Discussing Image-Based Modeling Technology for 3D Digital Archival of Physical Architecture Models

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Abstract. Besides drawings, physical models are important forms of representation commonly used for architectural design. They can serve as a useful resource for teaching and research, provided there is a proper archiving system that allows easy retrieval. Architectural models in 3D digital format seem to be able to overcome the limitation of physical constraints – they can be easily accessed anytime and anywhere over the Internet. The most common way of 3D model documentation is through geometric-based 3D CAD software. Image-based modeling (IM) allows the 3D digital model to be created from photographic images. Debevec (1998) investigated the hybrid geometry- and image-based approach whilst Tsou (2002) and Hawkins (2001) focused on the application of IM for GIS and digitizing cultural artifacts respectively. This paper aims to compare physical models and their IM counterparts in terms of communication of vital architectural information. Experiments were conducted to evaluate the extent the IM model resembled the physical predecessor in terms of its geometry and visual appearance qualities/faithfulness. A survey was subsequently carried out to compare their performance in terms of the communication of vital architectural information about building designs to the observers. The tabulated results were then examined to help understand the opportunities and weakness of IM for 3D archival of physical architecture models.

Keywords. Image-based modeling, architecture model, digital archiving, design resource

Introduction

The construction of physical architectural models has been an age-old means for architects to conduct design visualization and communicate ideas to other individuals. Architecture models are generally categorized into 3 types - they are namely the massing model, spatial model and detailed model.

The Massing Model is a very simple, exterior-only type of architectural 3D model, used to study the essence of the overall 3D form and proportions of an architectural design. The Spatial Model on the other hand, shows more details of the structure, which often includes some information about the interiors spatial qualities. The Detail Model is a relatively complete interior/exterior architectural 3D model that often includes material texture, surface ornaments or even furniture. It is intended to visually represent the full-scale built-form as far as possible to help the observer in comprehending the actuality of the design.The effective use of architectural model depends on managing the balance between the resources invested in its creation and its output quality. These objects take up physical space and have limited mobility. To view them, the viewer needs to be physically at the place where the model is sited. Alternative way is through drawings and photographs of which only be able to present information of such models in 2D.

Developments in CAD technology have changed all that. Virtual 3D models are not bounded by physical space and will not deteriorate with time. They can be created, archived and studied digitally anywhere in the world due to the advance development in computing technology and the Internet.

Conventional method of CAD modeling with geometric-based software usually builds from scratch, and often based on information extracted from 2D drawing. As a result, the archival of physical architectural model in CAD environment often do not take advantage of the information already found in the physical counterpart. Depending on the appearance of the latter, rendering the surface texture by conventional means require large amount of time and resources.

Image-based modeling (IM) tool on the other hand, provides an alternative way to create these objects. Spatial and visual information about the object is directly extracted from images representing it. It combined the advantages of the photo-realism found in photographs and dynamic 3-demensional quality of CAD modeling tools, thus enabling the reconstructed model to represent the real thing more closely.

Hypothesis

Presently IM is mainly used for movie making such as in the Matrix, where the malleable virtual 3D environment is imbued with the realistic imagery of the physical world to achieve the kind of visualization that was previously impossible.

The paper seeks instead to examine the prospect of IM for architectural education purposes. It can be a more effective application over conventional geometric-based modeling tools to digitally recreate the visual and spatial aspects of physical models for various types of design exploration and visualization studies

The need for a fast and effective solution to capture information digitally from physical models was given a strong touch of realism recently when Singapore was hit by the SARS outbreak. Overseas external examiners accessing the final year thesis projects in the Department of Architecture of the National University of Singapore were deterred from coming. Instead, they chose to view and examine the works from overseas. CD-Rom of digitized 2D drawings and images of physical models were mailed to them. Obviously, physical models could not be sent to them. As such, certain architectural ideas may not be well represented by 2D images. The ability to rapidly recreate the physical model from photographs could provide the students a better means to communicate their ideas in such circumstances if they do not already have a digital version of their project at hand.

Methodology

The investigation starts with a pre-chosen list of architectural models for IM reproduction. The main criteria of selection is based on the level of complexity for each of the model, the fashion in which their elements are arranged in relation to one another and the types of surface textures they have as shown in table 1.

Model Criteria	Type 1	Type 2	Type 3	Type 4
Spatial Complexity	Simple	Complex	Simple (curved)	Complex (orthogonal)
Texture Richness	Poor	Plain	Rich	Rich

Table 1. Categories of model types

The four completed IM models are subsequently compared against the actual physical model to evaluate the software image-based modeling capabilities with regards to forms and surface textures reproduction. This evaluation is based on the aspects Massing & proportion accuracy, surface texture rendering capabilities, transparency rendering capabilities, and performance in treatment of details. A survey is conducted to objectively compare the performance of both the IM and physical model in the presentation of architectural information to the observer.

Limitations

Models chosen for this paper will be based on the range of works most commonly found in the final architecture thesis projects. Majority were used to illustrate massing and spatial concepts. Few detailed models that highlight intricate interior/exterior spaces were available. In this light, such elaborate models will be excluded in the study.

Experiments

In the experiments, each of the models is given a fixed duration of about 1.5 working days to re-create with IM. Table 2 shows the level of completion for each model type within the given time frame and the amount of pictures taken and 3d locators set by the user in the modeling.

The placement of locators on a set of images

Table 2. Level of completion for each model type within the given time frame

	Type 1	Type 2	Type 3	Type 4
Spatial Complexity	Simple	Complex	Simple (curved)	Simple (orthogonal)
Texture Richness	Plain	Plain	Rich	Rich
No. of Pictures	[illegible]	[illegible]	[illegible]	[illegible]
No. of 3D Locators	110	100	120	120
No. of 3 Meshes	[illegible]	[illegible]	[illegible]	[illegible]
Level of Completion	25%	20%	100%	100%

is essential for the IM program to calibrate the 3D space present in this given set of images. Locators are also used to mark out spatial positions of objects and subsequently for the 3D meshes representing the object to be accurately created.

The following figures show the result of IM modeling the four architectural model types (remodeled parts outlined). Results in the modeling have shown that test subjects with a large numbers of minute and non-similar volumetric elements were difficult to complete within this time frame. Large urban scale massing models (Figure 1) with simple volumetric forms and surfaces textures would require a large amount of locators to be completed with IM.

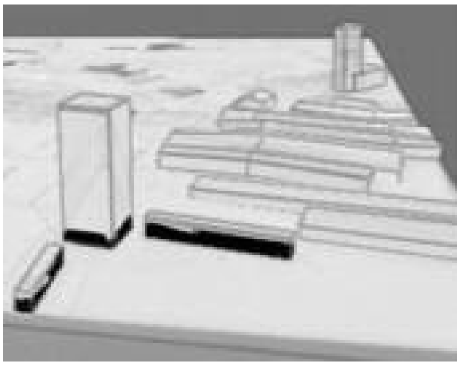

Figure 1. Type one, simple spatial complexity with numerous volumetric elements with plain colour and transparent surfaces.

Complex building forms and uneven terrain (Figure 2) are also unlikely to be effectively remodeled in such short duration.

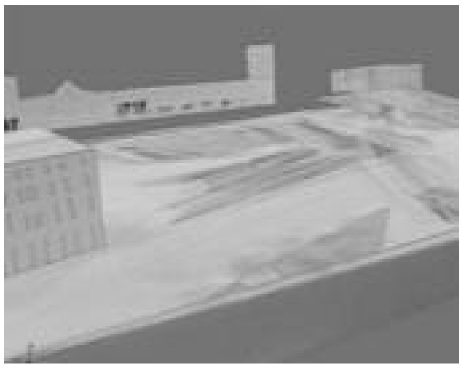

Figure 2. Type two, complex spatial complexity with unrecognized forms and shapes at the centre region and irregular terrains

More images will also be need in this case to visually expose all surfaces that would otherwise be occluded visually. Creating these models with IM is relatively inefficient compared to modeling with conventional 3D CAD software.

A great number of virtual 3D meshes required for modeling are not a major concern if the subjects are made up of groups of components with similar volumetric forms (Figures 3, 4).

Each duplicate mesh can be rendered independently, having their unique appearance retained by using the software's automated texture-wrapping function. Time needed for this the texture rendering procedure is minimal. As a result, only Type three and Type four are successfully re-created with IM in the given experimentation framework.

Figure 3. Type three consists of relatively simple massing blocks on the periphery with smaller objects in the centre region.

Figure 4. Type four is fully composed of interlocking cuboids. The transparent skins give rich surface texture maps to the model

Evaluation of experiments

Assessment of image-based models

The 2 completed digital models are examined against their analogue predecessor to see how close the IM productions can resemble the real. The assessment criteria shown in table 3 are the 4 basic aspects most architects are concern with in the visualization of CAD models. The rating (very good, good, acceptable, poor, very poor) is shown in table 3.

	Proportion accuracy	Texture rendering	Transparency rendering	Detail handling
Type 3	Good	Acceptable	N.A.	Poor
Type 4	Very good	Acceptable	N.A.	Very poor

Table 3. Resemble rating

Proportion and massing accuracy

Quantitative analysis of comparing the dimensions taken from both the real and the virtual models have shown that accuracy in photogram metric acquisition is highly reliable with most readings showing less than 1% deviation. However, the deviation escalated to almost 5% for 1 particular reading in type three when the measurement of a very small distance was compared. Resolution of the images and the skill of the user with photogram metric calibration are factors contributing to the phenomenon.

Texture rendering capability

The qualities of image maps rendered with IM were almost on par with the visual appearance of the physical model when observed at a short distance of no less than 0.5 meter away. This is indeed how observers view most massing and spatial models. However, when the zoomed-in view was examined, a visible degree of image blurring, overlapping and distortion can be seen.

Material transparency rendering capability

In physical model making, materials with various degrees of transparency are often juxtaposed with other opaque objects to create different types of visual layering effects. However, the present IM software has no means of differentiating between transparent and opaque material. All types of texture assigned to the IM model are the direct and non-interpretative extraction acquired from the images used in the software's photogram metric calibration process. Such inability is indeed a drawback for IM products as an effective substitute for physical architectural models.

Detail handling capability

IM can only render texture maps that are shown in at least one of the images used in the calibration process. Small intricate details in the physical models can often be visually obstructed by other elements, especially if they are found within the interior. Such elements are very difficult to be shown fully in photographs and hence will remain un-rendered in the IM model. The underside of the model shown in figure 5 which is not seen in any of the calibrated photographs

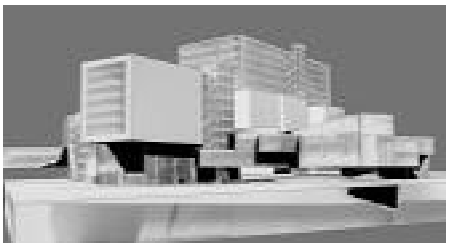

Figure 5. Substantial amount of details are omitted in the IM model (black faces)

appeared black. Rectification can be made by assigning these surfaces with image maps with photo-editing software.

It was clear from the experiments that IM is indeed an object surface modeler that has much difficulty in the modeling a cluster of objects that visually occlude one another. However, this shortcoming can usually be compensated by the realism IM rendering delivers, hence giving the viewer a comprehensive visual impression of the architectural details when observed from the exterior.

Performance survey of IM architectural models

A survey was conducted to test the performance of both the IM and physical model in their

Table 4. Survey assessment criteria

Criteria	[illegible]
1a	Spatial perception of the massing, proportion from bird's eye view
1b	Spatial perception of the massing, proportion from man's eye level
2a	Visualization of the interior to exterior relationship from bird's eye view
2b	Visualization of the interior to exterior relationship from man's eye level
3	Visual understanding of material texture
4	Different perspective views in a wide range of visual scale
5	3D immersive experience (walkthrough)

effectiveness to communicate ideas about each building design. This time, the presentation of vital architectural information within their respective medium was looked into in a more general sense. The survey criteria for the physical and the IM model are described in table 4.

The feedback for each criterion was obtained from the mean value given by the survey participants whose opinion ranged from strongly agree (4) over agree (3), neutral (2), disagree (1) and strongly disagree (0).

Survey Results Assessment

Figure 6 to 9 show the rating deviation chart for model type three and four for both physical and IM model. The rating deviation has shown extreme highs and lows in the survey for both IM

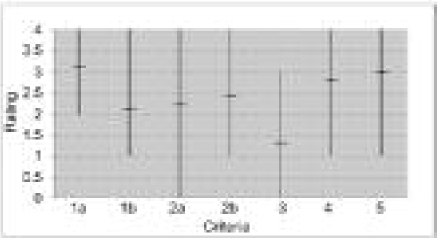

Figure 6. Deviant chart for feedback on IM model type three

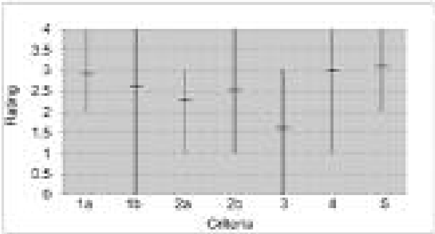

Figure 8. Deviant chart for feedback on physical model type three

models.

The large deviation may be due to difficulties in assessing the list of criteria for architectural model in the new representation medium (IM). Individuals being unfamiliar with the program's control interface could hinder their ability to understand its content. The fluctuations in the user rating were generally more stable for the physical models in contrast (figure 8, 9)

Survey results for criterion 1a and 1b have

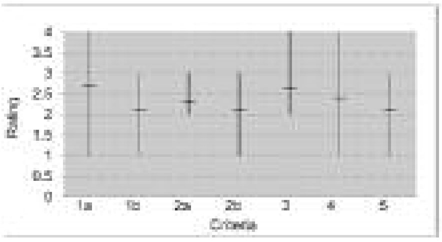

Figure 9. Deviant Chart for feedback on physical model type four

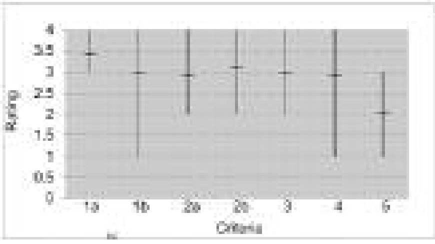

Figure 7. Deviant chart for feedback on IM model type four

shown that the there was no significant difference in the visualization of the geometries and spatial arrangement for elements in both the real and the IM model. (Figure 10, 11, 12).

The high reliability in photogram metric mod-

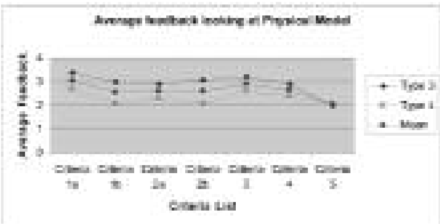

Figure 10. Comparing the average feedback for both physical models

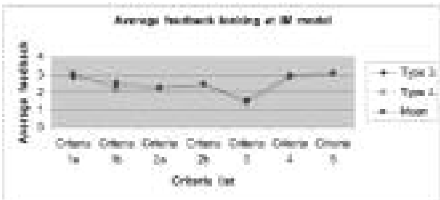

Figure 11. Comparing the average feedback for both IM models

Figure 12. Comparing the mean for physical and IM models

eling (reflected earlier in the experiment) enables the IM creations to match the quality of the physical model when viewed from afar or at closer distances.

For criterion 2a and 2b, the exterior to interior relationship depends on both geometry and image-map production faithfulness. IM produces good replication of form but there is some degree of image distortion and blurring, especially when observed at close range. Hence the user opinion is mixed in the survey. Conclusively, both the IM models fair slightly worse in this segment due to their affected texture renderings. This causes the observer to become confused, hence affecting its overall performance when compared against the physical model in these aspects.

IM performs most badly for criterion 3 against the real model when visual appearance qualities are compared directly. This is because unlike the IM model, the physical model does not have image distortion problem, this allows it fair much better in this aspect of user evaluation. It is interesting that the strongest features that made IM so unique and worth commending is also its weakest point when compared this manner.

IM fairs slightly better for criterion 4 as the 3D quality it possesses (CAD environment) allows some viewpoints that are almost impossible with the physical model, especially at human eye level in the model, to be revealed. However, as mentioned for criteria 3, distortion and blurring of texture maps at close-up views has its drawbacks and hence prevented good visualization of these virtual viewpoints.

Criterion 5 assesses the 3D immersive visualization potential of both models. Walkthrough requires some degree of imagination from the observer when viewing the physical model. This will be further hindered if he has to maneuver this mental view path across tight corners. In contrast, 3D CAD environment is immune to such problems, hence giving the IM model an obvious edge over the real one in dynamic 3D visualization (figure 12).

Figure 10 shows that the visual assessment of model type 4 has better overall results than model Type 3. Feedbacks from the participants in the survey have reflected that physical models with small elements are more difficult to see than models with larger components. The unfavorable condition in model type 3 was improved however with IM modeling. Performances of both models in the IM environment were almost on par (figure 11). This is believed to be attributed to its scale zooming capability, which enhances the visualization of certain types of physical model built at a smaller scale.

Conclusion

The research has shown the strengths and weakness of current IM technology in the reproduction of physical architectural models for digital storage. It is obvious the virtual model, being a replication of the physical one, can never be as good in many aspects of architectural visualization. However, it seems to display some advantages over its static predecessor in aspects of dynamic visualization such as scale shifting and visual walkthrough.

In comparison to conventional geometric-based CAD modeling, IM is effective in extracting 3D information from physical objects in many circumstances. Based on the experiments, the effectiveness of using IM depends largely on the nature of the physical architecture model. IM performs the best in creating models with simple orthogonal volumes and those with opaque and rich surface texture. However, digital conversion of urban scale massing models with numerous components are recommended to be done with convention CAD software. The program has also limitations in rendering complex visual layering effects since it cannot recognize transparency in objects. Nevertheless, IM presents a creative way to digitalized real-world architectural models that can be virtually retrieved and studied via the World Wide Web.

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