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CONSERVATION OF ARCHITECTURAL HERITAGE,
HISTORIC STRUCTURES AND MATERIALS

Colour

Specification and measurement




COLOUR

ARC
LABORATORY HANDBOOK

VOLUME 5/99

Andrea Urland

The ICCROM ARC Laboratory Handbook is intended to assist professionals working in the field of conservation of architectural heritage and historic structures. It has been prepared mainly for architects and engineers, but may also be relevant for conservator-restorers or archaeologists.
It aims to:

- ***offer an overview of each problem area combined with laboratory practicals and case studies;***
- ***describe some of the most widely used practices and illustrate the various approaches to the analysis of materials and their deterioration;***
- ***facilitate interdisciplinary teamwork among scientists and other professionals involved in the conservation process.***

The Handbook has evolved from lecture and laboratory handouts that have been developed for the ICCROM training programmes. It has been devised within the framework of the current courses, principally the International Refresher Course on Conservation of Architectural Heritage and Historic Structures (ARC).

The general layout of each volume is as follows: introductory information, explanations of scientific terminology, the most common problems met, types of analysis, laboratory tests, case studies and bibliography.

The concept behind the Handbook is modular and it has been purposely structured as a series of independent volumes to allow:

- ***authors*** *to periodically update the texts;*
- ***users*** *to work selectively with the volume relating to the particular problem they are facing*
- ***new volumes*** *to be gradually added in line with developing needs.*

1998 - 99 volumes:
(1) Introduction, (2) Porosity, (3) Salts, (4) Binders, ***(5) Colour specification and measurement***

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Rome, 1999

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1 INTRODUCTION

In recent years, the use of applied colour science in conservation and restoration practice has steadily increased.

In particular, colour specification and measurement have become essential tools for interdisciplinary teams of professionals dealing with architecture and works of art. When conventional methods of visual colour assessment are combined with instrumental methods, visual and aesthetic judgements are enriched with physical data that complement the capacities of the experienced eye.

Among the main fields of application of colour specification and measurement are:

- SURVEY AND DOCUMENTATION:
  architectural and decorative surfaces, stratigraphy or chromo-chronology.
  Visual and instrumental methods
- MONITORING:
  colour changes as an indicator of alterations, such as natural ageing due to environmental influences, effects and performance of treatments over time (e.g., assessment of light-induced fading, cleaning or protective treatments exposed to atmospheric pollution and climatic risk factors).
  Mainly instrumental methods
- DATA BANKS AND REFERENCE ARCHIVES:
  reference colour measurements for monitoring future changes, as lasting records of historic colour schemes, surfaces before cleaning or treatment.
  Visual and instrumental methods
- COLOUR SCHEMES, URBAN COLOUR PLANS:
  environmental colour assessment, restoration of historic colour schemes.
  Mainly visual methods

Other examples:

STUDY OF PAINTING TECHNIQUES (*Mainly instrumental methods),* STUDY OF COLOUR SCALES OF TRADITIONAL PIGMENTS for external painting 🗀1 *(Mainly visual methods),* STUDY OF VARIATIONS OF THE PERCEIVED COLOUR OF BUILDINGS DEPENDING ON THE OBSERVATION SITUATION. 🗀2 🗀3 (*Mainly visual methods)*

This Volume outlines basic concepts and information helpful for the application of colour science, colour specification and measurement to conservation and restoration practice. Some of the most commonly used systems and techniques are explained and illustrated by examples and a case study. Further practical information applied to conservation and restoration of architectural surface finishes will eventually be covered in a separate volume.

1.1 COLOUR CONCEPTS

The definition of colour still remains a subject of debate among colour scientists. There are basically two schools of thought:

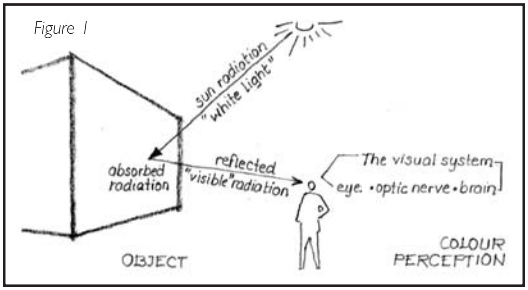
- The first claims to explain colour "objectively" as a physical phenomenon, i.e., electromagnetic waves. According to this interpretation,
  COLOUR IS PHYSICS
- The second claims to explain colour "subjectively" as a response to a physical stimulus[1]; the stimulus itself is not considered the subject of study. According to this interpretation,
  COLOUR IS PSYCHOLOGY

physical stimulus (electromagnetic radiation / light[2]) ----------→ *sensation / perception* (colour)

The relation between the physical stimulus (radiation) and the sensation (colour) is not direct. A one-dimensional change in the radiant flux may cause a multi-dimensional change in the colour perceived.

[1] The physical (colour) stimulus is an electromagnetic radiation entering the eye and triggering a sensation of colour, either chromatic or achromatic (Commission Internationale de l'Eclairage, CIE, 1987)

[2] The word "light" has been used for the physical stimulus for a long time. Reviewers of lighting vocabulary of the CIE are reaching agreement to adopt the more correct wording "electromagnetic radiation," which should replace the current usage. The wording "visible radiation" will most probably remain, although considered inappropriate as we cannot see radiations. (O. Da Pos)



This volume deals with *surface colours*,[3] also referred to as opaque object colours.

[3] Colour perceived as belonging to a surface from which the light appears to be diffusely reflected or radiated. (CIE, 1987) Object colour is defined as the colour perceived as belonging to the object. It is not the property of the physical object itself, but rather depends on the combination of its reflecting or absorbing power and its illumination as assessed by an observer.

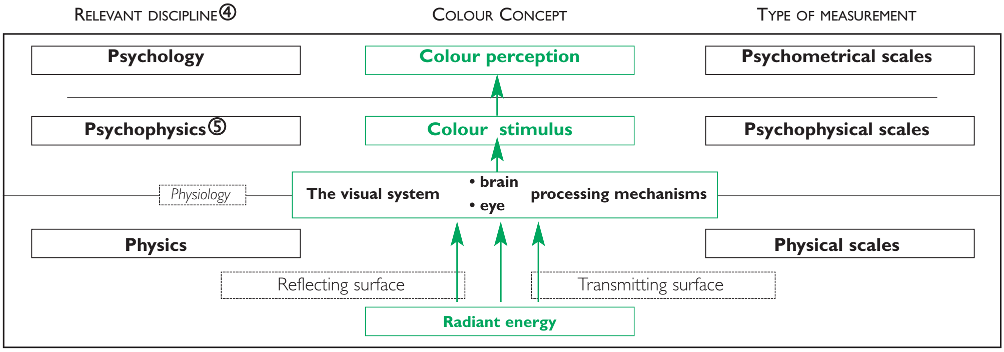
[4] Colour can be studied from the perspective of several disciplines, mainly chemistry, physics, physiology, psychology and aesthetics.

[5] Psychophysics is a branch of psychology that studies the quantitative relations between psychological events and physical events, or more specifically between stimuli and the corresponding sensations. [6]

[6] Terminology is currently under revision by the CIE.

[7] CIE 1987 indicates definitions of colour terms based on the International Lighting Vocabulary. [7]

An overview of colour concepts (based on similar representations [4]) is given in the diagram below, which should be read from the bottom up.



Respectively, the corresponding terminology [5] is:

PHYSICS	PSYCHOPHYSICS	PSYCHOLOGY
(Radiant energy)	(Stimulus)	(Colour perception)
Wavelength Wavelength-composition	Dominant wavelength Purity } Chromaticity	Hue Saturation } Chromaticness
Intensity	{ Luminance (light sources) Reflectance (objects)	Brightness Lightness

1.2 BASIC TERMINOLOGY[6] AND ACRONYMS

This section provides generally accepted definitions; the terms and related concepts are expained gradually in the course of the text that follows.

HUE: attribute of a visual sensation according to which an area appears to be similar to one of the perceived colours red, yellow, green and blue, or to a combination of two of them. (CIE, 1987)[7]

SATURATION: colourfulness of an area judged in proportion to its brightness. (CIE, 1987) It is the attribute of a colour perception determining the degree of its difference from the achromatic colour perception most resembling it.

BRIGHTNESS; LUMINOSITY: attribute of a visual sensation according to which an area appears to emit more or less light.

PSYCHOLOGY

Lightness: the brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting. (CIE,1987)

Chromaticness; colourfulness: attribute of a visual sensation according to which the perceived colour of an area appears to be more or less chromatic. (Formerly chromaticness denoted the combined perceptions of hue and saturation, i.e., the perceptual correlate of chromaticity). (CIE, 1987)

Chroma: colourfulness of an area judged in proportion to the brightness of a similarly illuminated area that appears white or highly transmitting.

PSYCHOPHYSICS

Chromaticity: property of a colour stimulus defined by its chromaticity coordinates, or by its dominant or complementary wavelength and purity taken together. (CIE, 1987)

Luminance/reflectance: a measurable physical quantity (intensity of radiation in a given direction) subjectively appreciated as brightness.

Dominant wavelength: wavelength of the monochromatic stimulus that, when additively mixed in suitable proportions with the specified achromatic stimulus, matches the colour stimulus considered. In the case of purple stimuli, the dominant wavelength is replaced by the complementary wavelength. (CIE, 1987)

Complementary wavelength: wavelength of the monochromatic stimulus (spectrum colour) that when additively mixed with the given colour in suitable proportions matches with a specified achromatic colour.

Excitation purity: simply stated, it can be defined as an expression of the degree of complexity of a colour stimulus with respect to its spectral composition. Monochromatic radiation consisting of only one wavelength has the highest spectral purity. [8]

CIE: *Commission Internationale de l'Eclairage* (International Committee on Illumination).
ASTM: American Society for Testing and Materials
ISO: International Standards Organization
OSA/UCS: Optical Society of America Uniform Colour Scales
NCS: Natural Colour System

[8] *The sensation of white corresponds to a radiation having a continuous spectrum containing all the components of various wavelengths in equal intensity.*

[9] *Spectrum colour is the colour perceived when the retina is stimulated by a monochromatic radiation of a single frequency wavelength.*

COLOUR

2 BASIC PRINCIPLES

2.1 Basic physics

There is no colour without an observer, just as there is no colour without light. *Light* is the perceptual correlate of a form of radiant energy, which acts as a stimulus to the eyes and causes the observer to see. [9] It comprises only a small portion of the total electromagnetic spectrum of radiant energy *(Figure 2)*. We perceive noon sunlight as white light, a neutral reference for normal colour vision. Sun radiation is composed of many wavelengths; a beam of white light (an equal energy beam)[8] passed through a prism will form a continuous *spectrum of wavelengths*[9] from about 700 nm (corresponding to red) to about 400 nm (corresponding to violet).

When white light strikes an *opaque surface*, some wavelengths are absorbed, others reflected. As a result we perceive the colour of an object.

Perception of white light can also be triggered by mixtures of *long* (l), *medium* (m) and *short* (s) wavelengths in suitable proportions. These radiations are called *additive primaries*, because in appropriate mixtures they can match lights of any hue.

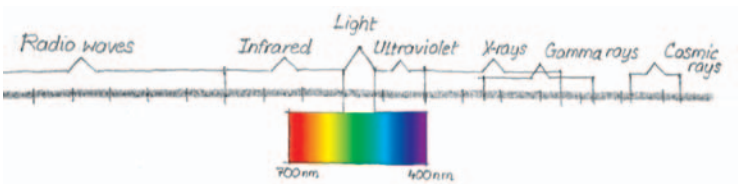
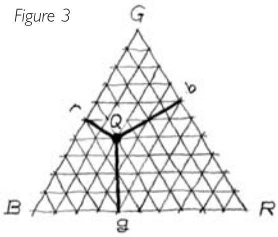


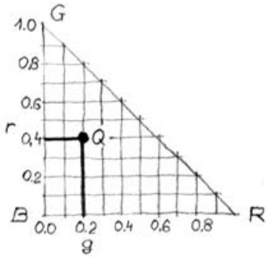
Figure 2

The electromagnetic spectrum – *schematic drawing with image of "visible" radiation*

Figure 3



THE MAXWELL TRIANGLE



Transformed to rectangular coordinates

The Maxwell triangle[10] shows the mixture of additive primaries graphically. The colour corresponding to any mixture of the primaries can be represented by a point in the triangle. The point at the centre of the triangle represents white. The *chromaticity* of a particular primary mixture can be expressed by the sum: $l + m + s = 100\%$, often quoted as r (red) + b (blue) + g (green) = 100% because of the colours perceived when each single primary stimulates the eye. This means that the percentages of only two primaries are sufficient to define chromaticity, which corresponds in a general way to the colour of a light without regard to its *brightness.*

2.2 COLOUR VISION

Vision is one of our five senses, and has both practical and aesthetic functions.

It is the response to a *physical stimulus* acting on our *visual system*: the eyes, optic nerve, brain. We see and perceive the world around us through colour (chromatic and achromatic[11]). Through colour differences we are able to perceive forms.

Under optimum conditions, an average person with normal colour vision distinguishes about 1000 *hues* and about 200 *saturation* degrees in certain hues. The number of distinguishable colours is estimated as 7.5 to 10 million.

[10] *James Clark Maxwell first used this triangle. Transformed to rectangular coordinates, it later became the basis for the chromaticity diagram (see page 13).*

[11] *Chromatic colour perception is defined as having a hue; achromatic colour does not possess a hue.*

[12] *The example of metameric pairs: two objects with different spectral reflectances match under one illumination, but may not do so under a second illumination.*

2.3 COLOUR PERCEPTION

Studying visual perception means explaining why we see and how we see.

At times, the same perception can be triggered by physically different stimuli or a physically constant stimulus can correspond to various perceptions in different situations. The relationship between physical stimulus and colour sensation is not constant.

A number of scientists have long stressed the need to distinguish between colours as visual qualities and the physical conditions or reasons for these phenomena, maintaining that the study of physics is unlikely to provide any information about the structure of the world of perception (also called *phenomenal* world), as one stimulus can give rise to two or more fundamentally different colour perceptions.[12] 10

Some of the physiological factors that influence the perception of colour are:

ADAPTATION: the adjustment of the visual system to the intensity or quality of the light stimulus. When the eye is exposed to a given illumination level for sufficient time, it accepts this level as normal and all other intensities are processed relative to it.

COLOUR CONSTANCY: a process that tends to make the colours of objects look the same despite relatively great changes in the stimulations.

COLOUR CONTRASTS: e.g., simultaneous colour contrast: the tendency of the eye to intensify the difference between different colours placed next to each other.

MEMORY COLOUR: the colour perception that a familiar object under normal illumination would arouse in the judgement of the observer. 11

AREA EFFECT: change in apparent colour caused by the size of the colour sample.

2.4 Colour Appearance

Colour appearance means the colour that an object appears to be. Colours are in constant change and transformation.

A recently proposed system 12 which helps to describe all the visual perceptions produced by light stimuli distinguishes:

- *spatial perceptions* (size, shape, location)
- *temporal changes in the intensity of light* (flicker, sparkle)
- *attributes of colour sensation* (brightness, hue and saturation)
- *cesia* [13] (includes glossiness, opacity, mattness, diffusivity, transparency, absorption, etc.).

[13] The term "cesia" is being used for that aspect of appearance which deals with the perceptions aroused by transformation in quantity and spatial distribution of the light that reaches the eye after being either partially absorbed and/or re-emitted by an object. 13 *Like colour, it is not an intrinsic property or attribute of materials and surfaces.*

[14] Colour space is a frame of reference in which a point representing a colour may be located in such a way that each of its attributes corresponds to a dimension in that space. 16

The apparent colour of an object depends on 14:

1. The light striking the object (= radiation, its spectral energy distribution)
   The spectral distribution of a light source is its relative energy at each wavelength of the visible spectrum.
2. The object itself (its spectral reflectance)
   The spectral reflectance of an object is the fraction of the incident light reflected by it at each wavelength.
3. The observer (her/his spectral response)
   An observer's spectral response is determined by his relative response to light at each wavelength. Assuming that the observer has normal colour vision, the ability to discriminate colours depends on training, experience, mental attitude, age, etc. Visual receptor response is governed by an individual's inherited and acquired capacities. 15

In other words, various factors influence the observed colour of a surface: the spectral quality of the illumination, the direction of the illumination and of viewing, the distance of viewing, the surround/background, the nature of the light reflected from the surface, surface material, texture, surface area and the state of adaptation of the eyes of the observer.

3 Colour Order Systems

Colour order systems are systems for categorizing colours.

3.1 Purpose, features and types

Purpose and functions

The existing colour order systems were developed for various purposes, mainly because of the practical need to *describe* colours accurately and to be able to *communicate* about them easily over long distances and periods of time. Colour order systems make it possible to:

- *identify, determine* a single colour, or
- *analyze and define the (aesthetic) relationship* among colours
- *choose, produce and control* colours unambiguously.

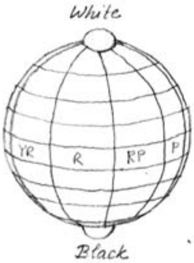
Characteristic features

These systems organize all existing colours in a *3-dimensional colour order*. Their own *colour spaces,* [14] however, can be restricted, depending on the concepts of "colour" on which they are based:

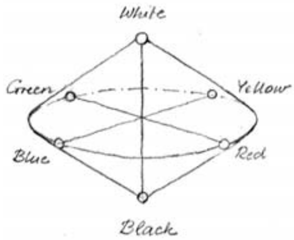
- colorant [15]
- primary lights
- perceived colour – subjective visual sensation.

[15] Colorants are substances used to modify the colour of a material or an object; they mainly include pigments and dyes.

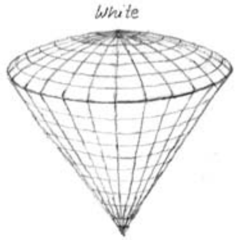
The 3-dimensional nature of the colour order as a framework is illustrated by a *color solid*, most often based on a sphere, a cylinder or a double cone. The systems sample the world of colour according to 3 basic *variables* or *colour attributes* that constitute the coordinate axes of the colour system.



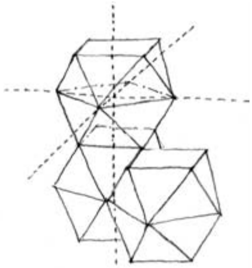
Munsell (1905)



NCS



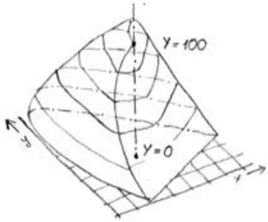
DIN 6164



OSA/UCS

EXAMPLES OF COLOUR SOLIDS

(Adapted from Gerritsen and Derefeldt)



CIE (Rösch)

[16] *Primary or basic colours are those from which all the other colours can be mixed, but which cannot themselves be mixed from other colours (e.g., for light: red, green, blue; for perception: yellow, red, blue, green, white, black).*

[17] *Inter-Society Color Council and National Bureau of Standards = Method of Designating Colour and Dictionary of Color Names, 1939. This is a system of colour names, in which colour limits for each name were defined in Munsell terms.*

Further differences between colour order systems lie in the principles they are built on, the number of primary colours [16] used, the types of variables or attributes by which they describe colours, the spacing of colours, etc.

In order to be a useful tool, they must meet two main requirements: uniqueness of description and replicability.

Colour order systems can be exemplified in the form of colour atlases and other colour sample collections.

Type	**1**	**2**
Systems based on	Systematic variation of the amounts of colorants, or amounts of the primary radiations (in an additive colour mixture)	Colour appearance (systems described and classified according to perception)
Type of use	Useful for restricted application in printing, dyeing, television, illumination	For general use

TABLE 1 🗁18

TYPES

Recent studies 🗁17 divide colour systems into two major groups *(Table 1)*:

1. *Colour-stimulus systems*, also called psychophysical colour systems, are mainly centered on the characteristics of the stimuli suitably measured.

2. *Colour-appearance systems*, also called psychological or perceptive colour systems, are based on appearance parameters psychometrically measured.

TABLE 2 🗁19

3.3.a Descriptive systems		**3.3.b Equi-spaced systems**
NCS (as descriptive Method) ISCC-NBS [17]	NCS colour atlas	Munsell DIN Coloroid OSA-UCS
Perceptively defined	Colorimetrically defined	

3.2 Colour-Stimulus Systems

The CIE colorimetric system (1931) belongs to this first group. The 1976 CIELAB and CIELUV are widely used in science and industry as approximate colour appearance systems. They offer the possibility of unambiguous colour stimulus specification and colour difference measurements *(see page 15)*.

3.3 Colour-Appearance Systems *(Table 2)*

Current colour appearance systems have been developed for surface colours. They follow the following principles 20:

a. Perceptual coordinates or scales: the description of colour appearance in relation to easily recognizable reference colours. Prevailing consensus is that of 6 reference colours. Colour samples are helpful, but not required. *(Descriptive systems)*.

b. Uniform or equal visual spacing [18] of colours according to the scales, where steps in colour notation should represent equal differences in appearance. These systems rely on description of colour appearance by physical colour samples, which are usually necessary for reference. *(Equi-spaced systems)*.

The following are examples of modern colour appearance systems that are among the most commonly used nationally or internationally:

- Munsell system (country of origin: USA)
- Natural Colour System (NCS) (Sweden)
- DIN-Farbsystem 6164 (*Deutsches Institut für Normung,* Germany)
- Optical Society of America Uniform Color Scales (OSA/UCS)
- Coloroid system (Hungary)

In many applications, the CIELAB and the CIELUV colour spaces are used as approximations to colour appearance systems.

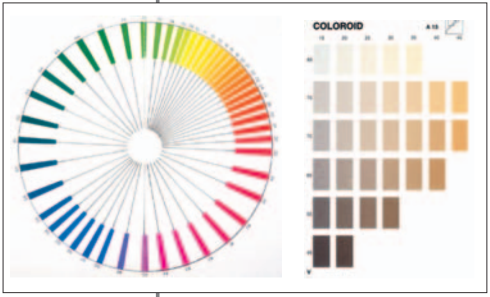
[18] *Concept of perceptually uniform colour space: uniformity depends on the colour-difference perception ability of the human visual system. The scales of the colour space are defined using perception-threshold measurements.*

[19] *Country of origin: Germany.*

3.4 Colour Atlases

Colour atlases are physical exemplifications illustrating colour order systems in a systematic and quite complete form. The function and importance of atlases depends on the respective colour order system.

- *Descriptive colour systems*, by concept do not rely on atlases. If they are accompanied by an atlas, its samples show the appearance corresponding to perceptively defined notations. The colorimetric specifications serve mainly to ensure the reproducibility of the samples, they do not define the system itself. 21
- The *equi-spaced systems* usually do rely on colour atlases.
- There are now also colour atlases (e.g., Eurocolor, RAL-system [19]) based *directly on colorimetric coordinates*, illustrating the CIE colour space. 22



Example of a hue circle and a section through the vertical axis of a colour solid (The Coloroid system exemplified by the Coloroid Atlas)

Characteristic features

Atlases sample the system's colour space according to 3 basic (perceptual) colour attributes that constitute the coordinate axes of the colour system. These usually are the hue, the achromatic and the chromatic colour dimensions. The hue circle is visualized by horizontal sections of the colour solid, and the other two colour dimension ranges are represented in vertical sections through the vertical axis.

Use instructions and restrictions

Each colour atlas provides guidance to proper use. Given the influence of the surrounding factors, the effects of illumination and the influence of the viewing conditions, various restrictions have to be taken into account when working with colour atlases:

- colour samples are to be viewed under conditions of standard illumination. The CIE recommends average daylight, represented by illuminant D_{65} or CIE illuminant C *(see page 14)*.
- colour samples are to be viewed against a homogeneous background – usually gray or white
- colour samples are to be illuminated and viewed at a certain angle.

A change in these conditions may cause a change in the sample's appearance. In colorimetrically defined colour systems and atlases, the definitions are valid only so long as the viewing conditions remain constant. Changes in appearance are, however, partly counteracted by the phenomenon of colour constancy.

3.5 General considerations

Several countries have adopted specific colour order systems as national standards, e.g.:

Munsell: USA, Japan, Italy; *NCS:* Sweden, Norway, Spain; *Coloroid:* Hungary; *DIN:* Germany. Given the wide variety of established colour order systems, it has not been possible to issue a single international standard.

The advantages and disadvantages of a system's colour space structure and variables, density of sampling, etc., emerge in practical use and should therefore be tested in advance. It is important to choose the right system with regard to **the conditions and final aim of the work**.

4 COLOUR SPECIFICATION AND MEASUREMENT

4.1 Colour specification - General aspect and methods

Colour specification is a description of colours, which varies in accuracy depending on the particular situation.

Object colours (surface colours) were first recorded by names, followed by more elaborate methods of designation. Although name identification is still widely practiced, it is of limited accuracy.

Knowledge of other more precise methods can therefore be very useful. An illustration of six levels of increasing accuracy is provided by Kenneth Kelly's *Universal Colour Language*: [23]

Level	Description / Method	Examples
1.	13 names (10 hues, 3 neutral)	Yellow
2.	29 names, including intermediate hue names	Reddish yellow
3.	267 names (colour name blocks of the ISCC-NBS)	Light reddish yellow
4.	About 1000 names (colour samples in the Munsell Book of Color)	Munsell notation 10 YR 6/4
5.	Interpolated Munsell notation (100,000 divisions of the colour solid)	9.5 YR 6.4/4.25
6.	CIE method, chromaticity coordinates x, y, Y	x=0.395, y=0.382, Y=35.6%

Colour measurement can be either *visual or instrumental*. For architectural surfaces and surface finishes it can be done *in situ* or in laboratories or studios if working with collected samples. In most measurement procedures, clear documentation of the position of the measurement points is important for future reference.

It is essential to bear in mind the actual purpose of measuring when choosing a certain method or level of accuracy. [20]

[20] ***Example:** In visual assessment, the human eye might record colour differently than instrumental measurements (e.g., variations of colour within weathered samples, where the eye tends to exclude the dirt).*

How to obtain accurate visual or instrumental measurements of colour appearance is still a largely unsolved problem of colour science, especially when dealing with complex scenes with a number of colours of different surface areas.

4.2 Visual colour specification and measurement

Visual measurements are generally considered easier to carry out than instrumental ones. Although less precise, they give us information on the appearance of the colour, which instrumental measurements do not.

Visual colour asssessment – colour identification, description or designation – is done by observation, using the following types of methods:

4.2.1 Methods without reference samples

These methods refer to descriptive colour appearance systems as a conceptual tool that can be used without reference samples. Chromatic surveys of architecture or urban spaces can be performed this way using the NCS system, for example.

4.2.2 Methods with colour samples through visual comparison (colour matching)

Colour matching is specification of object colour by visual comparison to colours whose specification is known, looking for equality or the closest similarity.

It is a visual procedure performed to decide whether or not two colours differ perceptually. Colour matching can be used for determining whether the two colours are identical (not distinguishable under all three variables) or it can focus on one aspect of the two colours, judging whether, e.g., the hue, or the saturation is the same.

Colour matching is useful in both identification of colours and their reproduction. It is done by direct observation of the *test* and the *reference samples*; more rarely an instrument (visual colorimeter) is used to compare the samples.

a. Using sketches

   In practice, sketches with matching colours are often produced directly on site, using colour pencils and/or paints to reproduce the colour of the test sample.

b. Using reference samples

   Another approach is to use various colour charts for quickly recording the colour of the test sample. These can be paint chips of various manufacturers, or the reference sample collections of colour order systems. In the first case there is generally no systematic ordering of the colours; this may not be important in the recording phase, but can be a major drawback as soon as any further study and communication are required. Therefore colour order systems, especially the standardized ones, are always preferable.

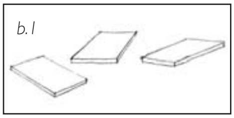
Tools:

Reference sample collections are all lightweight and easily transported for field use. They can take the following forms:

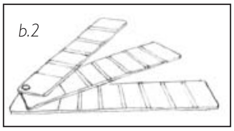
b.1 single paint chips
b.2 colour scales (colour samples of one-dimensional variation), indexes
b.3 atlases (collections of colour samples intended to represent a considerable fraction of all colours in a 3-dimensional variation).

Reference samples of the b.1 and b.2 type can be placed directly on the test sample surface for comparison.

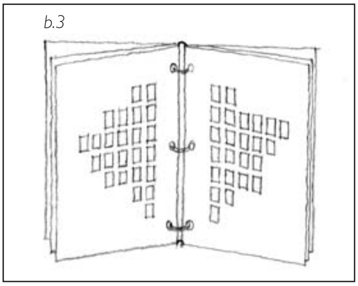
In the case of colour atlases, b.3, there are two possibilities. Usually the reference samples are fixed, and visual comparison is made at a distance. *Masks* (white or gray) can be helpful to place on the reference samples in order to limit the area of comparison for finding the closest match. Some atlases have removable reference samples which permit the same use as b.1 and b.2, i.e., direct contact



b.1



b.2



b.3

between test and reference samples, which often facilitates making a judgement.

If the colours of the reference sample collection are spaced sufficiently closely, the nearest match can be found by direct visual comparison; if not, an intermediate value can be estimated by *visual interpolation*.

As a rather small number of specimens has to cover the range of all possible colours, it is of great importance to choose the most appropriate tool (system and its companion reference samples) to work with, as each system is built in a different way.

Criteria to consider for the choice of tools can be:

- density of reference sample spacing in the colour area of the range of test samples (for architectural surfaces and surface finishes, certain hue, saturation and lightness ranges prevail);
- relationship of the reference samples to standards and to colour order systems;
- appropriateness of the variables on which the system is built, evaluated in relation to the purpose of the work (intended data elaboration and interpretation possibilities);
- compatibility and comparability of the colour measurement data with other related studies;
- cost of the reference sample collection with regard to the character of the work, its continuity, context, conditions, etc.

Rules

Matching to a colour chart or reference sample must follow certain rules; in the case of atlases, these are precisely described, and sometimes there are separate standard methods to apply, e.g., ASTM Standard Method of specifying colour by the Munsell system.

Typical precautions are: lay the samples flat and view them directly from above; have the illumination fall on the samples at an angle of approximately 45 degrees, etc. The standard practice is to view specimens illuminated by daylight from a slightly overcast sky or the equivalent of this illumination.

Reference samples should be stored and used with care (avoid direct touching, etc.), as they are also subject to ageing.

4.3 Instrumental colour measurement

Instrumental colour measurement consists of the analysis and description of colour directly by *colorimeters* or indirectly from data based on measurements using a *spectrophotometer*.

Instrumental measurement focuses on the physical stimulus, i.e., electromagnetic radiation (light) and is based on the CIE colour system.

Instrumental colour measurement has basically gone through three main **development phases**.

The first two phases were limited to two stimuli under identical conditions:
Matching: concerns whether or not two stimuli match each other;
Difference: attempts to quantify colour differences;
Appearance, the third phase, compares stimuli under different viewing conditions. The first models for predicting colour appearance [21] date to the early 1980s.

[21] Experimental research has shown that colorimetric matches do not necessarily produce a satisfactory visual match when the viewing conditions differ, i.e., colours having the same CIE coordinates need not appear identical if the material and the viewing conditions are not the same. For this reason, models that are capable of predicting the perceived change in the appearance under different viewing conditions are being developed and tested.

4.3.1 Colorimetry and Spectrophotometry

Spectrophotometry or "measurement of the spectrum" allows us to determine the relative way in which the total energy in a beam of light is divided among the wavelengths it contains.

The spectrophotometer breaks down the radiation reflected or transmitted by the measured object surface into its component wavelengths from short waves (about 400 nm) to long (about 700 nm). By a series of prisms, lenses and a mirror, a beam is directed at the object, wavelength by wavelength. The ray reflected from the object surface is then compared with the ray reflected from a virtually perfect diffusing surface [22] in the spectrophotometer. 🗁24 The differences in their relative reflectances across the spectrum are recorded and visualized as a curve (*examples in Figure 4*). By computation the spectrophotometric curve can be translated into colorimetric terms, such as CIE, that can be plotted on a chromaticity diagram. The instruments are usually also capable of converting the measurements into the notations of some colour order system, such as the Munsell.

Colorimetry works with the three additive primaries, corresponding to the physiological aspects conditioning colour perception, mainly the trichromatic nature of the normal eye. Results measured are expressed as the quantities of these radiations reflected from the object surface (tristimulus specification of colours).

Colorimetric data allow further study and evaluation of colour characteristics and differences. They are indispensable in any production (such as colour atlases) where exact colour reproduction must be guaranteed.

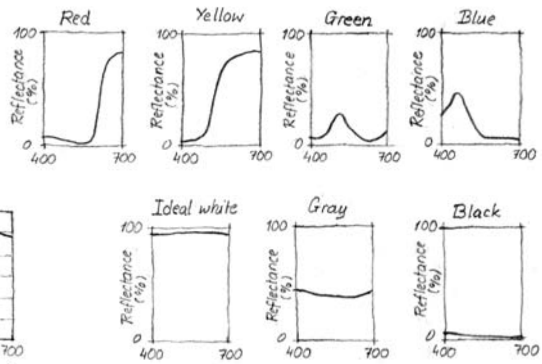
[22] *White, such as magnesium oxide.*

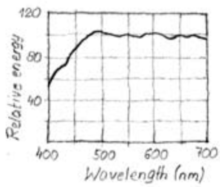
[23] *Tristimulus values are the amounts of the three reference lights (matching stimuli, primary colours) required to give a match with the test colour (light) by additive mixture.*

[24] *Chromaticity diagram: a plane diagram in which points specified by chromaticity coordinates represent the chromaticness of colour stimuli. (CIE, 1987)*

[25] *The Standard Observer is a theoretical average of human observers with a visual response mechanism possessing the colorimetric properties defined by the CIE and a known spectral response.*

Figure 4 🗁25





SPECTRAL ENERGY DISTRIBUTION CURVE *of sunlight*

SPECTRAL REFLECTANCE *of opaque materials of different colours*

4.3.2 The CIE System

CIE XYZ, CIE (x, y, Y)

The CIE colorimetric system was defined in 1931 as a standard system, enabling the specification of all colours as points within a 3-dimensional colour space. It is a system for colour stimulus specification. The spacing of the colour stimuli is not uniform, and as the system is not based on perceptual scaling of colours, it does not give appearance characteristics of colours. 🗁26 There are three defined real primaries: long waves (corresponding to a red perception, R), medium waves (corresponding to a green perception, G), short waves (corresponding to a blue perception, B), and three imaginary *mathematical primaries* X, Y, Z, also called *tristimulus values*. [23]

The main use of the system is in science and industry.

CIE Chromaticity diagram [24]

The chromaticity diagram is based on the method of colour specification known as the CIE Standard Observer [25] and Coordinate System recommended by the CIE. 🗁27 It shows the colours of the spectrum and all their possible mixtures. Pure spectrum colours with the corresponding wavelengths are located along the partly curved boundary line *(spectrum locus)*. Violet (approx. 400 nm) and red (approx. 700 nm) are connected by a straight line, representing their mixture into purple, which does not appear in the spectrum.

Any point within the boundary line can be located by *chromaticity coordinates,* ㉖ x and y.

The chromaticity diagram is based on the Maxwell triangle used to show graphically the mixture of additive primaries. The x values on the horizontal scale and the y values on the vertical scale represent the proportions of the theoretical X (red) and Y (green) primaries ㉗ respectively required to produce all possible colours; the partly curved boundary line represents the proportions of primaries needed to match all single wavelengths. The colour of any light can be fully specified by its chromaticity coordinates x, y and its *luminance/reflectance Y*, i.e., if we know both the proportion of the three primaries in the matching mixture and its luminous intensity.

The CIE chromaticity diagram indicates the chromaticity of a light without regard to its luminance, Y. A 3-dimensional solid showing the limits within which all real colours lie when viewed in daylight can be constructed, having for its base the chromaticity diagram with the luminance indicated as a vertical dimension *(page 8)*. The diagram provides no impression of the colour appearance of the object measured; nor is there a regular series of reference samples to represent the system.

From the chromaticity coordinates x and y, the *dominant wavelength* can be computed, as well as the *purity.* ㉘ These, together with Y (luminance/reflectance) are referred to as *Helmholtz coordinates* *(Figure 5)*.

Standard light sources are defined for the CIE system, with their temperature correlates in Kelvin degrees. Most often used are:

A, which represents common tungsten light sources (2,854°K)

B, with a spectral distribution that approximates noon sunlight (4,870°K)

C, with a spectral distribution that approximates average daylight (sunlight and skylight, 6,740°K)

D_{65}: spectral distribution that approximates average daylight ㉙ (6,500°K).

㉖ *Ratio of each of a set of three tristimulus values to their sum: (CIE, 1987)*

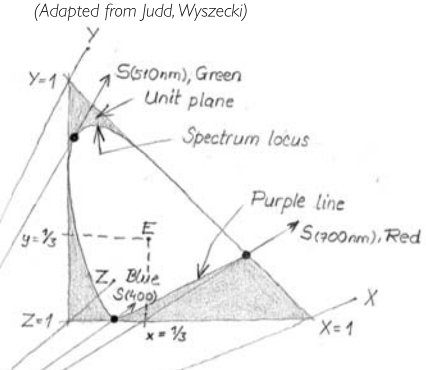
$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$

㉗ *Of course in the additive mixture there is also the theoretical Z primary in the z proportion.*

㉘ *Monochromatic radiation consisting of only one wavelength has the highest spectral purity and is located at the border of the diagram. The achromatic mixture has the lowest purity and is located at about the centre of the diagram: its actual place depends on the illuminant, being exactly at the centre for the illuminant EE (equal energy source).*

㉙ *Illuminant D_{65} is based on numerous spectrophotometric measurements of daylight at different locations in the USA, Canada and Great Britain.* 30 *The Munsell, NCS, DIN and OSA/UCS systems are based on average daylight, represented by D_{65} or CIE illuminant C.*

TRISTIMULUS COLOUR SPACE *(based on the CIE 1931 primaries X,Y,Z)* and THE CHROMATICITY DIAGRAM. *(Adapted from Judd, Wyszecki)*

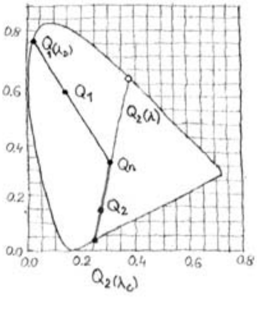


E *Colour of the equal energy stimulus (white light)*

x *Fractional part of the X primary in the stimulus*

y *Fractional part of the Y primary in the stimulus*

Figure 5 - DEFINING THE DOMINANT WAVELENGTH AND THE EXCITATION PURITY *on the CIE 1931 Chromaticity diagram* 29



Q_1, Q_2 given stimulus (colour Q_1, Q_2)

$Q_1(\lambda_D)$ dominant wavelength corresponding to the given stimulus

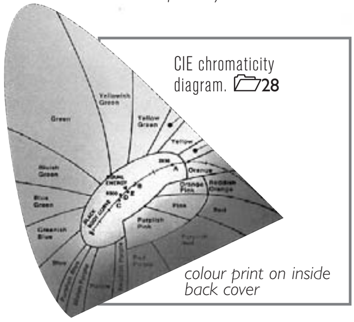
$Q_2(\lambda_C)$ complementary wavelength (in case of purple colours)

Qn achromatic stimulus (white light)

Excitation purity $p_e = \frac{|Q_nQ_1|}{|Q_nQ_{1(\lambda_D)}|}$ *for stimulus Q_1*, *or* $p_e = \frac{|Q_nQ_2|}{|Q_nQ_{2(\lambda_C)}|}$ *for stimulus Q_2*

$0<p_e\leq 1$;

$p_e = 0$ for achromatic stimuli



CIE chromaticity diagram. 28

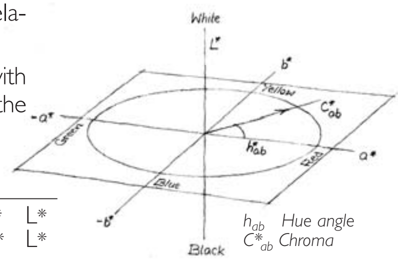
colour print on inside back cover

CIELAB, CIELUV

Responding to a generally felt need, efforts have been made since 1931 to make the spacing of colour stimuli on the CIE (x,y) chromaticity diagram more uniform with the purpose of computing colour differences corresponding to perceived differences, and to relate the system more closely to colour appearance. The *CIE 1976 uniform colour spaces* - CIELUV and CIELAB - were introduced as an improved coordinate system, based on mathematical transformations of the CIE 1931. [31]

Both systems were developed for the three main purposes of tristimulus specification of colour: to provide a means for recording colour stimuli, as a medium for specifying colours and colour tolerances, and for making it possible to quantify and visualize the relationships of colours.

In the CIELAB colour space the L*,a*,b* coordinates correlate with lightness, redness-greenness, and yellowness-blueness, even though the chromatic axes only approximately correspond to the unique hues.



CIE 1931, 1964			
Tristimulus values	X	Y	Z
Chromaticity coordinates	x	y	Y
Helmholtz coordinates	λ_D	p_e	Y

CIELAB 1976			
Cartesian coordinates	a*	b*	L*
Cylindrical coordinates	H°	C*	L*

4.4 Colour Differences

The calculation of colour differences is necessary for quantification of colour changes (e.g., for monitoring, in connection with cleaning of surfaces). Changes in colour are precisely and objectively recorded and analyzed. These measurements allow one to quantify and analyze which parameters or colour variables and characteristics have changed and to what extent (e.g., in cleaning, the exact deviations in hue, saturation and lightness, comparing the data of before and after the process). Interpretation of the data leading to the explanation of observed phenomena is important.
Depending on the precise needs and purpose of measuring colour differences, these can be quantified for one or more colour variables. Mostly instrumental methods are used.

Instrumental measurement of colour differences is practical especially for subtle colour differences and for cases when measurement (as in monitoring) of colour changes must be performed over a longer period of time and by various people.

Colorimetric practice often makes use of the CIELAB colour spaces for the measurement of colour differences; a colour difference is computed in a simple way as the Euclidean distance between two points representing the colour stimuli in the colour space. Therefore it is expressed by a single number independently of where the two colours are located in the colour space. The difference of two stimuli (L^*_1, a^*_1, b^*_1) and (L^*_2, a^*_2, b^*_2) can be calculated using the formula [32]:

$$\Delta E^*_{ab} = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2} =$$

$$=[(\Delta L^*)^2 + (\Delta C^*_{ab})^2 + (\Delta H^*_{ab})^2]^{1/2}\text{, in cylindric coordinates } (L^*, C^*_{ab}, H_{ab})$$

In CIE (x,y,Y) the colour differences are calculated as differences in the chromaticity coordinates, and the difference in luminance.

Visual measurements rely on colour appearance systems to measure colour differences. They are useful when judging perceived colour differences on larger surface areas, at certain distances, and of colours in the context of neighbouring colours. They are particularly useful for the analysis of phenomena connected to the chromatic characteristics of a site, the urban and natural environment, traditions of colour combinations, etc.
Given the notations of two colours, the differences in variables can be expressed in figures and/or graphically using the tools described in the section on visual colour measurement.

Perceived or instrumentally measured colour differences must be evaluated and elaborated and be judged acceptable or not, according to criteria defined with regard to the problem under study.

PRACTICAL 1

VISUAL COLOUR MEASUREMENT

Aim

Specify the colour of a given sample by colour matching, using the NCS and/or the Munsell systems.

Tools

Munsell Book of Color and/or NCS Colour Atlas or Index, white or gray masks with rectangular openings.

Principle

The colour of the test sample is compared to the colour(s) of the reference samples of the atlas or index, in order to find an equal or closest match. The notation of the reference sample describes the colour appearance of the test sample.

Procedure

- Place the test sample in natural daylight (close to a window, or outdoors) on a neutral background (white), having the light come preferably from the left side. Avoid direct sunlight.
- Follow the instructions in the respective atlas as to how to observe the sample (viewing distance, angle, etc.).
- Find the reference sample that is a closest match to the test sample.
- If a single matching reference sample cannot be found, find the most similar colours (2 to 4 samples).
- Read the notation of the reference sample and write it down in your table as the notation of the test sample. In the case of 2 or more similar samples, interpolate the readings of their variables/attributes.

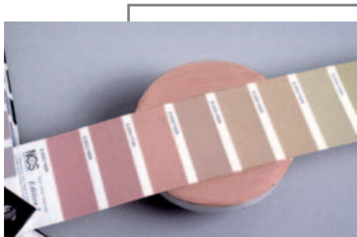
Example

For the given test sample:

- USING THE NCS SYSTEM

  In the NCS Index Edition 2, no single reference sample corresponded to the colour of the test sample. Three reference samples were identified as most similar to the test sample: S2020-Y50R, S2020-Y60R and S2010-Y50R.

  By interpolation of these notations, the notation of the test sample was calculated as S2015-Y55R.

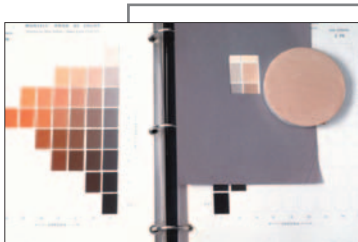

Colour matching using the NCS Index, Edition 2

- USING THE MUNSELL SYSTEM

  In the Munsell Book of Color, the closest match was represented by four samples lying in close proximity to each other:

  5YR 7/2, 5YR 8/2, 5YR 7/4, 5YR 8/4.

  By interpolation of these notations, the notation of the test sample was determined as 5YR 7.5/3.


Colour matching using the Munsell Book of Color

INSTRUMENTAL COLOUR MEASUREMENT

Aim

Measure the colour of a given sample instrumentally using the CIELAB system. Find the spectral distribution curve and the Munsell notation of the test sample.

Equipment

Portable colorimeter.

Principle

The colorimeter quantifies the light reflected from the surface of the test sample under the pre-selected standard illuminant. The spectral reflectance curve can be visualized (e.g., by connecting the instrument to a computer). As a rule, more than one measurement is taken of each sample; three are usually recommended to have a good average.

Example

In the example shown, the illuminant D_{65} was used, and data were requested in the CIELAB system, plus the Munsell notation.

Procedure

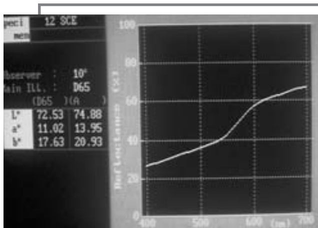
- Calibrate the colorimeter, following the instructions given with the instrument.
- Adjust the size of the opening for measurement to the size of the sample.
- Choose the illuminant; this depends on the purpose of the measurement. Usually D_{65} is recommended.
- Place the colorimeter on the test sample surface and activate the measuring procedure.
- Read the notation in the pre-selected systems on the colorimeter or computer.
- Calculate the average of three measurements to obtain the final data.

Compare the results of the instrumental measurements to the visual ones. Evaluate the differences, if any, and try to give reasons for them.

The following measurements corresponding to the spectral reflectance curve visualized on the computer screen could be read from the instrument:

A portable colorimeter and test sample
colour print on inside back cover

Colour measurement using a portable colorimeter; the results are plotted on a computer screen



The spectral reflectance curve of the test sample colour and the L*,a*,b* readings
colour print on inside back cover

Visual measurements		Instrumental measurements	
NCS	Munsell	CIELAB	Munsell
S2015-Y55	R 5YR 7.5/3	L*=73,40 a*=10,52 b*=17,08	5.1YR 7.3/3.5

When compared, the results of visual and instrumental measurements are rarely identical. Some difference between the visually and instrumentally obtained Munsell notations in this example can be observed for hue, value and chroma. They are, however, very small (especially for hue and value). The reasons could be inaccurate interpolation, effect of illumination, etc. Also, it could be recommended to do several instrumental measurements in various parts of the sample and consider the calculated average.

CASE STUDY

RESTORATION OF COLOUR SCHEMES IN HISTORIC TOWNS – experience of applied colour specification and measurement at BANSKÁ ŠTIAVNICA ㉚

Restoration of historic colour schemes within urban colour plans is one of the areas where applied colour science is used. Many successful examples exist and useful methodologies have been developed, yet each particular case requires its own approach.

㉚ Banská Štiavnica, a town in Central Slovakia, is inscribed on the World Heritage List.

Context and purpose

This pilot project was developed for the local authorities, especially for the town administration and the local office of the National Institute for Protection of Monuments, as a conceptual model to meet urgent needs of practice. There was no systematic study of the complex problem of historical colour schemes in their broader context, which could serve as the basis for day-to-day practice, coordination and control of the conservation and restoration process. The project involved the development of a working methodology and the elaboration of a colour master plan to achieve a visually coherent, functional environment that would correspond to the historical findings and enhance the values of the town's architectural and urban heritage. The project attempted to combine sound conservation and restoration principles with applied colour science. The work was carried out by a multidisciplinary team in less than 9 months of part-time work.

Problems and specific features of the project

The study focused on the existing façades in their current form (each had a complicated building history).

There were some limiting factors, such as the degree of knowledge regarding individual façades at the time of the study, the incomplete character of the available documentation and the limited time frame. The project included 130 buildings, located in 19 streets in the historic centre.

Colour specification and measurement aspects of the project; working method and phases

Preparatory phase:

- Archival research;
- Feasibility studies regarding the possibility of colour mapping of the façades, based on available tools and instruments.

  A survey was made to identify:
  1. what methods and techniques of colour specification and measurement had been used in local practice concerning the relevant buildings;
  2. what equipment was available and how familiar with its use were the professionals involved.

  The survey found that the general practice was the use of description of colour by name, more rarely in combination with a chip (mostly taken from a paint manufacturer's catalogue or sample collections to identify or indicate colours). The standardized colour appearance systems were neither known nor available.
- Experimental research attempting to define the objective factors underlying subjective aesthetic evaluations of architectural colour schemes. 🗀33

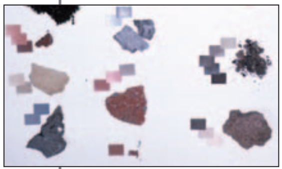
  This was a complementary, quite independent study involving analyses of colour schemes to comprehend people's present-day preferences.

Photodocumentation of the façades

colour print on inside back cover

Survey *in situ:*

- FAÇADES: surveys for determining the art-historical development and building history, state of conservation, historical colour schemes. Assessment of the currently prevailing architectural expression of each façade and corresponding colour schemes. ㉛ Earlier phases were also assessed where possible, by stratigraphic surveys ㉜ in selected points of the façades, 5-15 per façade, depending on its complexity. Site sketches, notes on plans, maps and elevations, and photographic documentation were used. On the basis of an overall analysis and evaluation of the character of the architectural surfaces of the buildings, as well as the character of the project itself, it was decided to work with visual colour assessment, or colour matching. The ACC system (see below) was chosen after prior testing of its appropriateness for the purpose. This system, exemplified in the Sikkens Colour Collection 2021, had a very good density of reference samples in the colour ranges concerned, whereas the standardized colour systems were of limited accessibility and costly for general use in the context. In studio and research work, Munsell and NCS systems were also employed.



Survey of the typical colours of elements of the environment

- ENVIRONMENT: colour survey and assessment of permanent built elements (roads, pavements, supporting walls, etc.) as well as natural elements. This provided data for analysis of the typical colour features of the site, i.e., the landscape and the town with their characteristic permanent and changing colours.

(31) Façades of the individual buildings and the historical surroundings were studied: style of the street façades, their dating; categories of façades with respect to their stylistic-architectural values; state of research on the individual façades; state of conservation, restorations of the façades.

(32) All were plastered façades. Gradual scraping to reveal colour layers was done for chromo-chronology; samples for cross-sections were not necessary for these buildings.

(33) Some of the most useful ones have been developed by G. Brino, A. Nemcsics and J.P. Lenclos.

Analyses

The collected data were analyzed to determine:

-The colour typology of the stylistic periods (from Gothic to present-day) with specified colour characteristics such as: prevailing hues, saturations, lightnesses; characteristic colour combinations, qualitative and quantitative relations between colours of wall and façade elements, types and levels of contrasts.

-The environmental colour palette with quantified ranges of the colour variables.

Synthesis

The synthesis of all information obtained in the previous phases of the project and its comparison with established criteria permitted the elaboration of colour schemes. Either one scheme was proposed, or alternatives within a defined range of colours.

In the final catalogue, the following were provided: a photo and a form for the street façade of each building with information on the façade's stylistic character, its technical characteristics, the colour scheme findings corresponding to the prevailing architectural style of the façade (described in words, shown by a sample and specified in the ACC system), recommendations for further research, indications on conservation and restoration interventions, recommended colour scheme. Graphic documentation consisted of plans 1:1000 of the present state, analyses and proposals.

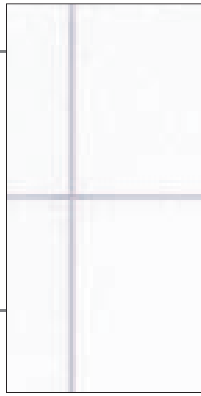


Illustration of façade colour typology studies for stylistic periods. Example: classicism, last third of 19th century

A system for organizing all relevant information on colour schemes into data banks was set up.

The final catalogue; example of the photo and related table for a façade

Discussion of results

- This experience confirmed that for each case and situation there is a need to develop an appropriate condition-specific working method. Other successful cases and well-established methodologies (33) can be of great help.
- The use of a colour notation based on a colour order system for data assessment proved to be very important, as it conditions the further analysis and elaboration of the data, including the possibility of creating

computerized data banks. Notation by colour names only (as is still often the practice) limits the usefulness of the information.

- Colour surveys and their elaboration should be carried out by experienced interdisciplinary teams, with at least one team member having practical experience with the characterization and measurement of colour.

Banská Štiavnica, 1996.
Example of implementation of the colour plan

Not all countries have an official standard colour system, and in many cases institutes and individual professionals are not equipped with colorimeters, colour atlases, indexes or other relevant material from any recognized colour order system. It is not always possible to have a collaborating colorist, or persons familiar with such systems and working methods, so compromises still have to be sought.

The ACC System 🗁34

The Akzo Nobel Coatings Colour Codification System (ACC System) is a colour ordering method that has been in use since 1974 by Sikkens Akzo Nobel Coatings (Holland). In 1978, the company introduced the Sikkens Colour Collection 2021, recently followed by the Collection 3031. These collections, developed by industry for façade and space design, are among those most widely used today.

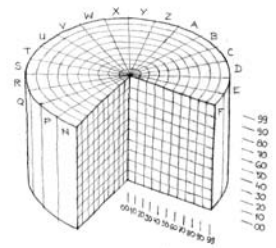
Guiding principles:
The system is based on colorimetric measurements of three basic colour variables (colours are coded according to hue, saturation and lightness) as well as on their perceptual evaluation by the human visual system. Its application of colour to architecture is expressed in the ordering of the reference samples and density intervals. The system's space is cylindrical.

Variables:

Hue, H: HC = Hue Codification. The hue circle is divided into 24 parts (letters A to Z, excluding I and O); each part is subdivided in 10 sections numbered 0-9.

Saturation, S: SC = Saturation Codification. Saturation is expressed by the distance between the central axis and the outer perimeter of the cylinder by a scale from 00 (for achromatic) to 99 (for highest saturation). Colours with a saturation lower than 03 are marked N.

Lightness, L : LC = Lightness Codification. Lightness on the vertical axis of the cylindrical colour space is numbered from 00 (minimum, ideal black) to 99 (theoretical maximum, ideal white).



The ACC Colour solid

ACC Colour Notation: HC. SC. LC   Example: E4.10.60

Special features
From the total amount of colours that the ACC System can describe, the collections 2021 and 3031 select 635 and 1243 colours respectively, based on response to trends and demand. Although they are meant for selecting colours and products for practice, they are equally useful for specification of existing colours, because of the very good representation of reference samples in those ranges into which façade colours most often fall.

Work with the collection is easy, developed on a logical basis and scientifically supported by the codification system (further analysis and study of the measured data are quite possible). The system and in particular the collections are widely known and therefore allow for good colour communication.

Sikkens Colour Collection 3031

7 APPENDIX

7.1 The Munsell system

The MUNSELL SYSTEM is a U.S. standard and has been recognized in other countries as well. (The standard method of specifying colour by the Munsell System is ASTM D 1535).

General characteristics and use:

The Munsell system is the oldest colour appearance system in worldwide use. The colour notation system was developed by Albert H. Munsell, artist and art teacher, with the aim of providing an aid in teaching colour, particularly to children.

History and development: 35

1905: **A colour notation** (conceptual structure of the system, published by Munsell)

1915: **Munsell atlas of color** published (first complete version for 10 hues)

1929: **Munsell book of color**, improved scales as result of subsequent studies at the National Bureau of Standards and in the Munsell laboratory. The system was defined by the spectral reflectance functions of the colour chips. The spacing of the samples was based on visual scaling experiments of value, hue and chroma (20 hues).

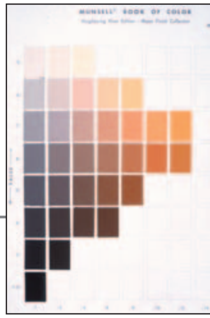
1943: **Munsell renotation system** [34] published. New scaling experiments were carried out; based on these data, new Munsell notations were specified for the 1931 CIE standard observer, standard illuminant C.

1976: **Munsell book of color** is the atlas with physical exemplification of the renotation system

[34] The Munsell Renotation was standardized by the ASTM in D 1535 Standard Test Method for Specifying Color by the Munsell System. The Standard system of colour specification is standard Z138.2 of the American National Standards Institute, as well as the Japanese Industrial Standard for Color JIS Z 8721; the German Standard Colour System DIN6164 includes Munsell notations for each of its colours. Several British National Standards are also expressed in Munsell terms (www.munsell.com).

[35] His "photometer" was the Maxwell disc. 36

Example of a Munsell Book of Color constant hue chart (section of the colour solid through the vertical axis)



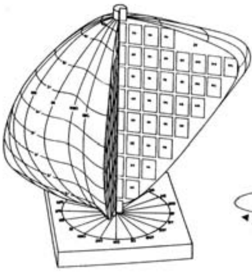
Guiding principles:

Munsell worked on having the system empirically anchored in both psychophysical scaling methods and physical measurement techniques. [35] Within each of the individual hue, value and chroma scales, the spacing is approximately uniform but not identical.

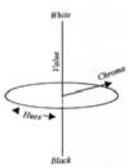
Variables: 37

Hue (H): The hue notation of a colour indicates its relation to a visually equally-spaced scale of 100 hues. The Munsell hue circuit is based on 10 *major hues* R, YR, Y, GY, G, BG, B, PB, P, RP (five *principal* and five *intermediate*). For each of the 10 major hues there are 10 hue steps, and the most representative hue is located in the middle of the interval: therefore the best red is 5R, the best yellow is 5Y, etc.

This form of hue notation – based on a combination of numerals with the hue initials – is considered the most descriptive. It has been used in the **Munsell Book of Color** on the 40 constant hue charts.

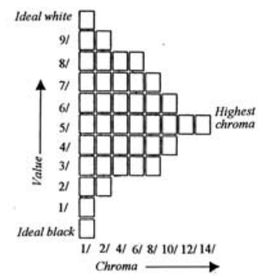


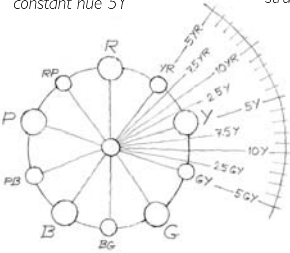
The Munsell colour solid
a quarter removed to show constant hue 5Y

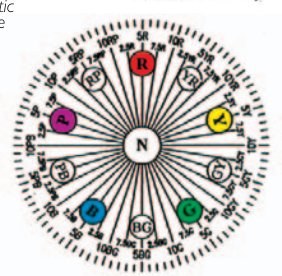


The solid's schematic structure

Vertical section through the solid







Diagrams showing the structure of the hue circuit based on 5 principal hues and 5 intermediate hues. 38

VALUE (V): The value notation indicates the lightness of a colour in relation to a neutral gray scale, which extends from absolute black to absolute white. Values are indicated by figures from 0 (absolute black) to 10 (absolute white).

CHROMA (C): The chroma notation indicates the degree of departure of a given hue from a neutral gray of the same value. The scales of chroma extend in equal steps from 0 for neutral gray to 10,12,14 or farther.

Munsell colour notation[36] **:** H V / C Example: 7.5Y 6/4.

When a finer division is needed, decimals are used for any of the attributes.

Tools, Munsell Color Communication Products[37]:

The tools most commonly used for colour assessment are:

- The MUNSELL BOOK OF COLOR, Matte Collection (about 1270 colour chips).
- The MUNSELL BOOK OF COLOR, Glossy Collection (about 1564 colour chips). Two-volume glossy edition with removable free chips.
- The MUNSELL BOOK OF COLOR Nearly Neutrals Collection (about 1100 pastel colours).

Costs vary from product to product.

7.2 THE NATURAL COLOUR SYSTEM (NCS)

The NCS colour notation system, the relationship between NCS notations and instrumental measurements, and the Colour Atlases have been Swedish Standards since 1979 and have also been introduced in several other countries.

General characteristics and use: 🗀39

- The Natural Colour System is a way to describe and order, by means of psychometric methods, the characteristic relationship between all possible colour percepts of surface colours.
- The NCS colour notation system is said to be general: it makes it possible to describe object colours as they appear in any given viewing and illumination situation. It is based exclusively on the possibilities and restrictions of human colour vision, and its use does not require any knowledge of physical or physiological attributes of colour stimuli.
- The psychophysical relationship between the experimentally derived psychometric colour scales in the NCS space and the corresponding physical parameters in the CIE-system has been determined.
- The NCS system is widely used in environmental colour design, and it is also being increasingly used in colour research (studies of colour combinations, people's perceptions and evaluations of colours in the environment, of aesthetic colour relationships, etc.).

History and development: 🗀40

The origins of the system go back to the six primaries of Leonardo da Vinci and Ewald Hering's theory about the "natural order system" of the percepts of colour (1874). The modern colour system is based on the work of Johansson and Hesselgren. Hesselgren published his Colour Atlas in 1952, with 507 colour samples, as a first attempt at physical exemplification of the variables of hue, saturation and lightness (not instrumentally measured). NCS research and development began in 1964, with the following key phases:

- 1964: The Swedish Colour Center Foundation was created. Its first task was the revision of Hesselgren's Colour Atlas using new psychophysical experiments, spectrophotometric measurements, collaboration of phenomenologists, physicists and pigment chemists.
- 1972-73: Swedish Standard for Colour Notation, SS 01 91 00.
- 1979: Swedish Standard Colour Atlas, SS 01 91 02 (1412 samples), developed by A. Hard and L. Sivik.
- 1995: Major revisons of the NCS Colour Atlas 🗀41 were made. The most important changes were: exclusion of toxic and environmentally harmful pigments; addition of 261 completely new samples (46 old ones withdrawn, about 1000 former samples changed slightly in colour, about 400 given a new notation). NCS Edition 2 has a total of 1741 colours, allowing closer colour selection and greater precision. Three quality levels[38] of products have been introduced.

[36] This is a system of letters or numbers, or both, by which the colour of any opaque object may be specified with respect to Munsell hue, value and chroma, written in the form H V/C (ASTM).

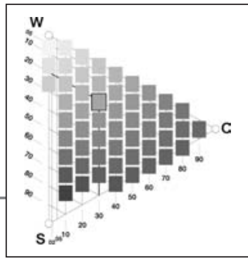
[37] GretagMacbeth, New Windsor, New York, USA. (www. munsell.com)

[38] Tolerance or accuracy requirements in their manufacture, i.e., allowed deviations from the primary standard and consequently different prices.

Guiding principles:

The NCS System: section of the colour solid through the vertical axis.

colour print on inside back cover



- The NCS was developed as a *descriptive colour notation system* on the basis of extensive experimental documentation and the concept that "colour is what we see, i.e., a subjective visual sensation".
- The system orders colours according to their perceptual *elementary attributes*, based on the resemblance of colours to the 6 *elementary colours* Red, Yellow, Green, Blue, Black, White. From the elementary attributes, the NCS *chromaticness* (c) and *hue* ($\varnothing$) are derived, and together with *blackness* (s) constitute the descriptive NCS notations, the Swedish Standard. The notations are derived from absolute estimations of the visual attributes ($s+w+c=100$). This means that a colour can be fully described by specifying how closely it resembles black s, white w and the full hue c. Only blackness s and chromaticness c are explicitly indicated, as whiteness w can be easily derived by the formula $w = 100 - s - c$.
- Visual equality of spacing is not a characteristic feature of the system.

Variables:

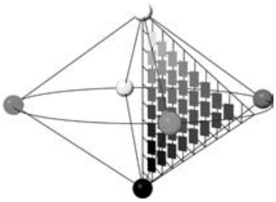
HUE ($\varnothing$) is defined in terms of the resemblance of the test colour to the two nearest chromatic elementary colours. The resemblance is expressed in percentage: e.g., Y30R means a hue which resembles Yellow at 70% and Red at 30%, i.e. the resemblance is expressed in % of the second hue.

CHROMATICNESS (c) is defined as the degree of resemblance of the test colour to the colour of the same hue having the maximum possible chromatic content.

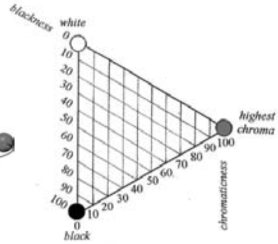
BLACKNESS (s) is defined as the resemblance of the colour to the perfect black. (For achromatic colours, lightness $v = (100 - s)/100$.)

The relationship between whiteness, blackness and chromaticness ($w/s/c$) is called the *nuance* of a colour.

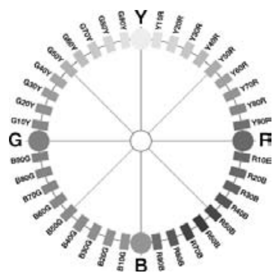
SATURATION (m) is the relationship between the chromaticness (c) and whiteness (w) of a colour; it is defined as $m=c/(c+w)$ and expresses the relative amount of chroma as compared with white and chroma taken together. 42



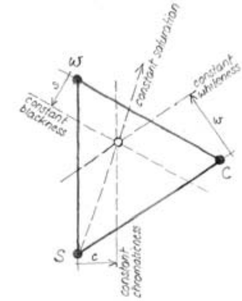
THE NCS COLOUR SOLID



NCS COLOUR TRIANGLE



THE NCS COLOUR CIRCLE



A nuance: the relationship (principles) between whiteness (w), blackness (s) and chromaticness (c)

Colour prints on inside back cover 43

Colour Notation: (s c - $\varnothing$) 7010 - G50Y (NCS 1979)   S 7010 - G50Y (NCS Edition 2, 1995)

nuance hue

Tools, NCS Products:

The NCS edition 2 products offered by the Scandinavian Colour Institute (Stockholm) are of three quality levels: standard (the highest), level 1 and level 2. The tools most commonly used for colour assessment are:

- The NCS COLOUR ATLAS, which illustrates the standard colour notation system, the NCS colour space. It is designed for general use under daylight conditions. Quality level 1.
- The NCS INDEX edition 2 as a low-cost alternative, which provides an overview of the 1750 colours. Quality level 2.
- The NCS SELECTION which gives 908 colours mainly used for building purposes. Quality level 2.

Costs vary with the quality levels.

A relatively new instrument is the NCS COLOUR METER which gives readings in the NCS system.

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ASTM D 1729: Standard Practice for Visual Evaluation of color differences of opaque materials.

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NORMAL – 43/93: Misure colorimetriche di superfici opache.

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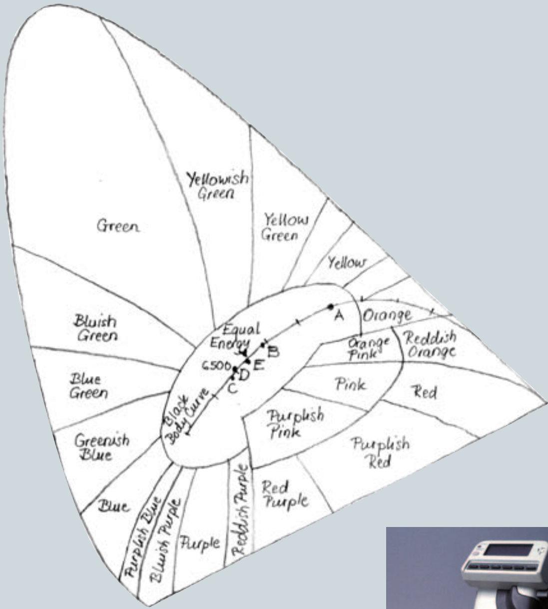
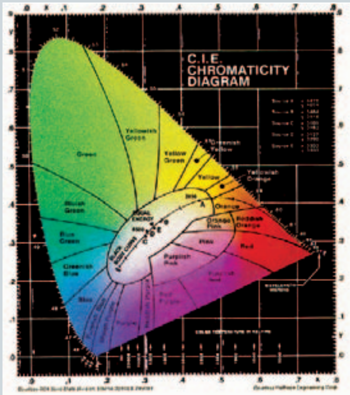
Disclaimer

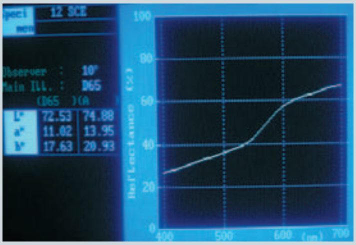
With regard to the selection, applicability or efficacy of the systems and tools mentioned, no endorsement or recommendation is implied on behalf of ICCROM, and no criticism is implicit in the non-mention of any system or product.





CIE chromaticity diagram.
(This printed version gives only an approximate idea of the colours.)

A portable colorimeter and test sample

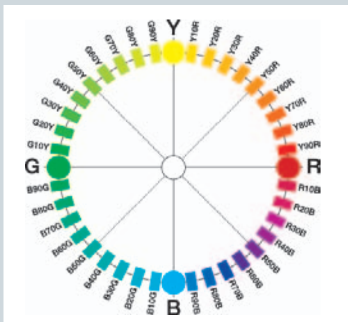


The spectral reflectance curve of the test sample colour and the L*,a*,b* readings

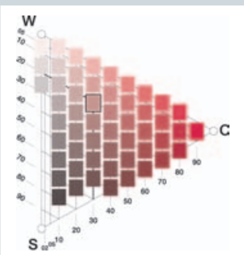
Photodocumentation of the façades

The NCS System

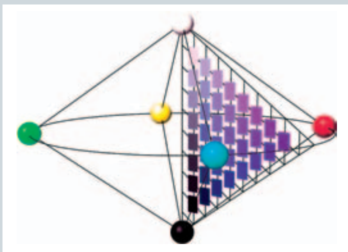
The NCS Colour circle



Section of the colour solid through the vertical axis



The NCS Colour solid



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