POST-MINING PREDICTIVE VISUAL QUALITY ASSESSMENT: A METHODOLOGY[1]

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Abstract: The study of landscape aesthetics has recently been brought into the forefront of research through the passage of various federal legislative acts which mandate the consideration of the quality of surroundings as a natural resource. Based upon relatively recent results, we believe that science based visual quality modeling has applications in reclamation projects. We developed a visual quality prediction methodology to assess various post-mining land-use treatments (housing development, agriculture, open water, naturalized vegetation, and existing condition) for surface mining applications. Our methodology allows an investigator to qunatitatively assess visual quality treatments through inferential statistics. To conduct the assessment, one must be able to digitize photographic images and construct the treatments with an imaging software package.

Additional Key Words: landscape planning, land-use planning, landscape architecture, visual resource management

Introduction

Only recently has the aesthetic quality of a space has become a "mainstream" concern. With a series of legislative actions the federal government brought the topic of environmental scenic quality to the forefront. Laws such as the Wilderness Act of 1964, National Wild and Scenic Rivers Act of 1968, the National Trails Act of 1968, the National Environmental Protection Act (NEPA) of 1970, and the Coastal Zone Management Act of 1972 all contain articles that pertain to aesthetic quality (Ruddell et al., 1989, Leopold, 1982, Brown and Daniel, 1991, Latimer, Hogo and Daniel, 1981, Arthur, 1977). The NEPA states "it is the responsibility of the federal government to use all practical means ... (to) assure for all Americans ... aesthetically and culturally pleasing surroundings" (NEPA, sec. 101 (b)).

The passage of NEPA marked the turning point in acknowledging the landscape as a visual resource (Brown, 1994). Many government agencies needed to adopt this new attitude which led to new goal setting policies. The Forest Service includes the visual landscape in its mission statement "as a basic resource, to be treated as an essential part of and receive equal consideration with other basic resources of the land" (USDA Forest Service, 1977) and "one of the management goals for New England's forests is the consideration of aesthetics" (USDA Forest Service, 1973).

With the need to preserve scenic values, the scenic quality of an area now had to be defined, measured and manipulated in order to preserve these qualities. New management models have, and still are, emerging to aid in the assessment of the visual landscape.

The purpose of this paper is to describe the techniques used in federal projects for possible use in local and private projects. These methods of predicting visual impact could be used as design and management tools on the local level to mitigate the effects of high impact development. We have chosen to utilize these methodologies in aggregate mining.

Aggregate mining is a local land use that is widely distributed across the country. Aggregate is a basic construction commodity that accounts for 43% of all mineral commodities produced in the United States (Dietrich, 1986). Michigan has an estimated 5,000 total mine sites (Wyckoff, 1992) with 357 operating mines in 1994 (US Department of Interior, Bureau of Mines, 1995). On average this accounts for a total of

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60 mine sites, with 4.3 being active, in every county across the state.

Most of the current research related to mining has centered on the physical impacts of mining, such as how mining affects the biological, chemical and physical properties in various locations (Burley and Brown, 1992). Few researchers have attempted to understand the visual impacts of mining, although it is this factor that often creates the most disturbance (Surface Mining of Non-Coal Minerals, 1980). Mines and quarries degrade the visual character of an area by creating scale, form, color and texture discontinuities as well as by removing vegetation (Dietrich, 1986).

Land reclamation is defined as the restoring of the land to a productive use and controlling the on-site and off-site impacts (Leopold, 1982). If one of the most prominent impacts of mining is visual degradation, then it becomes imperative to understand and mitigate this impact.

Literature Review

The first step in being able to analyze landscape quality is the ability to define it. Landscape quality has been defined by the features that make up the landscape, the characteristic elements and attributes, and then the degree of excellence which that landscape possesses (Daniel and Vinning, 1983).

Questions pertaining to landscape definition and landscape assessment have led to differing forms of landscape assessment models. In their review of various landscape models, Daniel and Vinning (Daniel and Vinning, 1983) categorized all landscape quality models into five classes. Within these classes some apply directly to landscape visual assessment while other models do not. Looking at the full range of classes is helpful in understanding the theoretical nature of the work.

Landscape Quality Models

Ecological Model. The ecological models are typified by McHarg's model that defines the landscape in terms of its biology. It places a high value on natural functions such as diversity and biomass production, while placing a low value on cultural values such as appropriateness and visual human impact (Daniel and Vinning, 1983). This class of model predisposes against human interference in the landscape and assumes that most human activities will have a negative impact. While this model has great ramifications for ecologically sensitive design, it only has limited applications in the field of visual quality modeling.

Formal Aesthetic Model. The formal aesthetic model is the most commonly utilized landscape visual assessment model as it is used by the Forest Service (USDA Forest Service, 1984) and the Canadian Ministry of Forests (Ministry of Forests, 1981). This model relies on the design principles to guide the designer to find the most appropriate solution. The appeal of this approach is that it allows agencies to utilize existing personnel, skills and often existing data to implement the model (Brown, 1994) making it cost effective (Leopold, 1982).

The formal aesthetic model has severe limitations in that it is capable of rating and comparing various landscape development alternatives only in a very rudimentary way. This model is a set of principles used to guide the designer.

Psychophysical Model. The psychophysical model creates a quantitative relationship between physical environmental stimuli and perceptual responses (Hull, Buhyoff and Cordell, 1987). This approach selects individual stimuli in the landscape and then develops mathematical models in order to explain the human response to the stimuli. Many of these models are oriented toward measuring the effect of a single-factor stimulus such as waterflow quantity (Brown and Daniel, 1991), atmospheric optical quality (Landphair, 1979) or forest visual quality (Ruddell et al., 1989). Other models have expanded this concept in order to determine the visual quality of entire landscapes (Shafer, 1969, Burley, 1995).

The strength of the psychophysical approach lies in its ability to relate change in manageable site characteristics to resulting impacts on visual quality (Ruddell et al., 1989). This model has direct applications to the field of visual quality management due to its ability to identify the portions of the landscape that elicit positive or negative responses and gauge the magnitude of change, allowing various landscape alternatives to be compared.

Psychological Model. The psychological models attempt to determine the users' response to the landscape in terms of their feelings and perceptions. This model rates landscapes on informational variables, such as how space organization is interpreted and whether the user understands this organization (Kaplan and Kaplan, 1989). The most notable psychological models have been developed by the Kaplans (Kaplan, 1979) and Appleton (Appleton, 1984).

This model incorporates the feelings that the landscape evokes within the viewer, expressing the landscape in terms of security, relaxation, warmth, freedom, happiness, stress, fear, insecurity, gloom, constraint, prospect and refuge.

Although the psychological model is strong theoretically, its use of conceptual variables makes it difficult to apply in predicting scenic quality.

Phenomenological Model. The phenomenological model places the greatest emphasis on individual feelings, expectations and interactions between the user and the landscape. The model typically elicits responses from the participant in the form of a questionnaire. The model then assesses the person-landscape-context interaction. This results in assessments that are extremely complex and too variable for this model to be used as a landscape management tool (Daniel and Vinning, 1983).

Visual Quality Applications

In order for any model to be useful in assessing landscape visual quality, it must be possible to use it as a development tool which guides the designer to find visually pleasing solutions. As a development tool the model must be predictive in nature, allowing the designer or manager to determine the visual quality before the landscape is altered (Arthur, 1977). Scenic resources should be evaluated in an objective and quantitative fashion (Carlson, 1977). The only models that have the qualities for determining landscape visual quality are the psychophysical and the formal aesthetic models.

Model Comparisons

Validity. Although the formal aesthetic model is the most widely used form of visual quality modeling, it does present serious drawbacks. The model presents serious reliability concerns as this model is the most dependent on expert judgment (Carlson, 1977) and it does not present a standard methodology for testing results. The results of applying the formal aesthetic model are not reproducible, so the outcome of applying the model cannot be duplicated to test its validity. Therefore, the validity of this model is solely dependent on the expertise of the designer.

The psychophysical model overcomes the validity problem associated with the formal aesthetic model; the application is more objective, being less dependent on the skills of the designer, and utilizes a mathematical model to determine the magnitude of the visual quality. This model allows different landscape alternatives to be quantified and tested against each other. This testing of alternatives removes the subjectivity from the process that is inherent in the formal aesthetic model (Miller, 1984).

Quantification. Both the psychophysical and the formal aesthetic models are predictive landscape visual quality models, that is, they both forecast the net result of landscape alterations on visual quality before the changes occur. However, the formal aesthetic model can predict only what the net effect should be, not the magnitude of the change; it can only suggest that the resulting view will improve or degrade visual quality.

The psychophysical model can also predict the direction of change as well as quantify the significance of the change. This allows the designer or manager to make informed decisions on the relative visual quality of the proposed changes.

Public versus Expert Opinion. The models split with regards as to whose interpretation of a landscape is the more appropriate to use. Though the expert may have the greater understanding of the landscape, the local public probably has the greater attachment to the land. The formal aesthetic model is clearly dependent on expert opinion, but the psychophysical model, such as Shafer's, is based on public opinion and public interpretation of the landscape. The research surrounding public versus expert opinion is confusing and often contradictory. A summary of 11 different studies that compared results of surveys of both professional and public opinion found that one third of the time they strongly agreed, one third of the time they strongly disagreed and one third of the time they were in moderate agreement, suggesting that there is no correlation between the two groups. This study did determine that the public tends to decide on perceived naturalism while professionals tended to be biased according to their own professional perspectives (Palmer, 1984).

This problem becomes more involved with the question of which public to use, tourist or resident? Rachel Kaplan (Kaplan, 1979) compared the results of testing residents versus tourists on visual quality. She found tourists were more interested in preserving the regional characteristics and the residents were interested in creating a regional flavor to a particular setting.

The questions of who the arbiter of landscape visual quality should be is confusing. No definitive study has been conducted to determine this. It could well be that the determining group could be dependent on the location, type, and intent of the landscape modification.

Landscape Representation. The model that has required the most validation for the techniques it uses is the psychophysical model. While many other models may use photography and computer generated depictions, the psychophysical model is dependent on them.

The validity of using landscape representations in place of the actual landscape has been an area of active research. The spectator of the natural environment is within that environment in a way which the spectator of a photograph is not withinin the photograph (Carlson, 1977). In early work Shafer even states that "complete understanding of the perceptual process requires the inclusion of experience and of its lasting traces in the memory (Shafer, 1969). A wide variety of studies have determined that black and white photographs and color slides are accurate representations of a landscape and participants react to the images in the same way they would react to the landscape itself (Stamps, 1992, Waztek and Ellsworth, 1994).

Using photographs in modeling has advantages and disadvantages. The use of photographs allows for techniques such as photomontage and photomanipulation so that accurate representations of the proposed changes can be constructed. The most important term here is "accurate". The models are a valid representation if the respondent cannot detect that the photo has been altered (Orland, 1994) and if representational deviations are less than 6% (Waztek and Ellsworth, 1994).

Other landscape representational techniques such as hand rendering or computer generated images, such as from CAD programs, do not elicit responses equal to the actual landscape and therefore are not valid substitutes for the landscape (Zube, 1984).

Model Considerations. Shafer's equation in the psychophysical model includes three primary implementation concerns. First, Shafer makes the assumption that aesthetic quality is correlated with a preference for that landscape. In fact, Shafer seems to use these terms almost interchangeably (Carlson, 1977). A preference for a landscape might, or might not, be directly related to the perceived beauty of a landscape.

A second concern of this model is that it lacks any theoretical basis. This psychophysical approach has received criticism as these models are developed without any theoretical basis (Weinstein, 1976). Although these criticisms are appropriate to consider, we do not believe that this invalidates the results. In other disciplines, statistical relationships are considered acceptable without accompanying theories (Burley, 1995). The third concern is the inherent negative attributes of this form of equation. When one considers the wide range of elements that occur in landscapes, it becomes clear that an equation in this form could never account for them all. To attempt to accomplish this would mean an infinite number of variables that could be added to the equation to account for all possible situations. But without testing for all of these variables it is impossible to know their effect on visual quality. Using this logic it may be possible to predict the primary influences in visual quality, but it becomes inherently impossible to account for all of the factors that may play a role.

Future Model Development. Landscape quality models seem to be moving in two clear directions. First is the theoretical basis. These researchers tend to discount current models for any long-term use as they fail to have any theoretical basis (Bourussa, 1991, Weinstein, 1976, Carlson, 1977). The models that do have strong theoretical bases are developing into biological models. They attempt to explain man's interpretation of his surroundings in terms of inbred biological responses. Appleton (1984) has used a holistic approach to attempt to explain human aesthetic responses by inbred biological needs. This model has two basic forms. First is the "prospect," where primitive man sat in a space viewing his prey without being spotted. Conversely, the "refuge" is a landscape where primitive man was able to find shelter and refuge from the environment and other predators (Appleton, 1984). Modern man interprets these as spaces that may elicit feels of security or exploration.

The Kaplans have conducted research in a similar direction. They tested for similar inbred traits from our ancestry to determine if responses to landscapes are influenced by man's ability to understand the landscape, to comprehend the surroundings, and to gather information (Zube, 1984).

A second direction is being called for in model development. Hamilton, et al., (1979) call for further development of the psychophysical models:

> "Much of the validity testing has been done; predicting for limited subjects, testing the validity of simulations, biases in research methods etc. What is needed is a more elaborate and theoretical model that predicts scenic beauty magnitude and estimates the change in value resulting from landscape modification. Planners need to ask how much better... Landscape quality models need to become landscape utility models that are equations that clearly show cause and effect relationships in landscape alterations ..."

The existing predictive equations were a first step but they now believe that it is time to move past these models. Researchers believe that these models could be used to move toward finding a theoretical basis for visual quality (Hull et. al., 1987).

Within the limits of the existing models, the psychophysical model appears to be the most capable of estimating the magnitude of visual quality changes. This is the only model that is capable of directly comparing landscapes or landscape alternatives, to determine their relative visual quality. This allows the landscape manager to determine the significance in visual quality that alterations on the landscape will have.

Problem Statement and Methodology

The Existing Problem

When a new aggregate operation is proposed within a community, the opposition that it faces can be severe. The local citizens are concerned about the negative impacts that the mine could have on the community. Some of these impacts, such as groundwater contamination, noise pollution, and increased truck traffic, are relatively easy to predict and monitor. Other impacts, such as visual degradation, have been difficult to monitor and measure. Impacts that are ambiguous and ill defined can result in arguments that are highly emotional, which tend to lead away from an objective decision making process.

Until recently, techniques for determining and measuring visual quality have not existed, and they are still developing. Although they may not have reached a high degree of sophistication they do provide a reliable yardstick against which proposed changes to the landscape can be measured. These models offer a methodology that takes visual quality out of the heuristic and personal judgment stages and places them in a form that can be quantified, analyzed, and compared to determine their quality within the setting.

This approach allows all of the parties involved to make more rational decisions, based on sound principles. It also allows them to determine if their existing assumptions regarding visual quality of mine sites and reclaimed sites are correct or how sites could be altered to improve their visual quality.

Approach

The approach described in this paper determind measurable visual quality differences between various landscape reclamation treatments and the existing mining conditions. To accomplish this research, photographs of the case study mine sites were altered to simulate various proposed post-mining conditions. The visual quality of the existing and post-mining views were then determined by applying Burley's (1997)visual quality equation and statistically analyzed using Friedman's two-way analysis (Daniel 1978).

A Typical Study Design

We would suggest taking a series of black and white photographs at each mine site using a SLR camera fitted with a 50 mm lens. This camera configuration was chosen as it best reproduces a view as seen by the human eye (Schaefer, 1992). Black-and-white photography is suggest because color is not a variable within Burley's visual-quality equation. Also black-and-white images require less memory when entered into a computer (Adobe, 1994).

The mining sites can be typically photographed from the perimeter of the operations area so that the resulting views are generally oriented into the active pit. The photos depict the conditions that can exist within an active pit including views of crushers, screeners, trucks, cars, cranes, shovels, waste piles, utilities, vegetation, standing water, reclaimed areas, steep eroded banks and sheer rock faces.

We would suggest choosing thirty photographs to represent each of the sites. At least sixty photographs can demonstrate the wide range of conditions possible between two sites. Once the photographs have been developed and printed, they can be scanned into a computer using a flat bed scanner at a moderate resolution of 150 lines per inch.

Along with the mining photos, we suggest scanning other landscape images at this time. Other landscape photographs taken throughout the study area create a library of scenes that could be used to construct post-mining treatments representing the reclaimed mine sites.

With scanned images, one can then construct images to represent the different post-mining treatments such as the existing mine site, agriculture, single-family housing, natural revegetation, and open water. We suggest picking a future period such as a 10 to 20 year time lapse from the time of mining cessation to assist in constructing an image of the treatment.

Once the treatments are complete, we suggest projecting these slides onto the rear of a translucent screen. The screen had an 8" x 10", 1/4" grid drawn on it for the tabulation of the visual-quality equation. The translucent screen allows one to work in front of the screen without blocking the projection of the image. From this grid one can count each variable and enter the resulting values into Burley's equation (Equation 1). The variables for this equation were developed by Shafer and Burley (Table 1). Within this equation, one variable requires further computation in order to gain a resultant. The environmental quality index is calculated from Table 2.

$$
\begin{aligned}
Y = {} & 68.3 - (1.878 * Health) - (0.131 * X1) \qquad (1) \\
& - (0.064 * X6) + (0.020 * X9) + (0.036 * X10) \\
& + (0.129 * X15) - (0.129 * X19) - (0.006 * X32) \\
& + (0.00003 * X34) + (0.032 * X52) + (0.0008 * X1 * X1) \\
& + (0.00006 * X6 * X6) - (0.0003 * X15 * X15) \\
& + (0.0002 * X19 * X19) - (0.0009 * X2 * X14) \\
& - (0.00003 * X52 * X52) - (0.0000001 * X52 * X34)
\end{aligned}
$$

Table 1 Visual Model Variables

Health = from the environmental quality index
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 buildings
X9 = area of vehicles
X10 = area of humans
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 landscape:X2+ X4+(2* (X3+X6))
X31 = closed landscape:X2+X4+(2*(X1+X17))
X32 = openness: X30 - X31
X34 = mystery: (X30 * X1 * X7) /1140
X52 = noosphericness: X7+X8+X9+X15+X16

Table 2 Environmental Quality Index

Purifies air	+1	0	-1
Purifies water	+1	0	-1
Builds soil resources	+1	0	-1
Promotes human cultural diversity	+1	0	-1
Preserves natural resources	+1	0	-1
Limits use of fossil fuels	+1	0	-1
Minimizes radioactive contamination	+1	0	-1
Promotes biological diversity	+1	0	-1
Provides food	+1	0	-1
Ameliorate wind	+1	0	-1
Prevents soil erosion	+1	0	-1
Provides shade	+1	0	-1
Presents pleasant smells	+1	0	-1
Presents pleasant sounds	+1	0	-1
Does not contribute to global warming	+1	0	-1
Contributes to the world economy	+1	0	-1
Accommodates recycling	+1	0	-1
Accommodates multiple use	+1	0	-1
Accommodates low maintenance	+1	0	-1
Visually pleasing	+1	0	-1

Using this formula, one can calculate the value for each component by counting the number of squares that each variable occupied on the screen and computing the score.

Numerical Analysis

In order to determine the significance of the results from the visual quality formula one can utilize the Friedman two-way analysis of variance by ranks test (Daniel, 1978). If the null hypothesis is rejected, at least one treatment was significantly different from the others. A multi-comparison procedure identifies which treatments are significantly different.

Discussion and Conclusion

Applications of the Visual Quality Equation

The most direct application of this quantitative visual quality equation is its use as a design tool. By utilizing the equation and maximizing the variables that have a positive effect while minimizing the negative effect variables, the visual quality of a view can be increased. Therefore it is not important to have a detailed understanding of the model. What is important is to determine which elements will raise visual quality, which elements will lower the visual quality, and then to use these variables to the design's advantage.

In the past these design decisions have generally been relegated to expert opinion. When any aesthetic issue was involved, the site manager deferred those questions to the architect, landscape architect, or the designer. Many have believed that the professionals who have been trained in the design principles have a deeper understanding of their surroundings. With the development of the visual quality equation this no longer needs to be the case. The site manager could use this model to gain insight into design and have a greater ability to work with the designer to find the most appropriate solution. An example of how the manager and designer could collaborate is in the design process. Many municipalities currently have landscape or aesthetic ordinances that regulate the quantity, density, and species of plant material that are required. The shortcoming of this approach is that they attempt to apply a standardized solution to situations that vary widely. The resulting landscapes are often inappropriate. Although they may serve the intended purpose, they may also create new conflicts because they cannot account for the variety of site variables.

The alternative is to set quantitative visual quality standards. In place of specifying planting plans the municipality could mandate that the existing visual quality could not be altered by more than a specified range. This would allow the designer to determine the most appropriate and economical method to achieve the standard. The designer would have the freedom to use site characteristics, such as topography, to develop creative solutions in order to mitigate the visual quality impact of the mine site. The municipality could be included in the process and have a better understanding of the constraints and tools that the designer used to reach the design solution.

One concern of this approach is that visual quality may not be the primary concern of the municipality. If the objective of the community master plan is economic development, then applying strict visual quality standards could be argued as being inappropriate since there is a predisposition in the equation to favor natural settings.

This should not be interpreted as meaning that the equation would be irrelevant. The visual quality equation could still be used as a design tool to mitigate the effects of the development. Its principles could be utilized to reduce the blighted appearance that many industrial zones now have. The effect could be one of the industrial campus that many firms are now promoting.

Conclusion

By quantifying visual quality both designers and regulators are now able to predict the visual impact that pit mining and various reclamation treatments will create. This ability to predict and systematically analyze the effect of proposed changes is important because it adds rational and objective decision making to a process that is currently highly subjective and emotional.

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