Colour measurement and documentation in historical buildings: the case study of the Kirna Manor House in Estonia

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ABSTRACT

Historical buildings and their decorative apparatus have a key role in the transmission of national and local traditions, requiring careful conservation of these structures and their overlapping decorative layers, mostly made up of stuccos and coatings. Unfortunately, the procedures and methodologies for both documenting and preserving such cultural heritage are not clearly standardised in Estonia, where most historic manor houses are managed by private owners who have no precise guidelines to follow during the restoration of such complex structures. To amend this issue, the Estonian Academy of Arts (EKA) organised an international workshop on “Colour Measurement and Documentation in Architectural Paint Research” with the aim to bring together several experts, techniques and tools from different countries in order to define, optimise and modernise the methodologies employed for the identification, documentation and preservation of historical painted interiors and colours. In addition to a theoretical session, the workshop held in October 2019 entailed practical work at the Kirna Manor House, analysing the entrance hall of the building. The paper presents the results of the research and the discussion between international experts.

KEYWORDS Colour measurement, Colour documentation, Colour vision, Architectural paint research, Historical interior restoration, Estonian manor house, Estonian Academy of Arts

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1. Introduction

The conservation of historical buildings and their ornaments is paramount for preserving national and local architectural traditions. Within this context, understanding the perception of colours and their use on original building decor constitutes a research topic which is relatively understudied. Furthermore, in many countries, including Estonia, the guidelines for standard procedures for colour determination and documentation in architectural paint research are not entirely clear or even unavailable. Nowadays in Estonia, as in several other countries, visual comparison using colour charts/fan decks is the main approach for colour determination in architectural frameworks. The current regulations set by the National Heritage Board of Estonia recommend studying colours using this method, without the mention of scientific measurement devices (appendix to the *Heritage Conservation Act*, 2019). The multitude of methods and the lack of specific instructions cause confusion among researchers, conservators and building owners, as the possibility of subjectivity leading to inaccurate colour determination remains.

In order to improve this issue, the Estonian Academy of Arts (EKA) organised an international workshop "Colour Measurement and Documentation in Architectural Paint Research", held in Tallinn (Estonia) on October 22–25, 2019. Conservators, art historians, specialists in colorimetry and digital reconstruction involved in paint research and conservation from 6 countries gathered to share expertise and gain international consensus on documenting, interpreting and visualising the colour information of historical buildings.

The workshop was organised in two parts: the first was a theoretical session with keynote lectures about the best practices in participating countries followed by a discussion; the second part was practical and carried out *in situ* in the historical interior of the Kirna Manor House (in Järva County, *ca* 100 km from Tallinn, Estonia). In the latter part, research teams were formed and assigned leaders who developed workflows for the identification of historical colour schemes, colour measurement and documentation. For the data acquisition, several systems were used, e.g. colorimeters, a spectrophotometer, colour charts and digital photographic equipment.

The use of various techniques allowed participants to learn from international expertise, compare different methodologies and eventually discuss how to optimise and modernise the identification, documentation and preservation of historical colour information on architectural surfaces in Estonia and abroad (Carbonell Rivera, Montalvá España and Lerma García, 2016; Giannattasio, 2019; Guarneri *et al.*, 2019; Verweij, Schade and Kutzke, 2019). Simultaneously with the paint research, a colour vision experiment was conducted with the workshop participants to test the accuracy of human colour perception. In the final roundtable discussion, practical solutions were suggested, which could be developed into a pipeline including both scientific measurements and historical/visual evaluations.

2. Aims of the workshop

The purposes of the workshop were: 1) to experiment with various paint research methods on the finishes of the entrance hall's vaults and their adjacent architectural features; 2) to test both destructive and non-destructive colour measuring techniques and tools; 3) to identify and date the paint layer stratigraphy, colour schemes, and the ambiguous constructional stages and additions in the hall; 4) to revise the adopted workflow and define the best practice in light of the workshop results.

The practical investigation was organised in five teams, each led by an international expert who instructed their team members according to the prevalent architectural paint research methods in their respective country. The results were documented separately by each team in the form of reports and paint exposure charts compiled by a student of the Department of Cultural Heritage and Conservation (Valge *et al.,* 2020). Finally, the teams engaged in constructive interaction, comparing their results to share reflections and proposals for research improvement.

2.1. *Historical overview of the Kirna Manor House*

The Kirna manor estate and the first wooden manor house were established in the 17th century by the Baltic German nobleman Hans von Fersen, whose family would keep ruling the estate for nearly 150 years (Maiste, 1985). The existing Neo-Palladian building was probably erected between 1760 and 1780 by Otto Wilhelm von Fersen, with Neo-Classical alterations having been made in the early 1800s by the new owner Carl Magnus von der Osten-Sacken (Danil *et al.*, 1985; Parek, 1973). Gothic Revival elements were added to the building in the mid-to-late 19th century when the manor belonged to the Pilar von Pilchau family. The manor estate has a long history of owners, uses and renovations, which is why many overlapping layers of architectural and decorative details and their finishes have been preserved.

The investigation was focussed on the central entrance hall of the building (Fig. 1), which has been extensively modified throughout centuries.

Fig. 1. The entrance hall of the Kirna Manor House, Järva County, Estonia (https://www.puhkaeestis.ee/et/kirna-mois).

3. Experimental methodology

The experimental part of the workshop consisted of: 1) general research documentation; 2) identification and dating of layers under the current finishes; 3) characterisation of the pigments and components used in the plasters and finishes; 4) colour measurements on the preserved paint layers; 5) an experiment for testing the accuracy of human colour vision.

3.1. *General documentation*

The documentation has been carried out mainly producing drawings/notes and photographic material before, during and after destructive exposures and samples. Data gathering dealt with capturing digital images with different devices (smartphones, compact cameras, DSLRs), adding a ruler for size reference and an X-Rite ColorChecker Classic/ Passport Photo 2 for colour reference. One team experimented with a more detailed system for storing image metadata and best quality data such as 1) shooting in RAW format to gather uncompressed data, 2) converting images into lossless compressed formats, 3) processing images, balancing colour and storing useful data for further digital processing (Gaiani *et al.,* 2016; Ramanath *et al.*, 2005).

3.2. *Analysis of hidden layers*

The study of the complex chromatic stratigraphy of the entrance hall was firstly analysed examining the existing photographic material starting from the early 20th century, which, albeit mostly in black-and-white (Fig. 2), helped to clarify some historical decoration stages and colour schemes.

Secondly, small mechanical paint exposures were conducted in strategic areas (i.e. where colour changes were detected in historical images), such as walls, pillars and pilasters, window and door openings, the stucco decor on the vaults. Although the latter is a relatively destructive technique, paint exposures proved essential in discovering previous decorative phases and paint colours. The revealed layers were identified with a shared indication system, numbered in chronological order starting from the oldest and compared in various areas to verify the layer order and chromo-chronology (Fig. 3).

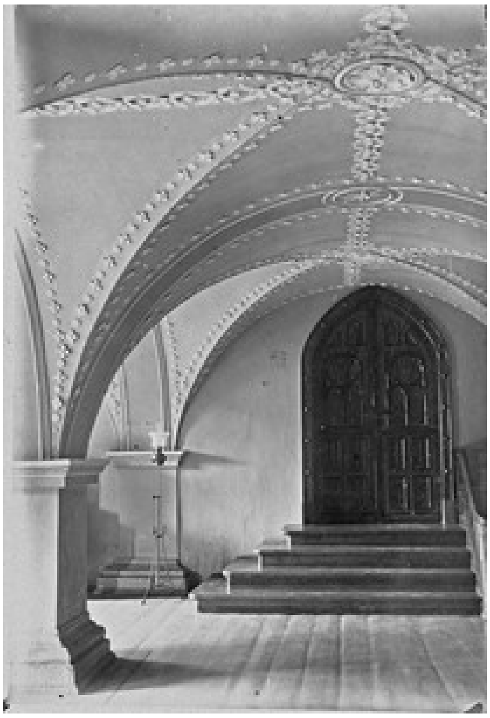

Fig. 2. One of the earliest photos of the entrance hall, ca 1910 (Estonian National Museum, https://www.muis.ee/museaalview/666779).

Fig. 3. A paint exposure with the finishes chronologically numbered.

3.3. *Analysis of hidden layers*

In addition to on-sight evaluations of the paint ingredients, paint cross-sections detached with scalpels were examined in the laboratory under a microscope under visible and ultraviolet light, and scanned with an electron microscope (SEM), which enabled to correctly identify the paint stratigraphy and some pigments (Fig. 4).

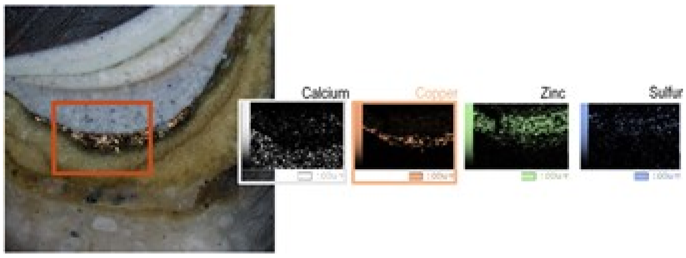

Fig. 4. The SEM analysis detected the presence of copper and zinc in a metallic paint layer uncovered on the decorative piping on the vault arch edges, which implies it is brass paint or gilding.

3.4. *Colour determination*

Different approaches were used for the colour determination in the entrance hall: a) colour measuring devices; b) image and colour processing software; c) naked eye perception which was mostly assisted by specific colour charts. The paint layers were examined using both daylight and controlled flicker-free artificial LED-lighting (Yongnou Digital YN1200, CRI>95+) given their indoor location.

a) The portable tools used for measuring colours were a Konica Minolta Spectrophotometer (CM 2300d) and colorimeters NCS Colourpin SE and NCS Colour Scan 1.0 (RM200). The systems use two different measurements methods: the spectrophotometer provides a spectral response of the colour to light stimulation, translated into physical colour space coordinates, CIE L*a*b* in this case, The operating range of wavelengths of the spectrophotometer is between 360 nm to 740 nm. This type of instrumentation is often used for quick analysis *in situ* or when moving an artwork is impossible (Sanderson, 2015; Ceccarelli *et al*., 2021). The colorimeters give a direct translation into the closest NCS notation and index (perceptive colour) along with related CMYK, RGB, L*a*b*; meaning that it represents the closest match to an existing colour in the NCS chart with its coded name (Kahu *et a*l., 2018).

b) Various pipelines have been developed by researchers for balancing captured images and specific software can be used to process images for documenting colours (Rieger *et al.*, 2016; Gaiani and Ballabeni, 2018). E.g., Adobe Camera RAW allows white balancing images captured with the colour reference X-Rite ColorChecker Classic or Portable; ProfileMaker Professional 5.0 can be used to create an ICC profile assigned to the images; Imatest Master 5.2.4 allows testing the colour fidelity between the reference ColorChecker patch and its radiometrically calibrated image in terms of the mean camera chroma relative to the mean ideal chroma in the CIE colour metric (ΔE^*_{ab}) to estimate perceptibility tolerance of colour quality (Mokrzycki *et al*., 2011; Gaiani *et al.*, 2019);

c) Visual colour determination using side-by-side comparison with colour charts/fan decks helped to define the closest colours to the historical paints.

Although much more accessible and affordable than colour measurement tools, this vision-based technique is reliant on the researcher's individual colour perception, colour differentiation expertise, lighting conditions and other factors.

The colour charts used were the NCS - Natural Colour System INDEX 1950 colour chart; the NCS colour chart *Kulturkulör för linoljefärg*, developed in collaboration with the Swedish National Heritage Board, which contains 300 colour samples with traditional pigments historically used in linseed-oil paint; and the Caparol 3D system Plus, a more affordable colour chart with a limited selection of samples which resemble historical colours. Alternatively to the use of colour charts, some experts mix a similar colour to the historical paint on site for illustrating it in research documentation, which, however, lacks standard classification.

3.5. *Colour vision experiment*

In the first part of the experiment, the 27 test subjects were asked to describe and determine the colour of two different historical paint layers uncovered on a window scuncheon in two lighting conditions (daylight and spotlight, see Fig. 5) using the NCS INDEX 1950 colour chart. Later, the colours were measured with the colorimeters NCS Colourpin SE and NCS Colour Scan 1.0 RM200, as well as the Konica Minolta Spectrophotometer CM 2300d. In the second part, the test subjects took the colour blindness test developed by Jean Jouannic and the X-Rite hue test online (see references) to evaluate their general colour perception and the ability to differentiate similar hues. Finally, the results of the colour vision tests were compared with the colour determination experiment to evaluate the potential correlation.

Fig. 5. The participants determining the colours of the paint patches in a) daylight and b) under a spotlight.

4. Results

4.1. *Architectural paint analysis*

During the two-day paint investigation, at least eight historical colour schemes (Fig. 6) were discovered in the entrance hall. The earliest pastel scheme probably dates from the Neo-Palladian remodelling conducted shortly after 1804. Another important discovery was that the pointed groin vaults of the room are an essential structure erected simultaneously with the late 18th-c building rather than a decorative form added during the Gothic Revival period. Meanwhile, the plastered surfaces as well as the stucco decor probably date from the early 19th-c Neo-Palladian modernisation of the building. Judging by the paint stratigraphy, the later added pointed doors and windows most likely originate from the mid-to-late 19th century.

Nevertheless, due to the limited time of the workshop, all preliminary findings presented in this section need to be confirmed and elaborated on with further research.

Fig. 6. Visualisation of two relatively recent colour schemes illustrated with the NCS values acquired on the exposures: a) ca 1960s; b) current state of the room.

4.2. *Outcomes of the colour vision test*

19 out of 27 test subjects determined colour matches which were noticeably dissimilar with the most common results of the NCS colour chart determination and colour measurement devices. The colour measurements carried out with three instruments were relatively similar yet visually differentiable, which implies that colorimetric results do not only vary across devices but are also heavily dependent on the specific measuring area.

The two spectrophotometer results for the first dark green colour were also identified by the participants in 14 instances (Fig. 7a). Meanwhile, none of the colorimetric results coincided with each other nor with the colour codes determined by the participants for the second lighter yellowish colour (Fig. 7b). However, the same NCS notation was identified by the test subjects in 24 instances out of 50. This suggests that while human colour vision is fallible and varies, it is still surprisingly similar considering how the results of precise colour measurement devices also differ. Another observation was that participants found it more difficult to identify the darker colour in insufficient natural light, which means ample lighting is paramount for more accurate visual colour determination.

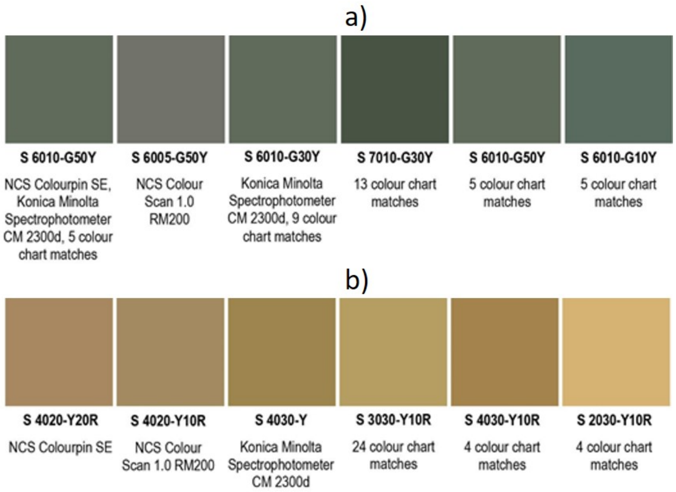

Fig. 7. The results of the colour measurement devices and the most common NCS matches determined by the test subjects for a) the first dark green colour and b) the second lighter yellowish colour.

All but a few test subjects had faultless results in the Jouannic test for general colour blindness while slightly less than half made a few mistakes in the X-Rite hue test. Most commonly, the test subjects had colour vision issues in the turquoise/green area of the spectrum. These results are consistent with the most common form of colour blindness, deuteranomaly (reduced sensitivity to green light; a milder form of deuteranopia, commonly known as daltonism) which effects 5% of males and 0.4% of females (Kalloniatis *et al.*, 2007). The fact that the results for the green colour varied much more also validated the hypothesis that it would be more difficult to ascertain the green colour than the yellowish one. This reflects the studies which have shown that colour blind people mostly retain blue–yellow discrimination, and most colour-blind individuals have limited discrimination along the red–green axis of colour space, with their ability to separate colours in this dimension being reduced (Sembulingam *et al.*, 2012).

4.3. *Colour measurement devices versus visual comparison*

Colour measurement devices enable to quickly and very accurately ascertain colour, although the results can still be dependent on lighting. However, since the historical paint on architectural surfaces is mostly unsmooth, faded, discoloured or cracked, the precision of the measurements depends far more on the measured spot than the specific device used. With instruments like the NCS Colourpin SE it is very difficult to locate an ideal measuring spot due to the lack of a viewing port. The human eye is hence a more precise tool for determining the exact area where the paint is most vibrantly (accurately) preserved. Moreover, while the colour measuring devices can only focus on a very small surface area at a time, our eyes can generalize, evening out the patchy colour of the historical paint surface more adequately. This skill is especially useful for identifying the colours of less opaque paint layers, which have previous layers showing through. Regardless, visual colour determination is still extremely dependent on surrounding lighting, personal colour perception and colour differentiation experience as the results of this experiment clearly showcase. Furthermore, commercial fan decks can be unsustainable due to being discontinued, and the inferior convertibility of the results. On the other hand, although the L*a*b* spectral data received with a spectrophotometer allows to preserve the most accurate and reproducible information about historical paint colours. In conservation practice (e.g. repainting) it is still usually necessary to convert this data into commercially used colour systems like NCS, which potentially causes slight conversion inaccuracies as seen in Fig. 8, which summarizes the colorimetric data acquired in several points.

However, colour charts also have a limited selection of colours, allowing room for imprecision. Still, they are accessible and cost-effective tools for most paint researchers, whereas spectrophotometers can be too costly and require consistent maintenance and re-calibration.

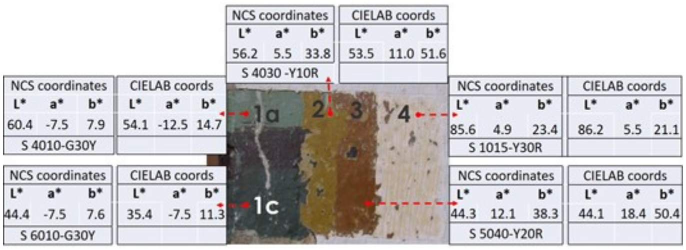

*Fig. 8. NCS and CIE L*a*b* coordinates for the 5 paint layers of an exposure.*

5. Conclusions

The workshop was a successful first attempt at determining the correlation and the differences between colour measurements obtained with visual, digital and spectrophotometric analyses. Additionally, the interdisciplinarity of the workshop participants provided a diversified viewpoint on the subject matter as well as reaching novel and insightful perspectives through international collaboration and expertise. The debate about the pros and cons of various colour measurement and documentation techniques and methodologies is not only applicable to this case study but also generally to the usual workflow adopted by experts with limited time and budget for paint research prior to restoration. The workshop also yielded tangible results in the architectural paint investigation carried out in the Kirna Manor House entrance hall, where many historical colour schemes were discovered.

In general, it should be taken into account that there is no absolute truth in determining the colour of historical paint due to it having been discoloured through time to begin with (see e.g. Krotzer, 2008, Van Velzen, 2018). However, it would be beneficial to implement precise colour measurement devices in architectural paint research more often, while acknowledging that it still requires a trained eye and good colour perception to see where to take the measurements from. Still, they are accessible and cost-effective tools for most paint researchers, whereas spectrophotometers can be too costly and require consistent maintenance and re-calibration. The use of portable and quick-capturing colorimeters could easily be adopted by researchers without excessive costs or added expertise.

Colour charts also remain essential tools because they display painted colours much more realistically than digital screens, thus enabling to directly compare a physical colour sample with the painted architectural surface. Even though colorimetric tools are more accurate than the average human eye, colour charts remain useful for cross-checking the results *in situ*.

Colour measurement devices enable to improve the speed and accuracy of colour measuring and obtain more objective and reproducible data, which can easily be preserved in online databases for subsequent in-depth analysis. Ultimately, visual colour identification and the use of colorimetric instruments are complementary methods which should be utilised in parallel to receive the most comprehensive and accurate results.

The results of the workshop are now used in the Department of Cultural Heritage and Conservation at the Estonian Academy of Arts for the development of a digital documentation system related to colour data collecting and presentation, with the aim of its future application to the restoration of other Estonian historical buildings and potentially also to international case studies.

6. Conflict of interest declaration

Authors declare no conflict of interest.

7. Funding source declaration

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12. Short biography of the author(s)

Claudia Valge - MA student in Cultural Heritage and Conservation and a lecturer on architectural paint research at the Estonian Academy of Arts. She has supervised several extensive paint research projects on historical wooden houses, carried out paint investigation in various other historical buildings, and was the main organizer of the international colour measurement workshop conducted in Estonia in 2019.

Sofia Ceccarelli - Conservation Scientist, PhD student in the Industrial Engineering Department at the University of Rome Tor Vergata with a thesis on the characterisation of hygroscopic painted supports in Cultural Heritage with non-destructive infrared imaging techniques. She has worked on the high-resolution 3D digitalisation of artworks, colorimetric studies on Cultural Heritage and the development of a web-based platform for sharing metadata in regional projects.

Silvia Bertacchi - Architect, PhD in Survey and Representation of Architecture and Environment at the University of Florence, Research fellow at the Department of Architecture of the University of Bologna. She is expert in 3D survey, photogrammetry, reality-based modelling and optimization for documenting and disseminating Cultural Heritage, including both shape and reliable colours. She is the author of several scientific papers on digitization of Architectural Heritage.

Andres Uueni - Estonian Academy of Arts. Andres has worked in different memory institutions, designing, developing information systems and led many cultural heritage digitisation and documentation projects, focusing on high-resolution imaging technologies. In 2014 Andres was a co-founder of Archaeovision LLC and he has also started a PhD program with the Estonian Academy of Arts which focuses on cultural heritage 3D documentation and multi-spectral imaging.

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Anneli Randla, PhD, Head of the Department of Cultural Heritage and Conservation, Estonian Academy of Arts. Studied art history and medieval studies in Tartu, Budapest and Cambridge, worked at the National Heritage Board and has taken part in many conservation projects. Her main research interests are: medieval ecclesiastical architecture, medieval murals, technical art history and the history of conservation.

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