A Selection of Interactive Design Tools

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Abstract:
The aim of this paper is to discuss the role that building performance modelling and simulation plays in the study and practice of Architecture. It argues that considerations such as the acoustic environment, lighting levels and thermal performance are of fundamental importance in the design of all buildings and should therefore be considered by the design architects at the very earliest stages of the design process. It looks at why this is not happening and introduces some design tools that have been developed by the authors to rectify this problem.

Introduction

In his historical outline of architectural science, Cowan suggests that "Environmental design replaces structure as the principal problem of architectural science" [1]. In response, more than 20 years later, Manning writes: "Despite enormous amounts of research that has been undertaken into many aspects of building environment, and the store of knowledge that has accumulated, design of the environment too often appears to be a matter of chance. Users of today's new buildings are just as liable as were users of earlier buildings to be uncomfortable." [2].

Comfort is an enormously complex criteria to design for, involving physical phenomenon and the wide range of physiological and psychological responses to them. However, it is an area in which comprehensive assessment can be carried out once buildings have been constructed, with much research having been done in this area. As a result, there exists a significant body of knowledge that can be used to reliably predict comfort levels from the fundamental physical characteristics of a design. In a later paper, Manning uses this as one of the main reasons why the design of the environment should be based, wherever possible, on the quantifiable findings of environmental science and much less on the subjective preferences that are common methods of aesthetic design [3].

In most large projects, environmental consultants form part of the initial design team, alongside the architect. This means that considerations such as thermal performance, daylighting and acoustic design criteria become important factors in shaping the form of the building and its interior. In many smaller projects, however, such considerations are tackled intuitively, if at all, at the formative stages. The basic geometry of the design, so vital to building performance, is determined by other factors. If consultants are brought in, then it is most likely at the end of the design process, in which case their findings usually result only in minor modifications.

There are many reasons why environmental considerations are treated so poorly by many architects. Some may view them as having very prescriptive solutions that tend to restrict design creativity. Others consider them peripheral issues in comparison to planning and aesthetic concerns. Some may even feel that they are of only trivial concern, easily resolved by adding more air-conditioning or increasing the number of luminaires. The majority of architects, however, would appear to recognise their importance, but lack the time and knowledge to adequately address them given the enormous range of other considerations they face.

The Need for Design Tools

In order to assist architects, and at the same time promote an awareness of environmental issues, much more attention needs to be paid to the translation of architectural science research into workable design tools. Traditionally, architectural scientists have focussed on particular areas and produced tools that, given a sufficiently detailed model, perform comprehensive simulation and analysis. For reasons of validity and accuracy, they require quite detailed information about each design,

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all of which must be entered manually. The amount of information required as well as the time and resources required for its input virtually assure the use of such tools only at the end of the process, after all of the major design decisions have already been made.

Architectural design is most often a process of gradual refinement. Many factors have to be considered simultaneously. Resolving competing or conflicting requirements takes time and results in a very dynamic initial definition of the building. If environmental issues are to be factored in appropriately at this early stage, some method of quickly assessing the impact of very non-specific design decisions needs to be provided. This means tools that work without the need for intricate detail. Tools that allow the designer to play around with simple shapes and forms whilst providing feedback on possible performance ramifications. Tools that don't require the tedious input of incompatible design data so common to many architectural science applications.

Designing Design Tools

There are many areas in which computer aided design tools can assist architects. Looking at the type of environmental modeling and analysis an architect may be expected to undertake, it is clear that, given the right information, they are each the product of relatively simple algorithms (even though sometimes involving complex equations). The main area of difficulty seems to be obtaining the right information in a format compatible with those algorithms.

Of all the architectural science software presently available, very few offer any form of data compatibility between either CAD packages or other similar software. Each appear to have developed independently unique user interfaces and file formats. This means that architects must enter building details many times and in many different formats if simultaneous analysis in multiple areas is to be attempted. Obviously some standardisation is required, both in terms of how a design is to be described and the mechanism by which it is input.

Given the penetration of CAD into even the smallest of practices, it is clear that architects are willing to enter details of their designs into a computer - if they can see a clear benefit. Rather than require that same data to be translated into a multitude of formats, is it possible to use existing 2D and 3D CAD drawings as the basis for comprehensive environmental analysis?

The Problems with CAD

The driving force behind developments in CAD has traditionally been the engineering industry, where assembling and manipulating components form a major part of the design process. Thus the basic interface and drawing structure of most CAD applications is geared towards the assembly of a set of basic geometric primitives.

Whilst such systems are not incompatible with architectural design, they make any form of design analysis quite difficult. The reason for this is that, whilst each primitive can have some associated attributes, they have no intrinsic relationship with architectural elements. Any primitive may equally form part of a door, window, wall or floor. Any analysis package must therefore assemble each element from its constituent primitives before it can determine important information such as position or surface area.

Defining specific architectural elements is a very important step in establishing some knowledge base within the CAD drawing. Apart from the obvious quantitative benefits, being able to establish the geometric relationships between individual elements is fundamental to almost all areas of environmental science. Traditional CAD packages, especially those in use by the majority of practices today, do not easily facilitate such definition.

Significant work is being done in the area of Computer Aided Building Design (CABD) [4-6], Knowledge-Based CAD [7-9] and expert systems [10-13] to address this inadequacy. Whilst concentrating mainly on knowledge representation, such systems are beginning to deal directly with architectural components, imbuing real information into CAD representations of a building. The work presented here is intended as an adjunct to these developments, looking at what areas of environmental concern are capable of being adequately addressed by such techniques.

Areas of Environmental Concern

There are surprisingly few areas in which architects may be called upon to perform any quantifiable analysis of a design. Eight major categories can be singled out as follows:

- Acoustic performance
- Building code adherence
- Climatic relevance
- Lighting performance
- Quantitative analysis
- Shadow and reflection analysis
- Structural integrity
- Thermal performance

Many of these areas are normally the responsibility of consultants and engineers. Acousticians, lighting consultants, quantity surveyors and structural engineers are regularly included as members of the design team. Not even the most optimistic of computer programmers would suggest that CAD-based design tools can completely replace an expert consultant, at least not in the immediate future. However, on smaller projects, where consultants would not normally be used, or even at the early stages of a much larger project, such applications could be of enormous benefit.

Their worth really lies in an ability to assess the ramifications of individual design changes, providing a level of feedback not normally possible with highly paid consultants. New ideas can be tested at any stage of the design process. In this way, such tools could actually enhance an architect's creativity by enabling experimentation without having to be completely dependant on the advice of the consultant.

Developmental Work

The aim in this work has been to develop simple tools that architects can use to investigate various environmental phenomenon and their effects upon built structures. This has resulted in a series of small applications, each complete within themselves but sharing common file formats and able to link back to a central database of information.

Given the inadequacy of existing CAD packages and the fact that no KBCAD systems are readily available as of yet, an attempt has been made to develop an interactive design interface that incorporates the knowledge required by these other applications. Whilst lacking much of the sophistication of traditional CAD software, it adds several important new features.

The first of these is the ability to design completely in three dimensions. This is made possible by fast and intuitive view controls as well as a fully three dimensional intelligent cursor. Whilst normally unrestricted in its movement, after 3 vertexes have been added to a plane, the addition or movement of further vertexes is restricted to the surface of that plane. This also applies to the insertion and movement of panels and openings within planar elements.

The second feature is its focus on zones, a concept taken directly from thermal analysis packages. Zones have been initially defined as areas of isolated air flow with common usage characteristics. They may comprise either single or multiple rooms with the only restriction being that they are formed by a closed envelope, isolated from both the outside environment and other zones. Obviously openings within the surfaces that comprise the envelope are still permitted, however the zone itself must have a completely enclosed shell. In this way, a building is constructed as a series of separate zones, each able to be independently selected and repositioned. Architectural elements become children of a specific parent zone whenever they are added or used in the construction of a new zone.

All architectural elements are assigned a particular set of characteristics upon creation. These characteristics are initially determined by the method used to construct the element, however, the user can edit these at any time. There are currently seven definitions in use. The first four, FloorObjects, WallObjects, CeilingObjects and VoidObjects, refer to the basic building blocks from which zones are constructed. The last three, WindowObjects, DoorObjects and PanelObjects refer to children that can be inserted within other elements.

An attempt has been made to eliminate any restrictions on the use of these elements. For example, walls do not have to be perpendicular to floor planes, ceilings and floors do not have to be horizontal or even flat. A window inserted in a ceiling plane simply becomes a skylight and a door a trapdoor.

Once elements are defined in this manner, an enormous amount of intrinsic geometric information becomes available. Walls can be automatically extended to intersect sloping roof planes. Windows and doors can be checked to ensure that they are totally within their parent objects and not obscured by intersecting walls. More importantly, areas of intersection between adjacent zones can be determined by simply detecting for coplanar elements.

Additionally, shortcuts have been introduced, based on common constructional techniques, that facilitate rapid data entry. These feature the ability to draw in the floor plan of a zone and have it instantly extruded with the addition of walls and ceilings. Whilst able to edit this configuration at any time, such a construction has the advantage of hierarchical linkage. Moving a vertex in the floor plan instantly updates all associated walls and ceilings. If internal walls are added to such a zone, the height of each segment is automatically adjusted to the ceiling height.

The final feature of this design interface is the assignment of materials from a central library to each element in the design. This library contains individual material definitions as well as composite constructions. A simple editor can be used to construct new composite materials as well as new doors and windows [Fig.1]. As only an index to a particular material is assigned to each element, the library definition of that material is not limited in scope. Each application that needs to refer back to the library simply ignores any information it cannot use.

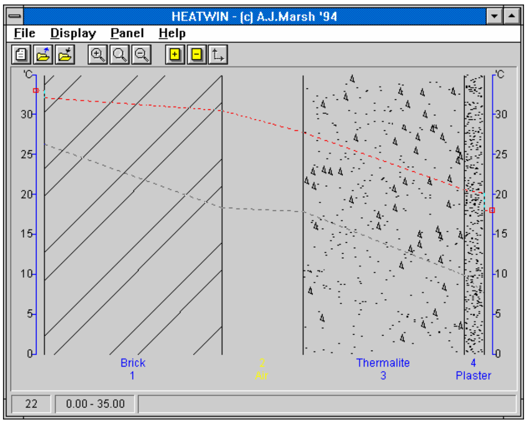

Figure 1: A tool for designing composite partitions within the central materials library.

With this type of building definition, environmental analysis becomes significantly easier.

Acoustic Analysis

The acoustic analysis of a design normally focuses on two areas, sound transmission between zones and acoustic performance. The idea of thermal zoning translates well when considering building acoustics. As each zone is isolated, and areas of inter-zone adjacency are easily determined, transmission between zones can be reasonably well estimated from surface areas and the transmission characteristics of assigned materials. Work is currently being done by the authors on the use of finite and boundary element analysis techniques to detect more complex transmission paths between zones, however this work is ongoing.

Work in the area of room acoustics has focussed on raytracing techniques and statistical acoustics. Given a single zone, the surface area and absorption characteristics of each plane can easily be determined from the geometry of each element and its assigned material. This allows classical formulae to be used to calculate simple reverberation time values.

A comprehensive acoustic raytracing application has been developed that can analyse each zone [Fig.2]. Whilst there is debate as to the absolute accuracy of geometric acoustics in the prediction of some objective measures of acoustic performance, it is one of the most effective tools used by acousticians in the determination of optimum room shape. As such, it is argued by the authors that relative accuracy is far more important than absolute accuracy at the formative stages of design. Being able to determine the relative effect on acoustic performance of any design changes, regardless of their absolute effect, is of significant value to the architect.

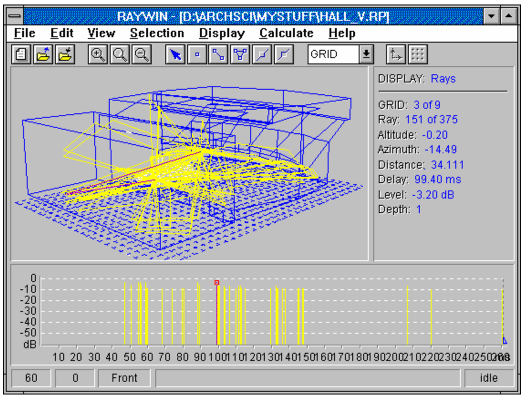

Figure 2: A comprehensive acoustic ray tracing application that allows direct selection of rays from either their geometric path or the impulse response.

Much attention has been paid to the relationship between ray paths and the resulting impulse response. This allows users to select rays directly from the impulse response and view their exact path between source and receiver. In this way, acoustic defects and spurious echoes can be detected at a very early stage and their solutions taken into account by the architect, not imposed later by a consultant. An application for the analysis of recorded sound decays and waveforms created from a convolved impulse response has also been developed [Fig.3].

Lighting levels
Rather than attempt to develop a new lighting analysis application when there are many excellent commercial and public domain examples already available, it was decided to provide compatibility with as many of these as possible. Currently, however, only the public domain radiosity package, Radiance, is supported [14]. The geometry editor outputs Radiance files directly, including within them surface characteristics and light sources taken from the central library. Views of the interior of each zone can then be rendered and accurate lighting levels on any surface determined.

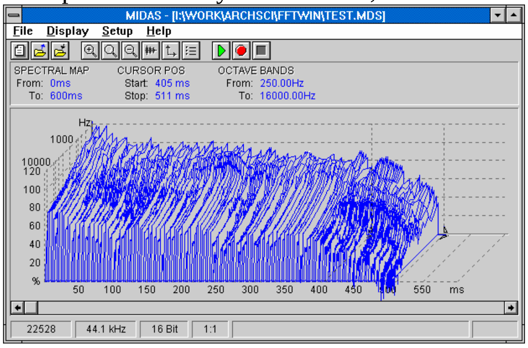

Figure 3: An application used for analysing recorded sound decays as well as convolving modelled impulse responses with dry signals.

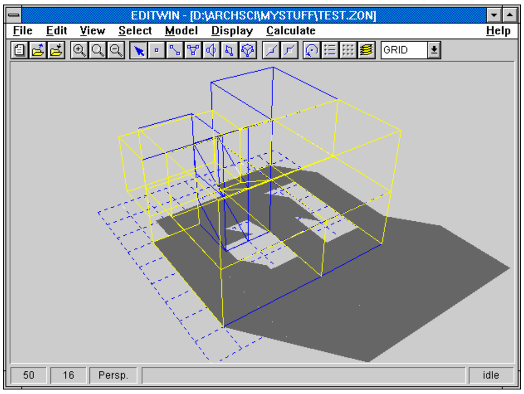

Figure 4: The geometry editor displaying selective shadow analysis of a simple model.

Shadows and Reflection analysis
Within the geometry editor itself, shadows and solar penetration can be viewed for any zone [Fig.4]. Solar position is calculated given the location, date and time. In addition, a comprehensive shadow analysis application has been developed that facilitates the design of windows and shading devices [Fig.5]. To invoke this application, the user simply double-clicks on a window and selects the Edit Shades button.

Additionally, support has been provided for SR [15]. This application allows full shadow and reflection casting over complex geometries and terrains. Its main benefit over other such packages is that shadow outlines can be saved in vector format as opposed to simple raster images.

Thermal performance
The ability to analyse the thermal performance of a design based on a full geometric model was one of the main driving forces behind this work. It was initially inspired by suggestions that the CHEETAH [16] package was to be re-written in C++ and provided as a dynamically linked library as part of the NatHERS program [17], however, this has not yet occurred. As a result, work has concentrated on the ZSTEP program, a close relative of CHEETAH, but the authors are closely monitoring developments in other such packages. ZSTEP data files can be output directly from the geometry editor.

**Adherence to building codes*
Work in this area has recently been completed by a colleague at the school [18]. Whilst concentrating on the observance of fire codes in building plans, many of the techniques used were considered readily applicable to many UBB and other statutory regulations. No work has yet been done by the authors in this area, however, it is planned in the near future.

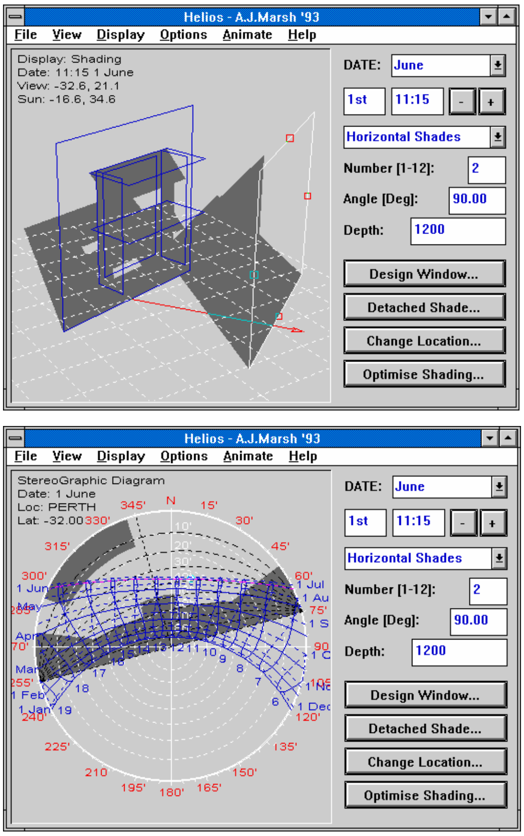

Figure 5: An application that has been developed to assist in the design of windows and shading devices.

Conclusion

Environmental design in an extremely important aspect of architectural design, however, this is not evident in the work of many architects. Whether this is the result of an education system that constantly devalues such concerns, or a perception that too much specialist knowledge is required to even consider this aspect, is not important. What is important is that the products of environmental science research be translated into a form easily assimilated into the design process. Only then will architects begin to use them early enough in their designs for such research to have any significant impact on the form of new buildings.

The work presented here, whilst being carried out in isolation, is an attempt to address the issues of compatibility, standardisation and integration.

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