Computer Aided Architectural Design
The Next Generation

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Abstract

Currently there is very rapid progress in the development of computer based
techniques for the visual simulation of those environments which are physically
inaccessible. Three such developments are discussed: advanced lighting models,
interactive animation and virtual reality. The paper then proposes, in the context
of building design, a more technically comprehensive approach to experiencing
architectural space.

1 Why Simulate?

There are many situations where it is more convenient, less costly, or indeed necessary to
simulate our experience of three dimensional space rather than to experience, directly, its
physical reality. The inaccessibility of the real world may be as a result of its remoteness, its
hazardous character or because it no longer exists, does not yet exist or indeed, never will
exist.

- remote environments;
lunar homesteads, polar outstations, orbiting space stations and off shore
oil drilling platforms are examples of spatial environments which are
significantly remote; it is certain that convenience and economy can be
served by providing an accessible simulation of the environment.

- hazardous environments:
environments contaminated by radioactivity, threatened by fire,
structurally unstable or biologically inhospitable are either dangerous or
expensive to make safe; economy and safety are promoted by appropriate
simulation.

- non-existent environments:
these fall into three categories:
- those environments which never will exist, e.g. the science fiction images
of Hollywood movies
- those environments of architectural or historical interest which once
existed but, due to the ravages of time, no longer exist, and
- the hypothesized environments of architects and planners which it is intended, ultimately, to bring into existence

This paper is concerned primarily with the application of emerging computer based visual simulation techniques to this last category, i.e. to the modelling of three dimensional environments which represent some future reality in a way which is meaningful to those who design/plan it and to those who, ultimately, will experience it in its full physical manifestation.

The design of the built environment has some significant differences from the design of other physical artefacts. The very high capital cost and extended life span of buildings preclude the 'prototype and production run' associated with, for example, the design of cars, toothbrushes, TV receivers, VCR's; this places great emphasis on the designer's ability to model and test, at the drawing board (or a workstation), the formal/functional cost/performance characteristics of emerging and competitive design hypotheses.

Advances in computer graphics hardware and software are offering architects and their clients high degrees of fidelity in the visual simulation of future built environments. Three significant advances are discussed in the following sections of this paper.

2 Advanced Lighting Models

Two mechanisms for the construction of computer generated images of buildings that have gained widespread acceptance are ray tracing and radiosity. Ray tracing can produce images of very high quality and realism, but they lack the optical validity to produce a physically accurate description of the global illumination necessary for the formal and functional evaluation of a lit space and are further hampered by their view-dependent nature.

Radiosity methods are capable of calculating the global illumination solution using physically correct techniques. The earliest radiosity methods could handle only very simple geometry environments with diffuse reflections; later models were capable of dealing with complex environments but still only in a diffuse manner. The most recent developments such as progressive refinement or hybrid radiosity/raytracing methods are capable of creating very high quality images often at near 'real time' speeds; the problem is that they can only handle diffuse models, require sophisticated hardware or need extended view-dependent post-processing. While these methods offer the highest image quality they are not really feasible within a general design environment.

The approach adopted by the ABACUS group in the Strathclyde University Department of Architecture and Building Science for the development of the first principal multi-chromatic inter-reflective lighting model known as DIM [VISUALSFX] was to build an extended radiosity model capable of dealing with diffuse and spectral reflections as the basis of the calculation engine for the design system.

The DIM system comprises three program modules addressing discretisation, ray tracking and result analysis. The first programme module DIMdis accepts user data which describe a zone's topography and topology. The objective of DIMdis is to transform this continuous zone model to a discrete numerical equivalent in a manner which maximises numerical accuracy. The output from DIMdis is a data structure of rays representing the total number of possible light flow-paths. The second program module of DIM is DIMray; this accepts the output from DIMdis and the user's specification and positioning of luminaires extracted from DIM's database. Luminaire photometric data is conceived as a number of vectors representing a three dimensional intensity distribution, with a number of monochromatic wave bands superimposed to represent spectral characteristics. The computational mission of DIMray is to process each vector, for each mono-chromatic wave band, through the list of rays representing the total range of inter-reflected possibilities. The output from
Figure 1: Simulation of an interior generated by the software DIM, otherwise known as VISULUX.

Figure 2: Simulation of floodlit Glasgow City Chambers generated by the software DIM, otherwise known as VISULUX.
DIMray is a data base giving, for each surface element, the spectral luminance distribution. DIMout is the analysis module which allows the recovery and presentation of this performance data. An auxiliary module, DIMdbm, is a data base manager for the luminaire and surface property data bases. It allows the display of existing entities and the insertion of new luminaires and surface textures as required.

DIM has been taken from the research environment into the practice of lighting design. Philips International have shared in the development of the program which they call Visulux. Figures 1 and 2 show the capability of Visulux in two very different contexts.

3 Interactive Animation

It has been pointed out by Lansdown [2] that we perceive and appreciate the built environment not as an immaculate set of coloured textured and lit "stills" but as a more jumbled, fuzzy, dynamic sequence of impressions. Such a sequence has, until recently, been compiled by painstaking capture on film, frame by frame, of discretely generated images.

Recent advances in the technology of computer graphics have brought a change in this scenario and offer a truly interactive dynamic interface with whosoever wishes to explore the environment - on foot, by bike or car, or on a 'magic carpet'.

ABACUS' opportunity to develop real-time animation software came when it was asked to evaluate the efficacy of the Silicon Graphics Iris workstation in the context of building design and urban planning. Silicon Graphics has built its reputation on the power of their 'geometry accelerators' which automatically carry out, at great speed, perspective transformations of any 3-D data set.

The software development work was carried out in the context of urban design. ABACUS decided to deploy students to build a 3-D model of the city of Glasgow through which architects, planners, developers and others could 'fly' (Figure 3).

In effect three data bases were constructed: the terrain, the road network and the buildings;

- Glasgow is a hilly city and it was considered necessary to model the topography; this was done by digitising the contours at 1:10000 scale over an area of 64 sq km
- The roads, over the central city area of 10 sq km were digitised as if they existed in one plane; they were then 'floated' down on to the terrain model until they took on the 3D shape of the landform
- The buildings required, by far and away, the greatest effort; the heights of buildings were obtained from a variety of sources, but were primarily captured from stereoscopic analysis of aerial photographs. These heights were entered onto the 1:1250 scale city map which was then digitised as 40 separate sections of the city. These 40 files was then floated down onto the terrain and combined to give a data base of some 10000 buildings extending over 10 sq km.

Development work is currently focused on ISSUE -an Interactive Software System for the Urban Environment [3] in which the used 'flies' to the part of the city in which he/she is interested and then, by 'pointing' in perspective, can open windows on the screen which provide archival information - textural and graphical - on particular buildings.
Figure 3: Computer generated aerial view of part of the database of Glasgow city centre.

Figure 4: Typical configuration of Cyberspace system as proposed by Randal Walser.
4 Virtual Reality

There is a significant difference between the simulation experience offered by the computer graphics systems described in Sections 2 and 3 and those offered by what has come to be known as 'virtual reality' (VR). Conventionally, computer graphics appear as hardcopy on an A4 page, or as a display on a 30mm raster screen. In virtual reality systems, the user (or 'traveller') has the experience of being within the 3D data-set (commonly known as 'cyberspace'). Additionally, the system may provide the means by which the traveller can move through cyberspace and the mechanisms for simulating physical interactions with virtual objects within the data set [4].

The basic elements of the hardware of VR systems (apart from a powerful processor) are typically:

- a helmet with earphones and 'eyephones', i.e., two small display screens one in front of each eye: 6D sensors allow tracking of head position and attitude which in turn determines the stereo images transmitted to the eyephones. Thus, as a user looks around, the stereoscopic image changes in a way which is similar to that which would be experienced if the user was actually 'inside' the data-set.

- a data-glove: 6D sensors allow tracking of the position of the hand and of individual fingers; pneumatic pads may be incorporated to allow sensory feedback as the user's hand, within the glove, closes on a virtual object within the data-set. Thus the user is given the tactile (and visual) experience of interacting physically with his/her environment.

- a motion platform: some physical prop such as a treadmill, stationary bicycle or car steering wheel and foot pedals which translate the actions of the user and move him/her through cyberspace. In the absence of such props particular hand gestures, such as pointing, can be translated through the glove, and programmed to move the user forward in a particular direction.

A typical configuration, including audio input/output, is illustrated in Figure 4.

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The images which can be delivered by the rapidly developing radiosity software described in Section 2 have, for architectural purposes, a high degree of visual fidelity. By contrast, the data-sets currently demonstrable in most VR systems are disappointingly crude and unrealistically lit. The obvious way forward in the development of VR systems which are appropriate for architectural purposes is to sacrifice the facility of dynamically changing the data-set with the data-glove. Provided the geometry of the data-set remains constant the entire environment can be pre-processed using a radiosity model such as DIM; the user can then move through and look around complex and realistically lit spaces.

Indeed with DIM, the pre-processing can include alternative light switching modes allowing the user, as he/she walks around the scene, to switch lights on and off at will.

But our experience of architectural space is not only visual; it is also acoustical and thermal. As far back as 1970 [5], ABACUS proposed the development of a kind of 'audio virtual reality' (Figure 5) in which the quality of the music heard through the user's earphones is filtered over the wave band spectrum according to where the user is 'sitting' in the concert hall and upon the geometry and acoustic attributes of the concert hall itself.
Figure 5: An early (1970) concept for 'audio virtual reality as proposed by Tom Maver.

Figure 6: The overlap between acoustic, thermal and visual computer models.