PRACTICAL ANALYSIS OF THE INFLUENCE OF WEAR-RESISTANCE OF CERAMIC MATERIALS IN RELATION TO THEIR USE DESTINATION

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Figure no. 1 expresses an attempt to represent the ceramic tile market. The various areas under consideration are shown in abscissas, while the aesthetic or technical requirements of the materials used for each of them are shown in offsets. No commment thereupon is needed to define the aesthetic requirements. It is necessary, on the other hand, to specify that by technical requirements should be understood the sum of the those which relate to:

Mechanical resistance
Resistance to chemical agents
Resistance to impact
Resistance to freezing

And lastly, though of fundamental importance, resistance to wear, the object of these considerations. As a commentary upon this, it may be observed that the sum of technical requirements (and of each of those in the above list) rises as the area considered moves towards the use sectors defined as heavy commercial or industrial.

RESISTANCE TO WEAR FOLLOWS THE SAME LAW.

As we move from the residential to the commercial (whether light or heavy) or industrial area, the wear requirement imposed is increasingly great.

Another notable fact is the slow but steady loss of surface gloss of the various materials as technical requirements increase.

We may remind ourselves of the evolution of porcelain stoneware. It is used as such in the areas to the extreme right, polished and glossed it is to be found in segments more similar to light commercial, or, in some cases, even in residential areas. We will remind ourselves later on of those aspects. For the moment we will devote our attention solely to resistance to wear. Rather than defining it, it is preferable to call it the capacity of a material to wear without showing that wear. There is no body which is not consumed in one way or another, for all are consumed. But some materials can wear more and show it less. And this is what is of interest to us — the fact that it shows: that it can be seen.

Wear resistance of a ceramic surface thus reveals itself in its capacity to be consumed under the action of mechanical components without any appreciable change in its VISUAL APPEARANCE.

The primary objective of this technical list is to bring to mind the fundamental optical actions, trying to apply them to the specified theme. And this because all the methods used so far, and probably to be used in the future, have consisted in carrying out rapidly and in a clearly defined manner a mechanical action on an original surface likely to lead to wear, followed by visual evaluation in relation to the original situation. It is therefore useful to spend some time trying to define the meaning of VISUAL APPEARANCE.

We should start by stating that when we see a body we do so by means of light. This is simply a manifestation of energy, with luminous reception being a direct function of energy received. We then see a body because it itself emits energy, generated by itself in one way or another, or because that body receives, modifies and sends back part or all of the energy received. In both forms, that energy is propagated in space under the form of electromagnetic waves of a particular length (λ), optical waves, and in certain directions (we sometimes speak of a ray of light; but the ray does not exist in itself, for the ray indicates only the direction in which optical energy is propagated).

Figure no. 2 shows this concept. The receiver sees the object because that object partly or completely retransmits the light it receives, having modified it in several aspects. Study of the latter will help us in our observations.

We know, then, that light is a particular form of energy, propagable according to direction under the form of optical waves of a particular length (λ). The set of waves of length between 300 and 800 nanonmetres (1 nanonmetre = 10^{-9}m) represents the visible part of the entire spectrum of electromagnetic radiation.

WITHIN THIS, THE HUMAN EYE DISTINGUISHES THE DIFFERENT WAVE LENGTHS UNDER THE FORM OF COLOUR.

Figure no. 3 expresses the luminosity of each λ, expressed in relative values. Our vision perceives green- yellow light much more easily than red or blue (which explains why amber is the intermediate light in traffic lights). (The sum of all the radiations is white light, while the absence of all of them is utter darkness.)

We shall look now at Figure no. 4.

This could be a microscope view of a yellow tile. We see that part of the incident light - and for the moment we see only that part -penetrates the body. On its way, part of it is absorbed by the colorant pigment, while the rest is formed of various reflections and refractions returned or sent back to the exterior, which is what we call reflection by diffusion.

We specify that:

Reflection is a change of direction in a single medium.

Refraction is a change of direction in two contiguous media.

Absorption means that some λ are absorbed by absorption of their energy.

In this case the yellow pigment has absorbed all wavelengths except that corresponding to its own colour (550 nm). The body therefore appears as yellow colour, with λ of this being the returned light captured by the observer. This quantity contributes to the VISUAL APPEARANCE of the object, as we shall see below, and identifies what we have so far been calling colour.

Colour is therefore determined by the selective absorption which the body exercises on the light which it receives.

We need hardly say that if a body carries out no selection, then it appears as achromatic - that is, black, grey or white - in function of the amount of energy absorbed over the entire spectrum (in everyday life we also refer to white, grey and black as being colours, although a black and white television cannot be thus defined).

Figure no. 5 is one of the many examples of how colour can be represented. In this, the so-called saturation or brightness (purity/depth of the indicated tonality) increases as the distance from the central achromatic point indicating grey increases.

We call the tonality-saturation dimensions chromatic dimensions (depending on what type of λ is absorbed and with what intensity). But colour thus determined may show up as lighter or darker, so that we need to integrate the schema with a third dimension indicative of a luminous characteristic, in this case the lightness of the amount of light (brightness) perceived by the observer.

We return now to Figure no. 4. In this case, tiles or ceramics in general, we see how the perception of colour is determined by what we have called reflection by diffusion, and this gives rise to the three preceding coordinates, two of them of chromatic type, that is, associated with the spectral variation of light, while the third is more closely linked to its spacial distribution.

The attributes of colour are thus:

tonality

saturation

lightness

Also rightly called elements of colour perception.

In order to complete the picture and obtain all the elements of visual appearance it is necessary to introduce another element always linked with how the light is distributed in space by the object under consideration. Looking at the figure, we can observe that to light reflected by diffusion is added another type of light, called specular reflection, a function of the superficial ending of a single surface. The brightness caused by this is a dimension linked to the geometrical or spatial distribution of the light sent back from any colour at all. In ceramic (non-metallic) bodies colour then reveals itself through predominant distribution of light reflected by diffusion; although secondary for didactic purposes, the last element considered is sometimes of great importance. We may therefore state that the elements of visual perception (visual appearance) depend upon the spectral and geometrical attributes of the light sent back. The former owing to absorption of the various λ, while the second are indicators of how the light is distributed by the body in space.

(In parentheses, these concepts should be considered as being not very common to the non-specialized person; suffice it to say that in metals there is practically no light penetrating into the body and that colour is determined by specular reflection which is selective to some λ).

On the contrary, light reflected on the more or less smooth surface of our example DOES NOT UNDERGO VARIATIONS OF COLOUR.

If the incident light is white, then the light reflected on its surface is white. When we observe an object of a particular colour under conditions of optical reflection, we say that we see it as shiny, shiny black if it is black, shiny green if it is green.

We should really say that we are observing different colours, ligher, less intense, "whiter", the most intense light upon them being simply white if the incident light is white.

A fundamental and unequivocal characteristic of this type of reflection (we have met two types, and will soon be seeing a third) is the equality of the angles of incidence and reception indicated in a general way in Figure no. 6. This is the classic reflection of our early concepts of optics. A primary consequence of all that we have brought to mind so far is what is indicated in Figure no. 7.

If the body is observed according to the manner indicated in the figure on the left no specular reflection is observed, just reflection by diffusion; we thus observe three of the four elements mentioned above, the three indicators of colour perception: tonality/saturation/lightness. By observing the body according to the modality indicated by the figure on the right we obtain perception of the three previous elements plus, at its maximum degree, the specular reflection which expresses spatial distribution of the light (geometrical characteristic), of the same colour as the incident light.

We now return to Figure no. 4, focussing our attention on what happens to the surface of our object. If optically smooth (roughness = < \ ) the white light reflected by it follows the law of classic reflection. But is the surface is matt, rough inherently or due to having been worn mechanically, reflection from it is diffused, propagated in all directions, as indicated in the diagram; it is added to it, but, as in the classic case, retains the colour of the original light.

We therefore have 3 types of reflection:

Two superficial:

> One classic, causing brightness, in function of the specularity of the surface, of the same colour as the incident light. This we have called SPECULAR REFLECTION.
>
> A second, also superficial, in function of the roughness or mechanical aspect of the surface, still with the same colour as the incident light, but diffused, propagated in all directions. This we call REFLECTION BY SUPERFICIAL DIFFUSION.
>
> A third owing to absorption by the body, already mentioned many times, and called REFLECTION BY DIFFUSION.

The time has now arrived for us to be able to state that a more or less worn ceramic surface cannot do without any of these five elements of perception without falling into the trap of over-simplification.

Tonality) Saturation) Lightness)	Attributes of the colour. Contained in reflection by diffusion.
Specular reflection) Reflection by superficial diffusion)	Attributes Spatial or geometrical

By way of example, we turn now to Figure no. 8, showing four tiles. The upper two are shiny, while the lower two are matt. At the same time, those on the left are observed under the mode of the PEI test (observation of the colour), while those on the right are examined under the contrary mode (observation of brightness).

The abbreviations correspond to:

Specular reflection	SR
Reflection by diffusion	RD
Reflection by superficial diffusion	RSD

The four present original and worn surfaces.

It is interesting to observe the tile in the upper left corner; this is a shiny tile examined under the PEI mode. In the original zone we see only light indicating RD colour, while in the zone subjected to wear we note, together with the new RD, which in this case we suppose to be the same, the simultaneous presence of the other superficial RSD component of the same "colour" as the incident light. This fact is explained by simple contrast, because light colours are enhanced in comparison with darker ones obtained from the same mould. Two enamels can be exactly the same in all chemical and physical characteristics, wear in the same way without any change of "colour" to their interior, but actually appear as visually different. The appearance of a different spatial distribution of light (RSD) of their colour penalizes the dark colours, enhancing, by simple contrast, the ligher colours. Thinking back to the definition which we gave at the start, it is only right that it should be thus. And the light colours are still enhanced in the opposite mode of observation.

The original matt surface in itself modifies these situations, and we shall leave all comment upon this at the liberty of each person. It should be noted, however, that given parity of technical characteristics, light colours do not always appear to be better than dark ones; this is due to other circumstances which are not the object of this meeting. This neverthess contributes to confirmation that complete evaluation of a ceramic surface cannot do without a whole series of partial analyses which go to make up a complex and not easily broken down matrix.

Having reminded ourselves of the principal notions of optics necessary for a better understanding of what is meant by VISUAL APPEARANCE, the need arises once again to evaluate this in function of the five elements of perception mentioned earlier, not to mention what we have every day on our floors and before our eyes.

The PEI test represents the best starting point in an attempt to achieve this practical result. What is wished is to integrate it by adding to it the special characteristic which is missing from it (at least as used nowadays), thus obtaining more extensive information. To this end, we have used the schema indicated in Figure no. 9. As can be seen, using only the central body means observing the object in the presence of specular reflection. On the other hand, raising its walls and letting the light enter from the exterior body allows us to carry out the observation under the PEI mode. As can be seen, there exists the possibility of superimposing the two and obtaining all possible combinations.

We should add here that the central body and the exterior walls are completely covered in fabric, black in the first case and white in the second. An example will indicate to us one of the modes of using the proposed schema, specifying beforehand that the method is above all comparitive, with no pretensions to rigour. The aim is simply to differentiate between materials which turn out to be the same under the normal PEI certification. To that end, some ceramic products submitted to normal PEI test and judged to be "PEI X" are placed in the central position indicated.

PEI X means PEI 1 -4, or more if wished, and these do not have to be similar materials; they can be glazed, matt or gloss, or non-glazed, klinker or brick, and also natural stone. (The method is comparative, and it is this sense that it is being presented).

The most important factor is that they have all emerged the same on the PEI test (at desire no. of turns) as used nowadays. By then raising the central body at its lower part and using the exterior light (adjustable with rheostat) one reaches non-perception of the area subjected to wear compared to the original, logically for all materials. Having done this, and observing always from the same point, the central illumination is gradually increased, adding to the the previous light and giving rise to the oft-mentioned specular reflection. The amount of light emitted by the central body is adjusted (at constant voltage) by a rheostat adjustable on a scale graduated from zero to one hundred: 0 - 100.

Material showing different visual appearance between the two contiguous areas, worn and original, under the amount of light obtained with the rheostat in position "yz" shall be called X yz. If the PEI class is 4 and the rheostat indicates 30, then the material is 430 (an absolutely matt material could be 499/599, while all materials are certainly 099).

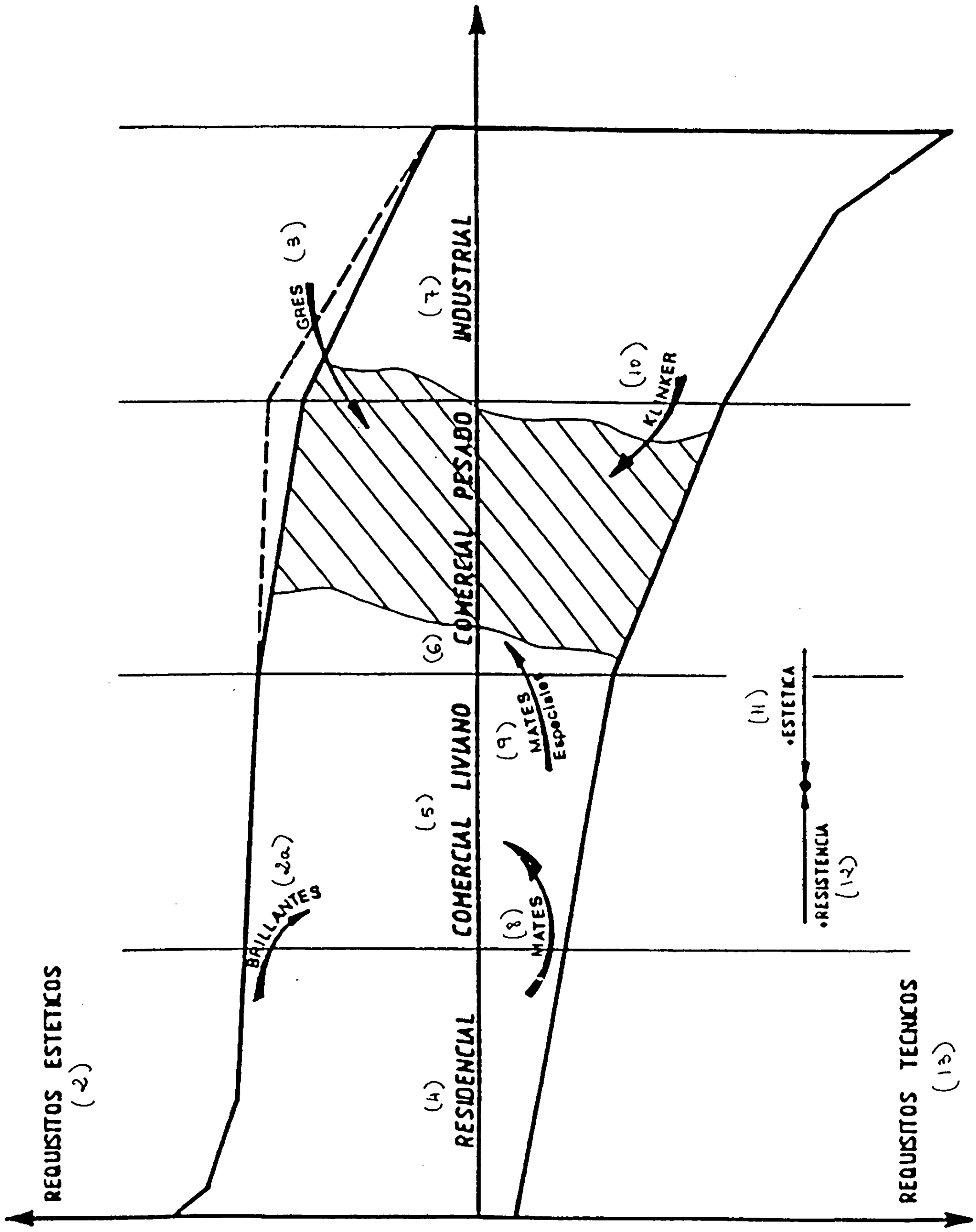
Such results are then carried over to Figure no. 10, where in abscissas we have the already indicated PEI turns, 0 - 600 - 1500 - 3000 - 5000, and in offsets the amount of light emitted by the central body beneath which appears the different perception mentioned.

Each material will therefore be characterized by a curve such as those shown. The more resistant materials will have a "high" and very "extended" curve, while the least resistant (especially if gloss) will have a "low" and rather restricted curve.

By way of commentary upon this, we must state again that the aim has only been to provide the ceramics technician with a simple and cheap instrument to allow new materials to be contrasted with any known product, whether artificial or natural.

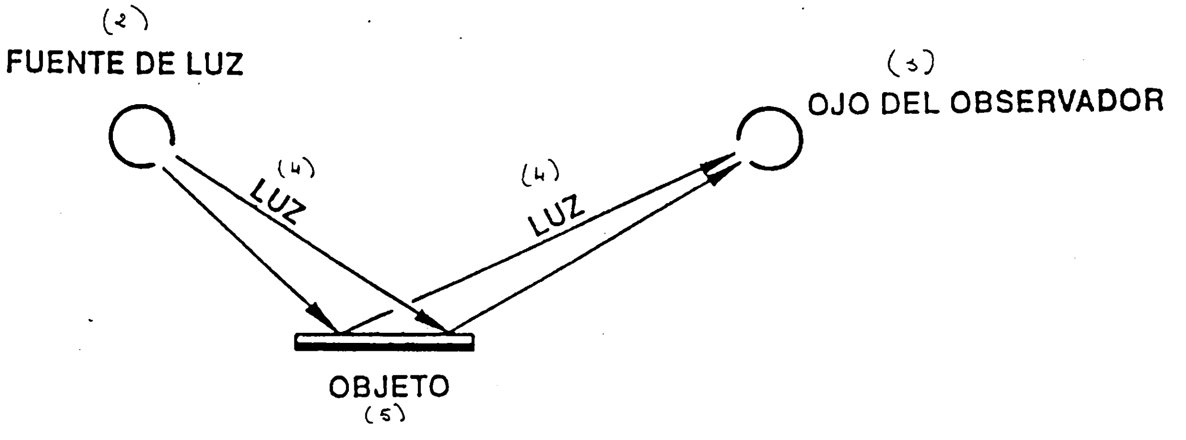
Direct experience will make up in practice for the lack of rigour obviously inherent in such simplified schema.

To conclude, we might add that a piece of "apparatus" such as this is available as of now, in the hope that it will prove useful to you.



1) FIGURE NO. 1

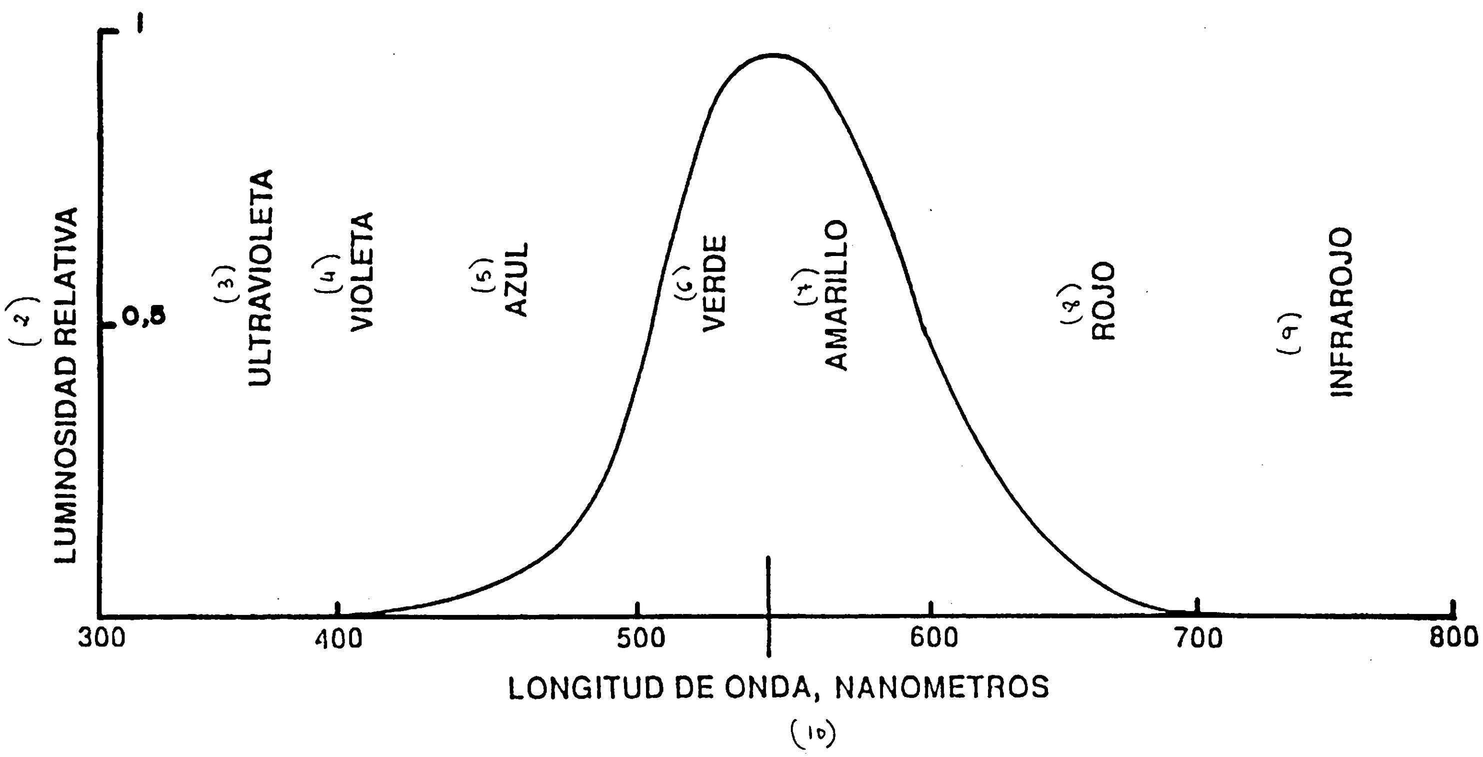
2) AESTHETIC REQUIREMENTS
2a) GLOSSES
3) STONEWARE
4) RESIDENTIAL
5) LIGHT COMMERCIAL
6) HEAVY COMMERCIAL
7) INDUSTRIAL
8) MATTS
9) SPECIAL MATTS
10) KLINKER
11) AESTHETIC
12) RESISTANCE



ELEMENTOS DE APARENCIA VISIVA (6)

FIGURE NO. 2

2) LIGHT SOURCE
3) EYE OF THE OBSERVER
4) LIGHT
5) OBJECT
6) ELEMENTS OF VISUAL APPEARANCE



1) FIGURE NO. 3

2) RELATIVE LUMINOSITY
3) ULTRAVIOLET
4) VIOLET
5) BLUE
6) GREEN
7) YELLOW
8) RED
9) INFRARED
10) WAVELENGTH, NANOMETRES

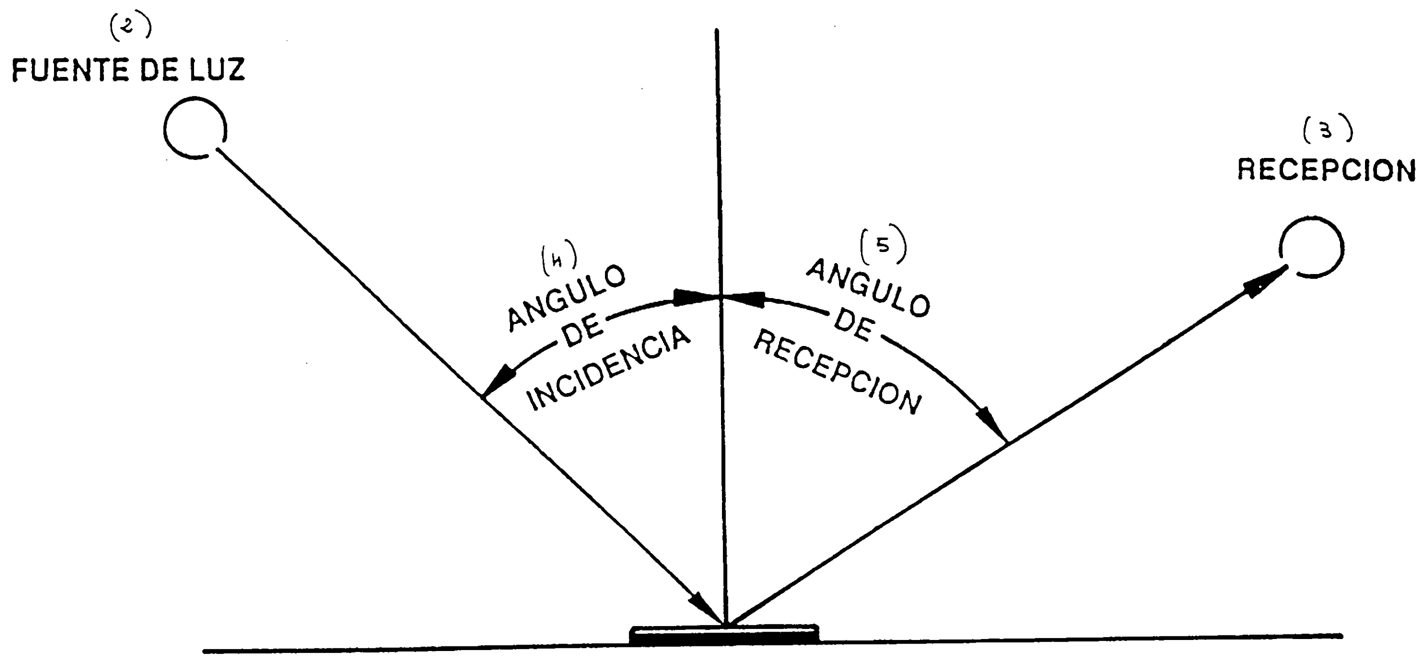
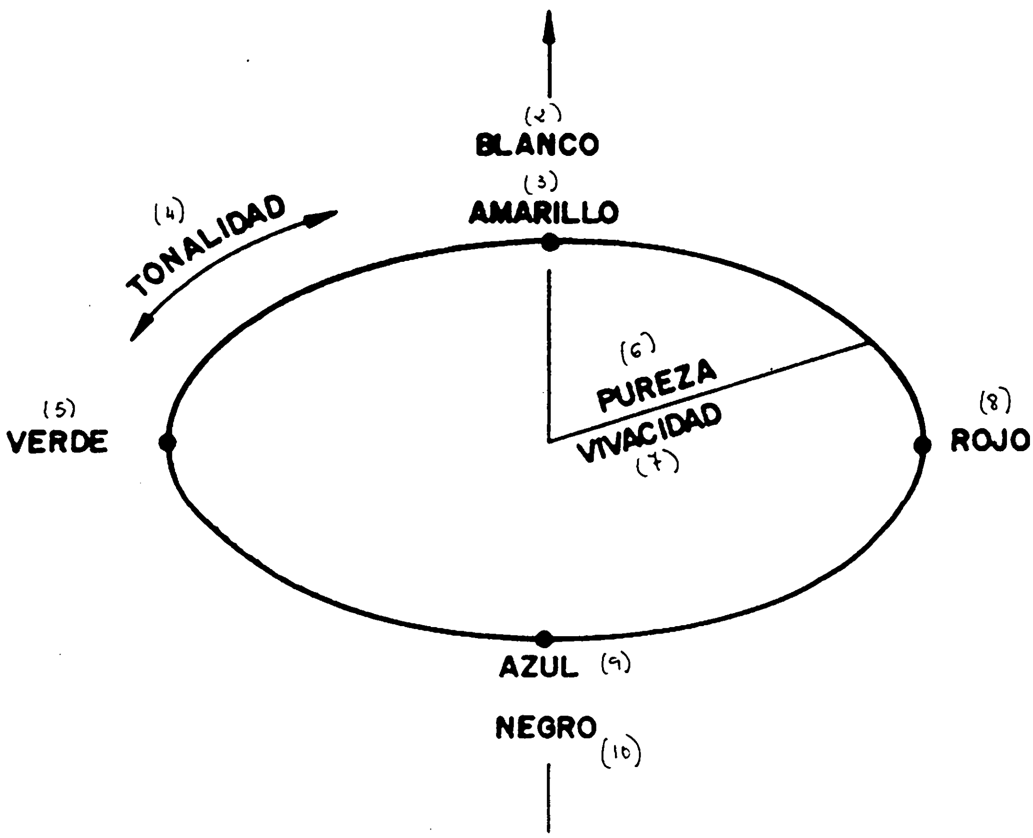


FIGURE NO. 4

2) INCIDENT LIGHT
3) SPECULAR REFLECTION
4) REFLECTION BY DIFFUSION
5) SURFACE 6) YELLOW PIGMENT **



REPRESENTACION TRIDIMENSIONAL DEL COLOR (11)

1) FIGURE NO. 5

2) WHITE YELLOW
3) TONALITY
4) GREEN
5) SATURATION PURITY
6) LIGHTNESS
7) RED
8) BLUE BLACK
9) THREE-DIMENSIONAL REPRESENTATION OF THE COLOUR.

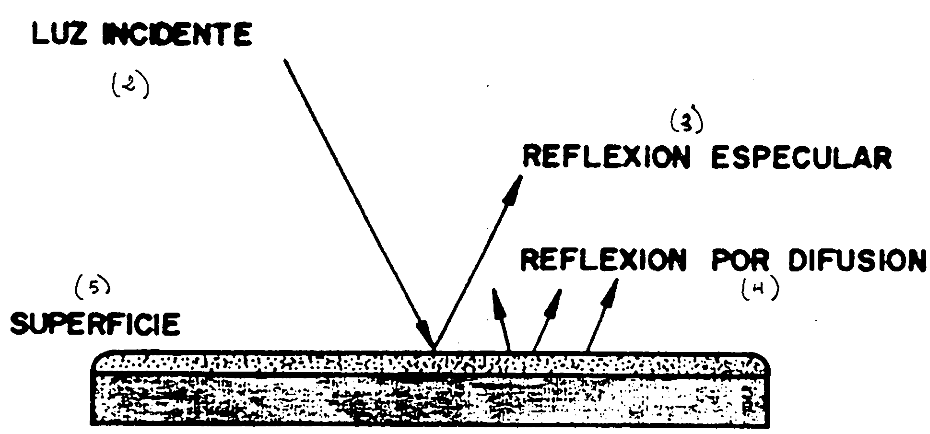
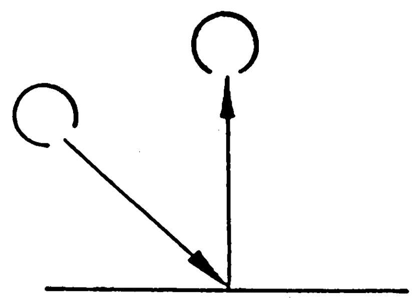
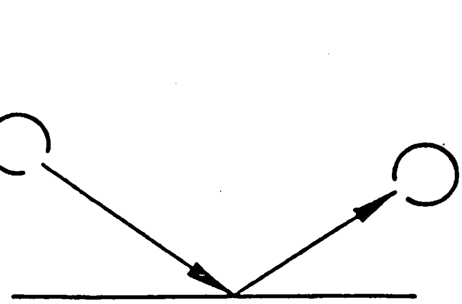


FIGURE NO. 6

2) LIGHT SOURCE
3) RECEPTION
4) ANGLE OF INCIDENCE
5) ANGLE OF RECEPTION
6) OBJECT





1) FIGURE NO. 7

2) OBSERVATION OF THE COLOUR
3) OBSERVATION OF THE GLOSS

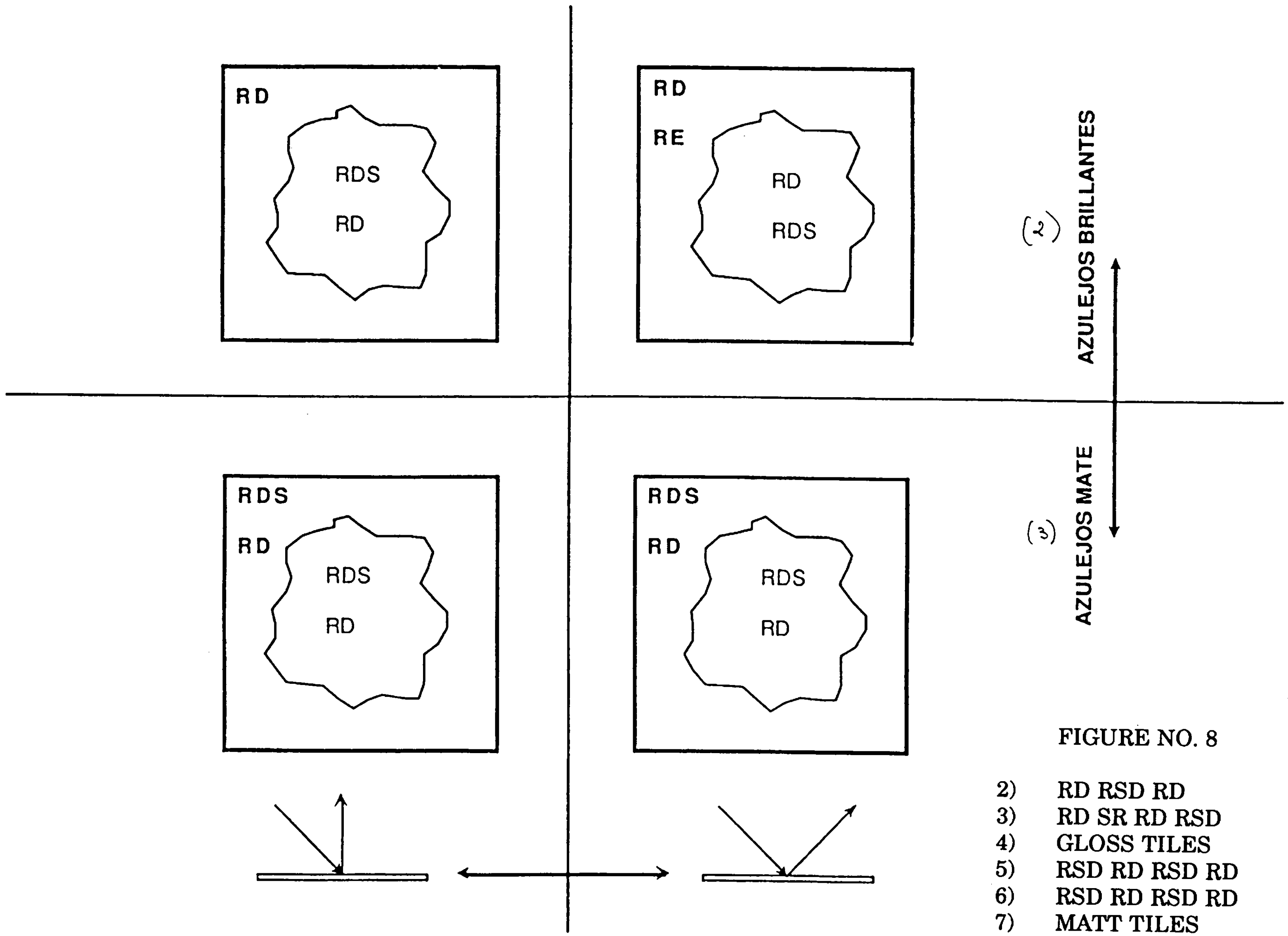


FIGURE NO. 8

2) RD RSD RD
3) RD SR RD RSD
4) GLOSS TILES
5) RSD RD RSD RD
6) RSD RD RSD RD
7) MATT TILES

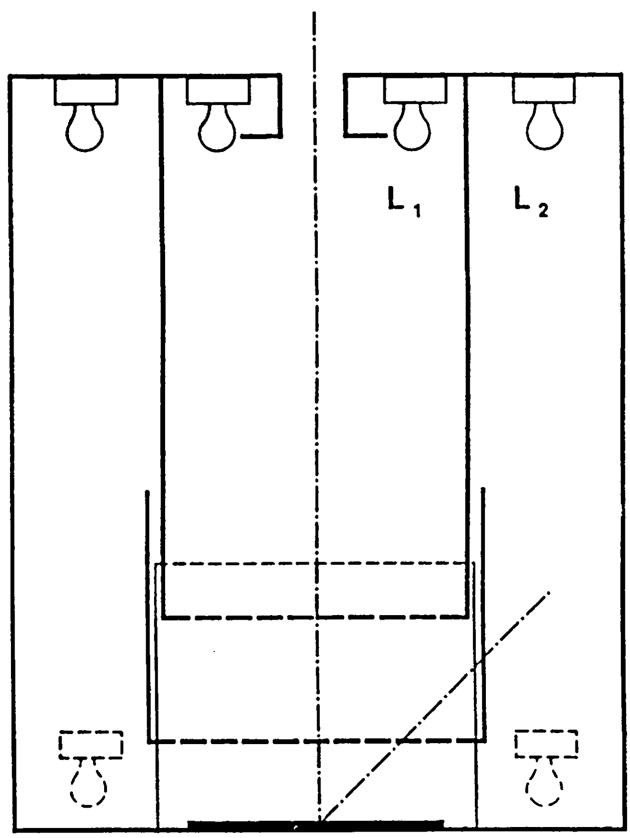


FIGURE NO. 9

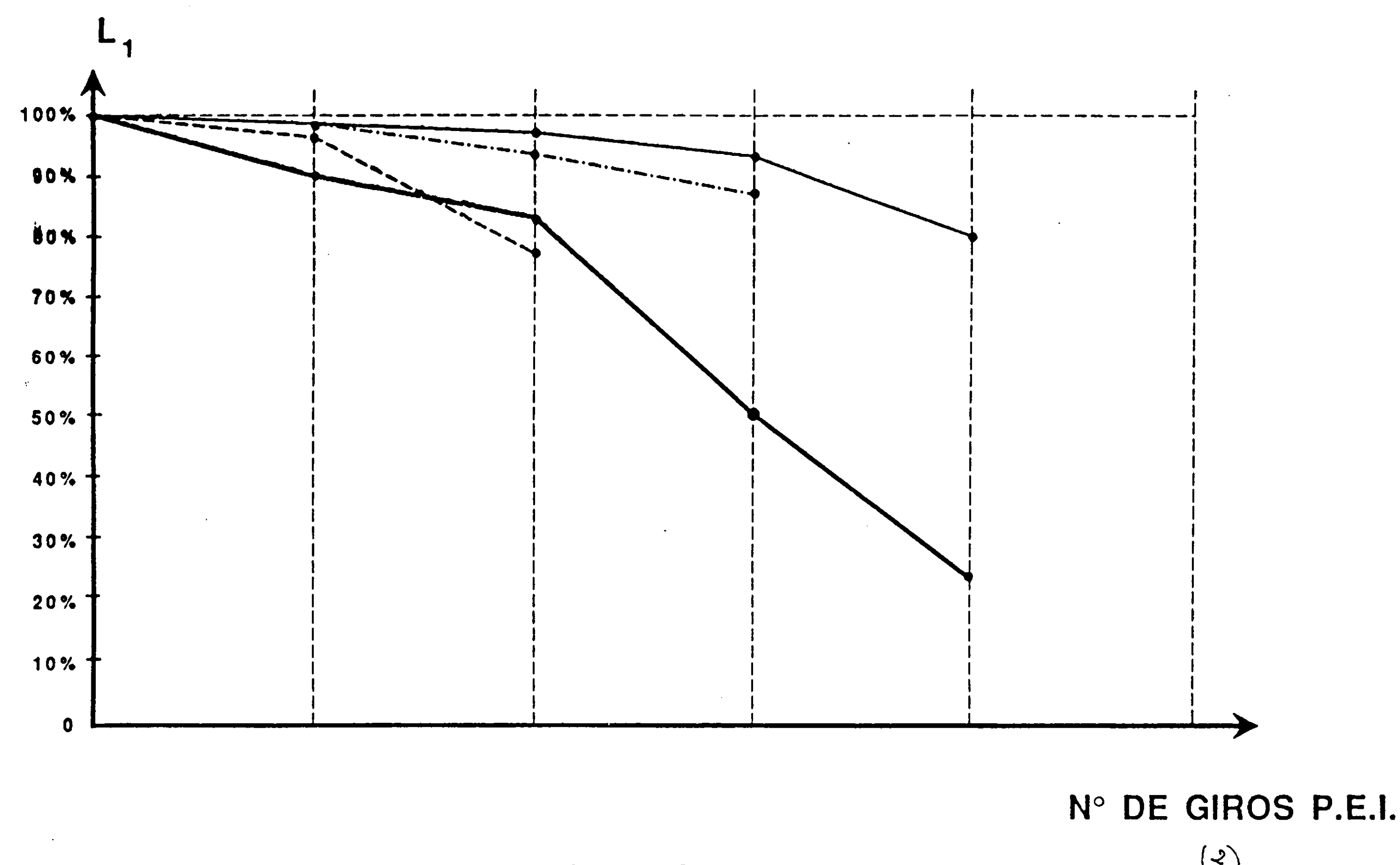


FIGURE NO. 10

2) NO. OF P.E.I. TURNS