Coloroid Colour System

Prof. Antal Nemcsics
Budapest University of Technology and Economics

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Abstract

The Coloroid Colour System, being elaborated between 1962 and 1980 at the Budapest University of Technology and Economics has been created mainly for architects and visual constructors constitutes a colour system of perceptions built on harmonic colour differences of perceived surface colours enlightened by daylight and sensed by an observer possessing normal colour vision, that well approximates aesthetic uniformness. From August 2000 it has been registered as Hungarian Standard MSZ 7300. The article expounds terms used by Coloroid colour system, denotation of colours through Coloroid colour characteristics, the mutually explicit transformation relation between Coloroid and CIE colour measuring system, specifications for the practical use of Coloroid colour characteristics, numerical and graphical representation of connections between colours, colour qualifications, creation of harmony compositions using Coloroid colour characteristics, displaying colors using Coloroid colour characteristics and usage of Coloroid colour denotation for design purposes.

1 Introduction

The COLOROID Colour System, being elaborated between 1962 and 1980 at the Budapest University of Technology and Economics has been created mainly for architects and visual constructors constitutes a colour system of perceptions built on harmonic colour differences of perceived surface colours enlightened by daylight and sensed by an observer possessing normal colour vision, that well approximates aesthetic uniformness. From August 2000 it has been registered as Hungarian Standard MSZ 7300.

The COLOROID colour system is aesthetically uniform, as between its neighbouring surface colours being characterised by integer numbers the same number of harmony intervals exist, therefore it is applicable to describe harmony relations and to create harmonic colour compositions.

The use of the COLOROID colour system for colour measurements, for comparison of colours does not require special laboratory environments, as its colour space is uniform, related to the non adapted eye.

With the help of the colour signals of the COLOROID colour system the colours of any colour system, colour standard, colour set, colour atlas, colour register can unambiguously be determined, as its colour space is continuous. Any colour, having the colour signals of COLOROID colour system, can be displayed, as a mutually unambiguous connection exists between its colour space and the colour space of the CIE XYZ chromatic stimulus measuring system.

The colours determined by the colour signals of COLOROID colour system can be created on monitors and printers within the limits of technical possibilities, e.g. by the help of the software made for the existing IBM PC and Mackintosh machines, as its colour signals are in transformational connection with the sRGB and other colour displaying systems.

The experiments determining the psychometric scales of the COLOROID colour system have been carried out in premises illuminated by lights reflected from the Northern sky, in the vicinity of the window. Illumination was between 1600-1800 lx. Samples (15-18 cm^2 surface sheets) have been demonstrated on horizontal surfaces, in front of a grey surface having a uniform Y = 30 CIE chromatic stimuli component, so, that the light incident through the window reaches them at approximately 45°. The samples have been observed with 90° looking angle. The number of persons participating in the experiment was altogether 70.000

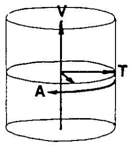
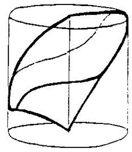


Figure 1:



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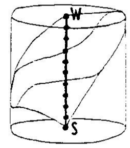

Figure 3:

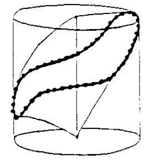

Figure 4:

2 Concepts of COLOROID colour system

COLOROID colour characteristics: This is the name of the following three quantities collectively. They enable to determine the colour in question unambiguously. (See Figure 1.)
COLOROID hue, denotation: A.
COLOROID saturation, denotation: T.
COLOROID luminosity, denotation: V.

COLOROID-coordinates: Semipolar coordinates, representing the members of the population of colours placed inside a linear circular cylinder, to be used for the explicit definition of colour points, namely the angular coordinate representing numerically the COLOROID hue of the colour (A), the radial coordinate representing numerically the COLOROID saturation of the colour (T), the vertical axial coordinate representing the COLOROID luminosity of the colour (V). (See Figure 1.)

COLOROID colour space: A colour space, in which the perceived colours are specified by COLOROID colour characteristics. (See Figure 2.)

Absolute white colour of COLOROID (W): It is placed on the upper limit point of the axis of COLOROID colour space. The colour of the surface illuminated by CIE D_65 beam distribution, with perfectly scattered reflection, having both COLOROID luminosity value and Y_w colour component value of 100. (See Figure 3.)

Absolute black colour of COLOROID (S): It is placed on the lower limit point of the axis of the COLOROID colour space. The colour of the surface illuminated by CIE D_65 beam distribution, perfectly light-absorbing ($\beta = 0$ luminance factor), having both COLOROID luminosity value and Y_s colour component value of 0. (See Figure 3.) The chromatic stimulus coordinates of the absolute white and absolute black colours of the COLOROID colour system agree with the chromatic stimulus coordinates of the D_65 point of the CIE 1931 colour diagram, thus $x_w = x_s = x_0 = 0.312726$ and $y_w = y_s = y_0 = 0.329023$.
COLOROID limit colours: The most saturated colours that can be drawn onto the nappe of the cylinder comprising the COLOROID colour space, located along a closed curve. (See Figure 4.) In the CIE 1931 colour diagram (MSZ 9620/2)

- colours located along spectrum colour lines between $\lambda = 450$nm and $\lambda = 625$nm, moreover
- colours located along the line connecting the points $\lambda = 450$nm and $\lambda = 625$nm. (See Figure 5, 6.)

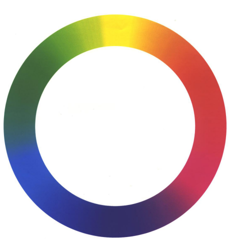

Figure 5:

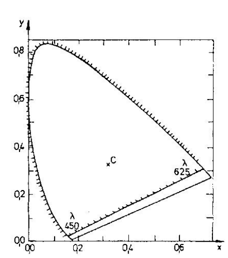

Figure 6:

COLOROID basic colours: 48 different COLOROID limit colours characterised with integer numbers, being located at approximately identical number of harmony intervals to each other.
The COLOROID basic colours are recorded in the CIE 1931 diagram by the φ angle. The φ angle is the angle of the half line originated from the D_{65} point of the CIE 1931 colour diagram to the x axis. (See Figure 7.)

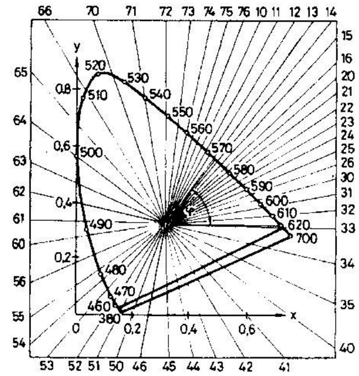

Figure 7:

COLOROID colour planes: The half planes delimited by the achromatic axis of the COLOROID colour space, having the same COLOROID hue and dominant wavelength. (See Figure 8.)
In each colour plane colours are inclosed by the neutral axis and two curves, the so called COLOROID delimiting curves. The shape of surfaces inclosed by delimiting curves is being different for each hue and depends on the luminosity of the spectrum colour or of the purple being located on one apex of the colour plane. Along the vertical lines of the nets drawn on the COLOROID colour planes COLOROID saturation values are identical, along their horizontal lines COLOROID luminosity values are identical. (See Figure 9.)
Colours implemented with various means or colours being created in the nature, belonging to individual colour planes are inclosed by internal delimiting curves of COLOROID. (See Figure 9.)
COLOROID basic hues: hues belonging to COLOROID basic colours. Similar to basic colours, there are 48 COLOROID basic hues. (See Figure 10.)
In COLOROID colour planes $A10, A11, A12, A13, A14, A15, A16$ yellow, in COLOROID colour planes $A20, A21, A22, A23, A24, A25, A26$ orange, in COLOROID colour planes $A30, A31, A32, A33, A34, A35$ red, in COLOROID colour planes $A40$. $A41, A42, A43, A44, A45, A46$ purple and violet, in COLOROID colour planes $A50, A51, A52, A53, A54, A55, A56$ blue, in COLOROID colour planes $A60, A61, A62, A63, A64, A65, A66$ cold green, in COLOROID colour planes $A70$, $A71, A72, A73, A74, A75, A76$ warm green hued colours exist. Figure 11 shows colours of a page of Coloroid Colour Atlas (e.g hue plane marked $A13$) attainable by printing technology.

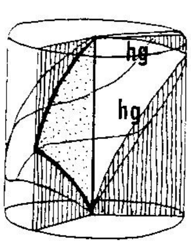

Figure 8:

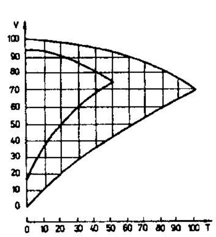

Figure 9:

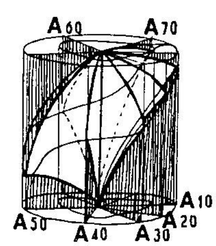

Figure 10:

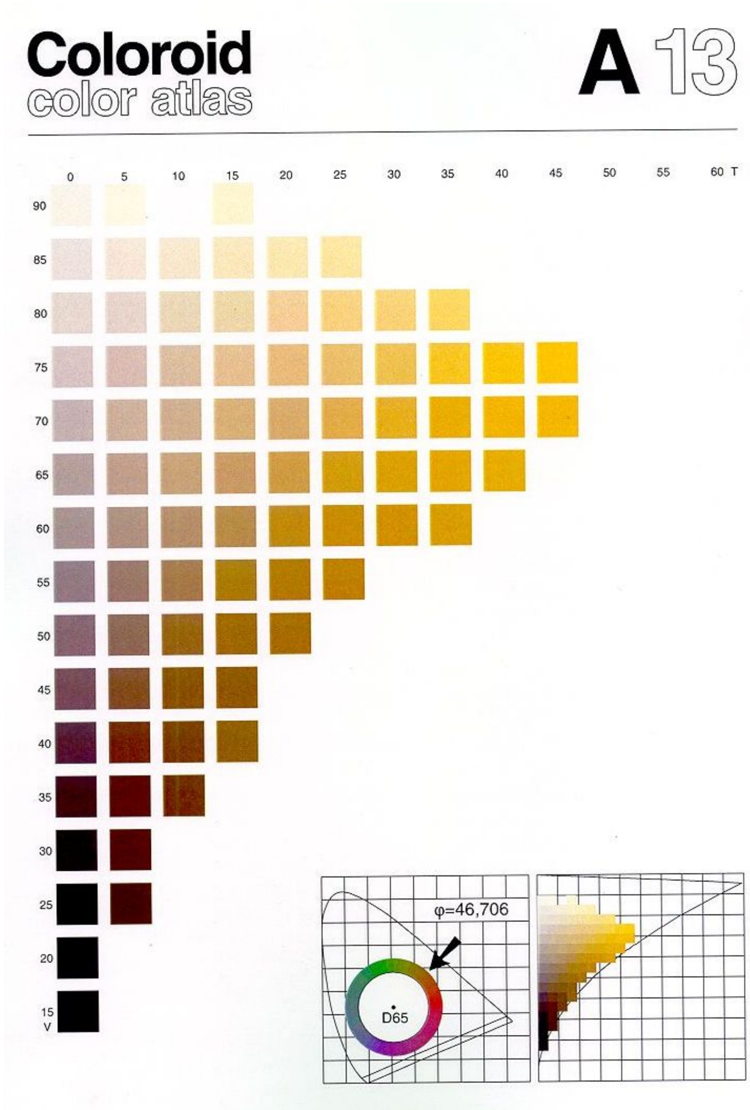

Figure 11:

COLOROID colour components: The common name of the following three colour components:

- COLOROID colour content, mark: p.
- COLOROID white content, mark: w.
- COLOROID black content, mark: s. (See Figure 12 and 13.)

These quantities represent the rates of chromatic stimuli listed below, if any of the surface colours are created by additive mixing of the chromatic stimuli belonging to a surface colour of COLOROID:

- the COLOROID limit colour (H) corresponding to the wavelength of the dominant surface colour to be created,
- the absolute white (W) colour of COLOROID,

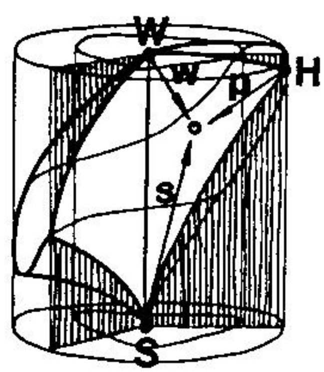

Figure 12:

- the absolute black (S) colour of COLOROID.

The sum of the COLOROID colour components is equal to one, i.e. $p+w+s=1$.

Note: The following relations exist between the CIE chromatic stimuli components of any colour of the COLOROID colour space (X,Y,Z) and the COLOROID chromatic stimuli components (p,w,s):

$$\begin{array}{lcccccc} X & = & pX_\lambda & + & wX_w & + & sX_s \\ Y & = & pY_\lambda & + & wY_w & + & sY_s \\ Z & = & pZ_\lambda & + & wZ_w & + & sZ_s \\ \varepsilon & = & p\varepsilon_\lambda & + & w\varepsilon_w & + & s\varepsilon_s \end{array}$$

where X,Y,Z and ε are the CIE chromatic stimuli components of the examined surface colour resp. one hundredth of their sum

$X_\lambda, Y_\lambda, Z_\lambda, \varepsilon_\lambda$ are the chromatic stimuli components of the COLOROID limit colour having identical wavelength as the examined surface, and the one hundredth of their sum

$X_w, Y_w, Z_w, \varepsilon_w$ are the chromatic stimuli components of the absolute white colour of the COLOROID colour system and the one hundredth of their sum

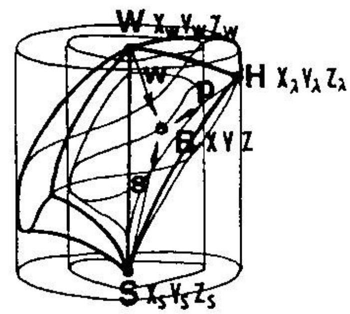

Figure 13:

$X_s, Y_s, Z_s, \varepsilon_s$ are the chromatic stimuli components of the absolute black colour of the COLOROID colour system and the one hundredth of their sum.

COLOROID-saturation: It is a characteristic feature of the surface colour quantifying its saturation, i.e. its distance from the colour of the same COLOROID achromatic luminosity measured on a scale that is aesthetically near to uniform. Its denotation is: T.

1. COLOROID-saturation of the COLOROID limit colours is equal to 100.

2. The COLOROID-saturation of the absolute white and absolute black colours of the COLOROID colour system and the grey (achromatic) colour made of absolute white and black, is equal to 0.

3. In the COLOROID colour space colours of identical COLOROID saturation are located equidistant to the achromatic axis of the colour space, on a coaxial cylinder (See Figure 14.) Identical COLOROID-saturation colours can be found on the laid out coaxial cylinders. (See Figure 15.)

4. The numerical value of the COLOROID-saturation of a colour is proportional to the content of limit colour p, it is the hundredfold of it:

$$T = 100p$$

5. Keeping at a constant value the chromatic stimuli coordinates (x,y) of a COLOROID limit colour and decreasing only its Y component, colours featuring less and less COLOROID saturation T are created, as a decrease of COLOROID luminosity of the COLOROID limit colours means an increase of black content s and a decrease of COLOROID limit colour content p in the COLOROID colour system, keeping the relation $p+s=1$ valid.

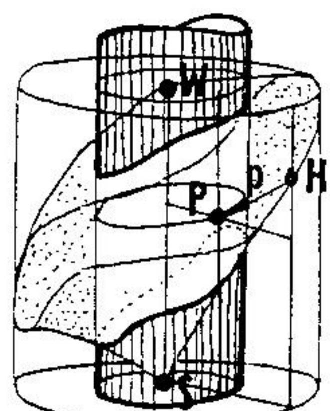

Figure 14:

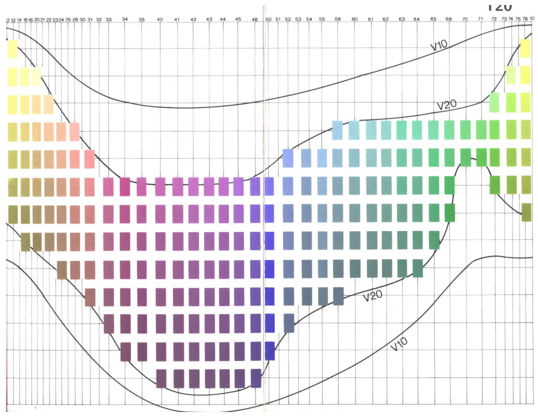

Figure 15:

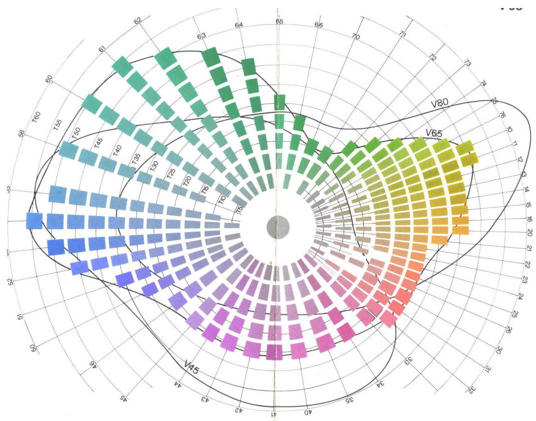

Figure 17:

COLOROID luminosity: It is a characteristic feature of the surface colour, denoting the distance measured from the absolute black colour of the COLOROID colour system on an aesthetically near uniformly graduated scale.

Denotation: V.

The COLOROID-luminosity of the absolute black colour of COLOROID colour system is equal to 0.

The COLOROID-luminosity of the absolute white colour of COLOROID colour system is equal to 100.

In the COLOROID colour space the colours of identical COLOROID luminosity are located in planes perpendicular to the achromatic axis of the colour space. (See Figure 16.)

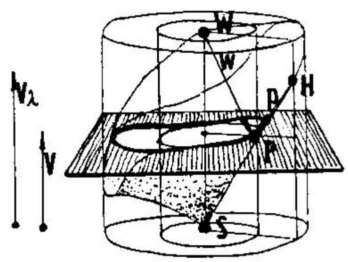

Figure 16:

Planes perpendicular to the achromatic axis possess colours of same Coloroid luminance. (See Figure 17.)

Numerical values of the COLOROID luminosity of a surface colour are determined by the expressions below:

$$V = Y^{1/2}$$

$$V = 10(pY_\lambda + 100w)^{1/2}$$

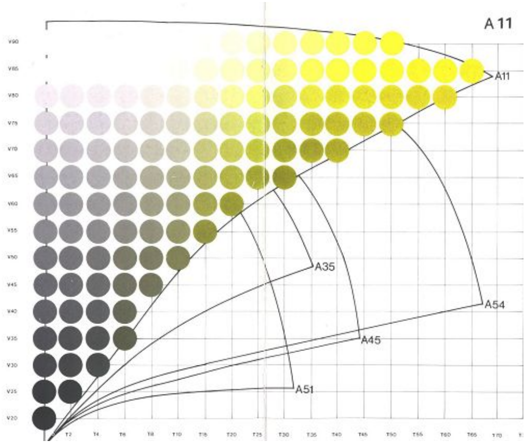

Figure 19:

COLOROID hue: It is a characteristic feature of the surface colour, denoting its hue on a scale distributed into 48 sections on an aesthetically near uniformly graduated scale. Denotation: A.

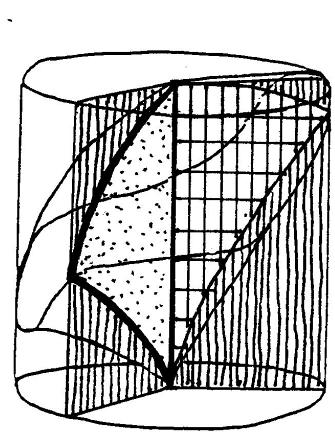

Figure 18:

The COLOROID hue of the surface colour is a function of dominant wavelength of the colour.

In a COLOROID colour space surface colours having identical COLOROID hues lay in the COLOROID colour planes. (See Figure 18, 19.)

The COLOROID hue of the colour is an integer number, provided that the hue agrees with any one of the 48 basic colours. It is a fraction, when its hue is located between the hues of two basic colours. In this case the fractional value of hue is calculated by linear interpolation between the φ angles of two neighbouring basic colours and the φ angle of the given colour. The COLOROID hue scale has an upper and a lower limit, the minimum number is 10, the maximum is 76, thus the neighbour of hue $A = 76$ is hue $A = 10$ because the colour cycle is closed. E.g. the colour $(76.9.T, V)$ can be generated by additive mixing $0,9$ part of colour $(76, T, V)$ and $0,1$ part of colour $(10, T, V)$.

COLOROID colour cycle: Circular representation of most saturated surface colours of 48 basic hued colour planes of COLOROID colour space. (See Figure 20, 21.)

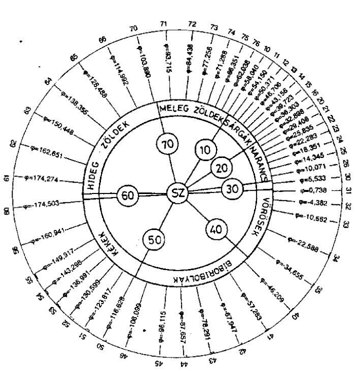

Figure 20:

The colours of the COLOROID colour cycle form an aesthetically nearly uniform sequence.

Complementary hues are in COLOROID colour planes deflecting at 180° to each other, therefore in the complementary colour plane the complementary colours are placed opposite to each other.

The joint existence of the approximately aesthetical uniformness of the sequence of COLOROID colour spaces and of the 180° deflection of complementaries to each other has the result, that the angular differences of the neighbouring hue planes of the COLOROID colour cycles are not identical (see Figure 15). E.g. the neighbouring basic hues are separated by smaller an-

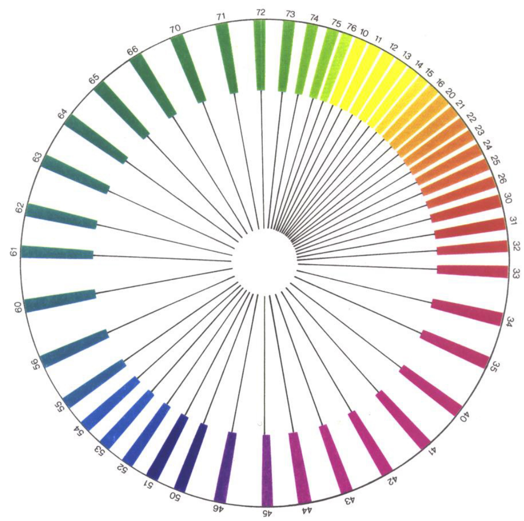

Figure 21:

gles in case of yellow colours, and bigger ones in case of blue colours

3 Denotation of colours in the coloroid colour system

The denotation contains the three COLOROID colour characteristics in the following order:
COLOROID hue - COLOROID saturation - COLOROID luminosity, i.e.

$$A - T - V$$

For instance, the notation of the colour of 13 COLOROID hue, 22 COLOROID saturation and 56 COLOROID luminosity is:

$$13 - 22 - 56$$

The first number denotes in which COLOROID colour plane the colour exists, the second denotes on which coaxial cylinder surface, at what distance from the achromatic axis it exists, the third one denotes, on which of the planes perpendicular to the achromatic axis it is to be found. (See Figure 22.)

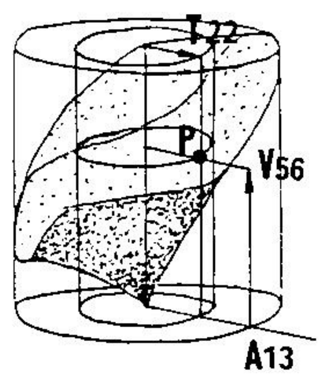

Figure 22:

4 Associating COLOROID-colour characteristics and colour samples

Any colour sample of any colour system or colour set can be associated to the colour characteristics of the COLOROID colour system, if it, as a result of measurement done with equipment, has the colour characteristics of the CIE 1931 chromatic stimuli measuring system, because a mutually unambiguous connection exists between the COLOROID colour system and the CIE 1931 chromatic stimuli measuring system.

Conversion of CIE colour characteristics to COLOROID colour characteristics
Recalculation is carried out by the help of the following expressions, if x, y, Y is given, then:

$$A = f(\text{tg } \varphi) \qquad \text{tg } \varphi = \frac{y - y_0}{x - x_0}$$

$$T = 100\frac{Y(x_0\varepsilon_w - x\varepsilon_w)}{100(x\varepsilon_\lambda - x_\lambda\varepsilon_\lambda) + Y_\lambda(x_0\varepsilon_w - x\varepsilon_w)}$$

$$T = 100\frac{Y(1 - x\varepsilon_w)}{100(y\varepsilon_\lambda - y_\lambda\varepsilon_\lambda) + Y_\lambda(1 - y\varepsilon_w)}$$

$$V = 10\sqrt{Y}$$

The COLOROID hue can be determined by using the tables of the Attachment M2.
To define the COLOROID hue of the colour it is to be decided, to which quadrant of the COLOROID colour space it belongs to.
The description of denotations used in the formulas can be found in Attachment M3.
Conversion can also be carried out by COLOROID converting software according to section 1.1.12

Conversion of COLOROID-colour-characteristics into CIE- colour-characteristics
Recalculation is to be carried out by the help of the following expressions, if A, T, V are given, then:

$$x = \frac{\varepsilon_w x_0(V^2 - TY_\lambda) + 100T\varepsilon_\lambda x_\lambda}{\varepsilon_w(V^2 - TY_\lambda) + 100T\varepsilon_\lambda}$$

$$y = \frac{V^2 + 100T\varepsilon_\lambda y_\lambda - TY_\lambda}{\varepsilon_w(V^2 - TY_\lambda) + 100T\varepsilon_\lambda}$$

$$Y = \left(\frac{V}{10}\right)^2$$

1. The description of denotations used in the formulas can be found in Attachment M3.
2. Conversion can also be carried out by COLOROID converting software according

5 Practical use of the COLOROID colour characteristics

Specification of colours with COLOROID colour characteristics.

After or instead of the name of colours that are to be indicated unambiguously in official statements, in plan documentation, COLOROID colour characteristics are to be used according to the following example:

$$16.07 - 22.45 - 68.39, \quad \text{or}$$

$$A16.07, T22.45, V68.39$$

The degree of accuracy of the individual characteristics determines the number of characters after the decimal point.
For users where the main aspect is not the visual displaying of the colour, the use of CIE XYZ colour characteristics or their transformations are accepted.
Specification of colours with COLOROID diagram.

In plan documentation for denoting the interrelations of more colours the COLOROID diagram is to be used.
The COLOROID diagram consists of two parts, namely the schemes of the COLOROID colour cycle and the COLOROID colour plane containing the current colour composition are printed next to each other, into which the colour points in question are to be drawn.
If the members of the colour composition to be displayed belong to more hues, the concerned colour planes can be drawn one above the other as well within the same figure. (See Figure 23.)

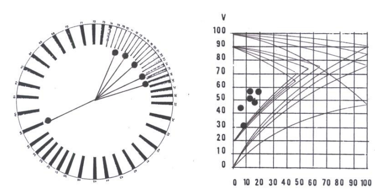

Figure 23:

Classification of colours by COLOROID colour characteristics.

The tolerance range of a nominal colour can be denoted with COLOROID colour characteristics according to the sample below:

$$\Delta 0.6 - \Delta 1.3 - \Delta 0.9 \quad \text{or}$$

$$\Delta A0.6, \Delta T1.3, \Delta V0.9$$

1. The smooth changes in the COLOROID colour characteristics mean smooth changes in colour quality. This colour qualification mode denotes the deviation from the nominal colour separately for each of the three colour characteristics, that corresponds to the requirements of evaluation by perception of those persons dealing visually with colours.

2. In those fields of industry where the visual evaluation of the deviation from the nominal colour is not required, this can be denoted by one of the ΔE chromatic stimuli formulas published by the CIE.

Creating harmonic colour compositions by the help of COLOROID-colour characteristics

Those colour compositions are harmonic, the members of which

1. have the same A and T colour characteristics, and their V colour characteristics constitute an arithmetical or geometrical sequence,

2. have the same A and T colour characteristics, and their T colour characteristics constitute an arithmetical or geometrical sequence,

3. Summing the above two special cases the colour characteristics are the same, but their T and V colour characteristics change jointly on one straight line, where the distances of the points of division constitute an arithmetical or geometrical sequence. The (T, V) pairs can be placed on more parallel straight lines as well, in each case according to the same arithmetical or geometrical sequence.

4. The above rules can be equally related to one or more hues as well. Among the many hues the 3-hues or trichrome harmony is of prime importance. The SET of possible trichrome basic colours belonging to the A basic hue are: $\{A \pm 1.0, A \pm 4.6, A \pm 6.6$, Complementary hue (K) $K \pm 1.0, K \pm 4.6, K \pm 6.6\}$ hues. From this set, the basic hue A and more two hues selected next to it, constitute a trichrome colour harmony.

5. Any two hues selected from the above set constitute a dichrome hue harmony even if A basic hue is omitted.

Creating polichrome harmonies, however, can only be done in special cases by the help of the above set. Because of conditions of exclusion by pairs, namely, several possible multi-component hue groups do not create harmonic polichrome hue harmonies. Harmony compositions with different messages are created depending on the angle exhibited by the straight line or straight lines in the current COLOROID colour plane or colour planes in relation to the achromatic axis, where the colour points of the colours participating in the sets are located on.

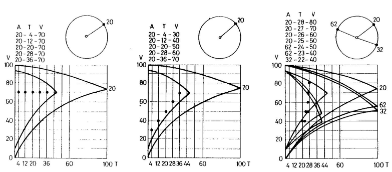

Figure 24:

Harmony compositions of different messages are originated depending on that - in the current COLOROID colour plane or colour planes - what ΔT and ΔV distances are between the colour points of the colours participating in the set. (See Figure 24.)

Displaying colours using COLOROID colour characteristics

To display the colour determined by COLOROID $A-T-V$ colour characteristics (p_t, w_i, s_t) the colours can be calculated with the functions below:

$$p_t = \frac{T}{T_t},$$

$$w_t = \frac{V^2 - p_t V_t^2 - (1-p_t) V_s^2}{V_w^2 - V_s^2},$$

$$s_t = 1 - p_t - w_t.$$

where T and V are the COLOROID colour coordinates of the colour to be displayed, T_t is the saturation of colour surface used for the mix, having identical hue as the colour to be mixed, V_t is the COLOROID luminosity if colour surface used for the mix, having identical hue as the colour to be mixed, V_w is the COLOROID-luminosity of the white surface used for the mix, V_s is the COLOROID-luminosity of the black surface used for the mix.

Colour design method using COLOROID colour characteristics

Design of certain visual appearance of facilities, building compositions, interiors and exteriors can be implemented expediently by the following steps:

1. Recording of colorimetric data related to the site, environment and the building materials to be used, applying COLOROID colour characteristics.

2. Recording of colour requirements related to future user demand and future functions of the facility.

3. After analysis and consolidation of data and requirements, delimiting colour ranges selected for the facility with COLOROID colour characteristics.

4. Recording with COLOROID colour characteristics, the harmony compositions, colour groups selected from the delimited colour ranges for the different colour appearances of the facility, according to the artistic ideas of the designer.

5. Preparing the colour dynamics design documentation using COLOROID colour characteristics.

6 Letter symbols used in the text and the figures

A	COLOROID hue
$A_2 0$	the concrete COLOROID basic colour, -hue or colour point
H	COLOROID limit colour
hg	COLOROID delimiting curve
p	COLOROID colour content
s	COLOROID black content
S	absolute black colour of COLOROID
T	COLOROID saturation
T_λ	saturation of COLOROID limit colour and COLOROID basic colour
V	COLOROID luminosity
V_λ	luminosity of COLOROID limit colour and COLOROID basic colour
w	COLOROID-white content
W	absolute white colour of COLOROID
x	colour stimuli coordinate of surface colour under investigation
x_o	colour stimuli coordinate of D65 point of the CIE 1931 colour diagram
x_w	colour stimuli coordinate of absolute white colour of COLOROID
x_s	colour stimuli coordinate of absolute black colour of COLOROID
x_λ	colour stimuli coordinate of COLOROID limit colour and COLOROID basic colour
X	colour stimuli component of the surface colour under investigation
X_λ	colour stimuli component of COLOROID limit colour and COLOROID basic colour with the same wavelength as the dominant wavelength
X_s	colour stimuli component of absolute black colour of COLOROID
X_w	colour stimuli component of absolute white colour of COLOROID
y	colour stimuli coordinate of surface colour under investigation
y_o	colour stimuli coordinate of D65 point of the CIE 1931 colour diagram
y_s	colour stimuli coordinate of absolute black colour of COLOROID
y_w	colour stimuli coordinate of absolute white colour of COLOROID
y_λ	colour stimuli coordinate of COLOROID limit colour and COLOROID basic colour
Y	colour stimuli component of the surface colour under investigation
Y_λ	colour stimuli component of COLOROID limit colour and COLOROID basic colour with the same wavelength as the dominant wavelength of the surface colour under investigation
Y_s	colour stimuli component of absolute black colour of COLOROID
Y_w	colour stimuli component of absolute white colour of COLOROID

Z colour stimuli component of the surface colour under investigation
Z_λ colour stimuli component of COLOROID limit colour and COLOROID basic colour with the same wavelength as the dominant wavelength of the surface colour under investigation
Z_s colour stimuli component of absolute black colour of COLOROID
Z_w colour stimuli component of absolute white colour of COLOROID
ß luminance factor
ε one hundredth of the sum of colour stimuli components of surface colour under investigation
ε_λ one hundredth of the sum of colour stimuli components of COLOROID limit colour and COLOROID basic colour with the same wavelength as the dominant wavelength of the surface colour under investigation
ε_s one hundredth of the sum of colour stimuli components of absolute black colour of COLOROID
ε_w one hundredth of the sum of colour stimuli components of absolute white colour of COLOROID
φ is the angle of the half line originated from the D65 point of the CIE 1931 colour diagram to the x axis. Its magnitude and slope characterises the COLOROID-hue
λ wavelength
λ_d dominant wavelength

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