A COMPUTER BASED EVALUATION TOOL FOR THE VISUAL ASPECTS IN WINDOW DESIGN

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Abstract. Windows in buildings must respond to five major issues – daylight, sunshine, view, ventilation and sound. Each of these processes in its own way can be critical to the synthesis of a successful architectural design. All factors except view are engineering criteria that can be evaluated by some mathematical formulae provided there is sufficient information for the calculations. In contrast, view being a qualitative entity has difficulty in being measured by using conventional mathematical tools but it is probably the major factor that leads to the satisfaction and comfort of the users inside the building enclosure. This paper introduces a new approach in analyzing views by the use of computers. One of the advantages of this analysis process is that the psychological aspects are less biased in the end product. This paper explains the methodologies, theories and principles underlying these modeling and analyzing tools.

1. Introduction

Windows are indispensable elements to most of the buildings. A window is here defined broadly as any opening that permits users to view out of the interior of a building. Obscure or translucent openings are not considered in this study, as they do not relate to the visual aspects of the user interaction. Most people prefer to own a building with good view. A flat of 100m² in Hong Kong with good sea view can be worth a million Hong Kong dollars (about US$130,000) more than another flat of the same size and in the same location but without a good view. This is not a special example, rather, it is quite typical in Hong Kong. The difference is very significant to the price and is a direct reflection of people preferences. Choosing optimal openings for windows can be critical in the synthesis of a successful architectural design because windows respond to five major issues — daylight, sunshine, view, ventilation and sound. Traditionally architects have to make their own judgments about their designs with respect to...
these aspects. Mistakes may be made due to their carelessness, lack of experience or misinterpretation of the surrounding environment. As computer technologies have advanced it has become more realistic to place computers in supporting roles to assist architects in making relatively unbiased evaluations of their designs.

All factors except view are engineering criteria that can be evaluated by some mathematical formulae provided there is sufficient information for the calculations. Research and evaluating tools for these areas have been extensively developed in the past two decades. On the contrary view being a qualitative entity presents difficulties in being measured using conventional mathematical tools but view is probably the major factor that leads to the psychological satisfaction and comfort of the users inside the building enclosure. Little research has been carried out on people preferences on view. Generally the results of the limited studies performed have been presented in descriptive forms that can be subjectively interpreted by human observers but these results have not been made computer compatible.

A typical analysis program requires the designer to extract relevant parameters from the design and to re-enter these values at the keyboard. Design and analysis are phased so there is no direct way to feed back the results of a simulation to improve the design (Gross, 1994). The idea of this evaluation tool is to provide real-time feedback to the designer so that modifications and refinements can be conducted in the earlier stage of the design process. In order to achieve that, a convenient way to input design geometry to the computer, as well as to make changes easy is extremely important and thus a modelling tool has been developed to achieve this purpose.

2. Modelling Tool

This modelling tool is presented as a simple interface to encourage use at the early stages of the design process. Only those factors affecting the quality of view such as building forms, floor heights, window placement, slabs, cores and internal partitions are implemented in the modelling tool.

For the sake of evaluation and of presentation of the results, a building is divided into cubes of 3m in dimension. 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. 3m dimension was chosen because it is approximately the typical height of a floor.

An architect can start designing the building form by specifying the number of floors. A building of rectangular form is assembled accordingly as a stack of cubes. The user can then remove unnecessary cubes from the rectangular block to form approximately any required shape no matter how arbitrary. Figure 1
shows an example of a prototype of a building constructed using this modelling tool.

![Figure 1.](image)

When the basic 3D form is established, the user can then insert different elements such as slabs, windows, cores and internal partitions into the massing model.

3. Evaluation Tool

In this study the view seen by a person standing inside the preliminary building is simulated and evaluated based on the geometry of the building design and its surrounding environment which has been input previously. The view being seen is not only passively determined by the physical limitations of eyes of the observer and by the surrounding context but is also actively governed by some design parameters such as window sizes, window locations, internal partitions and orientations of the building.

Since the major objective of this evaluation tool is to help architects to make better decisions with respect to the visual aspects of design but not to restrict them in their overall design approach, architects are allowed to incorporate their own preferences (different from others') to their designs by changing the membership functions and adding more rules to define their own interests. By going through this Evaluation-Modification process several times, the design can
be finely tuned to best suit the existing context.

3.1 METHODOLOGY FOR EVALUATION

Markus (Markus, Brieley and Gray, 1972) stated clearly that open space and green area were what most people preferred. The overall satisfaction was strongly a function of amount of grass around the house, distance between houses, garden size and open space. The sky factor was found to be highly correlated with the general satisfaction as did the amount of buildings in the view -- the more the buildings in the view the lower the overall satisfaction (Markus and Gray, 1972). However, in these studies, the factors affecting people preferences were isolated. Problems arise when these factors are to be integrated into a comprehensive consideration. It is sometimes impossible to tell which view is better from the results of these studies especially when the scene is composed of many different elements. For instance, is a scene which is composed of near trees better than another scene in which no plants but an empty open space can be seen? The difficulty in assessing "view" is that most factors are qualitative and fuzzy in nature. As a result a fuzzy reasoning technique is employed in this evaluation tool because it is good for very complex processes when there is no simple mathematical model and when the processing of (linguistically formulated) expert knowledge is to be performed.

The analysis of view in this study is based on Markus' comprehensive studies. Major factors identified by Markus are adopted as key factors in assessing the visual aspects of the surrounding environment. Five factors (fuzzy sets) are considered in this study – the quantity of plants (green area) in the view, the distance between the observer and 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. It was stated clearly that the first four factors were highly correlated with the general satisfaction. The last factor is specific to Hong Kong circumstances as stated in the introduction and it conforms to Markus' findings that people prefer more open space and fewer buildings in the view. Interviews were conducted to investigate the correlation between these factors and the users' general satisfaction with view conditions.

As a preliminary test 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 divided into two groups. One of them consisting of forty-five pictures was used to build up the rule base of the fuzzy model. Data from each picture in this group forms a data set. The ranking of each picture in this group was mapped to the range of 1 to 45. "1" was the highest ranking whereas "45" was the lowest. The average ranking of a picture in this group was treated as the dependent variable – the visual aspect performance index (VAPI). The other group containing the remaining five
pictures was used to verify the level of accuracy of the fuzzy model. The ranking of a picture in the second group was projected onto the rankings of the first group. A picture in the second group that fell between the fourth and the fifth pictures in the first group, for example, was assigned 4.5 as its relative ranking. The expected VAPI of these five pictures were evaluated by using fuzzy logic and have been compared with their (observed) average relative rankings.

3.2 FUZZIFICATION

The remaining part of the process is to convert real data into another form for input to computers. The procedure is known as fuzzification. The real-world data is converted into a degree of membership in the membership function of a certain element within a certain 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 among 0 and 1 indicates partial belonging (Zadeh 1965). Conventionally a triangular function is used as the membership function. Any data from the real world can be mapped into a suitable membership value by an appropriate membership function. A panel of 10 persons consisting of architecture professionals and architecture students was consulted in order to delineate the fuzzy subsets within each factor (fuzzy set). Each fuzzy subset membership is described by a membership function chart. Figure 2 shows an example of the membership function charts for the fuzzy subset, Distance between the observer and the surrounding buildings. The distance between the observer and the surrounding buildings is hard to tell correctly just by eye observation. The sense of visual nearness is largely determined by the angle of depression. (Higuchi, 1975) and the scales of the objects (Spreiregen, 1965). A person facing a small hut 100m away from him may feel it is "far", whilst one may feel "medium" if the hut is replaced by a building of 80m. In this study, large objects such as buildings, sea, hills and parks are considered. The scale of the membership function chart of distance is thus relatively large. The range for each subset is also large because of a variety of different observed objects. "far", for instance, is termed "1" when the distance is below 30m and termed "0" when the distance is beyond 400m. The membership value is decreasing linearly from "1" to "0" when the distance is increasing from 30m to 400m.
3.3 VERIFICATION OF THE FUZZY MODEL.

The fuzzy model developed is composed of the five fuzzy sets and forty-five fuzzy rules described by the first forty-five pictures. In order to confirm its accuracy, the other five pictures are used to verify its level of significance. The five factors in these five pictures, such as distance between the observer (i.e. the camera) and the surrounding buildings, proportions of the components in the picture are measured more accurately (though some of them are still in approximation). These values are put into each rule in turn by the popular max-min operation. The final result, a predicted VAPI value, is computed by using the center of gravity method.

If the level of accuracy of the model is perfect, the predicted values (p) should be exactly equal to the observed value and thus the model should be represented by a line $y = o$. The plotting of predicted VAPI against Observed VAPI, shown in Figure 3, shows that the predicted values (p) are close to the observed values (o) and thus it shows that this fuzzy model is reasonable in this prediction. The accuracy of this fuzzy model can be improved by incorporating more reliable fuzzy rules but the elegance of fuzzy reasoning is that even when only a small set of fuzzy rules is present a reasonable and usable result can still be achieved.
3.4 APPLY THE FUZZY SYSTEM TO A BUILDING DESIGN

According to findings in the science of vision, coordinated head and eye movements, in practice, permit the total dynamic field-of-view to cover the entire $360^\circ$ in almost every direction (a small region above and behind the head remains invisible) without moving the body (Carpenter 1991). As the simulation in this study is on the normal behavior of a person inside the building, it is unwise to limit the field-of-view to only the cyclopean retinal field by assuming that the person is facing a particular direction. The limitations of the field-of-view are the frames of windows and the floor to ceiling heights instead.

By using the model built in the Modelling Tool and applying the fuzzy system described above, the VAPI of the design can be predicted. A basic test unit of a building is a cube of which the person is assumed to be standing in the middle of the plan of the cube and his eye level is 1.5m above the floor, that is the eye is exactly at the center of the cube. Hence the vertical field-of-view is at its maximum when the person is standing in an outermost cube of the building, that is, $90^\circ$ in the vertical.
The program determines the view by emitting rays from the center of each cube to its surroundings in 360° in the horizon and in 90° in the vertical. By checking the obstacles hit by the rays the program can know what the objects are, how far they are, how the views are composed of and thus the values of the five factors of the fuzzy system can be derived accordingly. By aggregating the VAPI from the rule base of the fuzzy model for each cube, we can have a general picture of the VAPI allocation in each part of the building. The VAPI value of each cube is mapped to a color which is then assigned as the color of that cube. The final product of the Evaluation Tool is a building composed of colored blocks. Figure 4 shows an example of a building with colors on it. The lighter the color, the better is the quality of view.

![Figure 4.](image)

4. Conclusion

Architectural design is a cooperative activity which involves a sequence of decision-making processes (Mackinder and Marvin, 1982). When computers were first introduced into architecture they were used non-constructively as pens
and rulers in the drafting process. With the ongoing quest for artificial intelligence it is envisaged that computers will be able to make decisions for architects to make a wonderful world for our future. There are however certain principal limitations that artificial intelligence must overcome before it can supplant the prevailing design culture. These include primarily the ability to "have" or "think" intelligently (Gardner, 1985). There also exist several limitations in the utilization of human qualitative knowledge and creative skills. Computers, instead of making decisions for architects, can provide them with supporting information, analyses and comparisons so that besides saying "like that", architects can give solid evidence to support their decisions. This paper illustrates a way of using computers to help architects make decisions with respect to these qualitative aspects. Wong and Will (1996) showed a similar way of using computers as a design supporting tool for making decisions with respect to sunlighting on buildings.

5. Further Development

This study is still at an early stage. The user interface of the Modelling Tool requires refinement and enhanced features. The rules and fuzzy sets of the fuzzy model are not perfect. Modifications on the fuzzy sets and membership allocation charts are needed in order to improve the reliability of the fuzzy model. As a larger rule base gives a better result, more rules will be added to make the rule base more comprehensive and to increase the level of confidence of the final result. This modelling tool is envisaged as one element of a package of design decision supports that interactively respond as the architect manipulates his building in a creative and free manner. 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.

References


Markus, T. A., Brierley, E. and Gray, A.: 1972, Criteria of Sunshine, Daylight, Visual Privacy and Viewing in Housing, Building Performance Research Unit, Department of Architecture and
Building Science, University of Strathclyde, Glasgow.
Psychological Significance of Sunshine, Daylight, View and Visual Privacy, Proceedings of
Commission Internationale de l'clairage Conference: Windows and Their Functions in
Wong, W. C. H. and Will, B. F.: 1996, An Analysis of Using a Digital 3D sundial as a Design and
Decision Support Tool, Proceedings of CAADRIA '96 Conference, Hong Kong.