A Computer-based Approach for Teaching Daylighting at the Early Design Stage

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Abstract
This paper has reviewed the literature on the teaching of daylight systems design in architectural education, and found that traditionally such teaching has evolved around the prediction of the Daylight Factor (DF%), i.e. illuminance, via two methods one studio-based and another laboratory based. The former relies on graphical and/or mathematical techniques, e.g. the BRE Protractors, the BRE Tables, Waldram Diagrams, the Pepper-pot diagrams and the BRE formula. The latter tests scale models of buildings under artificial sky conditions (CIE sky). The paper lists the advantages and disadvantages of both methods in terms of compatibility with the design process, time required, accuracy, energy-consumption facts, and visual information.

This paper outlines a proposal for an alternative method for teaching daylight and artificial lighting design for both architectural students and practitioners. It is based on photorealistic images as well as numbers, and employs the Lumen Micro 6.0 programme. This software package is a complete indoor lighting design and analysis programme which generates perspective renderings and animated walk-throughs of the space lighted naturally and artificially.

The paper also presents the findings of an empirical case study to validate Lumen Micro 6.0 by comparing simulated output with field monitoring of horizontal and vertical illuminance and luminance inside the highly acclaimed GSA building in Glasgow. The monitoring station was masterminded by the author and uses the Megatron lighting sensors, Luscar dataloggers and the Easylog analysis software. In addition photographs of a selected design studio inside the GSA building were contrasted with computer generated perspective images of the same space.

Introduction

Daylighting is an extremely important subject in the architectural curriculum. Its importance stems from the recognition that it can be used as a form giving factor in architecture. Great architects and masters have always placed a great importance on daylighting as the medium through which man communicates with the environment inside and outside buildings. Also, daylighting has always featured poetically in the writings of great architects. For example, Le Corbusier stated that ‘Architecture is the masterly correct and magnificent play of masses brought together in light’. [1]

Another master, Kahn, whose architectural language has evolved fully around daylight, remarked that ‘The structure is a design in light. The vault, the dome, the arch, the column are structures related to the character of light. Natural light gives mood to space by the nuances of light in the time of the day and the seasons of the year, as it enters and modifies the space’.[2] His projects have increasingly demonstrated a variety of innovative solutions to daylighting problems. To Kahn the creation of the total architectural form has always been determined by the presence of a strong daylighting form.

Authors such as Lam have always argued that the difference between great architecture and mere building could be measured to a large degree by the skills exercised in daylight control and manipulation.[3] Such skills and structured knowledge about good daylighting design in for buildings has a very long history in Europe dating back to the Romans who introduced the first legal structure on safeguarding rights to light in urban planning.[4]

Nowadays, in Northern Europe there is a reawakened interest in promoting good practices of daylighting design for reasons of energy efficiency and human visual comfort and well-being. Current interest in green issues and the greenhouse effect has meant that the reliance on daylight to displace artificial light is to be maximised in order to increase energy efficiency in buildings and reduce carbon dioxide emission. On the other hand, visual comfort, as opposed to luminous comfort, depends not only on providing the appropriate illumination levels but also reducing both disability and discomfort glare.

Design Tools

At the early design stage, the designer often relies on certain aids/tools that enable him to predict daylight levels quickly and frequently. The prediction of lighting levels gives designers important insights into the quantity and the quality of daylight. It also provides some useful feedback on how to improve daylighting by changing certain design parameters such the size and position of windows, room depth, overhangs, reflectivity of room surfaces, etc..

Design tools for daylight calculation and prediction vary to a great deal in their scope, complexity, compatibility with the design process, time required, and levels of design information needed. However, they can be broadly categorised under two headings: theoretical (studio based) and practical (laboratory based).

Studio-based Tools: these have been covered in many lighting textbooks and they are either graphical or mathematical.

a) *BRE Protractors*: each pair of BRE daylight protractor consists of a primary protractor and an auxiliary protractor. Both protractors are usually used to calculate the direct daylight either at a particular point in a room, or at a number of points, thereby contours of equal daylight level can be drawn for the whole room. The section and the plan of the room have to be drawn first. The centre of the primary protractor is laid over the reference point on the section drawing and lines are drawn from this point to the upper and lower edges of the window. Points of intersection are then read off to give the value of the sky component of daylight. This value is then multiplied by that obtained from the auxiliary protractor when its centre is laid over the same point on the plan drawing and lines to the edges of the window are drawn.

b) *BRE Tables*: this method requires more time than (a). Daylight levels on a horizontal plane can be obtained from tables in the form of a sky component, the externally reflected component, and the internally reflected component. Three parameters are required to use the tables for the sky component: the width of the window (W), the height of the window (H), and the distance of the reference point (D) from the window. Similar tables are used to determine the other two components of daylight levels.

c) *Waldram Diagram*[5]: this diagram is usually constructed from multiples of 50 units in area where each unit represents a percentage of the sky factor. So if the diagram has a total area of 500 cm^2 (25 cm long by 20 cm height), each cm^2 on the diagram will then be equal to 0.1% sky component.

The vertical edges of the window have to be drawn on the diagram as vertical lines whereas the window head and cill can be constructed and plotted as curves on the diagram with the aid of guide lines called 'drop lines'. This diagram has been used extensively in the study of daylight in interiors obstructed by external buildings and objects.

d) *Pepper-pot Diagrams*[6]: in this method, the sky is represented in a stereographic projection and the quantity of daylight is proportional to the density of dots. The drawing of the visible sky (known as the 'screen figure'), through the window, from the reference point is plotted over the diagram. The number of dots that fall within the plotted outline are counted and multiplied by 0.1% to obtain the sky component of daylight. The process of preparing the screen figure from drawings and for existing buildings is onerous.

e) *Mathematical Formula*[7] : this method calculates the average daylight factor using a single mathematical formula which incorporates the area of the window, the total area of room surfaces and their reflectance, and the angle of visible sky. It is different from all the methods overleaf in that it requires only the area of the window rather than the area and the position of the window. However, unlike previous methods, the mathematical formula only gives a single value which represents the average daylight factor inside the room. Therefore, it cannot be used for the detailed study and analysis of interior daylighting.

Laboratory-based tools: these are experimental tools that involve the use of physical models and natural/artificial skies in daylight measurement and appraisal. One of the big advantages of using models to study daylight is that a subjective appraisal can be made about the character of lighting and the appearance of the interior. Models of design projects and/or buildings are constructed from a variety of materials, i.e. hardboard, timber, plastic/perspex, and tested either under natural or artificial skies. The scale of models to be used for photometric measurement and subjective appraisals varies from 1:12 to 1:50. Artificial skies are of two types: the hemispherical sky for top lighting and the rectilinear sky for side-lit interiors. Some artificial skies incorporate an artificial sun for the study sunlight in relation to natural lighting.

However, laboratory based tools, though accurate for involving photometric measurements, are expensive means for the study and analysis of daylight.

Computerised Tools For Daylight Appraisal

Studio-based tools use numbers-based performance criteria to evaluate the quality and the quantity of daylight. However, they are time consuming methods as they require repeated calculations of the sky component if light level is to be determined at several reference points. Also they provide no visual information to enable a subjective appraisal of the character of daylight.

Laboratory based tools, On the other hand, are accurate as they involve photometric measurements of daylight and provide visual information necessary for the subjective appraisal of daylighting indoors. However, they are expensive to use, pay little attention to surface finishes, and are no replacement for real life monitoring of lighting in real buildings. In addition both kinds of tools are limited to natural light and make no allowance for artificial lighting.

An alternative approach for teaching daylighting is introduced in this paper. It involves the use of **Lumen Micro 6.0**, a Computer Aided Lighting Software for the evaluation of **daylight** and **artificial** system designs at the early design stage. This is supplemented by the logging of photometric data inside existing buildings.

The use of computerised tools for the study of lighting has many advantages. For example, useful information in the form of an illuminance from daylight and artificial light or daylight factor map at the working plane height can be generated quickly. Also, because the design model is inside the computer any editing and manipulating the design parameters becomes easy. For instance, it is very simple to adjust the geometry, change surface reflectances, add light shelves, and recalculate to establish the new daylight factor contours. With the use of computers, such process becomes iterative, this is normally not possible with both studio and laboratory based tools.

A number of software packages for daylighting analysis are commercially available. These range from simple ones, such as Daylight 2[8] which cannot deal reliably with complexities of real buildings, to the very complex ray tracing programmes such as RADIANCE[9] which is difficult to use. Based on the results of the 1994 IESNA Software Survey[10] of more than 30 lighting design packages, the author opted for Lumen Micro 6.0 to be used as a teaching tool for a number of reasons. The types of analysis performed by Lumen Micro, which include horizontal and vertical point-by-point illumination, daylighting, visual comfort probability, and room surface luminance, are very useful to students during the design process. Also the output from the package in the form of 3D images and perspectives of indoor spaces, provide visual information vital for the subjective appraisal of the character of light. Other factors such as hardware requirement, price, user interaction, and types of input and output were also taken into consideration.

Lumen Micro 6.0

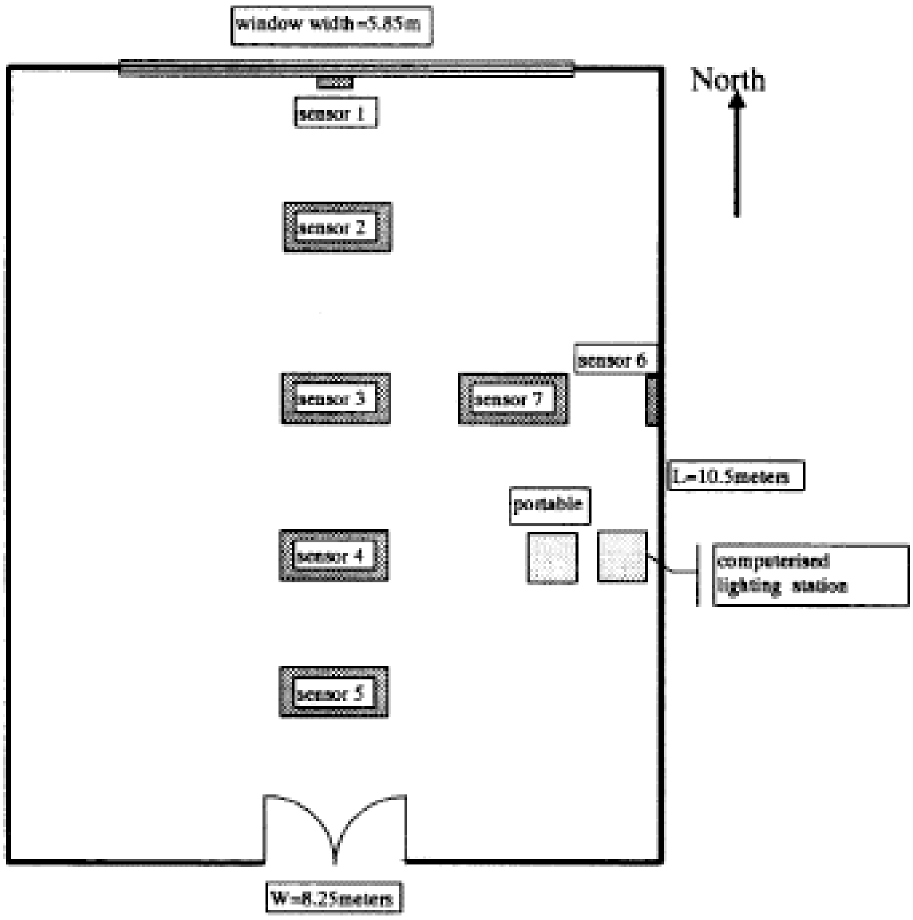
This package provides a complete analysis of daylighting from windows, skylights, lightshelves, clearstories and overhangs at any location, day or time, and under differing sky conditions. It also generates accurate light renderings and animated walkthroughs, both very useful for the subjective appraisal of daylight. Luminaries with any mounting and aiming can also be specified. Thus it represents a complete tool for lighting design and analysis.

Validation of Lumen Micro

A computerised monitoring station for measuring daylight and artificial light levels was built by the author and used to validate the software. The station consists of 7 colour corrected light sensors, 7 amplifiers and 7 dataloggers. It is operated and controlled by a remote portable running the EASYLOG software.

The monitoring took place in Studio 38 (L=10.53m, H=7.30m, W=8.53m), one of the Design Studios inside Mackintosh's Glasgow School of Art building. Daylight readings were logged over the period of 5 hours at a 1-minute intervals. Fig. 1 shows a diagrammatic representation of the plan with the orientation and location of the sensors. All the sensors were placed horizontally except sensor 6 which was mounted vertically on the East wall to measure the incoming daylight on a vertical plane. Logged results were pulled into EXCEL to produce the graphs shown in Figures 2 and 3.

Fig. 1 Plan of Studio 38, Glasgow School of Art



Output from Lumen Micro in the form of vertical and horizontal DF contours inside Studio and surface illuminance inside Studio 38 was compared with that from the recorded values, and a good correlation between the two was established. A statistical package, **Minitab for Windows**[11] was used to compute correlations between the two sets of daylight values.

Fig 2. Measured values of daylight on a horizontal plane (sensors 1,2,3- Calibration values: each volt=25000 Lux)

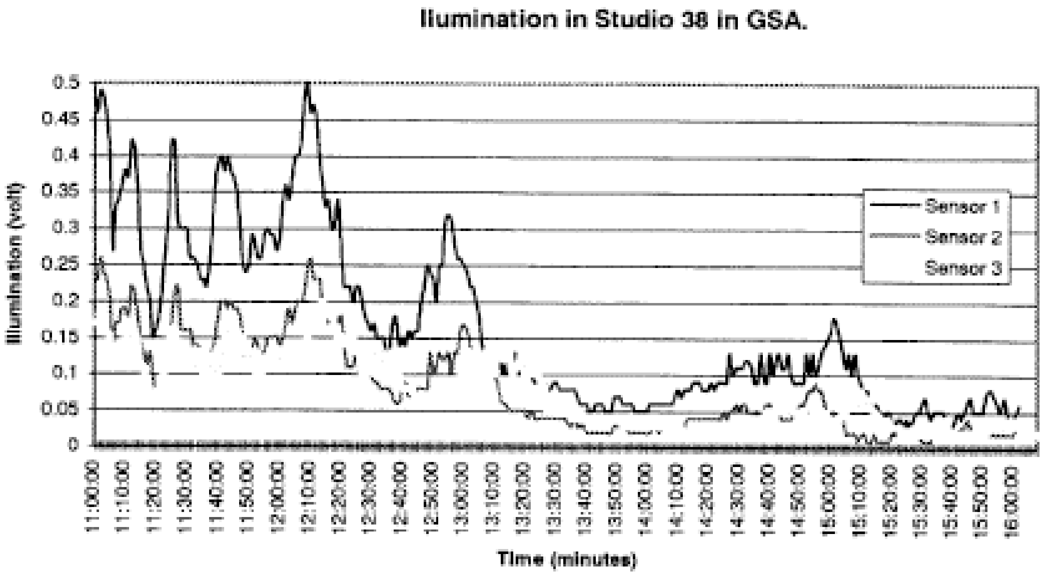
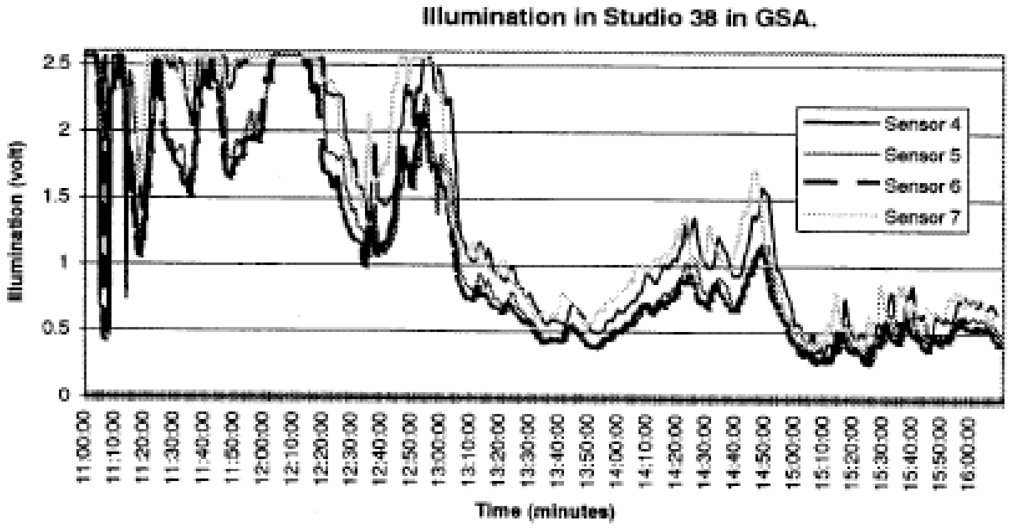


Fig 3. Measured values of daylight on a horizontal plane (sensors 4,5,7- sensor 6 measures daylight on a vertical plane- Calibration values: each volt=1000 Lux)



Having validated the package by empirical findings, this study concludes that Lumen Micro can be used as a teaching tool for daylighting design and analysis at the early design stage.

Fig. 4 Output from Lumen Micro: Daylight factor contours for Horizontal Illuminance

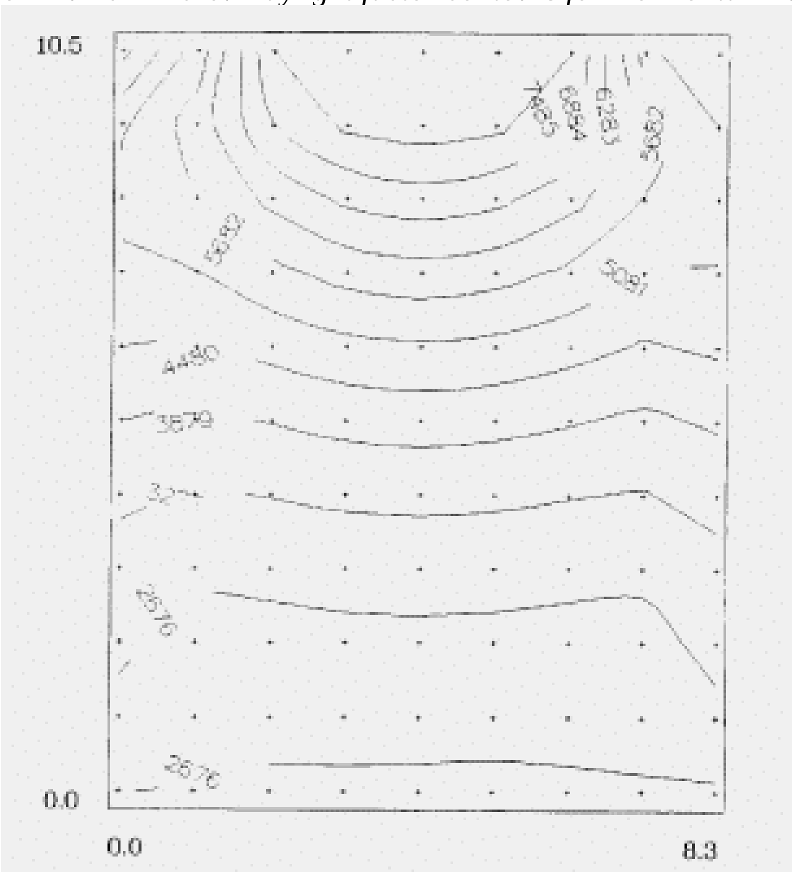


Fig. 5 Daylight factor contours for Illuminance on the East wall of Studio 38.

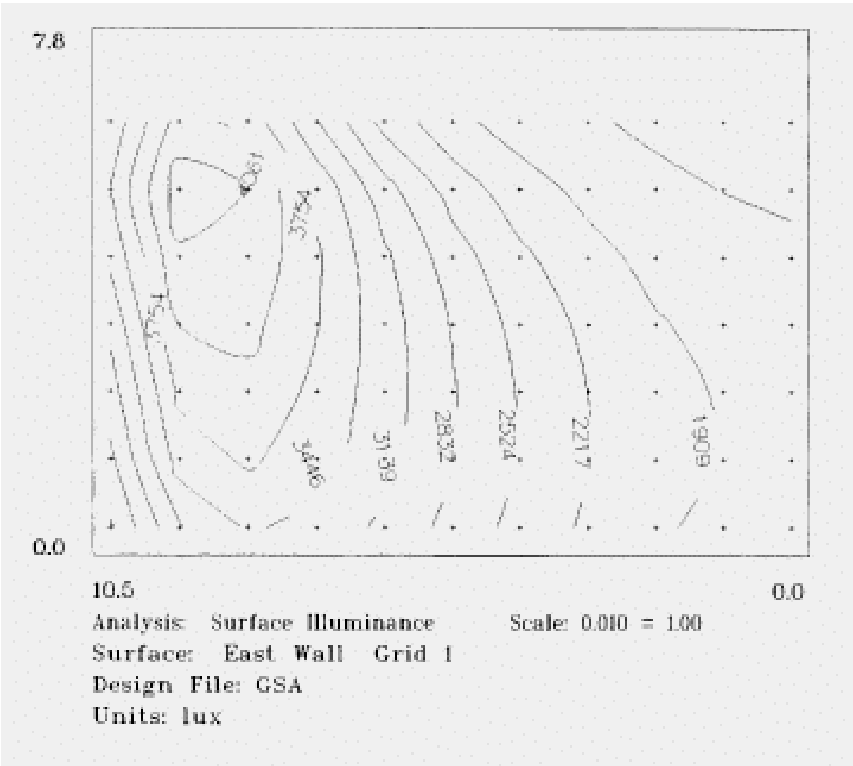
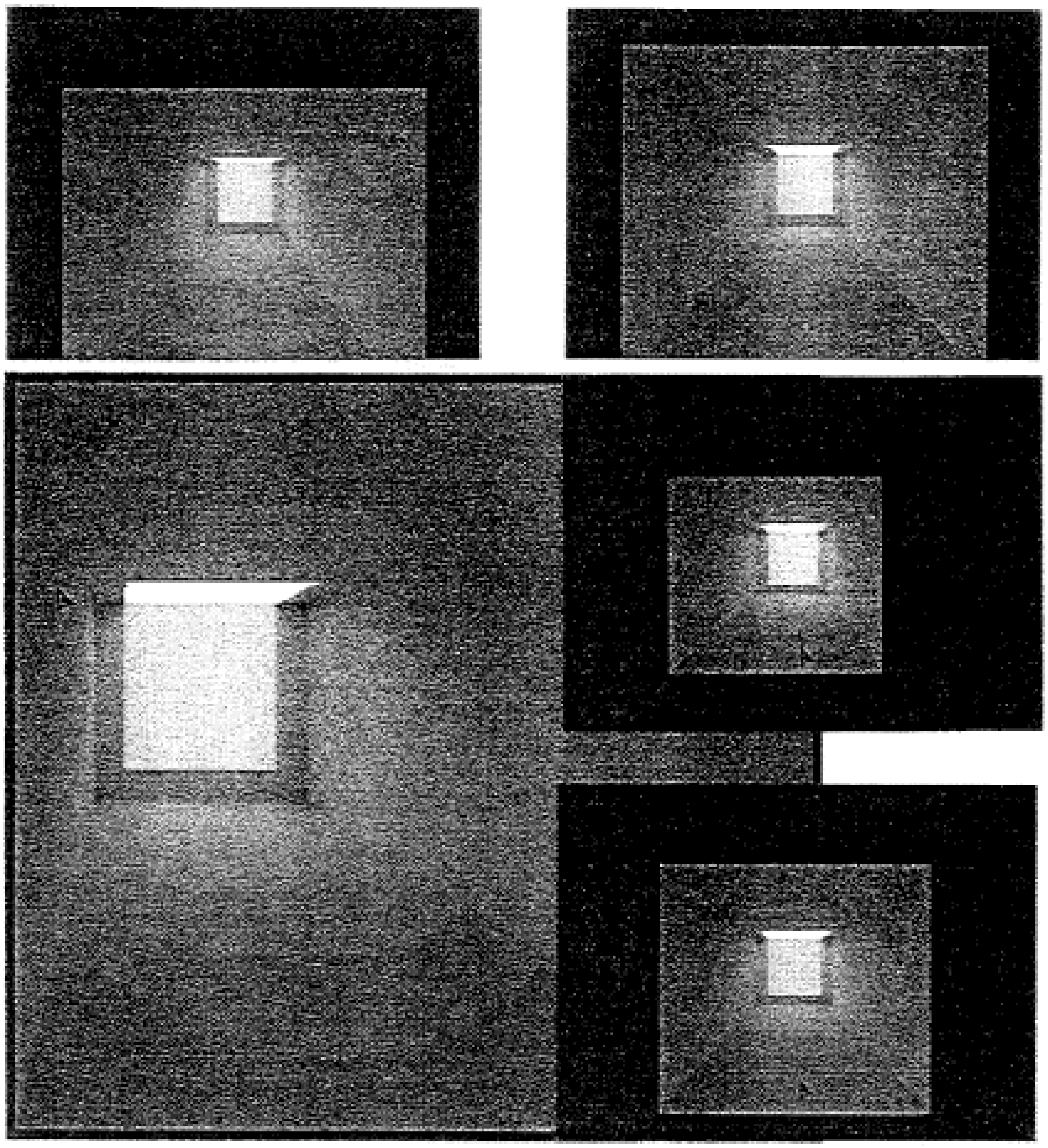


Fig. 6 Three Dimensional Graphics for daylight appraisal: perspective of Sudio 38 showing the Luminance at a reference point



A new Approach for the Teaching of Lighting

A two facet approach to daylight teaching is suggested by this paper. The first facet involves the use of a Computer Aided Lighting Design (**CALD**) for testing lighting design hypotheses where students can examine and assess the viability of various lighting strategies, systems and devices very frequently and very quickly. Such facet would also foster better integration between general CAD software, such as AutoCAD, Microstation, ArchiCAD, etc.., and CALD software for performance-analysis. For example, the DXF file format for exchanging data enables students to move between Lumen Micro and AutoCAD and link daylighting data from the former to design projects in the latter.

The second facet requires students' exposure to real life daylighting conditions inside buildings through measurements and monitoring. Empirical measurement should become an integral part of any daylighting teaching in the studios. It should also supplement any predictions from lighting design software. Instrumentation and experimentation are extremely valuable as they provide students with tools to relate theory and predictions to real life situations. Students need to know how to relate light units of illuminance and luminance such as Lux and Candela/m^2 to a perceptual schemata into spaces and buildings. Through measurements students would understand the perceptual meaning of a light level of, for instance, 100 Lux. By measuring the luminance of surfaces students would then be able to what a 4000 cd/m^2 means in terms of subjective brightness.

In addition to providing perceptual information about light units, monitoring gives students the opportunity to assess the subjective character of daylight indoors. This, in return, would yield better understanding of the totality and the nature of daylight as it covers various aspects ranging function and performance to quality and aesthetics. In the end a perceptual map would be established for both the subjective and the objective domains of daylighting in buildings. This should be the ultimate goal for the teaching and the design of lighting systems.

Student Trials

Prior to validating Lumen Micro student trials of the software were arranged by the author. Ten 2nd year students participated in a study to assess the package. The evaluation focused on different aspects of the software such as user interface, functionality and usefulness, overall satisfaction, input and output, and attributes of maximum use in design. The analysis of questionnaire results showed that 8 out of the 10 students rated the software as 'highly satisfactory' and 'very useful'. Daylight Factor (DF) contours and the 3D graphics and animation were viewed as the attributes with maximum use in the design process.

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