A COMPUTER-AIDED EVALUATION TOOL FOR THE VISUAL ASPECTS IN ARCHITECTURAL DESIGN FOR HIGH-DENSITY AND HIGH-RISE BUILDINGS

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Abstract

The field of view, the nature of the objects being seen, the distances between the objects and the viewer, daylighting and sunshine are some major factors affecting perceived reactions when viewing through a window. View is one major factor that leads to the satisfaction and comfort of the users inside the building enclosure. While computer technologies are being widely used in the field of architecture, designers still have to use their own intelligence, experience and preferences in judging their designs with respect to the quality of view. This paper introduces an alternative approach to the analysis of views by the use of computers. The prototype of this system and its underlying principles were first introduced in the CAADRIA '97 conference. This paper describes the further development of this system where emphasis has been placed on the high-rise and high-density environments. Architects may find themselves facing considerable limitations for improving their designs regarding views out of the building under these environmental conditions. This research permits an interactive real-time response to altering views as the forms and planes of the building are manipulated.

1. Introduction

"Visual aspects" are here defined as the responses perceived by users while viewing out of a building. The field of view, nature of the objects being seen, the distances between the objects and the viewers, and the daylighting and sunshine are some key factors affecting these aspects. Unlike many other engineering criteria such as structural loading, wind loading, and dimensions of escape routes, etc., the "view" being a qualitative entity presents difficulties in being measured using conventional mathematical tools but it is probably one of the major factors that leads to the psychological satisfaction and comfort of the users inside the building enclosure. Yet little research has been carried out on the visual aspects from the users' point of view whilst most concentration has been placed on the exterior appearance of the building and its external relationship to the built environment. Generally in addition, the results of the limited studies performed have been presented in descriptive forms or in drawings that can be subjectively interpreted by human observers but not by computers.

A "window" here is defined broadly as any opening that permits users to view out of the interior of a building. Obscure or translucent openings are not considered here, as they are not related to the visual aspects of the user interaction. Positions and orientations of window openings are crucial to the visual performance of a building as windows respond critically to daylighting, sunshine and view, of which each process in its own way can be decisive to the synthesis of a successful architectural design. The primary goal of this study is to find a way to assist architects in designing "visual efficient" buildings. Designers can use this evaluation tool in the early stages of the design process to evaluate the performance of their designs concerning the visual aspects. The evaluation results are shown on the computer screen in real-time. The designers can then modify or refine their designs according to the results. By going through an evaluation and modification loop an excellent architectural design with the visual aspects related to other design criteria can be achieved. In order to use this evaluation tool in the early design stages, a modelling tool has been developed to allow the designer to input the design geometry of the building to the computer in a user-friendly manner. As the result is in real-time, changes are immediately incorporated and evaluated.

The prototype of the modelling tool and the underlying principles and methodologies of the evaluation tool were first introduced in the CAADRIA '97 conference (Li and Will, 1997). This paper describes the further development of this system. The system development is concentrated on high-rise and high-density environments because of the fact that architects face many more limitations in improving their designs for better quality of view in such environments than in any other circumstance.

2. Summary of the previous development

This research relates to a single module of the Interactive Optimization Tools for Architects system (IOTA) which is currently being developed to assist architects in the design process. The modules of the IOTA are plug-ins and can be used individually or in concert. Obviously the more plug-ins that are switched on the greater the demand on computing power and the slower the overall process but the advantage is that more realistic and rational decisions can be made. This particular module can be divided into two parts – the modelling tool and the evaluation tool. In the early stages of the design process, most decisions about the design are not yet made nor is the geometrical information of the design stabilized. On that ground most of the existing commercial computer-aided design software, such as AutoCAD, ArchiCAD, etc., are not suitable applications in these early design stages. They all require a certain amount of information about the design geometry in order to build the computer model. They do not respond easily to amendments of the computer models once the geometrical data are input. This modelling tool is built so as to make the use of the evaluation tool at the earliest design stages easy. For the sake of evaluation and of presentation of the results, the shapes of the buildings are approximated by 3m-cubes. A cube represents a unit of space which may not necessarily be empty. There may be rooms, corridors, staircases or internal partitions penetrating a cube. As a cube is a basic test unit it can neither be too large nor too small. Setting the cube too large would lead to a rough approximation of the building form while setting it too small would increase the number of iterations for testing and thus slowing the interactive process. A cube of 3m dimension was therefore chosen since it is approximately the typical height of a floor and its centroid plays an important role in averaging eye heights.

An architect can start designing the building form by specifying the number of floors, location and dimensions of the building on the site. As a default value a building of rectangular form is assembled accordingly as a stack of cubes. The designer can then remove unnecessary cubes from the rectangular block to form the shape that is required. When the basic 3D building form is established, the designer can then insert different elements such as slabs, windows, cores and internal partitions into the massing model.

As the building form is undergoing changes the corresponding performance of the design related to the visual aspects is being tested in real-time by the evaluation tool. The view seen by a person standing inside the preliminary building is simulated and evaluated based on the geometrical information of the building design and its surrounding environment which has been input previously. A basic test unit of the building is a cube of which the person is assumed to be standing in the middle of it. The eye level of the person is assumed to be 1.5m above the floor, that is, the eye is exactly at the center of the cube. (Future developments will include standing and seated observers and averaging iterations.) The program determines the view by emitting rays from the center of each cube in a 360^o array horizontally and a 90^o array vertically. By checking the obstacles hit by the rays the computer can know what objects can be seen by the person, how far they are and what the views are composed of. These data are then fed to a fuzzy system for computing the expected Visual Aspect Performance Index (VAPI) value. The final product of the Evaluation Tool is a building composed of colored blocks for the sake of easy visualization of the performance.

The fuzzy system model developed consists of five fuzzy sets and forty-five fuzzy rules. The five fuzzy sets are the quantity of plants (green area) in the view, the average distance between the observer and the surrounding buildings, the number and size of buildings in the view, the proportion of sky in the view and the proportion of sea in the view. These factors are chosen based on Markus' comprehensive studies on the psychological aspects of views (Markus, Brierley and Gray, 1972; Markus and Gray, 1972). It was stated clearly by Markus that the first four factors were highly correlated with people's general satisfaction with their living environment. The last factor which is specific to Hong Kong is added by the authors. It conforms to Markus' findings that people prefer more open space and fewer buildings in the view.

3. Improvements on the Modelling Tool

In order to make the 3D model of the site environment realistic without increasing the loading on the computational power, texture mapping is incorporated in the modelling tool. The advantage of texture mapping is that photo-realistic visualization can be achieved easily without having to increase the complexity of the 3D model. The demand on extra computational power is low if there is a hardware texture mapping device. As a result real-time photo-realistic 3D computer models can be visualized on the computer monitors when the designers are making their buildings using the modelling tool.

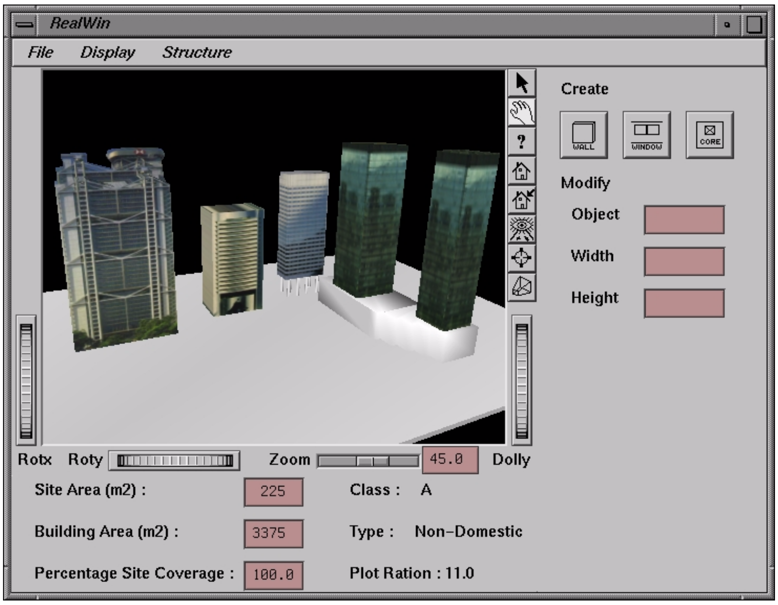

Figure 1

In the previous version of the program, as the form of a building was only approximated by 3m-cubes, flaws tended to appear when building models with curved faces were introduced. The resultant jagged faces were considered unacceptable and improvements were deserved to be made. One way of improvement is to decrease the dimensions of each cube so that the jagged faces can be smoothened. But as a block is a basic testing unit for the evaluation tool decreasing the dimensions of each block only results to the increase in the number of testing units and thus an increase in the time needed for the testing iterations. Another way is to deform the outermost blocks to fit into the building form exactly but this may require the manipulation of complicated Bézier surfaces in the worst case which will certainly degrade the performance of the computer. The technique employed in this modelling tool is to approximate the form by polyhedrons because the number of faces of a polyhedron is not much more than that of a rectangular block. The overhead required on the computing power is not significant compared with the Bézier surfaces. The outermost blocks can be deformed to any polyhedrons so that the building form can be approximated accurately. The mechanism of deformation is that the designers are allowed to add and remove vertices on the block. The designer can change the positions of these vertices by dragging the vertices interactively. The blocks can then become polyhedrons. The user interface of the modelling tool provides for the designer the ability to do the deformation from six directions of the rectangular blocks, such as top, bottom, left, right, front and back. Figure 2 to Figure 5 show three major operations – movement, addition and deletion of the vertices on the blocks. Multiple blocks can be deformed at a time in order to speed up the deformation process.

Figure 2 shows the TOP view of the block. Two vertically overlapped points are selected and moved simultaneously to form a trapezoidal prism.

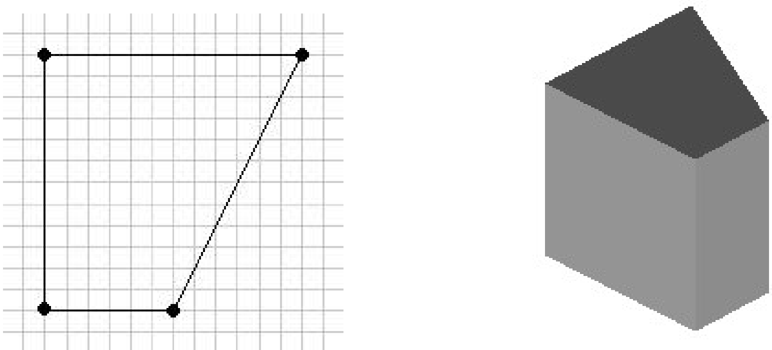

Figure 2

Figure 3 shows the TOP view of the block. Two vertices on the TOP face are moved inwards to form a trapezoid.

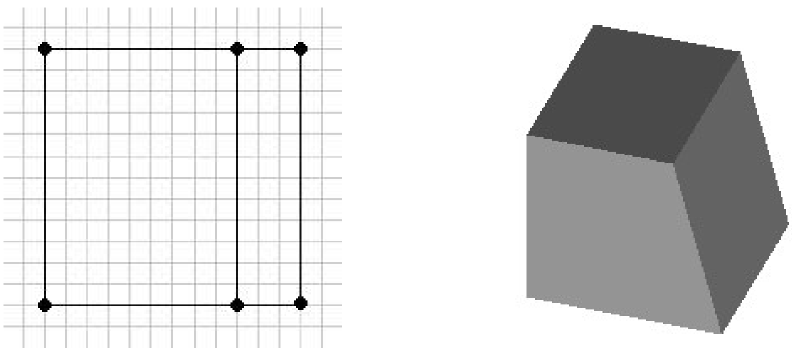

Figure 3

Figure 4 shows the TOP view of the block. Two vertically overlapped points are selected and deleted to form a triangular prism.

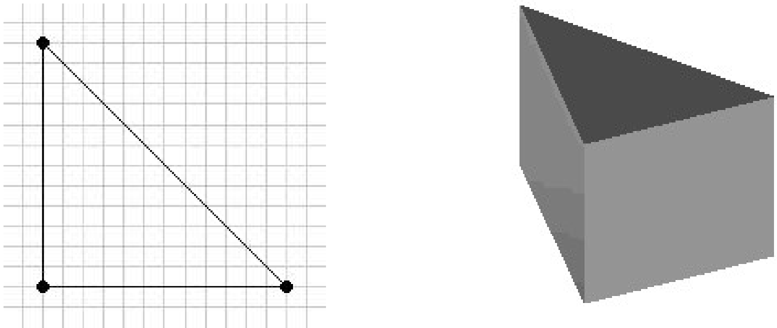

Figure 4

Figure 5 shows the TOP view of the block. Two vertices are inserted and moved simultaneously to form a pentagonal prism.

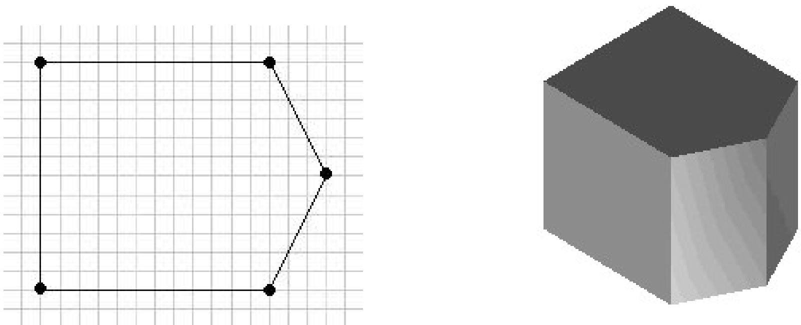

Figure 5

Furthermore, in order to prepare for taking sunlighting into account in the solar evaluation module, some features are added to this modelling tool to enhance its ability in modelling complex shapes and its ability to adopt sunlight into the considerations. Firstly, the building models can be moved freely within the site boundary so that the designer can choose the best position for the building to receive more sunlight in winter and less sunlight in summer. Secondly, the form can be extruded upward or compressed downward to form a tall and slim building or a short and flat building so that the building can be changed to other shapes easily to receive or escape from sunlight whilst keeping the plot ratio constant.

4. Improvements to the Evaluation Tool

In the previous development of the fuzzy system model, interviews were conducted to investigate the correlation between the five factors and the users' general satisfaction with the views. Fifty pictures of some common scenes in Hong Kong were shown to the interviewees who were requested to rank these pictures with respect to their preferences. These fifty pictures were taken in different areas in Hong Kong, from urban areas to rural areas, from construction sites to wasteland. In the previous studies, those fifty pictures were taken without any criteria, but were randomly taken in different areas in Hong Kong. As a refinement some factors other than those five fuzzy sets affecting people's general satisfaction can be considered. For example people may prefer a well landscaped and complete built environment to a construction site.

A few amendments have been made on the evaluation tool so as to improve the accuracy of the fuzzy system model. In this study only an urban area is considered not only because of the reasons set above but also owing to the fact that designing a building with a good quality of view in a high-rise and high-density environment is the most challenging for an architect. It is hoped that this system can help designers to achieve a better quality of view in their designs under such conditions. The number of rules is raised from 45 to 100. In this study 105 photos taken in the urban areas in Hong Kong were shown to interviewees to rank according to their order of preferences. The photos show nearly all types of views that can be seen in the urban areas in Hong Kong. Two examples of the photos are shown in Figure 6. They exemplify some of the differences that landscape can make in an urban setting.

Figure 6

Interviewees, besides being asked to rank the photos, were also asked to evaluate the five factors (included in Table 1). For example they might be asked if the proportion of green plants in a photo was "no", "low", "average" or "high". The verbal comments and the average ranking of the 100 photos were used to build the rule base of the fuzzy model. The average ranking of these 100 photos was treated as the dependent variable – the Visual Aspect Performance Index (VAPI). The five fuzzy sets and their corresponding subsets are shown in Table 1. Obviously these photos take into account only daytime views but in future the model will also consider comparable night views.

Fuzzy Set	Fuzzy Subset
Average Distance between the Observer and the Surrounding Buildings	Near distance (N) Medium distance (M) Far distance (F)
Proportion of Buildings in the scene	No building in the scene (N) Low proportion of buildings (L) Average proportion of buildings (A) High proportion of buildings (H)
Proportion of Sky in the scene	No sky in the scene (N) Low proportion of the sky (L) Average proportions sky (A) High proportion of sky in the scene (H)
Proportion of Green Plants in the scene (including mountains, trees, grass and artificial planting)	No green plants in the scene (N) Low proportion of green plants (L) Average proportion of green plants (A) High proportion of greens plants (M)
Proportion of Sea in the scene	No sea view (N) Low proportion of sea in the scene(L) Average proportion of sea view (A) High proportion of sea in the scene (H)

Table 1

The other five photos were used to verify the accuracy of the fuzzy system model. They were pixelated using PhotoShop. Different elements were outlined for the ease of counting the proportions in the pictures. The actual distances between the observer and the observed buildings were measured from a map to compute the average distance. Table 2 shows the parameters for the picture shown in Figure 7.

Figure 7

	Percentages of the elements in the Picture			
Distance of Buildings	Buildings	Sky	Plant	Sea
134m	53%	15%	32%	0%

Table 2

The membership functions of all fuzzy sets were amended to give a better approximation of the real world. A membership function converts real-world data of a certain element to a degree of membership of the fuzzy subset. The degree of membership is a real number in the interval [0, 1]. "1" indicates strict belonging while "0" indicates a certain element which has no relation with the subset. A value between 0 and 1 indicates partial belonging (Zadeh 1965). The new membership function of the Average Distance between the Observer and his Surrounding Buildings is shown in Figure 8.

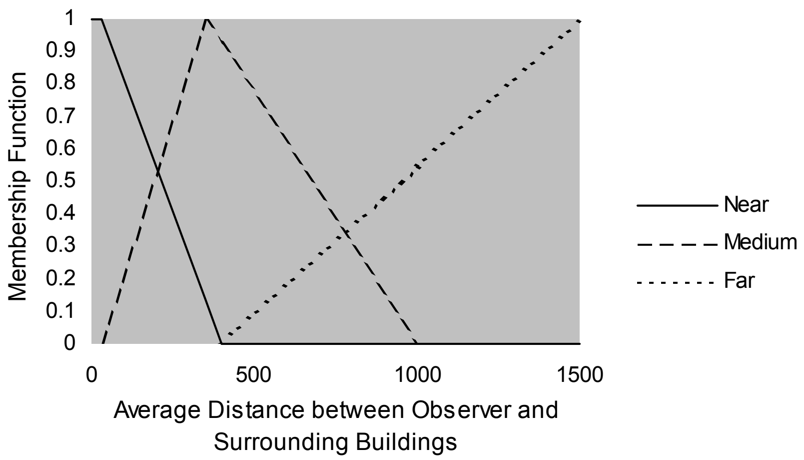

Figure 8 : Membership function of Average Distance between Observer and Surrounding Buildings

Table 3 shows the membership functions of the fuzzy subsets for the picture shown in Figure 7.

Average Distance of Buildings			Proportion of Buildings in the scene				Proportion of Sky in the scene				Proportion of Plants in the scene				Proportion of Sea in the scene			
N	M	F	N	L	A	H	N	L	A	H	N	L	A	H	N	L	A	H
0.72	0.33	0	0	0	0.88	0.12	0	0.75	0.25	0	0	0.4	0.9	0	1	0	0	0

Table 3

For example, by matching the fuzzy subsets with those in the rule shown in Table 4, the degree of belonging to the rule can be computed by the popular max-min operation.

min [0.72, 0.88, 0.75, 0.4, 1] = 0.4

Average Distance of Buildings	Proportion of Buildings	Proportion of Sky in the scene	Proportion of Plants in the scene	Proportion of Sea in the scene
N	A	L	L	N

Table 4

Applying the same process to each rule, we can derive a set of values. The expected VAPI is computed by the center of gravity method.

Using the parameters computed from the computer model of the building created with the Modelling Tool and applying the fuzzy system described above, the VAPI of the design can be predicted by aggregating the VAPI from the rule base of the fuzzy model. A general picture of the VAPI allocation in each part of the building can be established. The VAPI value of each cube is mapped to a color which is assigned as the color of the cube. The final product of the Evaluation Tool is a building composed of colored blocks. Figure 9 shows an example of a building with color mapping. The color goes from red, to yellow, to green and then to blue. Red indicates good quality while blue means poor quality. Each block interacts with its adjacent blocks so that blocks on the exterior of the building shade those inside. Progression through the blocks reduces the view quality assigned. Horizontal slabs also affect the available views for the inner blocks because of the reduced field of view.

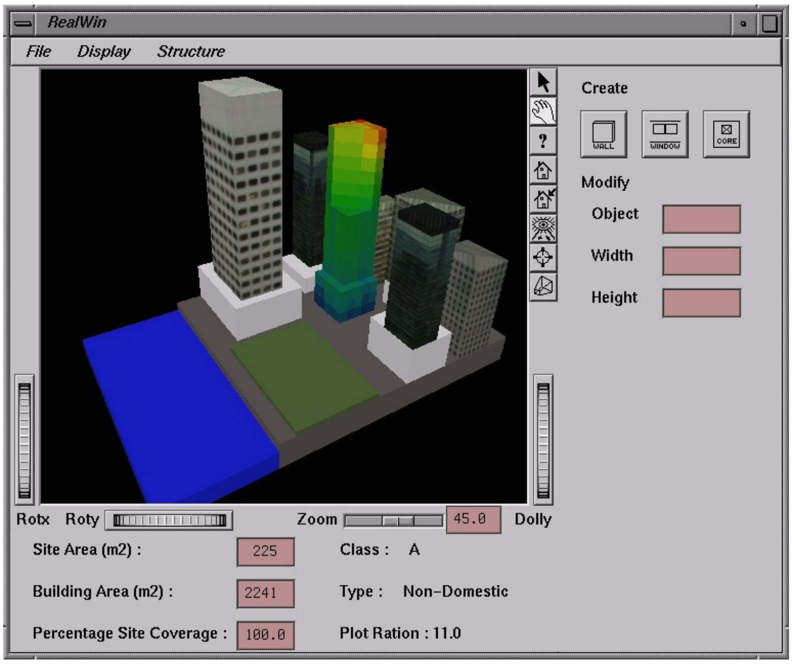

Figure 9

5. Conclusion

This paper not only demonstrates the way of using computers in helping designers to make better decisions on the visual aspects of buildings, but also illustrates the possibility of using computers in analyzing other parameters. Traditionally, designers can only predict the outcomes of their designs concerning such aspects as utilization of sunlighting, quality of view, complying with the building regulations, etc. by way of their own experiences, knowledge, and personal preferences. Often luck plays an important role in the success of a design solution. Computers, instead of making decisions for architects, can provide them with supporting information, analyses and comparisons so that architects can give solid evidence to support their decisions. This modelling tool is envisaged as one element of a package of design decision supports (IOTA) that can interactively respond as the architect manipulates his building in a creative and free manner. Future inclusions in this tool will permit the masking of an exterior wall to represent variable window openings, sill and head heights and column sizes and spacing. Light reflectors and refractors or shading devices will also be accommodated. These elements will respond directly to the inputs to the facade design mask which will interactively appear on the 3D model as it is manipulated in form and position. Alternative solutions can thus be objectively compared as the design process progresses and this is particularly relevant where qualitative assessments, such as the users' overall satisfaction with views from the building, vary with the changing design. This process can be carried out simultaneously with the external facade design of the building and can be related to the solar impacts from the sunlight tool already developed by Wong and Will (1996).

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