Chapter 8

Three-dimensional visualization: a case study

D.J. Vanier and Jamie Worling

8.1 Introduction

Three-dimensional computer visualization has intrigued both building designers and computer scientists for decades. Research and conference papers present an extensive list of existing and potential uses for three-dimensional geometric data for the building industry (Baer et al., 1979). Early studies on visualization include urban planning (Rogers, 1980), treeshading simulation (Schiler and Greenberg, 1980), sun studies (Anon, 1984), finite element analysis (Proulx, 1983), and facade texture rendering (Nizzolese, 1980). With the advent of better interfaces, faster computer processing speeds and better application packages, there had been interest on the part of both researchers and practitioners in three-dimensional models for energy analysis (Pittman and Greenberg, 1980), modelling with transparencies (Hebert, 1982), super-realistic rendering (Greenberg, 1984), visual impact (Bridges, 1983), interference clash checking (Trickett, 1980), and complex object visualization (Haward, 1984).

The Division of Building Research is currently investigating the application of geometric modelling in the building delivery process using sophisticated software (Evans, 1985). The first stage of the project (Vanier, 1985), a feasibility study, deals with the aesthetics of the mode. It identifies two significant requirements for geometric modelling systems: the need for a comprehensive data structure and the requirement for realistic accuracies and tolerances. This chapter presents the results of the second phase of this geometric modelling project, which is the construction of 'working' and 'presentation' models for a building.

8.2 Objectives

This chapter presents one attempt to model the envelope of a complex building, using sophisticated sculptured-surface software (Vanier, 1985). The objective of the project is three-fold:

1. To experiment with a geometric modeller as a 'presentation' technique in the design stage;
2. To provide an accurate visual representation of the building envelope; and
3. To modularize the building element database to permit manipulation of the information during the building design process.

It should be noted that this case study represents one attempt at modelling certain aspects of a specific building. The application of this
experience to other types of modelling, buildings or geometric modelling systems is not suggested because of the uniqueness of the curvilinear form of the building that was selected and the developmental stage of the software.

8.3 Case study

8.3.1 Selection of methodology

Since the major objective of the project was to experiment with a geometric modeller, a 'hands-on' approach was adopted. The selection of this type of approach was influenced by fiscal considerations. An experimental project would not provide sufficient justification for the purchase of a full three-dimensional modelling package. It was therefore decided to use modelling packages that are available at the National Research Council.

8.3.2 Software selection

The software selection did not entail an extensive evaluation of existing tools, a critique of their capabilities or a feasibility study on a number of systems. One modelling package already existed at NRC that met the data input requirements for a building application and had the graphics resolution required for proper visualization. The choice was simple; the software was available and it was free.

At this point it is necessary to outline the modelling system selected. The software, for example, does not employ fractals, ray-tracing or shadowing. However, it can display shading, lighting effects, highlights and 4 million simultaneous colours. It is able to display three-dimensional graphics more realistically than most commercial systems on general-purpose, scientific, minicomputers. The hardware is specially configured for the development of computer graphics software in a research environment. The processing power is not to the level of a 'supercomputer', but it is more powerful than a general-purpose, scientific, minicomputer.

8.3.3 Building selection

The building was also selected for practical reasons. The Canadian Museum of Man will be constructed in Ottawa in the near future. The architect, Douglas Cardinal, supported the concept. The curvilinear form used in his design lent itself to one available geometric modelling package. The modelling of the museum provided an exciting test for a computer system.

In order to appreciate the complexity of the data entry and image display it would be helpful if additional information on the building were provided. The building will consist of a museum, a holdings and research area, public facilities and underground parking comprising 39 000 m2. The 9.8-hectare site will provide display and research facilities for the 10 million artifacts of the museum. The initial estimate for the project is $80 million (Canadian). The Museum door is expected to be open to the public by summer 1988.
Based on the authors' knowledge, this is one of the most complex buildings ever attempted on a geometric modelling system.

**8.3.4 Problem identification**

Prior to data entry considerable time was spent analysing the requirements of the project and developing procedures for data entry and display. Several points were identified in the planning stage as principal concerns for the modelling task:

1. Available information;
2. Software capabilities;
3. Level of detail;
4. Identification of components; and
5. Accuracy and tolerance

The available information at the start of the project included drawings, physical models and hard renderings. Because of the complexity and size of these buildings, these three forms of information were essential to the authors. Cardinal's designs typically require additional information beyond a standard drawing set to convey sufficient information to the client and builders. Access to the physical models and perspective sketches greatly assisted the data entry by providing a three-dimensional interpretation of the finished structure. Contact with the project designers proved invaluable in the later stages of the data entry, greatly reducing the amount of time required to analyse the building plans.

The graphic package has capabilities beyond those required for traditional building design. This permitted unlimited modelling capability and eliminated any requirement to approximate building components. (An outline of the modelling system is provided *Figure 8.1.*

Since most of the building components could be generated, the level of detail for the modelling task had to be established. Every physical modeller encounters a similar decision when trying to display detail: when is the detail too small to be seen or appreciated? Some approximation of information (Phillips, 1979) and some artistic licence will always be required to produce the modelling task within a reasonable time frame. The original feasibility study indicated that details would be not visible on a 1000 x 1000 raster monitor depending on the viewer's distance from the building. It was decided to represent only the major building element and to simulate detail with interface definition. The liberties taken were similar to those taken by physical-model builders (Janke, 1978).

Each major building component had physical attributes of colour, texture, size and location. To meet the visualization objectives of the project, each building material had to be handled individually, enabling control of texture and colour. The feasibility study identified the need to distinguish borders between different objects. This was confirmed by physical modellers and this addition to the modelling provided a simulation of detail. Five different building element types were finally selected: walls/parapets, roofs/concrete slabs, windows, mullions and landscape.

Having identified the level of detail required, and having established the breakdown of components, the tolerances and accuracies were treated as a
Figure 8.1. Program layout
Figure 8.2. Data about surface texture, material colour and view location are keyed in, to generate a working computer image showing the beginnings of a panoramic view of the new Museum of Man

Figure 8.3. An artists model of DouglasCardinal’s design for the new Museum of Man
separate problem. Accuracies to the nearest metre on site were considered too coarse and would affect the final visualization. Accuracies to the nearest centimetre would multiple the data entry time without any significant visual improvement (for current display technology). As a result, a tolerance of 1 mm on plan (1:200 scale) or 20 cm on site was selected. The readers must keep in mind that the building is over 500 m long, so 20 cm is negligible for the model.

The analysis stage took place over a period of four weeks and entailed approximately 80 person-hours of work. It consisted primarily of analysis of the drawings and the interpretation of the building shape. In the data entry stage the time dedicated to the data input also equalled the interpretation time required during the data-input stage. This inordinately long time is due to the complexity of this building.

Figure 8.4. A completed panoramic computer image of the new Museum of Man. This photograph is created by splicing together two computer images generated from the same vantage point using different camera angles.
8.3.5 Data entry

Data for the Museum of Man was entered in two-dimensions, rarely proceeding to three-dimensions. In PLAN (Figure 8.1) graphical entry was possible in plan view and the elevations for the curves were entered alphanumerically. The building information was scribed from the architect's drawings and entered as a series of control points dictating the shape of the resulting curve (Barsky, 1983). In fact there are very few locations in the entire building where there is a straight section of concrete, wall or beam with the exception of the vertical dimensions. In the latter stages of data-entry, batch routines (series of typewritten code to replicate data entry from the keyboard) were developed to assist in the data entry and manipulation. The batch routine that produced the best results created variations on the columns for the Great Hall. This sequence automated the procedure for allowing variations in the repetitive entry of parameterized objects: the location and the rotation of all columns were known from the drawings. Modifications of one column were then quickly passed to all columns.

Observations
The data entry was a time-consuming, labour-intensive process. Interpretation time for the shapes was normally as long as the time required for data entry. There are over 1000 modules in the entire structure. At a rate of one module per 15 mm, this entailed over 250 h of work for the data entry. It was found to be easier to enter the data in two dimensions, as opposed to three, because the existing information was on architectural plans. The three-dimensional views for the data were useful at times, but the data entry was complicated because of the need to add the third dimension, perspective views and additional vertical levels of information.

A major portion of the work was design interpretation; if the designers had access to these tools then there would be a drastic change in the method of use. The model would be malleable to the designer, in place of an interpretation of information from the designers, as in this case study.

In true three-dimensional design the authors feel that there will be more of a reliance on three-dimensional data input, but the major mode will be two-dimensional, because buildings are typically two-dimensional extrusions of a floor plan, structural grid or envelope. By constantly carrying a third dimension, there is added information that is redundant.

8.3.6 Data checking

The data entry of the drawings located the building in three-dimensional space. In order to view the building it had to be rotated or the viewer's location had to be altered. This was carried out in MESH. The view location was selected using move, scale and rotate commands, and this positioned the building in the proper viewing port. After the location of one module was selected, the same transformation (move, scale and rotation) was passed to subsequent modules. Typically, a module could be recalled and displayed in 10 s and the final transformation view could be
saved for shading in another 10 s. Eight colours were used for the display of data and normally over 100 modules would be on the screen at one time. The mesh transformations were saved and transferred to the shading program automatically.

Since this project was completed, a hardware purchase enabled shading of the mesh automatically in MESH, thereby permitting data checks of the shaded model at this stage. In the latter stages of the project a batch routine for the creation of the final mesh model was developed to reduce data errors and to eliminate the need for the operator during this time-consuming process.

The fineness of the mesh is user controlled and dictates the resolution of the shaded image. A fine mesh produces a smooth object, whereas a coarse mesh creates a faceted object. In turn, since the computational time for shading is inversely proportional to the fineness of the mesh, a compromise had to be reached that would provide the requisite image accuracy.

Observations
The MESH program allowed quick visualization of the building data before the shading took place. This was essential, but speeds of display were unsatisfactory for the design environment. One mesh view of the building might take as long as 20 mm to display.

There was also a need for real-time manipulation of the data in the mesh form, if a module had to be rotated. This manipulation might be achieved on the screen with instant reaction from the computer. This would permit immediate data checking and facilitate the selection of display views. These are important features because the mesh model of a typical building contains too many lines to permit the user to discern errors of omissions.

8.3.7 Model visualization

The SHADE program applies opaque (or transparent) surfaces to the mesh model. This package also includes lighting selection, colour assignment and hidden surface removal. The lighting model produces the proper light location, intensity and reflectance based on the light-source location and viewer position. Because of the complexity of the building, 3 h of computation were required for each image.

The program will shade objects but is currently unable to cast shadows or recognize modules obscuring lighting onto others. Software development is proceeding in this direction. However, owing to the large number of complex shades in the Museum of Man, it is estimated that ray-tracing would consume over 24 h of computation-time for one building view.

Observations
The software employs 'Z-Buffer' techniques (Evans, 1984a) for hidden surface suppression. This is an effective means of quick display but does not permit elegant alterations such as anti-aliasing. The simulation of texture is achieved by altering the colour of the shading, depending on the location of the mesh grid. In this way, different colours can be arranged in a repetitive pattern to simulate texture. Texture was also simulated by
randomly perturbing the direction of the module surface pixels, thereby altering the reflected light within specific bounds to 'break up' the texture of the surface.

An extremely useful feature of the software was the capability to move independent light sources in real-time on a simplified version of the model using a digitizer (Evans, 1984b). This was used extensively to position the light sources for the final model. This ability was necessary since the selection of light-source location is not intuitive (as any photographer knows) and as the success of a specific lighting scene is not known until the entire view is shaded.

8.3.8 General

The visualization of building data using geometric models is a fledgling technique and requires research and development prior to its acceptance as a commonplace practice tool or technique. The models produced met the expectations of the authors and have advanced beyond the 'working model' level of accuracy and detail. The minor-image 'glitches' are a result of the approximation by the software (integer mathematics) and not the accuracy of the data. The images produced, with minor alterations, are considered by the authors to be 'presentation model' quality.

The manipulation of the data to reflect design change is possible and should be considered a major feature of any software package developed. This would allow the technique to be used as a modelling tool for designers rather than a presentation tool for modellers.

Observations

A major limitation is one of scale: buildings are generally too large for the type and resolution of display devices presently available. A typical building of about 50 m long and a number of storeys high, displayed entirely on a colour monitor of about 1000 x 1000 resolution, requires one pixel to represent an area of 50 x 50 mm. That 'all-important' pixel, even anti-aliased, has to display considerable detail. If the building is set back from the screen plane then the pixel has to represent a large surface of about 1 m square, which is not possible. As a result 'fly-throughs' are the only way to display all the information which would provide the necessary detail.

Additional assistance is needed at the final image stage to enhance the picture through electronic painting. This reduces the need to generate plants, trees and people using software, and permits the editing of the final image for minor image faults or inconsistencies.

8.4 Conclusions

This project completes the second stage in the investigation of geometric modelling techniques. Subsequent stages will involve other software programs and will emphasize database handling capabilities. This case study provides a unique opportunity to experiment with a powerful sculptured-
surface modeller. An advantage of this type of modelling is the freedom of shape creation and the ability to model these shapes properly and accurately.

The design architect, Douglas Cardinal, and his staff used the geometric model in the process of their work. However, at this time it can not be considered a functional design tool because of the complexity of data entry and manipulation.

Computer speeds for this phase are acceptable; however, there is a need for a quantum jump in the processing power of existing computers to make this type of modelling cost effective.

Requirements for accuracy and tolerance have to be established for this type of model by both the software developers and the users.

The actual use of geometric models in the design process is still unknown. Although physical modellers recommend increased modelling for all projects (Janke, 1978), the status of this new technology is not certain. In the early stages of design the geometric models are useful tools but the inherent lack of information at that stage in the design process limits their usage. At the latter stages, when the information is available, there will be less need for the model as a communication or a design tool.

In general, the present software is deficient in a number of areas. There is a need for a user-friendly interface to permit easy entry of design data. A strong database capability would also eliminate a number of problems encountered and would provide a more robust package. The software, in its present state, provides sufficient resolution for 'working models'; however, there is a requirement for additional features for 'presentation models'. These include paint options (available on an earlier version, but not implemented on the present one), ray tracing and fractals.

References


