals. Some of the causes: 1) There are no simple techniques for assessing lighting quality, an issue with positive and negative connotations for daylight. 2) Managing a light source of great variability in both intensity and direction is difficult. 3) Poor design or improper window management can result in occupant dissatisfaction and increased energy use, for example due to visual discomfort or excessive solar gain. A small drop in worker productivity can completely negate all economic benefits from daylighting.
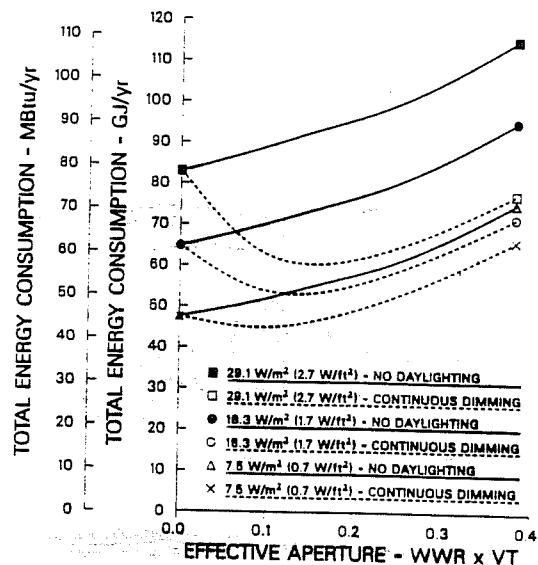

Fig. 1. Net annual energy consumption in south zone as a function of effective aperture with and without daylighting.

Despite an increase in daylit buildings since the energy crisis, the record is unclear regarding the real level of achievement. Post-occupancy performance data is rarely gathered and can be difficult to evaluate. We are thus looking to develop new tools to help designers make the best use of research results while avoiding potential mistakes.

LIMITATIONS OF EXISTING TOOLS

A number of design tools currently exist for daylighting and other areas of architectural research in the building sciences, but these tools do not yet enjoy widespread use among practicing architects. Additionally, most existing design tools are evaluation or optimi-zation tools for finished designs and have little impact in the early stages of design when the architect's decisions are the most far-reaching. Some of the reasons for the currently minimal impact of existing tools are as follows.

Not integrated into the overall design process. Computerized design tools currently available are very specialized and independent of each other and of the design process as a whole. Architectural design is more a procedure of compromise than optimization; many issues have to be considered simultaneously before the synthesis of a final design. Current tools focus on optimization by isolating individual building elements, which does not allow a designer to see the impact of such optimization decisions on other building elements. Current tools are also normally used in the later stages of design, when many of the major decisions have already been made. Both of these limitations make it difficult for a designer to explore an energy-saving strategy like daylighting, which affects many building elements and must be addressed in the early, more conceptual part of the design process.

Too time consuming. The specialization of current tools requires particular knowledge and skill for preparation of the input and for effective interpretation of the output of each tool. Learning the individual procedure for each tool is the designer's first hurdle. Each subsequent use is then

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preceded by a trade-off decision between prospective benefits and investment of time and effort. The use of several independent tools requires time-con-suming specialized processes either for formatting the same data in different ways, or for converting the output format of one tool to serve as input for another (Selkowitz, Papamichael and Wilde 1986).

Non-architectural format. The current generation of computer-based tools emphasizes design parameters that can be readily quantified. A designer willing to make the time commitment to these tools would still be frustrated by the lack of means for evaluation of such daylighting design criteria as aesthetic appeal, glare potential and view access. Furthermore, the information that is provided is usually not in the right format to be directly utilized. For example, the output of powerful tools for the evaluation of the interior luminous environment are often in the form of data tables and charts. Effective use of such information by a designer requires specialized knowledge and experience (Selkowitz, Papamichael and Wilde 1986). Tables and graphs are not the standard means for designers to evaluate building design decisions. It is crucial to recognize the visual nature of architectural design, suggesting more extensive use of images in design tools.

Difficult for architects to acquire information. The design of buildings requires an enormous amount of data, from a knowledge base that continuously increases. However, it has been the nature of the architect to rely on individual experience for knowledge rather than on the research of others, partly because there is no effective system in place for the sharing of knowledge in this profession (Burnette 1979). Current tools do not address this networking problem, where it might be possible to pool the experiences of many individuals, expert advice from specialized consultants, and new technologies and research findings.

WHAT A BETTER TOOL SHOULD DO

The limited impact of the substantial progress in daylighting research over the past decade has left many applied science researchers frustrated. We have thus turned our attention away from the narrow focus of quantitative building performance evaluation tools to broader "information" tools that address both the qualitative and quantitative aspects of building design, in a format better suited to architectural practice. Ideally, future design tools will combine the predictive power of evaluation tools with the ability to help the designer better formulate the problem definition as well as to help find a solution (Selkowitz and Griffith 1986). We expect "expert systems," new imaging technology, advanced graphic capability, and hypertext software to play an important role in this future work.

We are currently developing a prototype daylight design tool using available microcomputers and software, however the technical capabilities of these systems do not yet meet the needs of our ideal tool. We nonetheless have identified these needs as we wait for technical developments to catch up.

An ideal building design tool should:
- be useful for all building and occupancy types and all climates.
- be useful through all stages of the design process, addressing all design issues and design tasks.
- be useful throughout the building life cycle and "grow" with its users by storing project and post-occupancy data.
- be interactive with the designer.
- accommodate different users, with different goals, criteria, skills and experience.
- support the visual nature of design and enable evaluation of nonquantifiable design issues.
- provide guidance.
- be cost effective.

While all of these ideal attributes may not yet be realistic or feasible, the technology to realize those ambitious capabilities is expected to become available within the next five years. This expectation is based on the recent explosive growth in such fields as expert systems, imaging, and software innovations such as hypertext, plus the revolution in the development of powerful, affordable microcomputers with greatly enhanced computational power and storage capabilities.

In the interim, we have identified four basic goals that we feel are achievable given today's technology:

Match the design process. While existing design tools are structured with the expectation that the design process will adapt to them, a more appropriate tool adapts itself to the way in which a designer works. It should allow concurrent exploration of many issues and address the relationships between them. The process of design is not one of searching for the most correct answer, but rather it involves the simultaneous consideration and evaluation of a host of ill-matched issues. Exploration and intuition are two key elements of the process that are ignored by existing design tools. Furthermore, the design problem is often fully articulated or understood only during an attempt to solve it (Rittel 1970). This lack of a rigid structured procedure in design indicates a need for flexibility in design tools.

Present information in an appropriate format for architects. Designers are not research-oriented and, in fact, there are few effective means in place for accessing research information. Design knowledge is more typically derived from individual practical experience and from image-based reference sources like architectural journals or first-hand observ-ation of buildings. Our prototype daylight design guide emphasizes graphics over text, relevance of data to actual buildings, qualitative assessment, and provides "access" to real-life examples without the time and cost of an actual visit to relevant case-study buildings.

Break up and link the data. Data presented by such a tool should be in discrete chunks and in multiple layers of complexity. Data elements could be explored through built-in links or through random access, allowing a wide variety of users to access different kinds of infor-mation in different ways with equal ease. Time and budget constraints on the designer also dictate this data breakdown, since the needs are accommodated for both direct data searches and for information browsing (versus an in-depth learning session). It is important that no major time investment be required to use the tool.

Provide guidance. Finally, an ideal design tool is more than just an electronic reference book or number-crunching computer program; it should contain expert consultant advice or guidance. Most tools evaluate existing designs rather than assist in the more difficult process of generating new designs. Most design tools also assume a fully educated user who is looking for a specific answer to a well-defined question. A more useful tool, particularly in the early stages of design, accommodates the user who may not know all the parameters to the design problem or who may not even know exactly what the problem is. The on-line "expert consultant" helps a designer formulate the questions to ask and flags issues or trouble spots in the search for solutions.

A HYPERTEXT DAYLIGHT DESIGN TOOL

The ideal design tool described above may become a reality with hypermedia, a combin-ation of data, graphics, photographs, video, sound, and animation, made accessible to the designer through a computer as intermediary. Hypertext, the software binding this combination together, has existed in concept since presented by Vannevar Bush in 1945, but is just now seeing an explosion of exploration and practical development. Several software packages now exist, sharing the general features of screen-sized blocks of information connected by navigational links. Most existing hypertext applications address simple data base manipulation; a few have just begun

to explore the more difficult task of applying hypertext to a learning or design aid. For our exploration we chose to begin with Apple's *HyperCard* program, a hypertext-like package widely available and heavily promoted for the popular Macintosh microcomputer, although we will continue to evaluate other software packages as they become available.

What is *HyperCard?* We view *HyperCard* as a prototype hypermedia software environ-ment, although dissenters argue that a true hypertext application has yet to be developed. *HyperCard* uses the analogy of a stack of index cards in its terminology. The fundamental unit is a "card," a screenful of data and images, collected into "stacks." A card can have any kind of graphic or text, clickable "buttons" and built-in navigational links to other cards. The stack can include animation and sound features, can link to other software applications and can control external hardware devices like video disc or CD-ROM players for greater image, sound and data storage capabilities. The user's interaction with the stack is primarily through clicking the mouse. All action taken by the program is determined by scripts, written in *HyperCard's* programming code. *HyperCard* is a powerful toolbox combined with a kit-of-parts that gives a stack author an impressive creative range. However, one serious limit for an application as complex as ours is the inability to see more than one card at a time on the screen. The program is also limited by relatively poor image resolution and lack of sophisticated graphic manipulation abilities.

Structure of data in the tool. The core of our proposed design tool is a large body of data, the compilation of all of today's scattered daylighting references into one single electronic source. Since data has to be broken down into one-screen chunks, categories were determined and subdivided as necessary. We chose three main branches for subdivision: general "browsing level" information, more detailed "textbook" information, and "how-to" design detail information. For example, the main topic of *Skylights* might have general information screens available in the areas of *Choosing Skylights, Skylight Components, Lighting Design withSkylights,* and *Skylights and Energy Use* (fig. 2). Each of these screens may, where appropriate, offer *Textbook* or *Design* screens. All of these subdivision screens may further subdivide, depending on the complexity of the topic. The user has the choice of going deeper into a section as interest is aroused. Browse cards allow the user to skim a topic for interest; key points are presented, along with an illustration, which may pique one's curiosity enough to explore further or provide enough information to allow one to move on. The application of hypertext to this kind of irregularly structured information is ideal, since the body of information is primarily nonhierarchical but highly linked with other data.
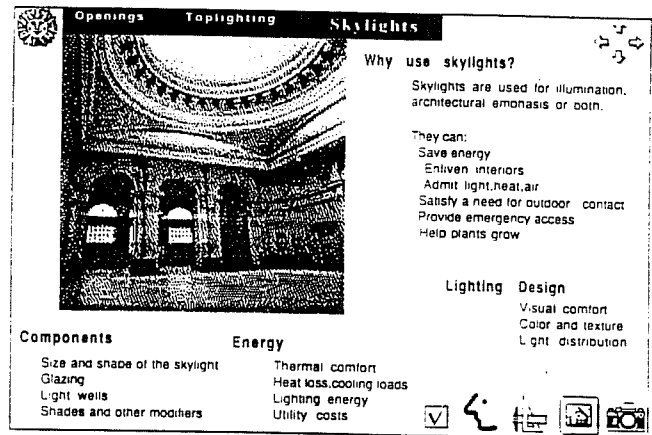

Fig. 2. Main screen for Skylights topic.

The tool is structured to perform as both a learning and a design tool, as these two functions are often simultaneous and co-supportive throughout the process of both architectural practice and education. The user begins a session with the tool by selecting a "learn" or "design" option which triggers the tool to emphasize particular information in order to help the designer efficiently focus on a specific task. "Learning" or "design" pathways, discussed in more detail below, may follow partially predetermined links and may be coupled with built-in "guidance," all with the goal of minimizing the time commitment of the designer.

Interaction through images and links. The balance of text and image on the screen is important, both for catching and holding interest, and for locking in a concept for the visually oriented user.

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Where a screen offers a menu of choices, graphic cues are used as well as text for the menu selection identifications. The user can also click on a variety of icon buttons for related activities. The main links to other, related information are identified as boldface words within a body of text on the screen. This is a common and simple hypertext linking technique that profoundly distinguishes the electronic document from a printed one. While both documents use a different type face to alert the reader to an important concept, the hypertext version allows the user to immediately access more information for further exploration of the concept by simply clicking on the text.

Other links are identified graphically; for example, the user might click on any part of a picture for more detail about that pictorial element. In the skylight example shown (fig. 3), various components of the system in the illustration are buttons that serve a double purpose: they provide their own graphic definition while serving as links.
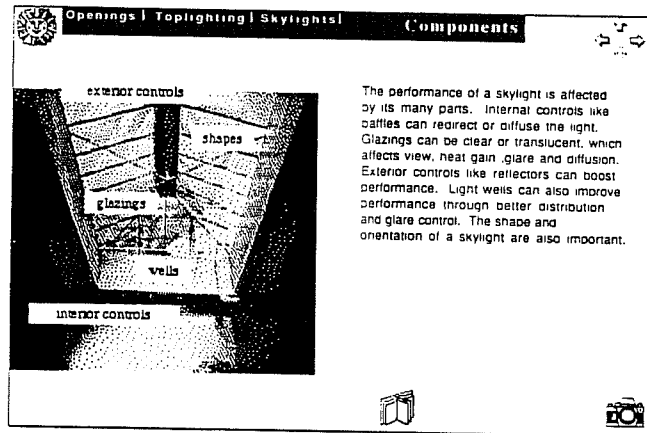
Interaction through customization . Direct interaction with or customization of the design aid is another rich feature available through hypermedia. Many people like to make margin notes in reference documents, so we have included "sticky notes" that can be attached to any screen, identified by user and project, and can either be visible or hidden. Similarly, architects and others predisposed towards visual note-taking can use a "sketchpad" function in the same way. The tool can also be thought of as a three-ring binder in the sense that users will be able to add their own information: perhaps their own slides or case studies, for example.

Fig. 3. Skylight Components screen.

Interaction through video manipulation. We are also exploring interaction with the video images, where the user can manipulate an image through parametric variations specified by clicking items on the computer screen. This could be an extremely powerful and effective method for visualizing the effects of design decisions on an architectural space, for viewing spaces under different environmental conditions, or for graphically comparing the importance of different design issues.

Navigation, paths, and maps. As our daylighting stack grew larger so did the possibility of losing a user in it. We became concerned with keeping track of the user's path, allowing the user to see the structure of the stack, providing options other than predetermined links for moving around, and allowing the user to retrace a path. A tree map (fig. 4) function is available, which is both a key to the structure and a method for the user to move directly to other topics. An index is also provided for direct access to specific topics. A number of peripheral navigational functions are always available to the user for backtracking and checking the current path. Pathways can be saved, identified by a user name and a project
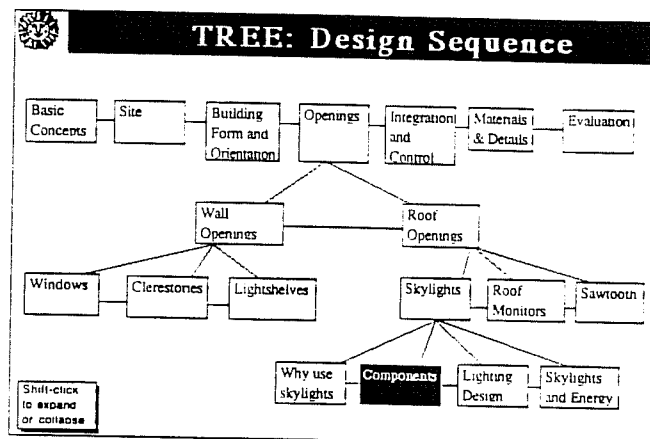

Fig. 4. One portion of the tree map for the path called "Design sequence," with the active topic highlighted. The user can click on any other topic if desired.

name, to be either filed for future project reference or to be continued at another time.

Case studies. Another feature that exploits the abilities of hypermedia is a case studies data base. Architects are heavily dependent on previously built examples as their primary source of reference information, which indicates a critical need for case study information in a design tool. Using a video disk, case studies can include slide shows, building tours, model studies, interviews, and video movies. The data base is fully indexed and cross-referenced, and linked with the daylight design stack so that at any time while reading about a design concept the user can view appropriate built examples. Images from the video disk can be simple illustrations to text, stand-alone video movies, or full-color (and possibly active) demonstrations for a concept being diagrammed on the computer monitor. For example, a building tour may run on the video monitor while the computer screen shows the viewer's movement on a plan drawing (fig. 5). Or the reflection of light from a light shelf can be shown in diagrammatic form on the computer and simultaneously as it appears in the real space. Sound can be used where it enhances comprehension of the concept. One interesting possibility for the use of sound might be case study "interviews" with designers or building users.
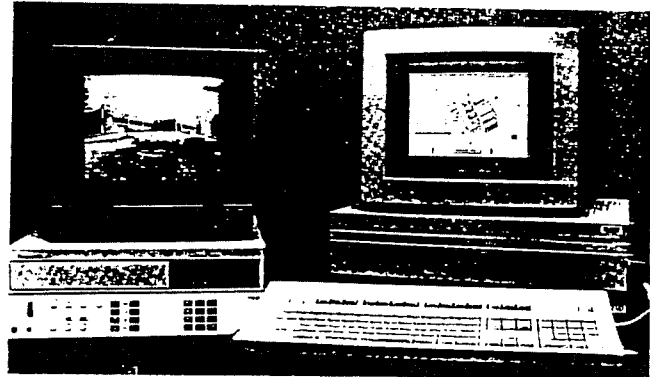

Fig. 5. A building tour of Mt. Airy Library. The user clicks an arrow pointing to the axonometric drawing for that view on the video monitor.

Guidance and expert advice. After structure, content and graphic format decisions, we addressed pathways, guidance, and expert advice. The stack has to be flexible enough to accept a large number of design and learning approaches. While far from offering any final solutions to this difficult task, we have focused on determining some sample pathways. One possibility is to request a role identification by the user, then provide a different path for a student, an architect, a mechanical engineer or a lighting consultant. Or pathways might be task-oriented, with the tool helping a user identify the appropriate list of constraints and criteria in solving the problems presented by the task. Learning paths might provide knowledge (facts) or judgement ability. Design paths might pursue a strategy approach or a building element approach. One difficult issue is giving the stack enough structure to provide help to a user with a specific task while remaining loose enough that exploration, adventure, and accidental discovery are not lost. The prototype stack employs predetermined structure and pathways, however the necessity for some sort of expert system is evident when one considers the large body of complex data and the very large number of possible pathways through it.

It is commonly understood that architects prefer people over books for information, and prefer to hire an expert rather than become one (King 1984). The ideal tool would therefore appear to be a design "consultant." However, like many existing tools, it is an insidious teaching device; a designer using the tool repeatedly may eventually learn intuition and visualization of cause and effect design decisions. The tool thereby ultimately affects how architects fundamentally approach design problems. One direct exploitation of this potential might be design quizzes linked to the video display. For example, a user might be asked to determine what design feature is causing the effect in an interior space displayed on the video monitor.

It is impossible for a design tool to guarantee "good" design, but it is reasonable to expect it to reduce the likelihood of poor design. Built-in guidance can help keep the user from making poor design decisions. We are currently exploring a rudimentary rule-based approach to this issue: the stack helps the user create a criteria checklist for the design problem at hand and processes

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decisions through rules intended to flag potential design errors. Hypermedia and knowledge-based systems are a natural fit, and we are actively pursuing that combination as our next step.

SUMMARY AND CONCLUSIONS

This paper has described why we believe current design tools and reference sources for daylighting have not been as effective as desired, our methodology for the development of a new kind of computerized design tool, and an experimental prototype for a hypermedia-based daylight design tool.

Our goals for this new tool include:
1. Satisfying the needs of many different users with many different tasks.
2. Overcoming the barriers to introducing research results to the design professions.
3. Anticipation of any user's needs throughout the design process.
4. Linking data so that navigational links provide inherent guidance to the user.
5. Building in expert consultant capabilities in all areas of expertise.
6. Fully exploiting the power of hypermedia to accommodate the needs of a wide variety of users and to address the important qualitative aspects of design.

Our vision is to the future with this project. We believe it is important to have a vision of where we ought to be regarding building design and energy efficiency, how we ought to get there, the role of lighting and daylighting, and the appropriate design tools to aid our objectives. A computer-based workstation incorporating interactive video, a current concept in development, is our design reference environment of the future (fig. 6). Full-color images linked with information and available for dynamic manipulation by the user will transcend today's reference sources. The ultimate goal is a product that is an electronic interactive combination of a master reference book and a master consultant, enhanced by a full video library. We welcome comments on any of the issues raised here.
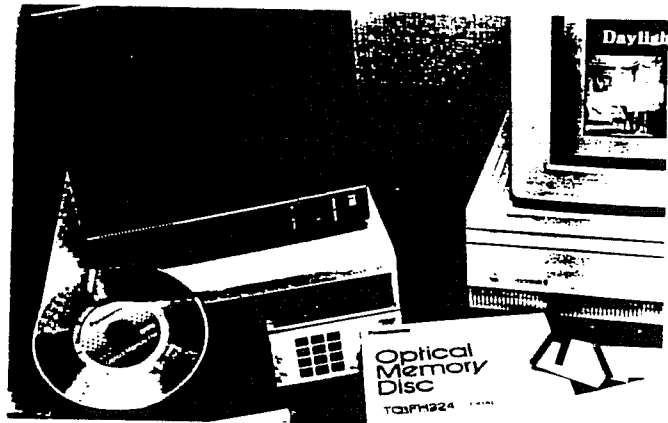
Fig. 6. The workstation today, with 8-inch analog optical discs, magnetic data discs, optical disc player, color video monitor and microcomputer. Future additions: CD-ROM data storage, digital optical storage, CD audio, and access to central network system.

ACKNOWLEDGEMENTS

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