A Study of the Accuracy of Daylighting Simulation of Heavily Obstructed Buildings in the Urban Canyons of Athens

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This paper deals with the use and evaluation of daylighting simulation tools in relation to a complex urban environment. The environment concerned is one commonly found in city centre areas where the proximity of buildings leads to the creation of 'urban canyons'; the result of this is that assessment and simulation of daylight requires a more sophisticated approach than for other situations. In urban areas building layout is the most important factor effecting daylight, sunlight and solar heat gain reaching a building. It also affects sunlight in open spaces, ventilation, shelter and the dispersal of pollutants. In order to produce a more realistic understanding of the dynamic effects of daylight, there is a need not only for the research and development of advanced CAD and lighting simulation tools, but also of the study of possible alternative methods in their application. In the work reported in this paper, an attempt has been made to move the focus of lighting and daylighting simulation from the scale of a room to that of a whole building; the building itself being surrounded by its specific urban environment (including its microclimate). The study evaluates if there is sufficient evidence that it is possible with such complexity to reach reliable computation results after executing the simulation. The case study presented uses a 4D model of an urban canyon to investigate the sensitivity of such a complex simulation system. It can also be used to find ways to analyse and predict how daylight is reflected, refracted, scattered, diffused, polarised, diffracted and absorbed as it traverses an urban environment.

***Keywords**: Daylighting, Simulation, Buildings, Urban-Canyon, Athens.*

Introduction

The need to ensure and optimise the daylight available to buildings adjoining a new urban development is very important. A badly planned development may make adjoining properties gloomy and unattractive. Some countries may have laws or planning regulations covering obstruction to existing buildings caused by new development, though often other problems occur where badly planned developments already pre-exist or the laws or planning regulations governing solar access are new, insufficient or non-existent.

In some cases, particularly in warm climates, the overshadowing resulting from other buildings (mutual shading) has been considered an important beneficial strategy. Mutual shading is an unavoidable characteristic of dense urban areas, although guidelines often exist, these are interpreted flexibly since natural lighting is only one of many factors of site layout design. In many circumstances the architect, engineer, developer or planning authority may wish to use different target values. The value of land especially in city centres has lead to tall buildings increasing the complexity. While the general macroclimate is beyond a designer's influence, design changes that interact at the microclimatic level can provide significant benefits.

Daylighting, perhaps more than any other phenomenon in architecture, is 'place specific'. The colour, angle and quality of light are dependent on the particular latitude, sky conditions and climate of a given locale. Daylight varies in both intensity and direction over time, ranging from virtually a point source to an almost diffuse source. In so doing it animates architectural design and challenges the lighting design process.

A good working knowledge of the climate is needed therefore before daylighting design can begin, and year-round performance must also be considered. The two factors that have major influence on the solar radiation received in a particular site: the turbidity of the atmosphere and the presence of geometric obstructions. Geometric obstructions can be classified into three general types: those related to the topography of the area; vegetation on or near the site; and nearby buildings.

The recent focus on use of natural "servicing" (lighting and ventilation) in building leads to a requirement for more sophisticated design and analysis methods in order to ensure that internal conditions match occupant expectations and performance requirements. This poses an additional burden in lighting design processes.

The use of daylight and sunlight as prime light sources causes the building itself (through its apertures) and its immediate surrounding to become the light fixture; and its design must be scrutinised with the same engineering exactitude bestowed on electric fixtures. However, unlike electric fixtures that can be modified, upgraded or replaced, a building is constructed once, and its light delivery characteristics cannot easily be explored either initially through an extensive series of prototypes/physical or virtual models, or changed if unsatisfactory in the built form.

Fortunately the abilities and functionalities of recent daylight simulation tools have now developed to the extent that they can be considered for use by a wider range of design professionals; they can also be used to analyse systems requiring complex solutions not available using simpler techniques. The sensitivity of the tools to the degree of detail used in the modelling of the surroundings still requires further study however.

In the past lighting and daylighting study investigations carried out were focused on simulation systems that dealt with individual rooms. The study of complicated cases was avoided mainly because of computer, software and time restrictions, however this is now changing.

Urban Canyons

The opportunity has been taken in the programme of work (of which this paper forms a part) to address the situation of 'urban canyons', these being buildings in close proximity found in cities, set in climatic situations where sunlit conditions predominate over overcast cloudy skies. Typically buildings of several storeys height face each other across narrow streets. The facades are complex and variable both in materials used and contours. In these situations the influence of surrounding buildings has strong effect on daylight penetration and it is also a situation in which the dynamic variations over time cause significant effects.

The urban canyon study described here therefore provides a unique opportunity to measure daylighting simulation ability in the case of a very complex and varying built environment. The study has examined the particular daylighting performance of heavily obstructed residential apartment buildings located in the urban canyons found in Athens, Greece. The methodology and results could be expected to have application in a much wider range of similar climatic and urban situations as well as in simpler situations where overcast skies might predominate.

Based on this study future work aims to develop a daylighting study methodology that could be followed with some confidence by designers in order to estimate or predict the daylight availability in room spaces found in densely built urban environments under conditions of high external obstructions.

The objectives of the current research address the following questions:

1. How can the performance of a building within a complex urban environment (for example in an urban canyon) be evaluated using global lighting simulation?
2. What are the additional inputs needed to describe such a large and complicated scenario?
3. What are the possible extensions needed in the description of the simulation system?
4. What is the role of the 3D geometry in the assessment (that is, what is described geometrically)? and how can it be recorded in order to be used as an input in the simulation?
5. What is the level of detail-abstraction needed in order to achieve accurate results?

Lighting Simulation Development

Recent progress in the development of global lighting simulation software has shown improved accuracy and ease of use. The lighting design community now often uses such simulations and has learned to trust their results, though their application has been restricted mainly to electric lighting assessment concerning relatively small-scale interior spaces. In order to make it possible to use these sophisticated prediction and analysis tools in investigations concerning the use of natural lighting, more research is still needed in order to identify their limitations.

In recent years the parameters of solar radiation and sky conditions have been extensively studied, described and modelled. See for example: Littlefair (1998, 2000), Tregenza (1989, 1995, 1999), Mardaljevick (2000), however the main focus of study has often been to determine the usefulness of simpler design tools or methodologies. The objective of this study is somewhat different to many: it is not the definition of minimum standards but rather the evaluation of performance not just under overcast skies but also throughout the year.

One of the most common assumptions made today in natural lighting assessment and simulation is that of ignoring external obstructions caused by the surrounding environment, as if the building is in a featureless plain landscape. For broad issues of daylight design, such an assumption may not be a problem however in detailed or complex lighting situations it could lead to error. The main difficulty is the exclusion from assessment of external features especially in climates where sun shading is used in the building envelope or mutual shading of buildings is common, or where surfaces of nearby building have a significant influence on daylight penetration.

The above issues are also related to the bigger problem of the lack of ability to properly describe the surrounding environment and microclimate. Topography, the surrounding terrain, and natural three–dimensional features (such as vegetation) which also experiences a seasonal variation, as well as many geometric features of surrounding buildings are excluded from the normal simulation/assessment system. One of the main difficulties is the recording and inputting such complicated data in the computer simulation software.

Resulting from the above analysis, this research investigation was devised in order to address the need to identify the factors that should be taken into consideration when trying to create and simulate complex urban environments, including finding ways to record them in order to include them in the simulation process. The work commenced a detailed comparison of results obtained by on-site measurements and calculation, and simulated results produced using both ray-tracing and radiosity lighting performance software methods.

The study is utilising a selection of advanced lighting simulation software running under the 'Windows' computer environment, (a system common to many building professional offices). The aim was to measure the sensitivity of the simulation system with regard to the level of detail abstraction used in modelling the microclimate, and the identification and quantification the level of detail (geometry and material complexity) that is required for the urban canyon to be described in order to achieve suitable simulation results.

Case Study in Athens

Athens was chosen for this case study for a number of reasons: it is one of the largest urban conurbations in southern Europe; the city is very densely built and has grown dramatically in a dynamic way through the last century; few precautions have been taken regarding its urban site planning; a large percentage of the 5 million population lives inside the city centre area; the city has developed its own 'urban climate' and shows strong signs of negative phenomenon such as thermal island effects, high level of atmospheric pollution etc., which make it important to seek for new ways to tackle environmental problems.

The characteristics of the Mediterranean climate of Athens are mild winters with few days of overcast skies and a low number of rain days with long periods of sunny days with clear skies (270 days per year). During the warm summer months (May – September) solar shading of building apertures is typically used to avoid solar gains. Under these conditions the use of natural lighting has very high potential, which is not currently utilised in an effective way. The high summer temperatures and risk of solar heat gain have lead to the adoption of sun shading at the cost of daylighting. This is also reflected in peak electrical demand during the summer months when demand for air conditioning rises together with a continued need for artificial lighting for shaded interiors (energy costs for lighting remain relatively constant throughout the year due to increased shading during the brighter summer months). It can be seen that correctly designed daylighting and sun shading has the potential not only reduce energy costs related to artificial lighting but also diminish the possibility of having the use mechanical devices to cool rooms overheated by direct solar gains.

Urban microclimates are particularly complex because of the number and the diversity of factors that come into play. Solar radiation, temperature

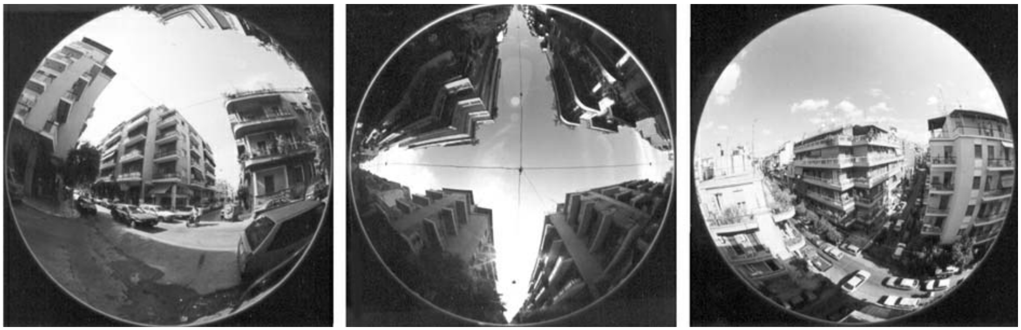

Figure 1. The residential apartment building and its surroundings

and wind conditions can vary significantly according to topography and local surroundings. In addition, layout density can provide further constraints: the precise plot division, the need for access and privacy, the noise and impact of atmospheric pollution must all be taken into account.

Methodology

A typical residential apartment building situated in an urban canyon of Athens was chosen. (figure 1.) [The study was carried out in three stages.

Prior to Site Visit

The full range of the blueprints of the existing residential building was acquired and these were translated in a 2D digital form. Gradually a full 3D geometrical representation of the principal building was created (Figure 2).

Three groups of rooms were selected to be examined during the visit. Each group had four rooms identical in geometry but differing in floor level forming a vertical column. (Figure 3).

During the Site Visit

The visit took place in the middle of October 2001 and began by photographically recording in full detail the surrounding environment. The photos were taken in such a way that would allow them to be used at later stage as an input for the reconstruction of the 3D geometrical model of the surrounding urban environment using digital photogrammetry technics. During this phase a full database of local materials was recorded which would be used to help describe the necessary material attributes needed as an input to be combined with the geometrical models. These data were required as inputs in the global lighting simulation software. It is important to note the difference here between global lighting simulation software and more simple rendering software

Next, the three pre-selected groups of rooms were photographically recorded (Figure 4). At the same time records were made of the illumination levels of the selected room spaces in the principal building and also at the level of the urban canyon for specific day-time-sky conditions. The purpose was to enable the recreation of the full scene in a computer simulation environment at a later time.

[After the Site Visit

The full reconstruction of the urban canyon's surroundings was performed using digital photogrammetry reconstruction and CAD techniques. This process it should be noted was time consuming and very demanding - for each building between 6 and 15 photos had to be combined and over 1000 points had to be identified and linked together. The resulting images and the later simulation showed this to be a suitable process leading to accurate

Figure 2. East & North facades

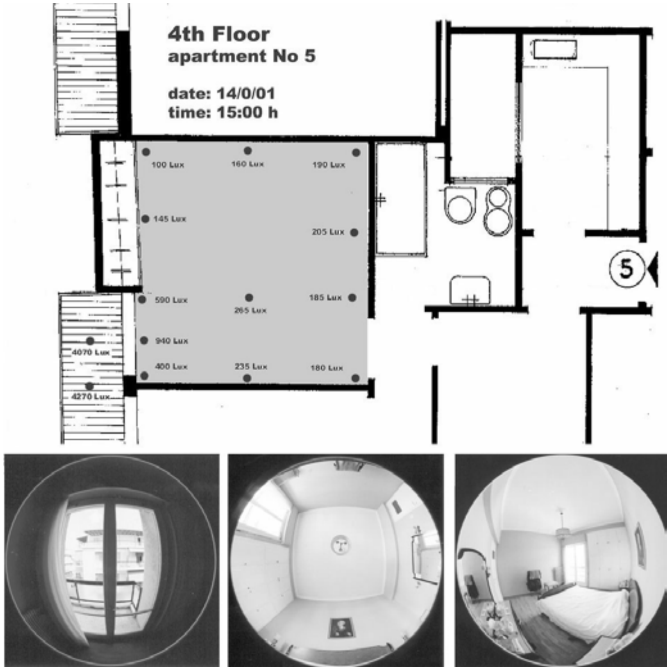

Figure 3. Typical plan of the residential building.(The grey areas show the position of the 3 vertical columns)

Figure 4. The measured points of illuminance (top) and the photographical recording of the room (bottom)

results; the error in the objects reconstruction geometry dimensions was below 3%.

The building simulation was then defined at three levels: the immediate surroundings; the principal building in which the measurements were taken; and the urban surrounding. The scene could be recreated as on the exact day of the measurements with the sky conditions as they existed. This allows a dynamic, realistic and more accurate determination of resulting daylight and gives information that could not be envisaged using simple daylight factor analysis.

Results: Simulation Issues

There was a need to undertake selective detail abstraction and decisions had to be made at an early stage regarding the detail of the modeling in order to allow successful simulation. A set of simple rules had to be created tested and then followed.

It was important to keep the number of surfaces describing the scene geometry limited in order to allow the simulation to be executed in reasonable amount of time. As part of this process it was found to be necessary to define what was 'view dependent' and what was 'view independent' and their relation with time.

Preliminary tests were conducted in order to confirm that the group of simulation software packages selected could deal with such a complex system description. This included the use of models representing the size of the 1/4, 3/4 and full version of the estimated final geometry. In most cases it was evident that modifications had to be made not only in order to optimise the simulation system but principally to allow the execution of the simulation.

It became clear that a number of the global simulation software packages could not serve the scale of the study. Some simulations halted part way through and others gave rise to incomplete solutions. Some of the problems were rectified by modification of the software and hardware environments though this led to a non-standard system which many designers would be unlikely to be using or capable of creating. These areas of weakness must therefore be addressed in future software development.

Hardware was challenged in such a way that a workstation with many additional capabilities compared to common desktops was created.

The work did help identify a secure methodology that can be followed in order to simulate urban environments for global lighting simulation however (Figure 5).

Results: Imaging

The results of the research programme so far completed are centred on the production of accurate models of the environment for study and upon an appraisal of the problems and issues of modeling using the software available in its current form (Figure 6).

Conclusions

This paper has dealt with an important area of building simulation and analysis, that of appropriate modeling to enable accurate use of daylight simulation software. As a result the issues of accu-

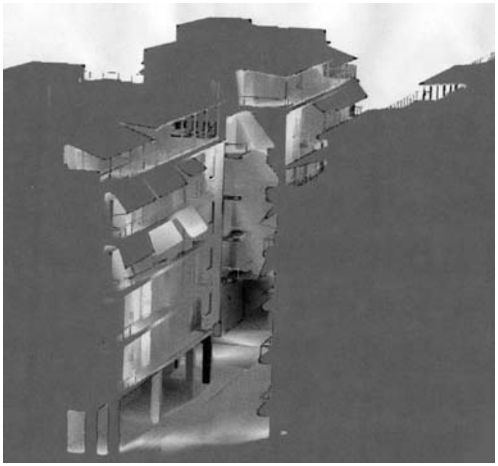

Figure 5. False-colour image showing illumination levels in the urban canyon.

Figure 6. Photorealistic image showing illumination levels of the opposite facade.

racy and validity when using computational simulation have been examined to study the particular daylighting performance of heavily obstructed residential apartment buildings located in urban canyons of Athens in Greece. The investigation was carried out in order to try to find what are the obstacles limiting ability to simulate highly complex urban environments for global lighting simulation.

In answer to the specific question as to whether the software available can be used to reliably compute simulation results the answer is not unequivocal – some package and methods show significant problems in dealing with the complex urban canyon situation presented, others offer real potential.

The work completed so far has shown: the need to identify and optimise the level of detail needed to model such a demanding simulation system, and the requirement to identify available recording and reconstruction computer tools that could serve to enable ease of use of the software and thus effective environmental design.

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