VISUAL PERCEPTION OF TEXTURE: DEVELOPMENT OF A SCALE OF THE PERCEIVED SURFACE ROUGHNESS OF BUILDING MATERIALS*

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ABSTRACT

The general question of how we can describe our experience in an environment was specified by asking how we can describe textural experience. As an initial step toward the full description of textural experience, the present paper focuses on the visual perception of surface roughness of different building materials. This study consisted of two parts: in Experiment I, 37 different finishes were judged by 20 subjects on an abbreviated semantic-differential scale. The relevance of surface roughness to the overall evaluation of texture and the effects of surface roughness on the "richness" of texture was found. In Experiment II, two different but closely related psychophysical experiments, both using textured plaster panels 12 cm x 12 cm in size as stimuli, were conducted. In the first one, a linear relationship in log-log coordinates was found between subjective visual roughness and physical roughness. In the second one, a linear relation between the rank score and grain size was obtained. The above two relations were combined to create a scale and a set of equations which are usable for the measurement of apparent surface roughness.

INTRODUCTION

Texture is an aspect of buildings and landscapes which environmental planners and designers always manipulate, yet with very little clear understanding of how people actually perceive or evaluate differences in texture. Other than some strictly laboratory experiments (e.g., Stevens, 1962), no research has looked at this phenomena in an environmental context. Texture is thus one of the important concepts in discussing the perception of the physical environment. The concept, however, is not easy to define. Originally, the word "texture" was a textile term, a quality of fabrics appraised and appreciated through the sense of touch. We can appreciate texture, however, not only by touching the surface of an object but also by viewing it. Once we have touched and viewed the texture of a certain material, we can visually feel its texture without touching it again. In other words, without requiring further tactile application, the previous tactile experience returns to our mind when we next appraise the texture visually.

Unlike form or object perception, texture may be appreciated without applying focal attention or tuned sense organs. Texture creates a background from which attended objects stand out, and contributes to enhance the subtle ambience or feelings of the environment.

The visual field surrounding us contains numerous objects, elements, and spaces differing continuously in size between the smallest and largest sizes theoretically visible. We selectively perceive visual objects of a certain scale, and at the same time we perceive texture which is composed of smaller elements not perceived independently. In other words, the elements which comprise texture belong to hierarchically lower levels of size and create background, as opposed to the object, element, or space to which an observer is paying focal attention.

The multi- and cross-modal property of texture perception, the subtleness in its effects, its unfocused attention, and the wide range of size and scale involved, all make the concept of texture illusive. They also suggest the importance of the systematic study of it as a part of a total understanding of environmental perception.

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The characteristics of texture perception are just like those of environmental perception in general. Ittelson (1973) discussed and defined environmental perception as contrasted with object perception with which virtually every major school of psychology in the past 100 years has concerned itself. The study of texture perception, inasmuch as it is the study of "backgrounds," and of ambience, not of focal objects in space, may, I believe, help to show an alternative to the traditional object-oriented approach still taken in much of the study of environmental perception.

Context

Artists and architects have long been concerned with textural effects (Arnheim, 1954; Rasmussen, 1959). Systematic research, however, has not been done in the field. Interest in texture as a variable in vision research has stemmed mainly from the work of J.J. Gibson (1950). Gibson's discussion extended to various effects of texture in visual perception, but subsequent attention from psychologists has been focused on fairly limited topics like the effects of texture on the perception of surface slant or curvature (e.g., Smith and Smith, 1961). Another relatively new approach to textural effects in visual perception has emerged in a part of psychophysics which has investigated perceptual process of pictorial stimuli generated by computers (Julesz, 1962; Picket, 196+). Studies of visual texture in this field deal mainly with the descrimination of texture using a computer-generated random dot or grid-type texture. Since the pictorial stimuli are controlled by computer, this approach may be appropriate to investigate the structure of texture, but they cannot represent the richness of the global (or environmental) impression of texture. It is doubtful that those abstracted patterns can evoke textural impressions.

The set of experiments reported below are part of a first attempt, therefore, to systematically study the visual perception of texture as a part of environmental perception. The step taken in the present experiments was to work directly with real textures of actual building materials (slightly abstracted to control some unwanted variations, such as in color).

Experiment I

It is often said that a certain material looks most beautiful with a particular finish treatment. It is also noted that materials with poor textural effects are improved by deep relief, while materials of high quality can stand a smooth surface and, in fact, appear to best advantage without relief or ornament. In practice, architects control textural effects by selecting both the material and the finish treatment. One of the variables frequently manipulated is the roughness of the finish. Experiment I investigated the psychological effects of roughness of finishes on the appearance of different building materials.

Method

Subjects - Twenty male university students from the School of Architecture at the Tokyo Institute of Technology served as subjects.

Measures and Procedure - Thirteen kinds of materials, each with two or three degrees of roughness, for a total of thirty-seven different finishes, were judged by each subject on an abbreviated semantic-differential scale. The scale consisted of six bipolar adjective pairs: rich-poor, rough-smooth, bright-dark, hard-soft, heavy-light, and warm-cold. These adjective pairs were selected from a previous study (Ohno, Chatani, & Suwa, 1972). The stimuli, 15 cm x 15 cm in size, were presented in random order to the subjects through identical windows opened in a 90 cm (wide) x 180 cm (high) white painted wall. They were lit with an angle of incidence of 45^{0}. The observation distance was 1 m.

Results

The correlation coefficient between adjective pairs was calculated from the data (Figure 1). A significantly high correlation was noted between "hard-soft," "heavy-light," and "warm-cold." "Hardness" was therefore taken to represent the other two.

On "hard-soft," there was a significant difference in subjects' perceptions of materials but not between the different roughnesses of finishes (Figure 2). On "rough-smooth," however, there was significant difference in the perception of finishes but not between different materials (Figure 3). There were no significant differences on the other two pairs, "bright-dark" and "rich-poor."

However, when examining each material individually, an inverse relationship was found. For materials without patterns in their structure, e.g., concrete, degree of richness was directly related to degree of roughness, while for materials with patterns, e.g., marble, the opposite was true, namely degree of richness was related to the degree of smoothness (Figure 4).

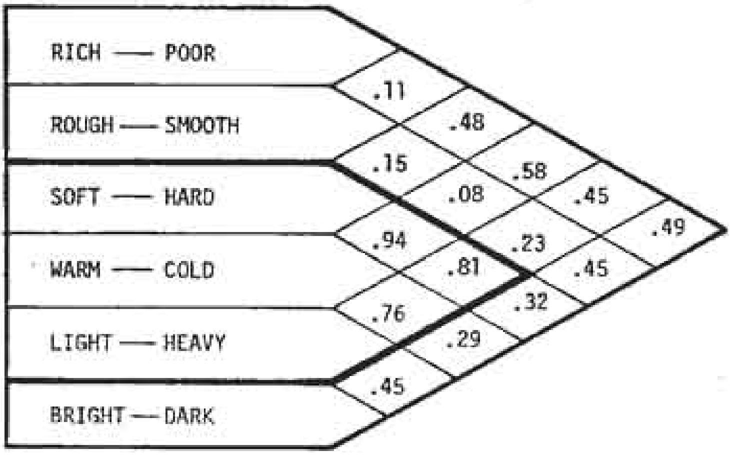
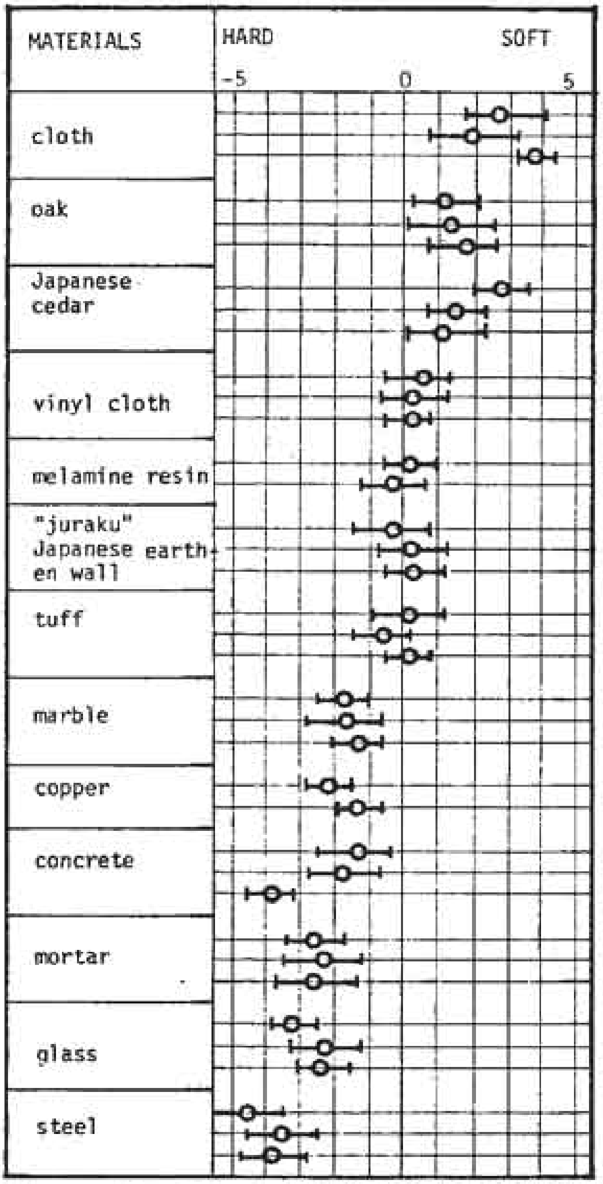


Figure 1. The correlation coefficients between adjective pairs.



(○:geometric mean, ⊢⊣:95 % confidence interval)

Figure 2. Sample materials evaluated on the "Hard - Soft" scale.

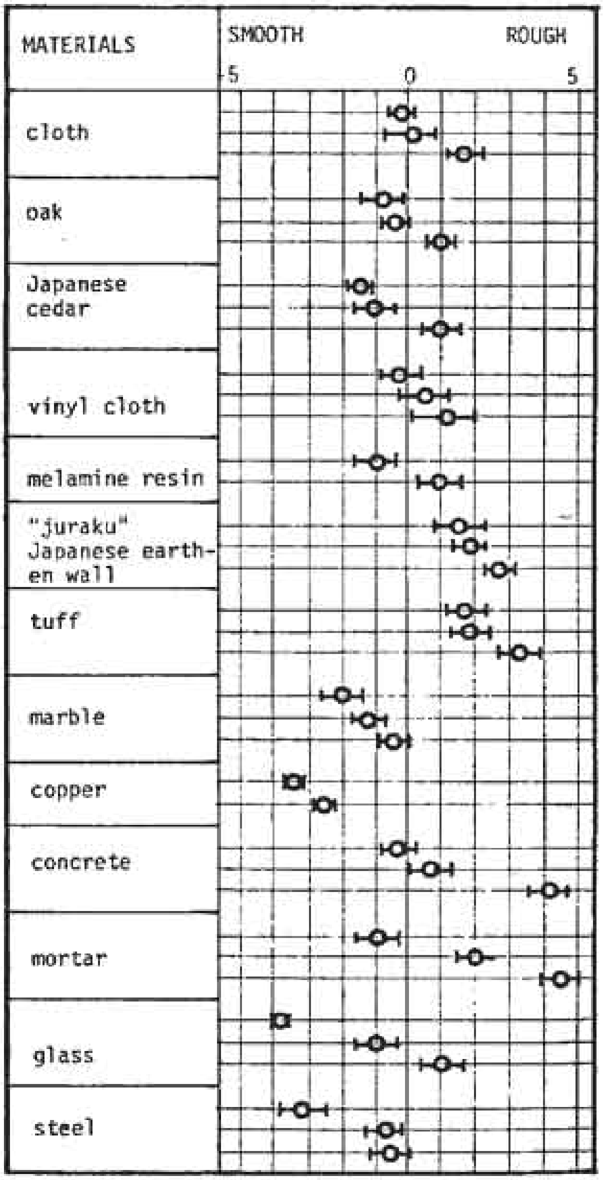


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Figure 3. Sample materials evaluated on the "Smooth - Rough" scale.

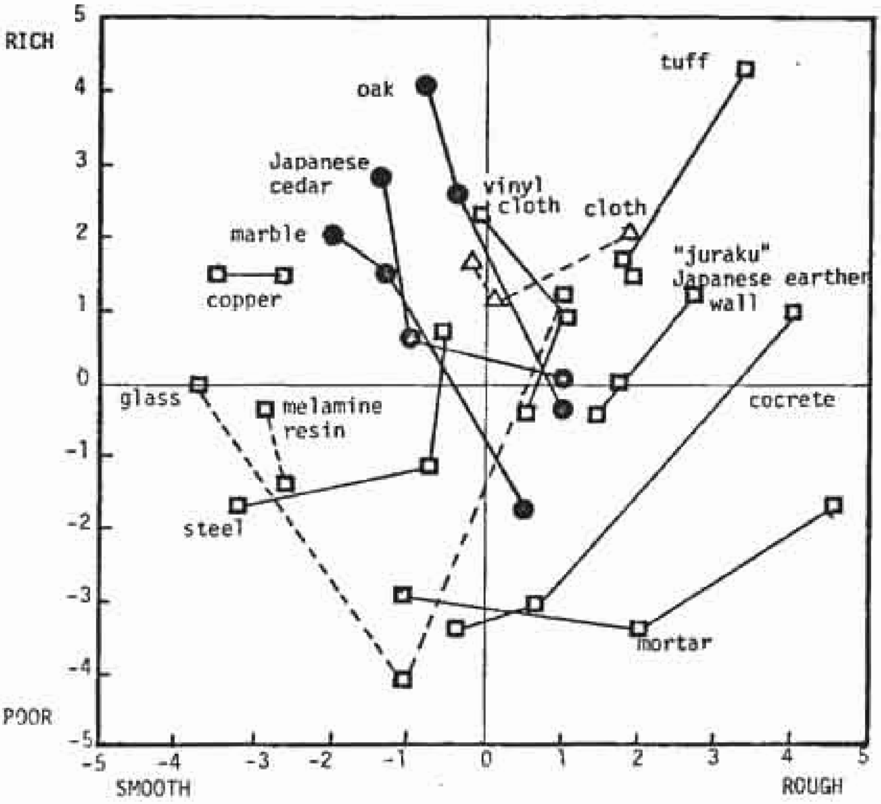

Figure 4. The relationship between the apparent roughness of a finish and the richness of its texture.

Discussion

As a result of Experiment I, we see that perception of surface roughness is a factor in evaluating building materials even though there aren't many steady relationships between roughness and appearance. Although this has been well recognized before, there is no common scale to measure the surface roughness of different materials and to communicate it.

It would be convenient for designers to have a standard scale indicating the subjective surface roughness of any given material--i.e., through the "eyes" of actual building users. Instead of using finishing instructions like "hammered," designers could then base finishing instructions on an empirical perceptual scale.

Experiment II

Experiment II attempted to develop and test a scale of subjective visual roughness and to establish a method for estimating the degree of visual roughness of actual material finishes.

Stevens (1962) conducted an experiment on judgments of tactual roughness and smoothness by using sandpaper. The first part of this experiment follows Stevens' method--the method of magnitude estimation.

Experiment IIA

Method

Subjects - The subjects were five architecture students from the Tokyo Institute of Technology. Each subject performed the below task 8 times for a total of 40 subject-times.

Measures and Procedure - The stimuli were 20 textured plaster panels that varied systematically in terms of roughness. The panels were constructed of plaster which was made of different grain sizes of sand and larger aggregate spherical particles (e.g., roughness equivalent to very fine sandpaper versus equivalent to pebbles). The size of the textured area of the panel was 12 cm x 12 cm.

Magnitude estimation was employed to obtain the relationship between subjective visual roughness and physical roughness (grain size).

The standard panel with 1.00 mm grain (No. 14) was presented first and each subject was told to call it 10 (ten). Each of the 5 subjects was asked to do the task twice a day, totally 8 times. The instructions of the task were: "I am going to present a series of surfaces that vary in roughness. Your task is to tell me how rough they feel by assigning a number to each. The first will be the standard roughness which we will call 10 (ten). Your task is to assign numbers proportional to your subjective impression. You may use whatever numbers seem appropriate."

Results

The results for each panel (the average response for all 40 subject cells) is shown in Figure 5. The data from those panels (No. 1-No. 5) which were found difficult to judge in terms of their roughness were eliminated from the analysis.

The magnitude estimation of roughness (S_r--subjective visual roughness) was found to be approximately linearly related to grain size (D) when plotted in log-log coordinate (Figure 5). The linear regression equation for this relation was found to be the following:

$$\log S_r(D) = \beta \log (D-D_0) + \log \alpha \text{ , or} \qquad (1)$$

$$S_r(D) = \alpha (D-D_0)^{\beta} \qquad (1')$$

where α = constant (unknown at this time)
β = constant = 1.5
D_0 = absolute threshold (unknown at this time)

This seems to meet the psychological power law. The exponent 1.5 implies that the increase in subjective roughness of different textures is a function of something between the diameter of a grain (D) and the area of a grain (D^2).

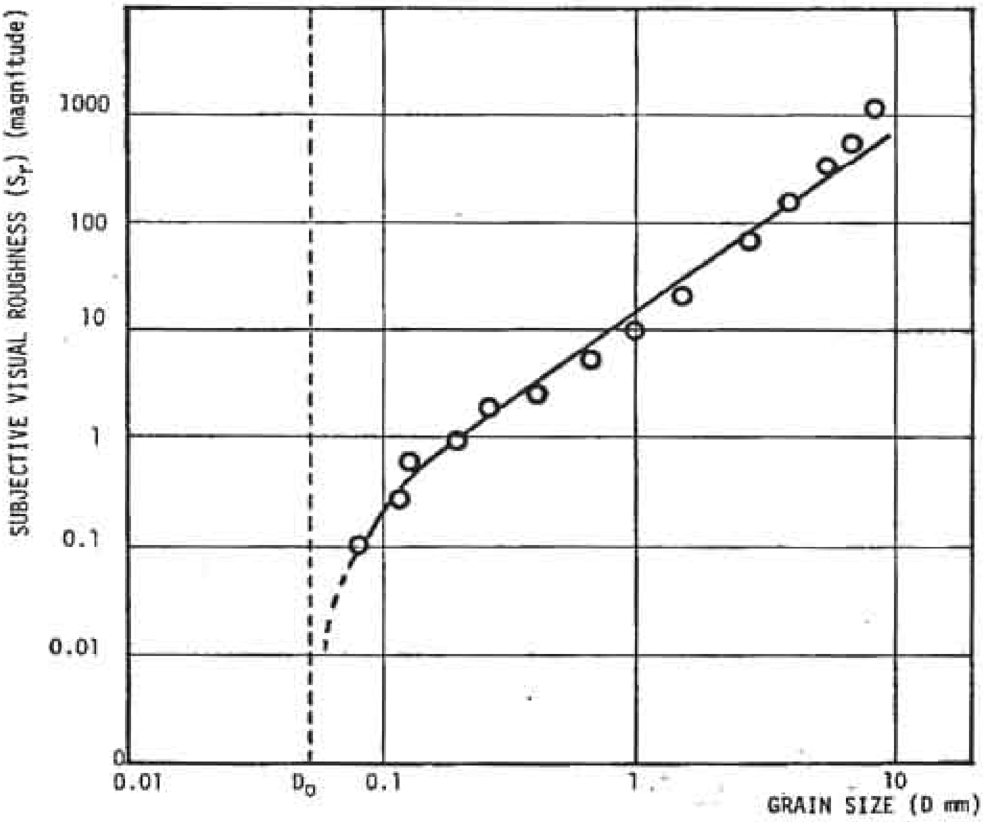

Figure 5. The relationship between grain size (D) and Subjective visual roughness (S_r).

Experiment IIB

Method

Subjects - The subjects for this experiment were 20 architecture students from the Tokyo Institute of Technology.

Measures and Procedure - In addition to the 20 standard granular panels, another set of plaster stimuli were prepared. Their surfaces were constructed of plaster casts of 33 different finishes of actual building materials, such as hammered granite, sprayed resin, concrete block, and so on.

Both sets of plaster panels, totaling 53 stimuli of identical size, were randomized and presented as a group to each subject. The subject was asked to sort the 53 panels into categories of relative roughness versus smoothness. The subject could use as many categories as he or she wished, and could place as many or as few panels in each category, including the possibility of a category having no actual sample panel in it. The categories of the resulting dimension, however, had to be an interval scale.

Results

The data was normalized by the following equation:

$$S_i = 10 \times \frac{n_i}{N}$$

where S_i = normalized rank score for each sample panel i,
n_i = ranking of category to which panel i belongs
N = total number of categories used by the subject

In Figure 6, the results of average rank score (S_0) for each standard panel (the geometric mean response for all 20 subjects) is plotted against grain size (D) in semi-log coordinates.

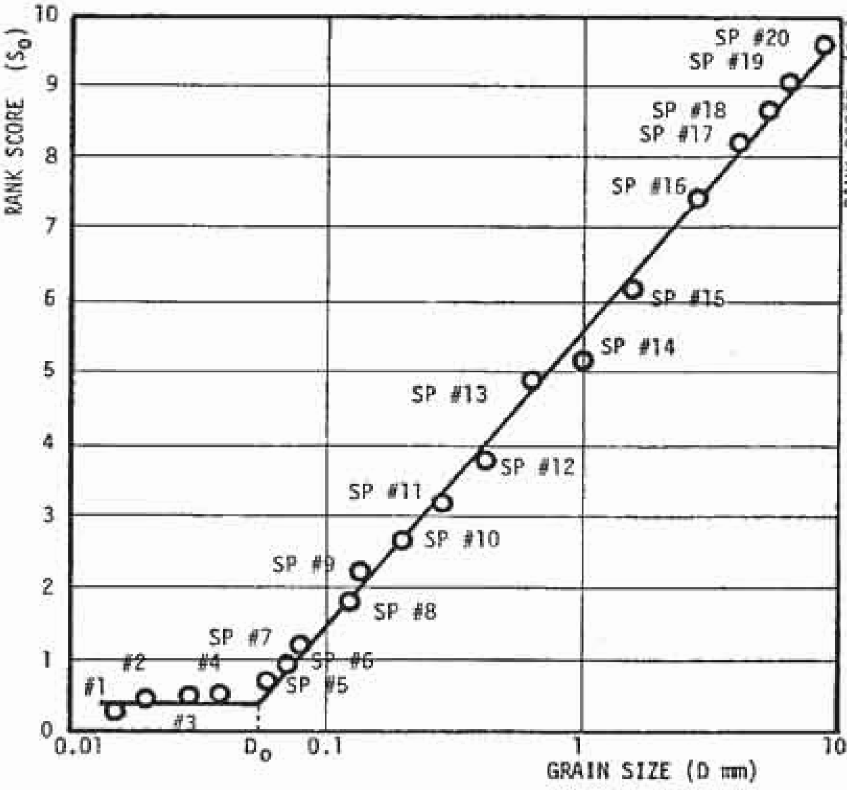

Figure 6. The relationship between grain size (D) and rank score (S_0).

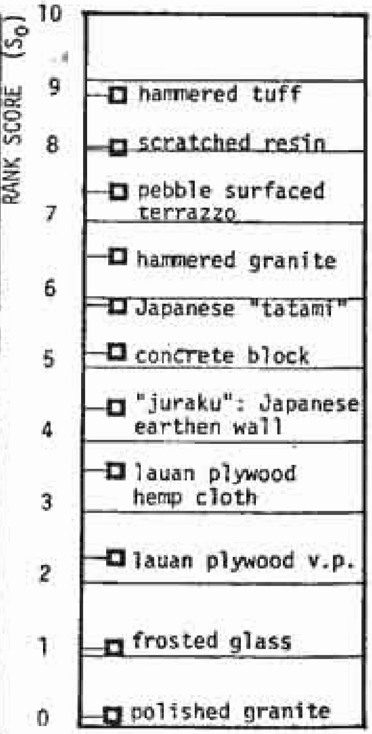

Figure 7. The average rank score of finishes of actual building materials.

The relationship between the average rank score for the standard panels and the logarithm of grain size of the standard panels was found to be linear and to be described by the following equation:

$$S_o(D) = \alpha \log D + \beta \qquad (2)$$

where $S_o(D)$ = average rank score
α = constant = 4.1
β = constant = 5.6

The point of inflection (around $D_o = 0.05$ mm) can be thought of as a threshold of visual roughness because four standard panels whose grain sizes were different but all finer than D_o were perceived equally in terms of roughness-smoothness.

The average rank score for each of 33 non-standard panels (plaster casts of finishes of actual building materials) was calculated in the same way. Figure 7 shows a part of the result.

Discussion of Experiments IIA and IIB

In order to define the physical roughness of each non-standard panel in terms of grain size, the above obtained equation (2) was transformed as follows:

$$D = 10^{\frac{(S_o - 5.6)}{4.1}} \qquad (2')$$

where D = grain size
S_o = average rank score

The degree of perceived surface roughness of a material, whatever the structure of the material, is thus shown by the grain size of a standard panel which provides a subjectively equivalent impression of roughness. For example, the equivalent grain size of the hammered granite ($S_o = 6.6$; see Figure 7) is 1.8 mm, which means it appears as rough as the standard panel with grain size of 1.8 mm.

The values of the unknown constants (D_o, and α) in equation (1') of Experiment IIA were determined by the result of Experiment IIB (the point of inflection in Figure 6). Thus, we obtained:

$$S_r(D) = 11(D - 0.05)^{1.5} \qquad (3)$$

Translated, this means that the subjective roughness of a surface is a function not of its diameter, nor its area, but is a function of a constant times something between its diameter (D) and its area (D^2), namely the exponent 1.5.

CONCLUSIONS

There are two major results from this set of experiments.

1. The effect of surface roughness of finish on the overall perception of textures has been found to have two inverse tendencies which seem to relate to the homogeneity of the structure of materials. Materials with perceptual patterns (like marble) are evaluated as being richer proportion to the smoothness of their surface finish, while materials without patterns (like concrete) are evaluated as being richer proportion to their roughness.

2. A systematic method of measurement has been developed and tested which relates apparent (subjective) surface roughness of building materials to their actual construction in terms of equivalent grain size. This method thus allows two operations important in the study of environment-behavior phenomena and in their application to architectural design: (1) the estimation of perceived roughness of a chosen building material and surface finish; and (2) a systematic way to select different building materials and finish conditions so that they will have a desired textural impact.

Though the method is still in its infancy, when finalized, it would work as follows: to find out the subjective visual roughness of a new building material (i.e., one not on the chart in Figures 6 and 7), the investigator would first compare it with the standard plaster panels of already tested materials in order to determine its roughness, i.e., to place it between two other materials on the rank order scale (the diagonal line of standard panels (SP) in Figure 6). Second, using this rank score value (S_ρ), it is possible to determine the equivalent grain size (D) by using the formula in Equation 2. Having the equivalent grain size (D), it is now possible to determine an estimate of subjective roughness ($S_r(D)$) by using Equation 3. Alternatively, to get approximate answer, the investigator could go to Figure 6, and starting with the rank score of the material read off the approximate equivalent grain size (bottom axis), and then going to Figure 5 read up to the diagonal line and to the left in order to obtain the approximate roughness in comparison to other materials.

While the rank score scale is an interval scale on which two values can only be compared in respect to their difference, the subjective roughness scale is theoretically a ratio scale, in which two values can be compared in respect of their ratio, i.e., a surface texture with $S_r = 10$ ($D = 1.0$ mm), for instance, is two times rougher than a surface texture with $S_r = 5$ ($D = 0.7$ mm). However, it seems to be too early to conclude such a quantitive matter. At the present time, more qualitative findings should be emphasized: (1) the psychophysical power law appears to be applicable to the relation between subjective visual roughness and physical roughness; and (2) it was noted that the judgment of roughness by matching against a set of standard panels is rather stable. In other words, whatever the structure or finish of a material, the degree of perceived surface roughness of it can be measured and indicated in terms of grain size.

Finally, although the stimuli (casts of real building materials) used in these experiments were far extended from the abstracted ones used in other previous studies on texture (and thus come closer to a real environmental psychology; cf. Moore, 1978), we should note that the above results were extracted under special laboratory situations. Nevertheless, as an initial step toward the full description of textural experience, the present study may be regarded as a basic guide to further study.

FOOTNOTE

*This study is based upon a part of a Master of Architecture thesis under the direction of Professor Gary T. Moore which will be submitted to the University of Wisconsin-Milwaukee. Preliminary work on this study and the experiments were done while the writer was a graduate student at the Tokyo Institute of Technology in Japan.

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