14 An Analysis of Using a Digital 3D Sundial as a Design and Decision Support Tool

Waycal C H Wong and Barry F Will
Department of Architecture, University of Hong Kong

INTRODUCTION

The rapid speed of computer development brings new technologies, and these advances require innovative investigations to apply them optimally in the field of architecture. Burkett (1984) demonstrated that computer graphics can 'provide an excellent opportunity for exploring solar issues in building redesign' (p188). With one of the latest computer technologies, the "hyper-model" environment, this research investigates how the environment can become an aid in the design and decision support area. The research first reviews the communication between the architect and the client as described by Salisbury (1990). The review indicates that an interactive 3D hypermedia paradigm, with quick response, fast data manipulation and 3D visualization, offers a better communication media between the architect and the client. This research applies the "hyper-model" environment to design and develop a new methodology in collecting, analyzing, and presenting solar data. It also endeavors to show the possibilities of using the environment in design process.

Communication between Architect and Client

When communicating a design solution between the architect and the client, Salisbury (1990) defined one of the briefing processes as testing the feasibility of the project and site. He identified two of the objectives in this briefing process as (1) to prove the suitability and adequacy of the site and its features and (2) to help the client determine the form in which the project can proceed. During the briefing process, both the architect and the client try to take account of all the possible outside influences. In the communication between the architect and the client on these outside influences on the design proposal, problems may arise where (1) the design group cannot provide a quick response when the client asks "what-if" questions about alternative forms of the development scheme, or (2) the changes of the design generated by the meeting have to be held over for another meeting before all the data can be updated. Moreover, the conventional presentation materials, which represent 3D spatial forms and ideas by the use of 2D media such as plans, elevations and sections, may not be sufficient for the client to imagine the design in 3D form.
A "Hyper-Model" Environment

In addition to using plans, elevations, sections, perspectives, and models in presenting design solutions by the architect to the client, this research assumes that a computer system using a "hyper-model" environment can help the architect and the client prove the suitability and adequacy of a site, and determine the form of a project with reference to the above problems. It investigates how a real time 3D model with "hyper-model" linkages in a hypermedia environment can facilitate the communication between the architect and the client. The result of this research can show the possibilities of using a real time 3D hypermedia environment in presenting a variety of design solutions and enhances the decision making processes in the preliminary design stages.

1.0 METHODOLOGY

This research constructs a digital 3D sun dial to collect solar data within a virtual environment and relates solar data to a 3D solar volume. A set of interactive visualization tools are programmed to visualize the 3D solar volume three-dimensionally.

1.1 Design of the "Hyper-Model" Environment

The "hyper-model" environment provides a feature where a 3D model in a real time visualization environment can be associated with other digital information. The feature is utilized to construct models with site-related solar data. Given a site boundary and a group of buildings surrounding it, a program is designed to present data of solar exposure under the given environment by different points of observation within the site boundary. The raypick action offered by Open Inventor (Wernecke 1994a) is used to determine the solar exposure by emitting rays three dimensionally in a virtual scene and locates automatically which rays are blocked. By using the computational power of a modern computer, a 3D volume of solar exposure data is collected and can be represented in an interactive three-dimensional form.

1.2 Construction of 3D Solar Volume

The solar exposure data is collected according to the shading mask technique, where the overlap of a solar chart of a particular latitude and a fisheye lens photograph of the environment is used to locate times of solar exposure. With reference to the shading mask technique, a solar chart at a particular latitude is first represented digitally. From the solar chart, positions of the sun are input as are parameters of azimuth and altitude. A "3D sun dial module" is programmed to emit light rays from a point of observation to locations of the sun as shown in figure 1. Buildings surrounding the site in context are input as Open Inventor file format (Wernecke 1994b).

As illustrated in figure 1, a point of observation within a site is located (1). The module emits light rays from the point of observation to every sun locations in a month (2). The module can determine whether a light ray is blocked by the surrounding buildings (3). The ray determination process is repeated for each month in a year (4). As each light
ray has a different radiation, an accumulated shadow value for the point of observation is formed by summing all the sun radiation of non-shaded light rays as follows:

Accumulated shadow value = \( \sum S_{mt}R_{mt} \) for \( m = \text{Jan. to Dec. and } t = 6 \text{ a.m. to 6 p.m.} \)

where \( m_t \) is the month and time variable \( (m,t) \),

- \( S_{mt} \) is either 0 or 1, which depends on whether the light ray at \( (m,t) \) is shaded by the surrounding building or not, and
- \( R_{mt} \) is the radiation of each light ray at \( (m,t) \).

<table>
<thead>
<tr>
<th>Digital 3D Sun Dial</th>
<th>Shading Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) A point of observation is located within a site.</td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Digital 3D Sun Dial" /></td>
<td><img src="image2" alt="Shading Mask" /></td>
</tr>
<tr>
<td>(2) Light rays are emitted to the sun locations of a month.</td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Digital 3D Sun Dial" /></td>
<td><img src="image4" alt="Shading Mask" /></td>
</tr>
<tr>
<td>(3) The &quot;3D sun dial module&quot; can determine which light rays are blocked.</td>
<td></td>
</tr>
<tr>
<td><img src="image5" alt="Digital 3D Sun Dial" /></td>
<td><img src="image6" alt="Shading Mask" /></td>
</tr>
<tr>
<td>(4) The ray determination process is repeated for all the months of a year.</td>
<td></td>
</tr>
<tr>
<td><img src="image7" alt="Digital 3D Sun Dial" /></td>
<td><img src="image8" alt="Shading Mask" /></td>
</tr>
<tr>
<td>Digital 3D Sun Dial</td>
<td>Shading Mask</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------</td>
</tr>
<tr>
<td><img src="image1.png" alt="Digital 3D Sun Dial" /></td>
<td><img src="image2.png" alt="Shading Mask" /></td>
</tr>
</tbody>
</table>

(5) The iteration is performed for a 3D array of points within the site boundary.

Complex,  
Time Consuming, &  
Limited Application

![Figure 1: Digital 3D Sun Dial Construction](image3.png)

Besides taking an accumulated shadow value throughout a year, the module can consider a light ray at a particular time \((m, t)\) or consider light rays for a period of time, such as the summer or the winter period. The process of calculating accumulated shadow value can be iterated repeatedly for different points of observation within a site (5).

A site within the environment is then defined by a bounding box. The plan perimeter of the bounding box is the site boundary and the height of the bounding box is the maximum plot ratio allowed by the relevant local legislation. In calculating the accumulated shadow value, the bounding box is divided into a 3D array of unit cubes and the "3D sun dial" module is applied to each centroid of the unit cubes. For visualization purposes, each accumulated shadow value is matched to a color value. The low shadow value is represented by a color with high hue value and low lightness value while the high shadow value is represented by a color with low hue value and high lightness value. The intermediate shadow value is represented interpolating linearly between the low and the high values colors. A 3D shadow volume is thus constructed as shown in figure 2.
1.3 3D Visualization Tools

In order to analyze the 3D shadow volume, a viewer is programmed to display the volume in real time with interactivity. Users can look at the volume from any point of view and each view can be changed and updated instantly. Users can also interactively decompose the volume into layers and sub-volumes for analytical purposes.

Layers Visualization Tool

This tool allows users to visualize the volume layer by layer. A dialog box with three sliders is provided to control the layer visualization in horizontal, side, and front directions. When users move one of the sliders, the viewer displays a section of the volume in the corresponding direction accordingly as indicated in figure 3. In the horizontal direction, the viewer shows clearly how accumulated shadow values change their profile in the relevant plan level. In the side and front directions, the viewer shows the penetration of accumulated shadow values in the relevant section. These areas of information support design decision making such as the layout of various rooms or volumes in plan or vertical and horizontal zoning possibilities.
Threshold Value Visualization Tool

This tool allows users to visualize sub-volumes of a particular range of accumulated shadow values. A dialog box with two slides is provided to specify a threshold accumulated shadow value and a range around the value. The viewer can thus restrict display to unit cubes which are within the range specified in the dialog box as indicated in figure 4. This forms a 3D sub-volume which is within the given range of accumulated shadow values. This sub-volume can be used to identify 3D sub-regions for positioning design elements which require a particular shadow value. It facilitates vertical zoning and space organization arrangements.
2.0 ANALYSIS

The constructed 3D solar volume quantifies the amount of direct sunlight on a 3D array of points of observation and this can be visualized by layers, sections, and sub-volumes. The volume shows the solar impact of the environment on a site digitally and thus it permits analysis of the suitability of the site in terms of solar impacts. The accumulated shadow value of each point of observation shows how much light is blocked by the environment for a period of time. The total of all the accumulated shadow values in the volume functions as an indicator of solar impact on the site. The smaller the total means the site is exposed to more sunlight while the higher the total means the site is more shaded by the surrounding environment. The relative color representation of the accumulated shadow values in the volume shows which volumes of the site are shaded most or least. This helps to determine whether the site has a large enough volume to position a building element which responds to given solar requirements as established by the designer.

2.1 New Development Scheme Analysis

The 3D shadow volume is able to test a design idea related to solar issues. Once a design idea is modeled digitally as in figure 5, users can build a 3D shadow volume and use it to test how much shadow the design would receive at any position within a site boundary. This aids in determining what the configuration of the design will be if optimal solar effects are required. As different configurations of a building block have different solar effects, Bryan (1984) has shown that 'building bulk, placement on the site, setbacks and the notching of corners can have a great impact on the amount of daylight that reaches a street' (p173). A "design module" is thus programmed to allow interactive manipulation of the design model in terms of its position, height, width, depth, and rotation so that users can identify the proper location, form, and orientation of the design project with respect to the 3D shadow volume.

Figure 5: Design Model
2.2 Depiction of Energy-related Site Selection

By the use of the position tool from the “design module”, users can drag and change the position of a design model. The “design module” can locate the sub-volume of the 3D shadow volume bounded by the design model at any position. The shadow information in the sub-volume can give an indication of how much shadow the design model receives at that position. Figure 6 shows how users can drag the positions of the design model and obtain the bounding sub-volumes from the 3D shadow volume.

![Old Position & its Bounding Matrix](Image)
![New Position & its Bounding Matrix](Image)

Figure 6: Bounding Matrix

2.3 Determining Orientation and Form of a Project

Using the height, width, and depth tools from the “design module”, users can change the form of the design model while keeping a plot ratio constant. When the height of the design model is changed, the width and depth are changed accordingly so that the volume of the design model is unchanged. When the width is changed, the depth is changed inversely and the height is kept constant.

The “design module” can extract the transformed points’ coordinates from the design model and apply the “3D sun dial module” to update the accumulated shadow value on each point. The effect of the accumulated shadow value is shown by different color mapping on the surface of the design module.

Once the location and form of the design model is fixed, users can apply the rotational tool to change orientation of the design model. The shadow effect on different elevations of the design model changes as the orientation of the design model changes. Figure 7 shows the shadow effect on different forms and orientations of the design model.
2.4 The Benefits of the "Hyper-Model" Environment

The developed "hyper-model" environment can provide a 3D visual and computational approach to collect and analyze 3D solar data within a digital 3D environment. The environment can be used to test design alternatives with respect to solar impact of a particular site environment. The 3D volumetric representation of the solar data under a real-time 3D visualization environment allows users to comprehend complex 3D data.
with ease. The advantages of fast computation offered by recent computers permit the visualization and analysis of accumulated 3D solar data over a perennial period. The reality of collecting and manipulating 3D data demonstrated in this research extends the conventional 2D analysis to a 3D analysis. Although this research uses a very simple algorithm in collecting solar data, it takes an average of 0.0158 seconds to determine whether a 3D ray is blocked by a virtual environment and around 10 minutes to establish a 3D shadow volume with 540 points of observation required to simulate a period of a year. The time taken is much faster than that required by any other conventional method for collecting the same solar data. The environment is expected to aid the design processes in the preliminary stages by examining solar data three-dimensionally.

CONCLUSION

This research uses the "hyper-model" environment to design and develop a 3D shadow volume for solar impact assessment. The shadow data is collected by the use of the raypick action to determine the solar impact within a three-dimensional space, where buildings surrounding a particular site are constructed digitally. The analysis of the 3D shadow volume is aided by a set of interactive tools for layers and threshold value visualization. The analysis demonstrates that the "hyper-model" environment can help to depict energy-related site selection and to determine the optimal form of a project with respect to solar issues. The whole process of collecting and analyzing shadow data is performed and presented in a real time three-dimensional computer graphics environment. This facilitates the communication between the architect and the client. This investigation shows that the use of the "hyper-model" environment can play a positive and active role in collecting, analyzing, and presenting three-dimensional data and this aids in communicating design solutions and enhances decision making processes in the preliminary design stages.

ACKNOWLEDGMENT

Special thanks are addressed to Michael K.W. Yim, Cecilla W.H. Suen, and a group of students from the Building Systems II Course 1995-96. The support from the Department of Architecture, The University of Hong Kong has made this research possible.
REFERENCES


