PREDICTING VISUAL QUALITY WITH GIS BASED LAND-USE DATA: AN OLD MISSION PENINSULA, MICHIGAN CASE STUDY[1]

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Abstract. Predictive visual quality equations and preference modeling have evolved into important design tools for the landscape architecture profession and reclamation specialists. By using predictive equations, designers and other landscape professionals aim to produce landscape designs that are environmentally sensitive yet effective in terms of improving landscape aesthetics in the post-mining environment. Likewise, new technologies in the area of landscape modeling have brought the computer to the forefront of the design process. By examining and manipulating photographic images of a landscape, one can analyze existing problems and suggest possible solutions with realistic, computer enhanced models and images. However, investigators and practitioners are interested in methodologies which minimize the amount of field work necessary to evaluate visual quality. Many predictive visual quality procedures call for the use of photographic images. In our study we investigated the possibility of using GIS based land-use data to substitute for photographs in a visual quality study. We used the Old Mission Peninsula in Grand Traverse County, Michigan and GIS layers for the study area with 3-dimensional visualization software to determine if computer generated images were similar in visual quality assessment as actual photographs. Through statistical analysis of the data, it was determined that the relationship of the two datasets are in concordance and significant to the 95 percent confidence level. We conclude that visual quality can be assessed through remote, off-site methods.

Additional Key Words: environmental science, post-mining land-use, landscape planning, land-use planning, environmental psychology, 3-D visualization

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Introduction

Planners, designers, environmental specialists, governmental agencies, non-profit environmental organizations, educators, and citizens are interested in assessing the properties of the landscape to evaluate the impact of proposed spatial treatments upon the environment, including surface mine reclamation planning and design projects, housing development, recreation related projects, commercial development, industrial properties, transportation planning projects, and for natural resource protection. Consequently, investigators and practitioners are engaged in applying research-based predictive models to study the effects of specific landscape planning, design, and management treatments upon built and natural settings. These approaches often require the use of photographic images to assess the visual quality of the landscape. Capturing images through photography can be costly and time consuming. In our study, we were interested in predicting visual quality through the use of off-site databases to generate a 3-dimensional image, thereby removing the need to travel to the site to gather a photograph. Our study presents a brief literature review concerning visual quality predictive modeling, a description of a predictive equation developed by Burley (1997), a research investigation comparing both photographs and Geographic Information Systems (GIS) derived images, and a discussion that attempts to determine whether GIS derived information can serve as a substitute for photographs.

Literature Review

The modern era of visual quality assessment began with Elwood Shafer Jr. and colleagues by their publication of predictive visual quality equations (Shafer Jr. and Tooby 1973, Shafer Jr. 1969, Shafer Jr., and Hamilton Jr., and Schmid 1969). They employed social science research methods to statistically obtain a perception-based evaluation of black and white rural landscape photographs. They measured various properties of the photographs (independent variables) and statistically related several of the properties with the preferences of the respondents (dependent variable). Shafer's work was then examined in a forest management setting to illustrate the utility of the research (Brush and Shafer 1975). Shafer's work was heavily criticized (Bourassa 1991, Carlson 1977, and Weinstein, 1976), Critics indicated that the equation seemed unlinked to any formal, predictive theory to explain the relationships between the variables measured in the photographs and the preferences of respondents. From a scholarly perspective, the criticisms seem valid; yet in some respects Shafer's work was somewhat unfairly denounced because engineers, ecologists, economists, and agronomists often gain wide acceptance for developing statistical relationships between variables without having a single theory to explain the relationships. While it may be helpful, developing a theory is not a prerequisite for developing an equation. Nevertheless, Shafer's research was difficult for some to accept. During this formative time in the assessment of landscapes, some of the contents within the landscape such as buildings were not yet entertained as variables for examination. By the late 1980s, numerous visual quality studies had been conducted by an assortment of recreation scientists, landscape architects, and environmental scientists (Kaplan and Kaplan 1989, Kaplan, Kaplan, and Brown 1989, Taylor, Zube and Sell 1987, and Smardon, Palmer, and Felleman 1986). In the 1990s and early 2000s, visual quality research often focused upon spatial modeling tools and techniques to simulate the three-dimensional qualities of the environment (Nothhelfer and Pietsch 2002, Buhmann and Ervin 2002, Ervin and Hasbrouck 2001, Hagerhall 2001, Buhmann et al. 2000, Lothian 1999, Al-Kodmany 1998, Buckley, Ulbricht, and Berry 1998, Bishop and Hulse 1994, Crawford 1994, and Orland 1994).

Illustrative Example

To understand the implications of the "state-of-the-art," it is helpful to examine a pair of photographs and their visual quality scores as developed by Burley (1997). We have chosen an image from a roadside somewhere south of Reno, Nevada near Lake Tahoe containing a billboard (Fig. 1). Some of the image is comprised of mountains in the background, a utility pole and wires, some woody vegetation (mid-ground and background), and a billboard. There is no woody foreground vegetation and no foreground exposed substrate. In the image cars and pavement are not in the view, so the image concentrates upon the view of the roadside. The score for the image is 65.5, where the larger the score the lower the visual/environmental quality. Compared to some images, the score for Fig. 1 is about average. Some scenes studied have rendered scores of 100.00. The image's moderate score is attributed to the fact that even though there is a billboard and utility structures, there are mountains in the background and the remaining portion of the scene is devoted to vegetation. In many respects, this is a very nice setting for the billboard. However, if the billboard and utility structures are removed (Fig. 2),

Figure 1. 1988 roadside image near Lake Tahoe, Nevada.

Figure 2. A revised roadside image near Lake Tahoe, Nevada.

the score moves to a value near 22.9. The visual image improves. Here is a case where the inclusion of utility structures and the billboard have made a detectable negative difference. The respondents would say that the first image (Fig. 1) is significantly worse than the same image without the structures (Fig. 2), as indicated by applying the graph with the images scores, testing the two images for statistical difference (Fig. 3). Since the tails of the images do not overlap, the images are significantly different ($p \leq 0.10$).

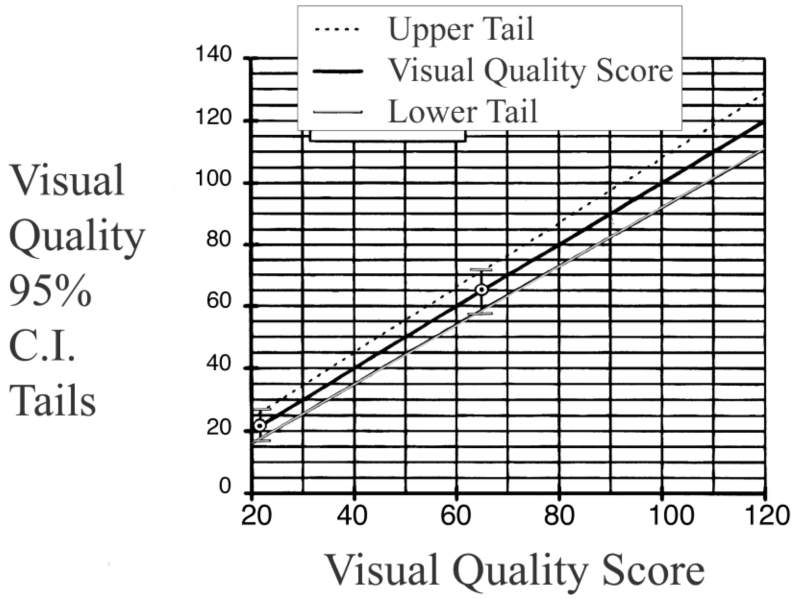

Figure 3. The 95% confidence scores for Figure 1 (65.5) and Figure 2 (22.9), with the predicted scores and the 95% confidence tails. Since the two tails do not overlap, the two images are considered different ($p \leq 0.10$).

Method

The Old Mission Peninsula is located in the northwest of Michigan's lower peninsula, near Traverse City, Michigan. It possesses some of the most picturesque landscapes and scenery, as well as some of the most sought after real estate in northern Michigan. For this study, fourteen viewsheds within the peninsula were selected, representing a variety of views. These viewsheds are each protected agricultural landscapes that are adjacent to the roadside. They were identified and selected by the Peninsula Township Planning Commission as scenic and incorporated by the residents of the Peninsula Township in their land-use plan.

In the summer of 1993, 50 mm photographs were taken in each viewshed, noting location and orientation. The photographs were scanned and imported into a computer. Fifteen photographs were used. The images contain a variety of physical attributes including buildings, utilities, roads, vehicles, water, vegetation and nonvegetative substrate across woodland, agricultural, and grassland cover types.

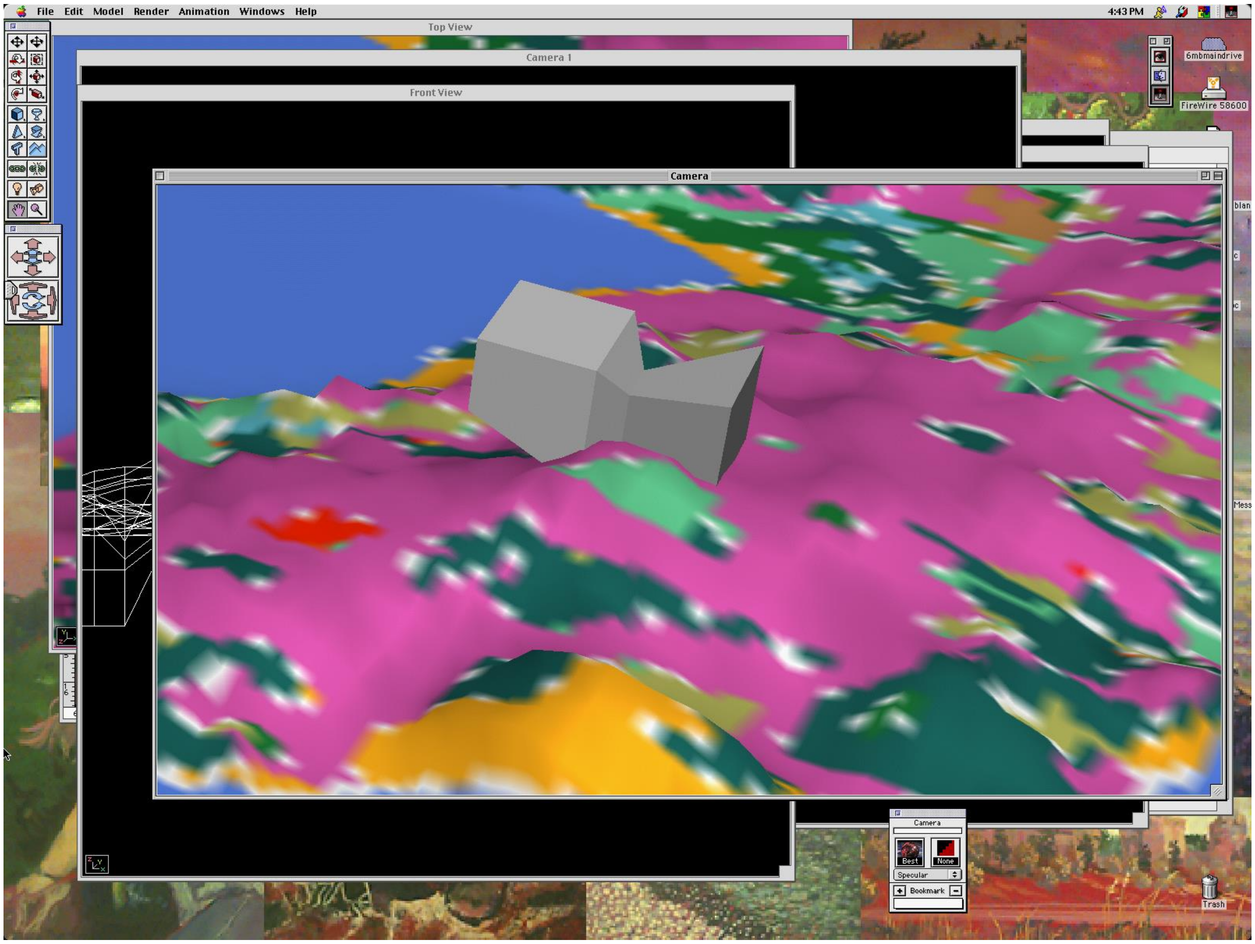

Figure 4. A computer desktop image of the Old Mission Peninsula with Infini-D, illustrating the 3-D nature of the land-use draped over the topographic grid. For illustration purposes a camera containing a particular view is looking east, floating over the peninsula. These cameras can be moved and positioned to capture the desired view.

In addition to the photographs, computer maps were generated to represent the Old Mission Peninsula landscape. The somewhat dated computer program Specular Infini-D was selected for use in this study due to its age (not cutting edge), landscape modeling abilities, and the program's accessibility to the researchers. A raster grid 3-dimensional mesh model was obtained from data originating with the United States Geological Survey to represent the topography of the peninsula. Then a two dimensional image map representing land-uses on the peninsula, gathered between 1990 through 1993, was draped over the mesh model to obtain a three dimensional land use diagram of the peninsula. The fifteen photo-points in the fourteen viewsheds were located on the model in Infini-D. Once the photo-points were identified, the software was employed to produce views of the landscape from similar positions to those within the photographs (Fig. 4). These views (both photographic and computer generated) were then printed and measured in accordance with procedures described by Burley (1997) and Equation 1.

$$
\begin{aligned}
Y= 68.30 &- (1.878*HEALTH) \\
&- (0.131*X1) \\
&- (0.064*X6) \\
&+ (0.020*X9) \\
&+ (0.036*X10) \\
&+ (0.129*X15) \\
&- (0.129*X19) \\
&- (0.006*X32) \\
&+ (0.00003*X34) \\
&+ (0.032*X52) \\
&+ (0.0008*X1*X1) \\
&+ (0.00006*X6*X6) \\
&- (0.0003*X15*X15) \\
&+ (0.0002*X19*X19) \\
&- (0.0009*X2*X14) \\
&- (0.00003*X52*X52) \\
&- (0.0000001*X52*X34)
\end{aligned}
\qquad \mathbf{(1)}
$$

Where:

- HEALTH= environmental quality index (Table 1)
- X1= perimeter of immediate vegetation
- X2= perimeter of intermediate non-vegetation
- X3= perimeter of distant vegetation
- X4= area of intermediate vegetation
- X6= area of distant non-vegetation
- X7= area of pavement
- X8= area of building
- X9= area of vehicle
- X10= area of humans
- X13= area of herbaceous foreground material
- X14= area of wildflowers in foreground
- X15= area of utilities
- X16= area of boats
- X17= area of dead foreground vegetation
- X19= area of wildlife
- X30= open landscapes = X2+X4+(2*(X3+X6))
- X31= closed landscapes = X2+X4+(2*(X1+X17))
- X32= openness = X30-X31
- X34= mystery = X30*X1*X7/1140
- X52= noosphericness = X7+X8+X9+X15+ X16

Table 1. Environmental Quality Index, adapted from Smyser (1982:95).

Variable		Score
A.	Purifies Air	+1 0 -1
B.	Purifies Water	+1 0 -1
C.	Builds Soil Resources	+1 0 -1
D.	Promotes Human Cultural Diversity	+1 0 -1
E.	Preserves Natural Resources	+1 0 -1
F.	Limits Use of Fossil Fuels	+1 0 -1
G.	Minimizes Radioactive Contamination	+1 0 -1
H.	Promotes Biological Diversity	+1 0 -1
I.	Provides Food	+1 0 -1
J.	Ameliorates Wind	+1 0 -1
K.	Prevents Soil Erosion	+1 0 -1
L.	Provides Shade	+1 0 -1
M.	Presents Pleasant Smells	+1 0 -1
N.	Presents Pleasant Sounds	+1 0 -1
O.	Does not Contribute to Global Warming	+1 0 -1
P.	Contributes to the World Economy	+1 0 -1
Q.	Accommodates Recycling	+1 0 -1
R.	Accommodates Multiple Use	+1 0 -1
S.	Accommodates Low Maintenance	+1 0 -1
T.	Visually Pleasing	+1 0 -1
	Total Score	________

To analyze the visual quality scores, the scores for photo-pairs of pictures and GIS images were ranked from one to fifteen, with the lowest score receiving a one and the highest score receiving a fifteen. The two columns of scores were compared using Kendall’s Coefficient of Concordance *W* (Daniel 1978), testing for similar agreement.

Results

The methodology generated a series of photo-pairs (Fig. 5). Overall, the scores ranked on the low end of the scale, with 22.53 as the lowest score assigned and 45.02 as the highest score assigned (Table 2). Each column of scores has an associated ranking. In Kendall's Coefficient of concordance, a *W* value of 0.8744 was generated. A corresponding Chi-Square table was consulted to determine if the derived value for Chi-Square was significant ($p \leq 0.05$) at fourteen degrees of freedom (Daniel 1978). Since the derived value of 24.48 is greater than the table value of 23.69, we rejected the null hypothesis and accept the hypothesis that the two sets of numbers are in concordance ($p \leq 0.05$).

Figure 5. An example of a photo-pair (pair number 9) from the study.

Table 2. Final Data Scores, Ranks, and Calculations.

Image	Picture Score	Picture Ranking	GIS Score	GIS Ranking
1	25.39	3	28.07	9
2	39.6	14	33.63	14
3a	22.53	1	23.63	2
3b	31.44	11	27.16	6
4	28.75	7	26.81	4.5
5	30.14	10	31.14	13
6	33.56	12	29.29	11
7	29.02	9	25.48	3
8	25.11	2	23.48	1
9	36.57	13	29,43	11
10	27.22	5	27.86	8
11	29.00	8	29.27	10
12	45.02	15	35.01	15
13	26.39	4	27.39	7
14	27.84	6	26.81	4.5

Discussion

In our study, we purposely selected 3-dimensional software that generated rough, somewhat pixelated images. Current state-of-the-art 3-demnsional software can generate much more refined representations. But we were more interested in determining if much less precise procedures would generate significant results. Our reasoning was that by using less precise software, we could examine the methodology to test for significant concordance under less than ideal conditions. In addition, we chose a set of images with somewhat low variation (rural agricultural landscape scenes) and only 15 pairs of images to also test the ability of the methodology to detect significant concordance.

The results of this research help to elevate the role GIS could serve in visual quality studies and the professional practices of landscape planning and design. Instead of needing photographs to judge the physical quality of a landscape, GIS images seem to produce comparable results to that of a photograph. This potential role of GIS could also have significant implications for the way designers and other landscape professionals perform preliminary inventory, analysis and design work. Initial site visits may be reduced by using readily available GIS data to perform preliminary inventory of landscape visual quality and analysis of where improvements need to be made. Early design ideas can be environmentally assessed with predictive equations and GIS data, all without having to repeatedly visit the site. There is potential for saving time and money, as the predictive equation is relatively simple to use and understand, and GIS data are already available and useful to many landscape professions. Overall, GIS may serve as a reasonable substitute to photographic images when determining the visual quality of an existing site.

Although the possibilities for GIS seem endless, additional research into the limitations of GIS in visual quality studies need to be performed. In response to the research conducted here, a reverse study could be performed where a map of visual quality is developed solely by evaluating GIS images of a specified area. GIS scores can be assigned to specific views covering a wide area of the test site; combining the scores would result in a GIS-based visual quality map. Once the map is completed, photographic images corresponding to the GIS images should be taken and evaluated under the same process as the GIS images. Comparing these two sets of data, with the GIS images serving as the primary data source, would help to determine whether or not GIS is fully reliable in a visual quality investigation. This reverse methodology could ultimately validate GIS as a valuable tool for future visual quality studies. In addition, the methodology described in this article could be examined with more precise spatial software to examine the capabilities of the procedures under more ideal conditions.

From our perspective, it seems that this approach has some merit for assessing landscapes and, in the planning and design stages, for development and natural resource protection. At a minimum, there is a science based statistical test to compare images. Nevertheless, there are some limitations to the current status of the work, especially with the current equations. First, a more "in-depth" study of visual quality containing an even larger set of images with varying landscape treatments needs to be conducted. In addition, there is one predictor which has not been studied that may explain individual variations in perception about human intrusion features such as billboards, buildings, people, and pavement --a sense of ownership. For example, if an industrial complex positively affects the economic well being of a person or if one is a fan of a local baseball team, the perception of the industrial site or stadium may be much more positive than someone who has no direct interest in the landscape features. The sense of ownership issue may account for some of the variance across respondents. Also, the perception of different respondent groups needs to be assessed for variations in response. It is possible that various respondent groups may perceive visual quality differently. Very little testing has been done in this area.

Conclusion

In an age where sensitivity to land quality and visual value is growing, we as landscape stewards need to analyze possible implications proposed landscape treatments within the existing environment. Visual quality assessments are but one way for landscape professionals and reclamation specialists to analyze existing conditions and proposed treatments. Often, however, site visits can be costly in terms of time and money spent. With GIS-based land-use maps so easily accessible and helpful to many other processes of site inventory and analysis, there is a need to determine the role GIS can serve to provide cost-effective visual quality assessment and predictive models.

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