Survey on the Use of Lighting Design Software in Architecture and Interior Design Undergraduate Education

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With the steady development of global illumination algorithms over the past four decades, lighting design software is no longer the domain of a specialist. Easy to use interface, built-in flexibility, reliable calculation models, and compelling visuals has made today’s lighting design software useful to architects and interior designers. However, despite these advantages, the use of lighting design software is not widely included in the undergraduate architecture and interior design education. This paper summarizes the results of an online survey of a sample of accredited architecture and interior design schools in the United States conducted to (a) determine the extent of use of lighting design software in teaching and learning lighting at the undergraduate level and (b) to assess design educators’ attitude toward their usefulness in design education. This paper discusses directions for the future based on the survey results.
1. INTRODUCTION

Almost two decades back, Greenberg lamented in his 1987 Coons Award lecture that, “for computer graphics to attain its potential for design and aesthetic evaluations, it will be necessary to accurately represent the appearance of objects as they look to us. Most computer graphics images are pictures that have no real correlation with the actual appearance or with our visual perception and the way we see environments”[1]. With the maturing of rendering algorithms this has changed tremendously. Today, lighting design software use ray tracing and radiosity methods to produce acceptably accurate calculations and compelling visuals with a fast and comparatively easy user interface [2]. These software tools are able to both complement and extend past other simulation methods such as scale models and manual calculations with their flexibility, interactive interface, walk-through capability, and ability to conduct physically accurate computations. A recent online international survey reported a drop in the use of physical scale model measurements and increase in trust in reliability of daylighting software tools, indicating that lighting design software is fast gaining acceptance in the design profession [3].

Despite recent advances, the use of lighting simulation tools remain limited in the undergraduate curriculum in most architecture and interior design schools. The accreditation organizations of both architecture and interior design schools, National Architectural Accreditation Board (NAAB) and Council for Interior Design Accreditation (CIDA) respectively, emphasize that holistic understanding of lighting design is vital at the undergraduate level. The NAAB states that architectural students must have an understanding of the basic principles, appropriate application, and performance of environmental systems including acoustics, lighting, climate modification systems, and energy use, integrated with the building envelope [4]. Lighting courses have a more specific role in interior design programs. CIDA’s Professional Standards states that students must be able to design within the context of building systems, demonstrating understanding that design solutions affect and are impacted by lighting systems [5].

It is undisputed that a thorough investigation of lighting during the design process can lead to aesthetically pleasing, psychologically comforting, environmentally suitable, and energy-efficient spaces. According to the US Environmental Protection Agency’s ENERGY STAR Program, lighting is the largest end use of commercial energy with lighting within buildings being estimated to account for 23% of national electrical consumption. Consequently, improvements in lighting efficiency represent an important goal for the industry as well as for the state and local policymakers [6]. Integration of lighting design software in the design process can increase the chances of efficient use of daylight and electric light leading to energy conservation. Today, lighting design software provides a tremendous opportunity to conduct iterative design processes for decision-making, and
graphically communicate design performance results. The capabilities of this technology range from conducting photometric/photorealistic analysis to providing an integrated ‘workspace’ for design, testing, and application of lighting solutions.

Unfortunately, the use of computer applications in the undergraduate design curriculum in architecture and interior design schools is largely consigned to producing alluring imagery by ‘painting’ light intuitively or randomly. The outcomes of this form of design investigation give a false sense of knowledge to students by making it possible for them to make their projects look ‘finished’ [7]. The results demonstrate a lack of understanding of the physics of light, and are insufficient to judge the environmental or even aesthetic implications of the design decisions. Intuition is not sufficient for good decision-making; simulation tools with their relatively accurate photorealistic and photometric capabilities are more true to performance of light in a space – hence useful in the design process.

Most architects believe that the role of university education regarding building performance simulation tools is important but addressed less than adequately in design schools [8]. As architects or interior designers are usually the pivot of a design team, bringing in and directing the consultants, they need to have the expertise to co-ordinate the decisions that occur in the design process of energy-efficient environments [9]. So far, the field of computer-aided simulation is still considered an advanced domain, suitable only for graduate students. However, in an imminent future of increasingly limited energy resources, lighting simulation understanding needs to be inculcated at the undergraduate level so that when these students go into the workforce they are better-informed designers and able to play key roles in solving related environmental issues.

The specific aim of this project is to recognize the untapped potential of computer technology for meaningful environmental design investigation and visualization in contrast to the more conventional computer graphics-based ‘image making’ within the design curricula. Some of the primary reasons for the tenuous use of simulation software at the undergraduate level in a design curriculum may be due to skeptical attitude towards the accuracy of simulation tools, lack of awareness, perceived steep learning curve, and/or simply lack of inclination to familiarize with relevant software programs. Therefore, there clearly is a need to assess the extent of use of lighting design software in undergraduate design education and identify the barriers in the use of these tools. In this paper, the author discusses the results of an online survey of lighting design educators in accredited undergraduate architecture and interior design programs in the United States.
2. LIGHTING DESIGN SOFTWARE

2.1. Development of lighting design software

In the IES Century Series, article on lighting and computers, Altman states “designers and researchers have been calculating the effects of light for centuries—well before the use of computer technology. Many of the formulae and concepts used by lighting design software have been around since the late 1800s. However, exponential growth in computer-related lighting design developments has occurred only within the past four decades [10]. Each subsequent improvement or addition to software technology offers more efficient and effective production capabilities.

Beginning in the early 1970s, direct reflections were empirically modeled by the Gouraud and Phong algorithms. Modeling the propagation of light through an environment was started in the late 1970s. The “global illumination function,” exemplified by ray tracing, was presented at the Chicago SIGGRAPH conference in 1979. The radiosity approach, based on thermodynamical heat exchange, was started at Cornell University in 1984, where the “Cornell Box” made history as the first radiosity image [1, 11]. A combination of radiosity and ray tracing is found in most lighting simulation software tools today that take advantage of the strengths of each one of the two methods—radiosity’s ability to render view-independent diffuse reflectivity and ray tracing’s ability to render view-dependent specular reflection and refraction [12].

2.2. Use of design software within design profession and education

To date, no surveys have been conducted to specifically determine the use of lighting design software in design education in the US. Surveys have been conducted on the general use of CAD software in the design education and/or profession, and the non-academic use of lighting design software in the design profession. Most of these surveys show a steady rise in the popularity of the software packages.

A survey of 200 European architecture schools, collected at the eCAADe conferences during the 1990s showed that the use of exclusive lighting simulation programs such as Rhino and Lightscape is on the increase (15-25%) [13]. In 2002, Jacobs and Henderson conducted a web survey of 198 building design professionals including architects, engineers, and contractors in the US and Canada to assess the use of whole building simulation methods. They found that 27% of respondents reported using lighting design software for lighting and daylighting decisions [14]. Results of a similar international survey of design practitioners on the use of daylight simulations during building design reported that 79% of participants used computer simulations. This survey had a strong sample bias but was able to identify the design practitioners’ needs and the weaknesses of existing tools. The participants cited difficulty in using software and insufficient...
documentation as the primary limitations of existing programs [3]. In stark contrast to the above studies, a survey conducted by McLain-Kark and Tang two decades back investigated the attitudes of the American Society of Interior Designers members toward use of computers in the interior design field [15]. The results indicated that the most common use of the computer in design production was for facility management and space planning. The use of computers to conduct lighting simulation was marginal with only 6% of the designers reporting using computers for lighting analysis and 3% for energy analysis. Around the same time, a regional survey of lighting education resources among design schools reported that mainframe computers were the least needed resource category in teaching interior design [16]. Another survey, a decade later, revealed that 41% of interior design educators in the US instructed their students how to create fully rendered modeled objects and scenes in CAD, which included the assignment of materials, placement of light and shadow, and adjustment of views. The study, however, did not specifically inquire about the use of lighting design software, but it did indicate that attempts to integrate computer software programs to conduct lighting investigations in the design education were on the rise [17].

The preceding literature review shows that lighting software tools are gaining acceptance in the design profession with more and more design professionals turning to these tools for quick, iterative, and accurate photorealistic analysis since 1987 when surveys by McLain-Kark and Kesner showed marginal use of computers for lighting simulation. Although more user-friendly tools are now available [18], better software documentation, and training opportunities remain a high priority for current and potential users [3, 14]. None of the aforementioned surveys is based on an extensive assessment of the use of lighting design software amongst design educators in US. Moreover, we do not have a clear understanding of why few design students are being instructed in the use of lighting design software [7, 8], in spite of the availability of a number of software packages that can be used at varying stages of the design process.

Given this need and the obvious opportunity to instruct a large number of new professionals on the use of lighting design software, it is worth investigating why the design education field has not more broadly embraced and encouraged the use of these software tools at the undergraduate level. As a result, this study was developed to seek answers to several important questions: (1) How is lighting design taught in interior design and architecture curricula, and what teaching methods are used? (2) What lighting design software programs are used, if any, in the lighting design courses? (3) What are they primarily used for and why? (4) What are the desired features, and limitations/ capabilities of software packages as perceived by educators who use or do not use them? (5) Is adequate knowledge of software packages considered important for students before entering the design profession?
3. LIGHTING DESIGN SOFTWARE SURVEY

A web-based survey on the current use of lighting design software in teaching lighting design in the design curriculum was administered from mid-January to mid-March 2006. The total survey population included design educators from 107 NAAB accredited architecture and 134 CIDA accredited interior design in the US, who taught lighting design. Because of the relatively small number of design programs, all the accredited schools were included in the survey sample. The first step in this investigation was to contact each school to gather the contact information of educators who taught undergraduate level lighting design courses. Survey questionnaires were sent out to a national sample of 239 educators, one from each accredited design school. If the contacted individual was not the right person to answer the survey, they were asked to pass it on to the faculty in their department/school who would be the most appropriate respondent.

The survey questionnaire was conducted online. Using this administration mode enabled the inclusion of interactive features, reduced administration costs, and provided a means for receiving readily usable electronic data [3]. The survey included a combination of different question types: single answer, multiple answer, matrix type, open-ended text, and Likert scale using QuestionPro, an online survey-authoring tool. The survey was designed to lead participants to respond to one of three sets of questions depending upon responses to key questions in the survey (see Figure 1). Piloting of the survey involved random administration to 10 lighting design educators in architecture and interior design schools. The pilot survey responses were used to modify and refine the design of the survey questionnaire and then sent to the remaining lighting design educators.
4. SURVEY FINDINGS

The survey received 89 responses out of 239 schools that were successfully contacted. Responses were analyzed using SPSS, a statistical analysis software package. When appropriate, data comparisons were tested for statistical significance using Chi-square analysis and an alpha level of 0.05. The survey results are discussed below.

4.1. Survey Sample

The total percentage of the lighting design educators teaching in undergraduate architecture and interior design curricula who responded to the survey are 43.3% and 41.8% respectively. Table 1 shows the distribution of the total number of survey respondents based on their discipline. Some educators reported teaching lighting design courses in both architecture and interior design discipline in their university.

<table>
<thead>
<tr>
<th>Discipline</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>33</td>
<td>37.1</td>
</tr>
<tr>
<td>Interior Design</td>
<td>42</td>
<td>47.2</td>
</tr>
<tr>
<td>Architecture and Interior Design</td>
<td>14</td>
<td>15.7</td>
</tr>
</tbody>
</table>

4.2. Lighting design courses

Lighting design courses taught by the survey respondents in architecture and interior design discipline are summarized in Figure 2. The survey results show that 81.8% of architecture and 69.0% of interior design lighting design educators primarily teach lighting design in lecture classes. Lighting design is usually taught as a part of an environmental or building systems course in architecture schools. In contrast, it is taught almost exclusively as a class devoted to lighting in interior design schools.
A significant percentage of lighting design is addressed in general design studios in both disciplines. However, design studios with a focus on lighting design are more common in interior design schools. Approximately 45% of lighting design classes is held in the third year (junior) level of both architecture and interior design curriculum.

4.3. Lighting design teaching methods

A comparison of lighting design methods used by architecture and interior design educators to teach in a lecture class and a general design studio are shown in Figure 3 and Figure 4 respectively.

From Figure 3 it can be seen that in the context of a lecture class, manual lighting calculation methods (such as lumen method, etc.) are the most used, followed by manufacturer’s literature and rules of thumb by educators teaching lighting design in either interior design or architecture schools. However, rules of thumb method is used most prominent teaching method employed by educators who teach in both architecture and interior design departments. Computer software was reported being used by only 27.3% of architecture and 16.7% of interior design educators in their lecture classes, whereas it is used by 40.9% of educators who teach in both disciplines. Overall, the educators who teach in both architecture and interior design departments utilize various simulation methods in a lecture class more than educators who teach in only one discipline.

In a general design studio environment, rules of thumb (21.2%) and scale physical models (15.2%) are the most common design methods used in an architecture design studio, whereas manufacturer’s literature (23.8%) is used more often than any other simulation technique in an interior design studio. This difference could be attributed to the fact that interior design requires design investigation at an intimate scale; hence, thorough investigation of...
lighting fixture qualities and specifications are important to be considered during the design process. On the other hand, in architecture design studios lighting design is one of the several broader design issues to be addressed; hence rules of thumb is considered to be faster and more appropriate means to conduct design investigation. The popularity of scale physical models in architecture design studios compared to interior design studios may be due to the fact that scale physical models are usually considered suitable for daylight investigation. Interior lighting design usually takes place in a given space with existing fenestrations and involves design of electric light, the effects of which are hard to replicate at a scaled down version. Computer software packages were reported to be used marginally in general design studios by only 3.0% of architecture and 4.8% of interior design educators. Once again, the educators teaching in both interior design and architecture curricula were the largest software users (14.3%).

4.4. Use of lighting design software

A comparison of the distribution of users and non-users of lighting design software showed very little difference between the interior design and architecture educators, as shown in Table 2.

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Users</th>
<th>Non-users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>43.3%</td>
<td>56.7%</td>
</tr>
<tr>
<td>Interior Design</td>
<td>42.9%</td>
<td>57.1%</td>
</tr>
<tr>
<td>Architecture and Interior Design</td>
<td>50.0%</td>
<td>50.0%</td>
</tr>
</tbody>
</table>

It is worthwhile to note from Table 2 that out of the total number of 89 respondents, a greater percentage of lighting design educators teaching in both architecture and interior design disciplines use software programs in their teaching. This may indicate that design educators who are familiar with both disciplines see the value of lighting design software in contributing...
effectively to the lighting design learning process.

The most popular lighting design software used in teaching lighting design are Autodesk VIZ (16.2%) followed by AGI32 (13.5%) and 3ds Max (10.8%), as illustrated in Figure 5.

The popularity of Autodesk VIZ and 3ds Max may be because they are both geared specifically to architectural applications. These software programs are used commonly by architects and interior designers for modeling, rendering, and animation. The inclusion of photorealistic and photometric capabilities in these programs makes them the most attractive choices. AGI32, though used more commonly by lighting designers, has an integrated modeling interface and is available free to the academic community, which are probably the principal reasons for its wide acceptance. In addition to the software programs listed in Figure 5, other software programs used by design educators for lighting design and analysis include SketchUp, Luxicon, DIALux, Adobe Photoshop, SPOT, EcoAdvisor, AutoCAD, Rhino, GE Light Beams, Superlite and eQuest, Ecotect, Energy-10 and Lumen Micro/ Designer are primarily used during the early stages of the design process, while programs like RADIANCE, DOE-2, Lightscape, and AutoDesk VIZ are more widely used in the later stages of the design process.

The pie charts in Figure 6 show the reasons for use of specific programs by the design educators. Software programs that are considered easy to learn and use are Lumen Micro/ Designer (25.0%), Ecotect (22.2%) and Autodesk VIZ (21.1%). According to the survey respondents, AGI32 has a good software help menu (21.1%) while Autodesk VIZ has flexible import/export features (21.1%). Accuracy of Lightscape (30.8%) and Lumen Micro/
Designer (25.0%) and AGI32 (21.1%) is considered to be higher than other software. Ecotect (33.3%), AGI32 (26.3%) and Lumen Micro/Designer (25.0%) are preferred due to their low cost for academic users. The survey results also illustrate that Autodesk VIZ, 3ds Max, and Radiance are preferred over other software to generate photorealistic images. To compute electric light usage, Autodesk VIZ, AGI32, Ecotect, Energy 10, Lumen Micro/Designer and Form-Z are mainly used. Further details on lighting aspects most simulated using various lighting design software by design educators are shown in Table 3.

<table>
<thead>
<tr>
<th>Software</th>
<th>Lighting aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>3ds Max</td>
<td>Photorealistic imagery, interior illuminance, interior luminance</td>
</tr>
<tr>
<td>AGI32</td>
<td>Electric light use, interior illuminance</td>
</tr>
<tr>
<td>Autodesk VIZ</td>
<td>Photorealistic imagery, interior illuminance, electric light usage</td>
</tr>
<tr>
<td>Ecotect</td>
<td>Electric light usage</td>
</tr>
<tr>
<td>Energy 10</td>
<td>Electric light usage</td>
</tr>
<tr>
<td>Lightscape</td>
<td>Interior illuminance, interior luminance</td>
</tr>
<tr>
<td>Lumen Micro/Designer</td>
<td>Electric light usage, interior illuminance, interior luminance,</td>
</tr>
<tr>
<td></td>
<td>Daylight factor, daylight autonomy, photorealistic imagery</td>
</tr>
<tr>
<td>Radiance</td>
<td>Daylight factor, daylight autonomy, photorealistic imagery,</td>
</tr>
<tr>
<td></td>
<td>Interior illuminance</td>
</tr>
<tr>
<td>Form-Z</td>
<td>Electric light usage</td>
</tr>
<tr>
<td>Visual</td>
<td>Interior illuminance, electric light usage</td>
</tr>
</tbody>
</table>

4.5. Attitudes towards lighting design software

The main drawback in the use of the lighting design software is seen as the software cost (51.2%), as shown in Figure 7. This may be because popular software packages like Autodesk VIZ and 3ds Max, while desirable due to their integrated modeling, rendering and lighting design interface, are expensive even in an academic setting. This implies that design educators need to be informed of several low-cost lighting design software packages available today, such as AGI32, Ecotect, and Lumen Micro/Designer.
In addition, considerable percentages of design educators cited the lack of adequate resources to learn and use software packages (50.6%) as a drawback, and were of the opinion that using the software programs require specialized technical skills (46.4%). Only 12.1% of lighting design educators agree that simulation tools produce inaccurate results, confirming their increasing confidence on the performance of available lighting simulation software programs.

When asked about the potential capabilities of lighting design software, a vast majority of users (89.8%) think that lighting simulation tools expand the resources traditionally available to the students, and enable them to interactively experiment with different lighting scenario. In addition, a large percentage of architecture educators (73.3%) compared to interior design educators (62.5%) think that lighting simulation tools help the student become active learners and gain wider access to lighting design resources; for example, luminaire distribution models from the lighting manufacturers.

The most desirable features mentioned by the survey participants are further software development to make the software packages easy to learn (57.0%) and better import/export features with other programs (53.2%), followed by better graphical user interface (48.1%) and general lighting simulation help modules (40.7%), as shown in Figure 8. Not surprisingly, the users of lighting design software want the software to have a better graphical user interface more than the non-users, while the non-users desire accuracy more than the users. General help modules were stated as the most desirable/desirable feature by the interior design educators (89.5%) more than the architecture educators (65.5%).
When asked if it is important for students to be proficient in lighting design software upon entering the design profession, 70.3% of users were of the opinion that it was important/very important as opposed to only 40.9% of non-users of lighting design software (see Table 4).

![Figure 8: Desired features in existing lighting design software by all design educators.](image)

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Important/Very Important</th>
<th>Useful but not critical</th>
<th>Marginally Important/Not important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users</td>
<td>70.3%</td>
<td>27.0%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Non-users</td>
<td>40.9%</td>
<td>54.5%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>

A chi-square test of independence was performed to examine this relation between users and non-users of simulation tools on their perceived importance of the simulation tools for students. The relation between these variables is significant, \( \chi^2 (2, N=81) = 7.0, p<0.03 \). This difference may be explained by the unfamiliarity of non-users of lighting design software programs with the current advances and capabilities of software programs. A need to spread awareness of the benefits of the software tools amongst the lighting design educators who are non-users is obvious by this difference.

5. DISCUSSION

The purpose of this study was to assess the use of lighting design software in design education. While the literature review shows the acceptance of these tools in the design profession lately, there was no specific evidence of its use in design education. The findings of this study are not representative of the entire population of lighting educators in architecture and design schools. However, the number of responses received is sufficient to identify...
patterns and conduct cross-discipline analysis. The survey offered valuable insights on the use of computers for lighting design education today — filling the research gap.

The majority of lighting design is conducted in a lecture class environment. With regard to the use of lighting design software, it is interesting to note that lighting design software is used by 10.6% (see Figure 3) more architecture educators in lecture classes compared to interior design faculty. In addition, a greater percentage of interior design faculty (41.0% compared to 69.0%) believe that simulation tools are not as necessary for the students to be familiar with as they enter the design profession. These results could be attributed to the additional emphasis in the architecture discipline on the overall integration of lighting with the architecture and its ensuing environmental issues such as energy efficiency and heat load. These issues are believed to be easy to define and hence successfully compute. However, more emphasis is put on the psychological and physiological effects of lighting in the interior design discipline. Some educators consider it difficult for the computer-graphics environment to define and simulate these subjective and immeasurable aspects of lighting. One of the survey respondents commented on how the ‘sensual’ aspects of lighting are essentially missing from the computer environment. These observations are, however, in stark contrast to some of the recent findings.

Essa and Mahdavi conducted an empirical study to determine if subjective evaluation of lighting in architectural spaces can be reproduced using computers [19]. They found that computationally rendered images could reliably represent certain aspects of lighting conditions in real spaces such as psychological impression, perceptual clarity, light distribution, formality, and thermal/ acoustics/ haptic association. Another recent study discussed and successfully demonstrated the use of computers in design education to explore the role of light in shaping an environment. In this study, computers were considered from the view of their capability to inspire design through light, movement and time simulation, and iterative testing procedures [20].

Thus, the apparent benefits of lighting design software are clear in literature. Design educators who are skeptical of them need to be made aware of the capabilities offered by today's generation of robust software tools, so that they can provide their students the much-needed lighting design software knowledge in the workplace.

Several resources are available today to decide between lighting design software programs. One can refer to the comprehensive annual software survey published by the Illuminating Engineering Society of North America (IESNA) Computer Committee that cites a list of lighting software programs with their current features, vendor contact information, and computer hardware requirements available to designers and engineers for design and analysis of interior or exterior space or spaces. The latest survey
report was published in the September 2005 issue of LD+A magazine [21]. In addition, quite a few publications present comparison between different lighting design software programs that one can use to determine the applicability of lighting design software to a specific design issue [21-25]. However, for designers to take advantage of software tools to provide more efficient and comfortable buildings, development of materials and web resources to demonstrate the value of software and promotion of whole building design approach needs to take place [14]. Some of the surveys conducted earlier found that web resources on simulation help modules would be useful for the end-users of software programs [3, 8, 14]. Recognizing this fact, the survey respondents in the present study were queried if an online learning module based on lighting design concepts and computer simulation concepts would be useful for them in their undergraduate level teaching. A total of 66.7% of all survey respondents said that such a resource might be useful. The most requested features in this learning resource were lighting simulation examples and lighting simulation software concepts such as radiosity and ray tracing.

6. FUTURE WORK

Future work on addressing these resources could involve the development of learning modules on lighting that bridges the gap between digital media and responsible building design, elucidating the relation between lighting design concepts and lighting simulation concepts. The modules could be designed as a self-paced discovery environment so that users (design students, educators, and professionals) can verify physical concepts and learn procedures for conducting photometrically accurate lighting predictions to guide their design decisions, without being tied to specific application programs. The author is currently working towards developing these lighting design resources.

The high interest shown by undergraduate students in the use of digital media, and the growing demand for digital media proficiency in the workplace makes the findings of this project very timely.

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