Perceived façade colours in different daylight situations: Survey in the Old Town of Warsaw

Anna Sochocka[1,2] and Karin Fridell Anter[3]

[1]*Faculty of Architecture WUT, Warsaw, Poland*
[2]*Faculty of Architecture NTNU, Trondheim, Norway*
[3]*SYN-TES Colour and Light Network, Sweden*
Emails: asochocka@gmail.com; karinfa@explicator.se

The study was initiated by a debate on the methods for selecting façade colours in the reconstruction of the Old Town in Warsaw. In this debate, the difference between the nominal façade colour and the façade colour as perceived in the cityscape was not acknowledged. The nominal colour is here defined as the colour that the surface would have if viewed in the standardised situation used in the definition of Natural Colour System (NCS) samples, including standard light, viewing distance and surrounding colours. The nominal colour is expressed through the NCS notation of the colour sample that is the most similar to the façade in direct comparison, and for a newly painted façade it corresponds to the NCS notation of the paint. The aim of the present study is to investigate the difference between perceived colour as seen from a distance of approximately thirty metres, and the nominal colour of the same façades. The method is based on previously published work by Fridell Anter using the NCS for survey and analysis. The perceived colours of nine façades are determined under different weather conditions, in a total of 84 observations. The analysis shows that the perceived blackness of the façades is generally lower than the nominal blackness. This result agrees with previously published studies in other parts of the world, and we draw the tentative conclusion that it is valid, irrespective of hue and geographical position, and not influenced by localisation, daylight conditions or type of wall finishing.

Received 25 July 2016; revised 06 September 2016, 11 October 2016; accepted 18 November 2016

Published online: 11 January 2017

Introduction

A starting point for the study presented in this article was a dispute regarding the reconstruction of the 'original' colour scheme of a baroque façade of the Royal Castle in Warsaw. Like the rest of the Old Town of Warsaw, the castle was completely destroyed during World War II. Since then it has been rebuilt as a part of the ambitious plan of 1947 to recreate the city, and the latest stage in this was the reconstruction of a colour scheme of its North-East or 'Saxon' façade. The colour reconstruction was made in 2012 and led by paintings conservators Anna Kozłowska and Jacek Czeczot-Gawrak [1].

In the reconstruction of the Old Town after World War II, an important source of information about the architecture of Warsaw was the numerous *vedute* painted by Bernardo Bellotto (1721–1780), known as Canaletto, who worked as the King's court painter in Warsaw from 1764 until his death in 1780. In the recent castle façade reconstruction, one of his paintings of the Polish capital played an important role as well. The final choice of the colour scheme for the 'Saxon' façade was based on analyses of Canaletto's painting *Widok Zamku od strony Pragi* [View of the Castle from the side of Praga (Warsaw's historic city district located on the east bank of the Vistula River)], from 1770 (Figure 1). This painting depicts the building in pale and soft colours lit with reddish light of the sunset reflected from the clouds (Figure 2). The assumption of the conservators was that Canaletto painted what he perceived with a certain adequacy. The painting was digitally analysed and the layer of reddish sunset light was removed to obtain the colours of the castle façade [1]. However, this method of a colour reconstruction neglected the difference between the colour perceived from a distance and the colours of the surfaces when viewed and measured directly on the coloured surface.

Eventually the final result of this restoration (Figure 3) caused a long discussion over the suitability of the colour scheme [2]. The 'Saxon' façade is now perceived as a 'cold' white. Yet in the Saxon period the façades in Warsaw were of warm cream-greyish colours due to the use of local building materials like sand and lime [2-3]. As today's discussions on Warsaw's colours do not use any general colour notation systems (e.g. Natural Colour System, NCS) it is, however, difficult to know what colours are being referred to.

Figure 1: Widok Zamku od strony Pragi [View of the Castle from the side of Praga], 1770, painting by Bernardo Bellotto (1721–1780), known as Canaletto[1].

[1] Source: https://pl.wikipedia.org/wiki/ Bernardo_Bellotto#/media/File: Bellotto_View_of_Warsaw_from_Praga.jpg

Figure 2: Detail of Canaletto's Widok Zamku od strony Pragi [View of the Castle from the side of Praga] representing the North-East or 'Saxon' façade of the Royal Castle of Warsaw, Poland[2].

Figure 3: The North-East or 'Saxon' façade of the Royal Castle, Warsaw, after the reconstruction of the colour scheme by Anna Kozłowska and Jacek Czeczot-Gawrak. Photo: Anna Sochocka, 2016.

[2] *Source: http://www.skyscrapercity.com/showthread.php?t=214856&page=92*

This approach raised the question if a colour observed and registered by the painter from a long distance should be chosen as the colour for the façade paint. Professional experience and earlier research have shown that distance changes the perceived colour of a surface, and even when viewed up close, the perceived façade colour is not the same as its nominal colour. The term 'nominal colour' is defined as the colour that the surface would have if viewed in the standardised situation used in the definition of NCS samples, including standard light, viewing distance and surrounding colours (for specification see Fridell Anter, 2000 [4 p24]). The nominal colour is expressed through the NCS notation of the colour sample that is the most similar to the façade in direct comparison, and for a newly painted façade it corresponds to the NCS notation of the paint. For further discussion about this concept and its use, see Concepts and Theoretical Basis for the Study. Nominal colours of façades can be determined visually through comparison with standardised colour samples, and compared to visual assessments of the perceived colours of the same façades in different viewing situations, including in different lighting conditions. Methods for assessment of nominal colour and perceived colour and for analysing and comparing them have been presented by Fridell Anter in: *What colour is the red house? Perceived colour of painted façades* [4]. In her extensive study of nominal colour versus perceived colour on a number of Swedish façades, Fridell Anter found consistent patterns of variation, both for hue and nuance, between nominal and perceived façade colours.

The objective of the study presented in this article is to examine the relation between perceived and nominal colours of façades in the Old Town of Warsaw, using the method developed by Fridell Anter. By this, we hoped to find out whether the results of the Swedish study were applicable also for the different conditions in Warsaw. In addition, we wanted to get a preliminary understanding of the perceived façade colours' variations due to different light situations, a matter that was not dealt with in detail in the Swedish study.

The Old Town of Warsaw

The Old Town of Warsaw is an odd example of architecture, as it is not old at all. The view towards the King's Castle and tenement houses forming the Old Town (Figure 4), is a convincing image of the hundreds years old historical city. The colour scheme of this view is accepted as a relevant without questioning. In 1945 this view did not exist as the rest of the Old Town. The scale of destruction brought upon Warsaw during World War II is described by Jan Knothe in his book *A tu jest Warszawa* [Here is Warsaw]. Figure 5 shows described places on the aerial map.

> *"The former view of Krakowskie Suburb towards King Zigmuntus Column set off against the background: The King's Castle, tall crammed tenement houses forming Old City area with the dominating silhouette of the Cathedral with the Jesuits' Tower – all was clearly depicted in the inspector's memory. The view now – was as if somebody had erased the central part of the picture. The eye met a void. Low fragments of rubble and still standing ruins were offset by an overwhelming extent of the sky. Possibly everything is dead here – he thought with a sudden heartache – there is no Old Town anymore."* [5 p30]

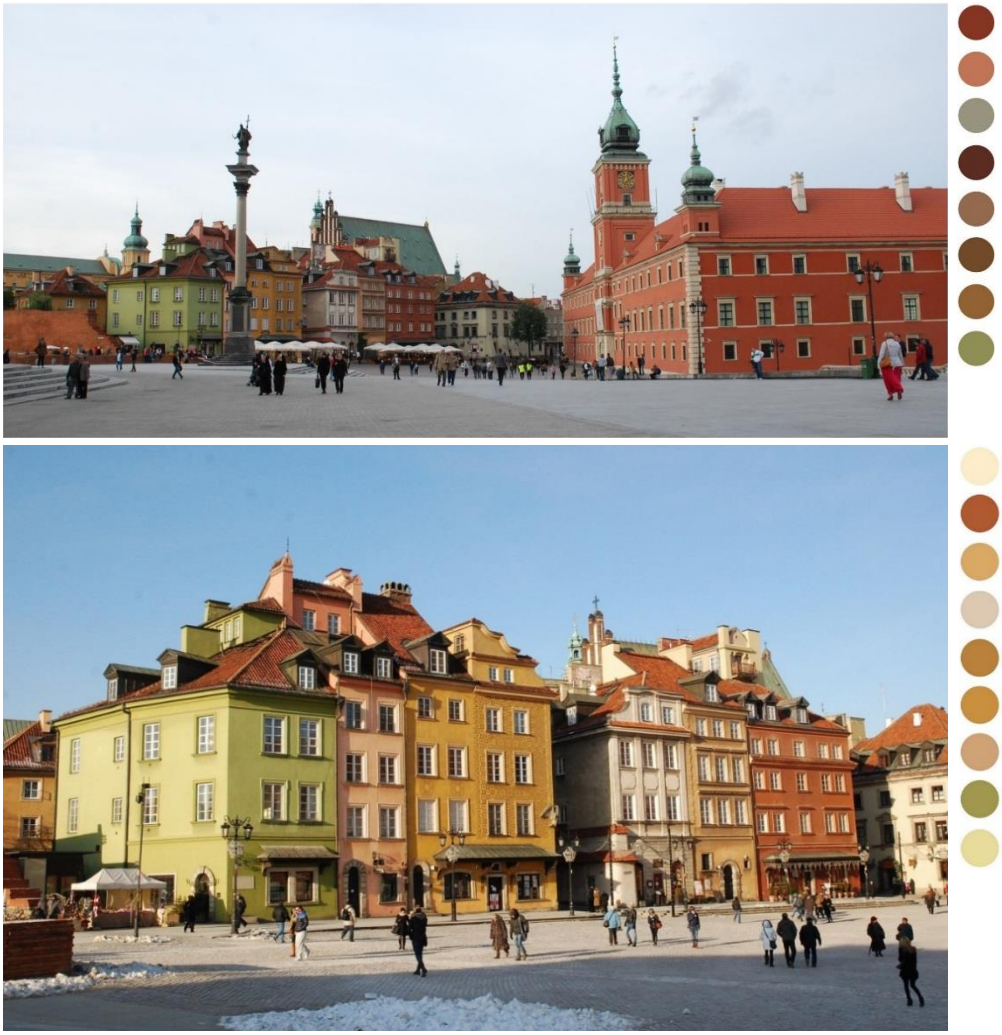


Figure 4: Buildings reconstructed after World War II in Castle Square (Plac Zamkowy) in Warsaw's Old Town. Colours of façades extracted from pictures using Adobe Photoshop. Photo: Anna Sochocka, 2016 (top) and 2012 (bottom).

Different European countries elaborated their own methods and doctrines that allowed rebuilding their cities and monuments after war damages. Contradictory decisions were made by different authorities in different countries but in similar physical conditions as with Piotr Biegański and Alfred Lauterbach:

"However, it was in this phase that the problem emerged – a problem that was extremely difficult to solve. What path should be taken with respect to the universally obligatory historic preservation premises that, in their essence, did not then recognize the reconstruction of seriously damaged structures?" [6 p18]

"Starting from a theoretical assumption, one may take the position that history cannot be reversed and that certain historical facts, including the destruction of historical monuments, must be acknowledged. Thus, the return to old forms in the case of destroyed structures is not justified. However, the desire to bring back to life values which we do not have to surrender and where our technical capabilities and knowledge allow their rebirth is more potent than theory." [7 p64]

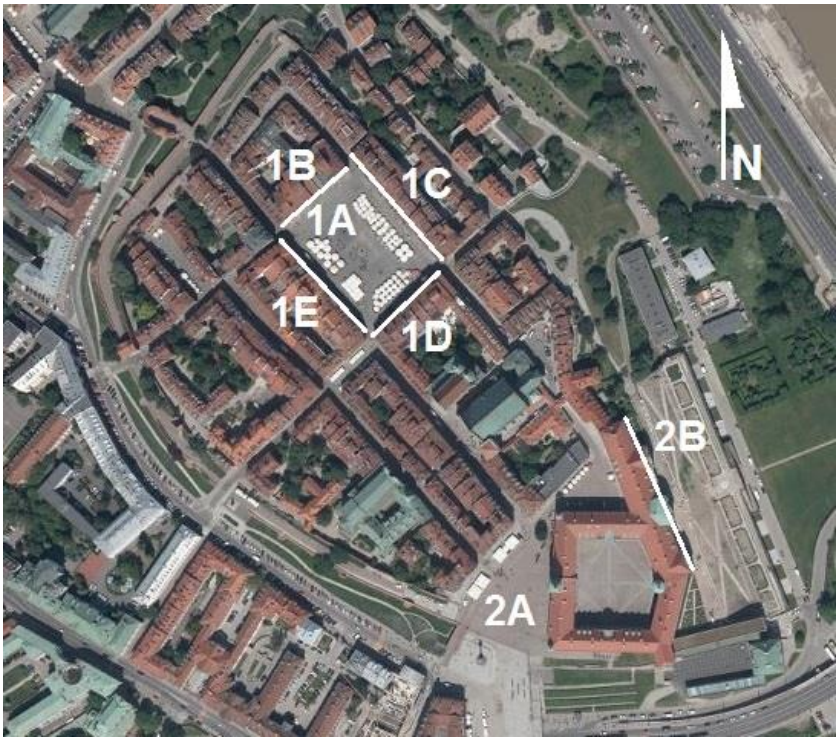


Figure 5: The Old Town of Warsaw: 1A – Old Town Market Place; 1B – Façades of the Dekert's side (North); 1C – Façades of the Barss's side (East); 1D – Façades of the Zakrzewski's side (South); 1E – Façades of the Kołłątaj's side (West); 2A – Castle Square; and 2B – 'Saxon' façade of the Royal Castle[3].

In 1947, the Polish Parliament enacted a law on rebuilding Warsaw as the capital of Poland, and the architectural heritage was reconstructed with no regard for foreign criticism. The a priori decision was made to use original building materials if found on the site. If not, apply traditional building methods to replace them during reconstruction. There were two main sources of information about the architecture of the buildings. The first one was archival, iconographic, and photographic material with numerous panoramas and landscape paintings (i.e. Canaletto's). But at that time, paintings were not recognised as a source of information about colours. The second one was inventory measurements of the buildings done during interwar and occupation times by professors (e.g. Oscar Sosnowski) and students at the Faculty of Architecture of Warsaw University of Technology (WUT), as well as the Department of Polish Architecture. During the war, these archives were concealed and saved, and could thus contribute to the process of reconstruction later on.

From the beginning it was assumed that this process had to be based on studies on former architectural forms that are in accordance with scientific criteria. Even if the criteria of authenticity could not be fulfilled, the reconstruction should fulfil the social expectations of reliability. This statement allowed for a reconstruction that was not merely a theatrical model. During the removal of rubble, new architectural discoveries were made and registered. Despite these efforts, the colour schemes were lost; mainly because of the lack of technical capabilities to register them.

The colours of the reconstructed façades were decided by the Heritage Protection Department. Urszula Zielińska presents the difficult history of façade decoration in the Old Town Market Place in Warsaw (Figures 5-9).

[3] *Source: http://www.mapa.um.warszawa.pl/*

"It was decided that a grey-green tone should prevail on Dekert Side... The Barss Side should feature a lot of gilding, The Kołłątaj Side with a strong emphasis of the Fukiers' tenement house should gain warm, red and ginger colours, and the Zakrzewski Side was the most colourful with the paintings of Zofia Stryjeńska which survived the war at the corner tenement house of Zapiecek... Two painting techniques were mainly used during the decoration of tenement houses; wet calcareous (true fresco), except for the Fukiers' tenement house, where a paint with casein binder was applied (which is why its colours stand out), and the graffito technique consisting in covering the wall with few layers of coloured plaster and selective scraping the wet layer off according to a specific drawing... The bricks painted in various colours became a catalogue and pattern book of colours." [8 p70]

Figure 6: Façades of the Dekert's side (North) – the photograph was taken after the recent restoration. Buildings reconstructed after World War II in the Old Town Market Place in Warsaw. Photo: Anna Sochocka, 2016.

Figure 7: Façades of the Barss's side (East). Buildings reconstructed after World War II in the Old Town Market Place in Warsaw. Photo: Anna Sochocka, 2016.

Figure 8: Façades of the Zakrzewski's side (South). Buildings reconstructed after World War II in the Old Town Market Place in Warsaw. Photo: Anna Sochocka, 2016.

Figure 9: Façades of the Kołłątaj's side (West). Buildings reconstructed after World War II in the Old Town Market Place in Warsaw. Photo: Anna Sochocka, 2016.

Aim and objectives of the research

The basic question in this study concerns the difference between the colours seen and experienced by inhabitants and visitors in the city and the colours chosen for and applied on to the façades as defined by colour samples or paint mixtures. Previous research has shown that the colour seen on a chosen colour sample does not coincide with the perceived colour of the finished façade. How can this difference be described, in order to enable conscious colour choices with predictable results? As a starting point, we used Fridell Anter´s study of this difference, including about 3600 observations of (mainly) timber façades in Mid-Sweden [4].

The aim of the present study is to investigate the difference between perceived colour as seen from a distance of approximately thirty metres, and the nominal colour of façades. As it was only possible to survey a limited number of façades, there is no ambition to find coherent and statistically significant patterns. Instead, the question is posed whether the findings in Warsaw suggest variation patterns that coincide with those found by Fridell Anter on Swedish timber façades. In that case, we could draw the tentative conclusion that her results are valid also for plaster façades in Warsaw.

Concept and theoretical basis for the study

In this study, colours and the relations between colours are defined and analysed by means of the Natural Colour System (NCS) (Figure 10). NCS is entirely based on colour perception, and does not consider pigments, radiation or eye/brain activity that give the physical or physiological grounds for perception. For the presentation and discussion of its categories 'hue' and 'nuance' as well as other basic definitions for this study, see Fridell Anter's publication [4 p23-27].

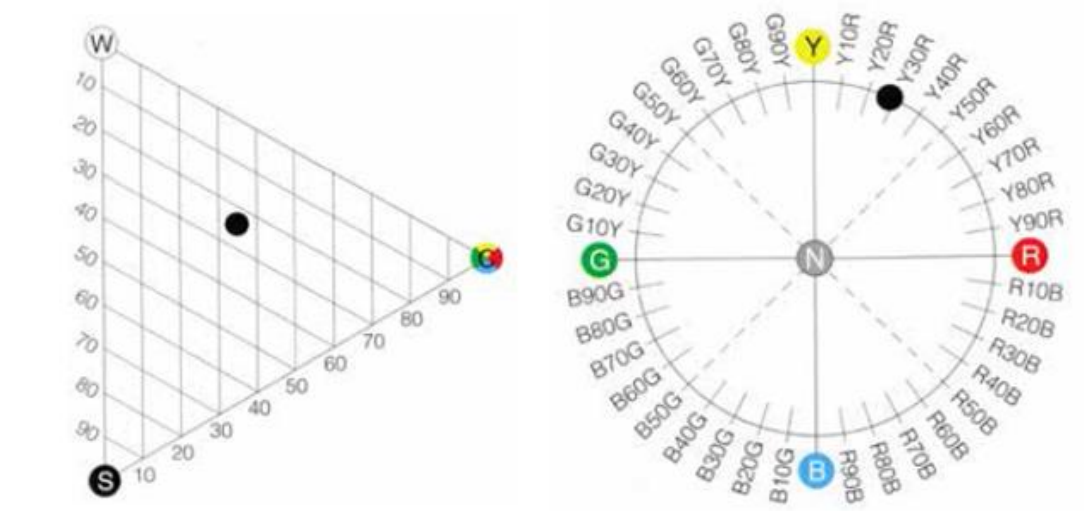


Figure 10: NCS triangle showing nuance, and NCS circle showing hue. The black dots mark the location of the colour 2335-Y28R in the triangle and circle, respectively.

Theoretical starting points

In this study, colour is defined as a visual phenomenon. Colour, as we perceive it, is constantly changing. The colour that we perceive as belonging to an object is not an attribute of the object alone but rather varies with the light [9]. It also varies with viewing distance, with surrounding colours and the observation attitude, presumptions and previous experience of the observer [4 p39]. This means that there is no true colour of any object.

In the field of architecture there is a great need for understanding the relationship between on the one hand the colour samples with their corresponding colour notations selected for a building, and on the other hand the range of colours that will be perceived on the finished building. Such an understanding can be achieved by comparing the nominal colour of the façade (further discussed below) with the perceived colour in different situations. The comparison does not aim at exact specifications but rather for usable understanding of general tendencies that can be applied in architectural practice [10].

Perceived colour

It is the colour that an observer perceives on an object at any given time, a particular light and viewing situation. For façades seen in daylight there is a range within which the perceived colour can vary, depending on the observer and the situation. The perceived colour is, however, not a constant quality, and in each situation it can be assessed only approximately.

Nominal colour

It is the (perceived) colour that the object would have if it was observed under the standardised viewing conditions, a prerequisite for the NCS colour samples to coincide with their specifications. The nominal colour is a potential that is realised only under these specific situation, and as such a potential it is a constant quality of the object and does not depend on external conditions (apart from bleaching, pollution and other physical changes of the object itself). Under daylight conditions similar to those of the standard situation, it can be determined through visual comparison with NCS colour samples placed directly on the surface. Originally this concept was called 'inherent colour', but the term was easily misunderstood and eventually Fridell Anter suggested the term 'nominal colour' as a more suitable synonym [11 p50].

It should be noted that 'nominal colour' is used as a supporting concept and not as an expression of the 'true' colour of the object (as there is no such thing). The nominal colour is the colour of the object under the standard viewing conditions. Façades cannot be placed in laboratory boxes and thus can never be seen under these conditions, but their approximate nominal colour can be assessed by several methods. The method chosen in this study is visual comparison with standardised NCS samples, placed directly on the façade surface.

Method

Selection of façades

Façades to be observed in this study were selected in the Old Town of Warsaw in Poland, with the geographical position of 52°13'56"N, 21°00'30"E. All of them were reconstructed after 1945. The façades were chosen to fulfil demands regarding observer distance and colour homogeneity. Many façades are richly decorated with historical details or interwar polychromy. Colours also vary due to the weather's impact on the ageing process of façades. This limited the number of possible façades, as the surface to be observed had to be relatively evenly coloured.

Fridell Anter's Swedish observations [4] were mostly made from a distance of thirty to fifty metres, and in order to allow comparison between the two studies, an observation distance of thirty metres was chosen. The medieval urban structure of the Old Town is characterised by narrow streets, which means that most façades cannot be observed from that distance. Thus, the chosen façades are mainly situated in the squares: façade F – Rynek Starego Miasta (the Old Town Market Place that is a 90 by 73 metre rectangle), façades A and B – ul. Brzozowa, façades C, D, and E - ul. Kanonia, façade G – ul. Szeroki Dunaj and façades H and I – Plac Zamkowy (Castle Square) (Figures 11-12). Chosen façades of tenement houses or public buildings are part of the street frontage. As well, two façades of the Royal Castle (but not the above mentioned 'Saxon' façade) were chosen to be part of the study after their recent restoration.

The chosen façades fulfil the following criteria:

- the height is three to six storeys;
- the wall finishing is plaster – a surface (with sand size grain) that is reasonably smooth, not heavily textured, and matt;
- the façade is unicoloured, although windows, doors and smaller façade details have different or contrasting colours;
- the façade is flat: the details and decorations are not formed into irregular three-dimensional wall configurations.

They also fulfil the following criteria regarding the observation situation:

- the façade can be observed from a distance of approximately thirty metres;
- the façade can be observed when either totally shaded or totally sunlit (with the exception of small shadows of architectural details);
- there is direct access to the façade that enables nominal colour registration.

In total, seventeen façades were chosen. For three of them, there were not enough registered observations, regarding unfavourable daylight conditions. Five façades were excluded for other reasons such as a difference between daylight conditions on façades and on NCS Atlas during observations. For nine façades, the observations were further analysed (Figure 13). All of them had hues between the elementary hues Yellow and Red. The chosen façades had a relative uniformity of surface colour.

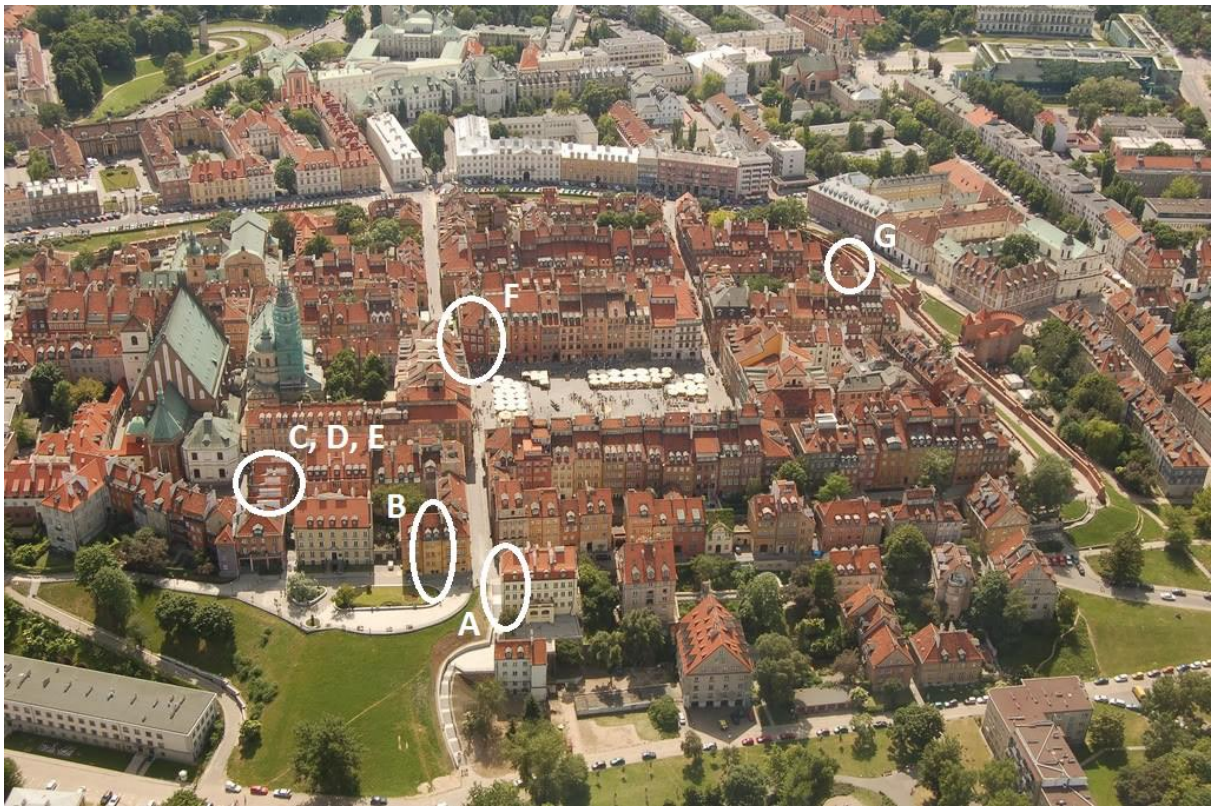


Figure 11: Warsaw's Old Town with façades that were observed and analysed as indicated. (Façades H and I) are located in an area that is not covered by this image)[4].

[4] Source: http://www.skyscrapercity.com/showthread.php?t=265790&page=23

Figure 12: Warsaw's Old Town with all observed and analysed façades marked[5].

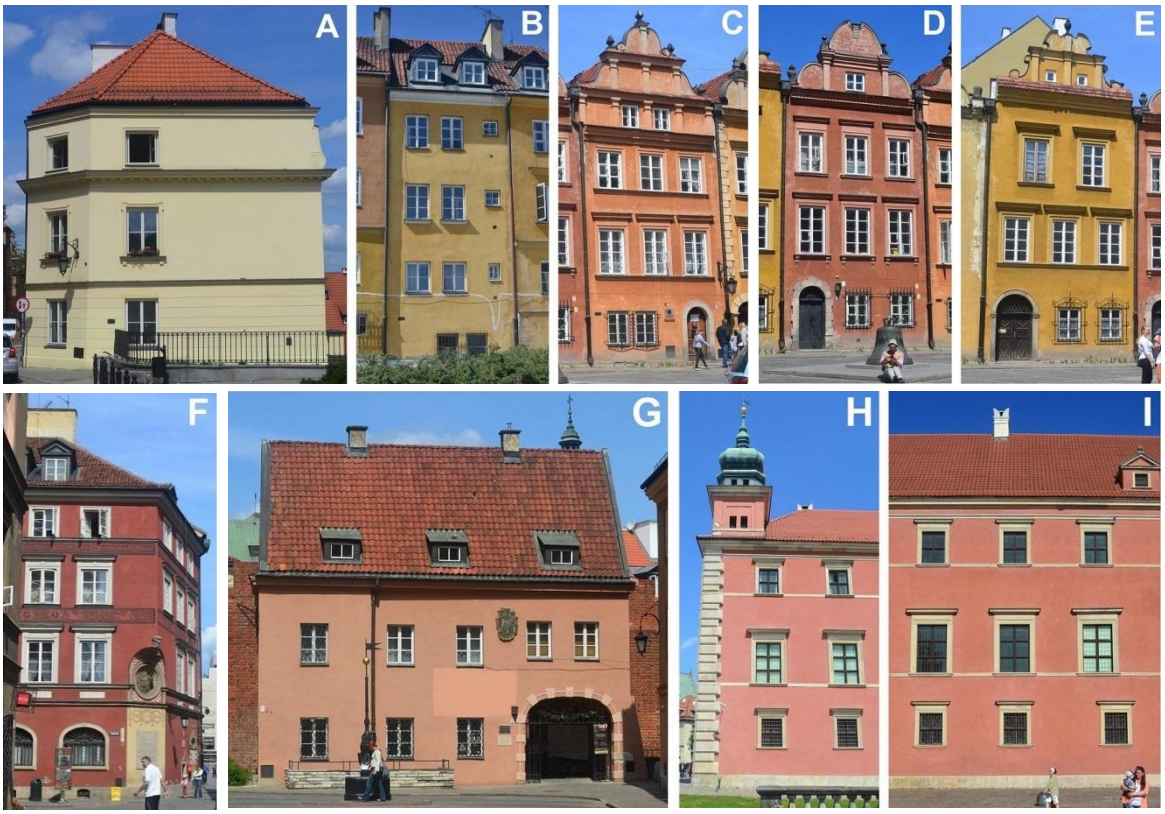


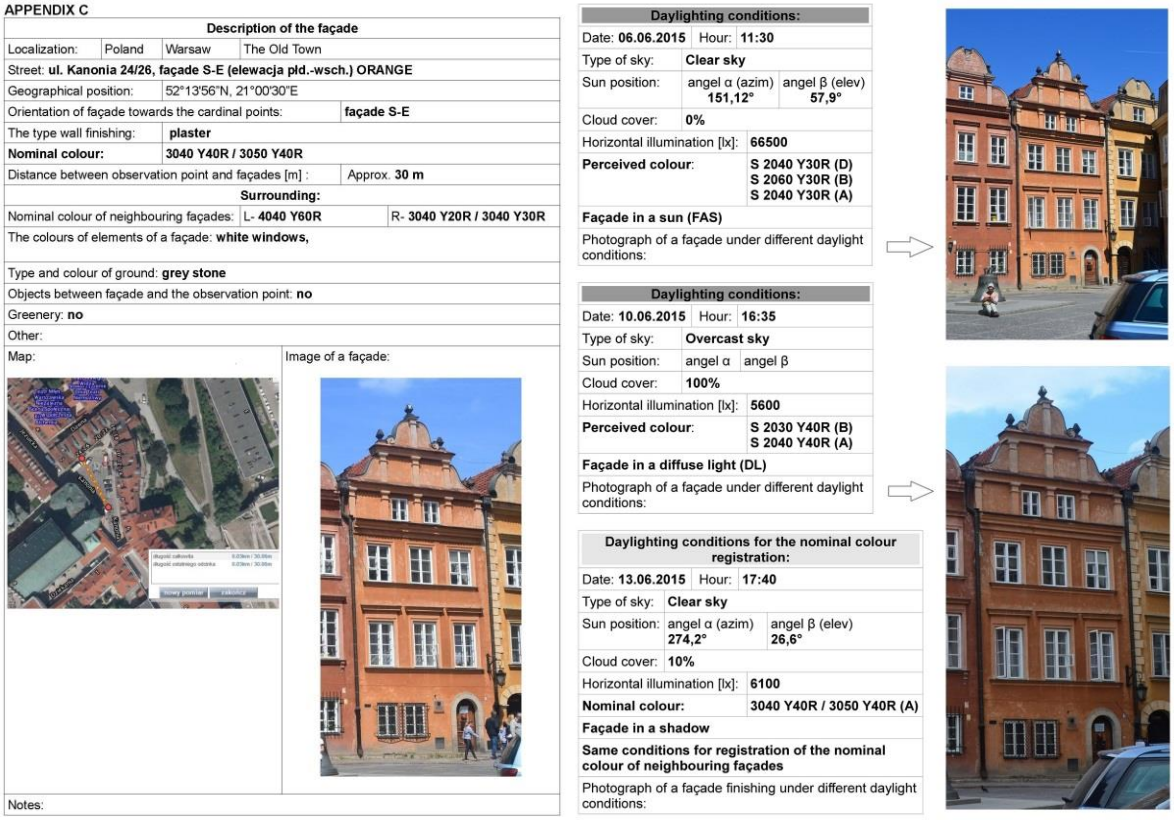
Figure 13: The nine analysed façades, A to I. Photo: Anna Sochocka, 2015.

[5] Source: http://www.mapa.um.warszawa.pl/

Description of façades

For each façade, their characteristics were registered once: the colour of windows, roofs, adjacent houses, and the colour of the vegetation in their surroundings.

Descriptions also included colour notations of the closest surrounding: neighbouring façades, roofs, ground, objects and greenery between the façade and the point of observation. They also included orientations of façades towards the cardinal points, as a basis for analysis of the direction of incidental direct sunlight. They did not, however, include a description of the coating or paint types used, as this would require both equipment and knowledge that were not available. The information for each façade was gathered in tables, e.g. Figure 14.



APPENDIX C

Description of the façade			
Localization:	Poland	Warsaw	The Old Town
Street: **ul. Kanonia 24/26, façade S-E (elewacja płd.-wsch.) ORANGE**			
Geographical position:	52°13'56"N, 21°00'30"E		
Orientation of façade towards the cardinal points:		**façade S-E**	
The type wall finishing:	**plaster**		
Nominal colour:	**3040 Y40R / 3050 Y40R**		
Distance between observation point and façades [m] :		Approx. **30 m**	
Surrounding:			
Nominal colour of neighbouring façades:	L- **4040 Y60R**	R- **3040 Y20R / 3040 Y30R**	
The colours of elements of a façade: **white windows,**			
Type and colour of ground: **grey stone**			
Objects between façade and the observation point: **no**			
Greenery: **no**			
Other:			

Map:

Image of a façade:

Daylighting conditions:		
Date: **06.06.2015**	Hour: **11:30**	
Type of sky:	**Clear sky**	
Sun position:	angel α (azim) **151,12°**	angel β (elev) **57,9°**
Cloud cover:	**0%**	
Horizontal illumination [lx]:	**66500**	
Perceived colour:	**S 2040 Y30R (D)** **S 2060 Y30R (B)** **S 2040 Y30R (A)**	
Façade in a sun (FAS)		
Photograph of a façade under different daylight conditions:		

Daylighting conditions:		
Date: **10.06.2015**	Hour: **16:35**	
Type of sky:	**Overcast sky**	
Sun position:	angel α	angel β
Cloud cover:	**100%**	
Horizontal illumination [lx]:	**5600**	
Perceived colour:	**S 2030 Y40R (B)** **S 2040 Y40R (A)**	
Façade in a diffuse light (DL)		
Photograph of a façade under different daylight conditions:		

Daylighting conditions for the nominal colour registration:		
Date: **13.06.2015**	Hour: **17:40**	
Type of sky:	**Clear sky**	
Sun position:	angel α (azim) **274,2°**	angel β (elev) **26,6°**
Cloud cover:	**10%**	
Horizontal illumination [lx]:	**6100**	
Nominal colour:	**3040 Y40R / 3050 Y40R (A)**	
Façade in a shadow		
Same conditions for registration of the nominal colour of neighbouring façades		
Photograph of a façade finishing under different daylight conditions:		

Notes:

Figure 14: Excerpt from one of the tables of observations.

Observation conditions

The observations were led by Anna Sochocka. Similar observation conditions were established for all façades. They were all observed:

- during the same season – in early summer;
- from a similar distance from the façade to the observation point – approximately thirty metres;
- directly from the front.

A variable during the observations was the outside daylight conditions. For every observation, the viewing conditions were registered and written down by the observation leader:

- the date and time;
- the weather (type of sky);
- the light quality and angle towards the façade (diffuse, in shadow, in sun under the described incident angle);

- the vertical illumination measured with a standardised luxmeter (Hagner Digital Luxmeter EC1 -X) at a height of approximately two metres above the ground.

Observations were made when the façade was evenly lit. For each observation, the façade was photographed as part of the visual documentation.

Observers

The observations were made by four observers. Three of them were from different age groups without colour deficiency and without special colour training before the experiment. The fourth observer was the observation leader, who had special colour training before the experiment. None of the observers knew the façades' nominal colours during the registration of perceived colours. Observations and registrations of perceived colours were organised in sessions during one week at the end of May and the two first weeks of July 2015, with two to four persons attending each session. All observers observed all façades, but not under all daylight conditions.

Before the first session, observers were trained. First, the NCS was explained. Later, the method for colour registration was demonstrated. The training was carried out on a separate façade that does not belong to the group of the chosen façades for observations. The training included all elements of a procedure for recording the perceived colours using the NCS. After training, the observers were fluent in the use of the NCS Atlas. They understood the variables of the NCS so they were able to find the sample most similar to the colour of the façade.

Method for the determination of perceived colour

In her Swedish study, Fridell Anter tested and evaluated a number of methods for the determination of the perceived colour of façades [4 p67-77]. The method that was found most fruitful was the one labelled 'B', which is described below. In the present study, all determinations of perceived façade colour were done with that method (Figure 15).

Figure 15: Illustration of the method for assessing perceived façade colour with the NCS Atlas. In the Warsaw study the distance between observer and façade was approximately thirty metres.

The study involved 84 observations in total, carried out by four observers, according to the procedure described by Fridell Anter, as *method B* [4 p69]. The observers were positioned in front of the façade at the appointed distance, holding the NCS Atlas approximately vertically. During the observation, the atlas had to be lit as similarly to the façade as possible. The reference samples were compared against the white background of the atlas page (Figure 15). Observers worked independently of one another. They asked themselves the question, *What colour do I see on the house right now?*, then they found a

matching colour in the NCS Atlas in three stages. First, the preliminary hue was chosen. Second, the nuance was found in the chosen NCS triangle or, in the case of a greyish façade, on the atlas page with greyish samples. It was possible to interpolate between samples if the observer was unable to decide between two of the closest samples. Third, the observer verified the hue by comparing it with adjacent triangles. After that the notation of the chosen sample was written down.

Method for the determination of nominal colour

The registration of a nominal colour is carried out by the observation leader after all perceived colour determinations are finished. The method, in which NCS samples are placed directly onto the façade surface, is described and discussed in Fridell Anter's study [4 p59-64]. There she concludes that a trained observer who uses the method as prescribed would most often have no difficulty finding the NCS sample that is most similar to the colour of the façade surface. She found, however, some colour categories were more difficult to determine, but none of these categories were present on the studied Warsaw façades.

An important argument against the validity of the method of visual assessment through comparison is metamerism. This is the phenomenon that occurs when two surfaces look the same in one type of light and different in another. Fridell Anter concludes in her discussion [4 p61-62] that it is reasonable to assume only minor effects of metamerism when assessing façade colours. One reason for this is that outdoor illumination is natural full spectrum daylight, and the illumination in the standard situation is artificial light simulating daylight (D65), which is designed to be very close to daylight. Another reason is that the NCS samples are produced with non-selective pigments, chosen and combined with the aim of avoiding metamerism. Also, façades are most often painted with such pigments, as they are comparatively cheap and technically stable.

As a conclusion of her evaluation method, Fridell Anter states that the method, for the colour range studied in Warsaw, has a preciseness of +- 5 units for the variables blackness, whiteness, chromaticness and hue.

For practical reasons, in this study was used the NCS Index instead of NCS Blocks (with samples approximately four times larger) that were used in Fridell Anter's Swedish study. Due to the smaller size of the samples and the wider tolerances in their production, this could lead to marginally diminished assessment preciseness. The white paper between the samples was carefully covered not to influence the observer (Figure 16). To minimise the effect of gloss difference between samples and façade surface, and between the flat samples and the granular surface texture of façades, determinations of nominal colour were made in diffuse daylight (overcast sky conditions or clear sky conditions in the shadow).

All registrations of nominal colours were made in full daylight (between 11:00 and 17:00) under diffuse light. The observation leader estimated which part of the façade was most typical of its colour, placed the NCS Index flat on the façade surface and visually selected the sample that was most similar to the façade. If none of them was clearly closest to the façade colour interpolations between samples were made. The vertical illumination was measured on the façade not more than fifty centimetres above the sample. The most representative sample or interpolation between two samples was chosen from three possible determinations. The figures were rounded off to the nearest 5 units for blackness, chromaticness, whiteness and hue.

Figure 16 (left): The method for determination of nominal colour with NCS Index. In the Warsaw study the plaster finishing of façades was smoother (see Figure 17).
Figure 17 (right): Example of plaster finishing (façade D) in the Warsaw study. The plaster is based on sand so the grain of the texture is small.

Method for analysis of observation results

Façades were grouped according to their nominal nuance and nominal hue. The nuance area definitions corresponded to those used by Fridell Anter [4 p99-101], with whiteness as the primary classification criteria and chromaticness as the secondary. Figure 18 shows nominal nuance areas of 125 façades identified in the Swedish study. As shown in Table 1, only four of these nine nuance areas were represented in the Warsaw study, i.e. Q1, Q4, Q6, and Q8 (Table 1). The reason for this was the limitation discussed above regarding the accessibility and the colour scheme of the façades present in Old Town.

The hue range definitions were chosen to allow comparison with Fridell Anter's results regarding hue shifts [4 p107]. The definitions of these groups are in Tables 6 to 8.

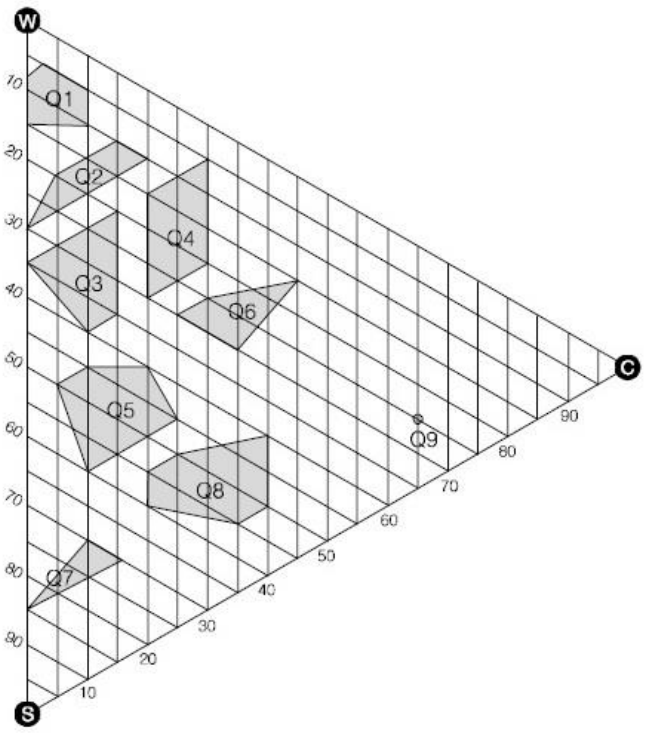


Figure 18: Nominal colours of façades grouped into the nuance areas defined in the Swedish study by Fridell Anter [4]. The Warsaw study only included facades in the areas Q1, Q4, Q6 and Q8 [4 p101].

Façade	Street name	(s) AL*	(c) AL*	(w) AL*	Nominal colour	Orientations of façades
NUANCE AREA **Q1**		05-15	0-10	80-		
A	ul. Brzozowa 6/8				0510-Y20R	E-S
NUANCE AREA **Q4**		05-30	20-30	50-65		
B	ul. Brzozowa 1/3				2030-Y20R	N-E
G	ul. Szeroki Dunaj 13				3020-Y60R	E-S
H	pl. Zamkowy 4				3030-Y70R	S
I	pl. Zamkowy 4				3030-Y70R	W
NUANCE AREA **Q6**		15-30	25-45	30-45		
C	ul. Kanonia 24/26				3045-Y40R	E-S
E	ul. Kanonia 24/26				3045-Y10R	E-S
NUANCE AREA **Q8**		40-60	20-40	10-25		
D	ul. Kanonia 24/26				4040-Y60R	E-S
F	R. St. Miasta 15				4030-Y85R	E-S

*Table 1: Nominal colours of façades (shown in Figure 18) grouped according to nuance areas of the Warsaw study. Explanation of symbols marked with *: (s) AL – Blackness area limits; (c) AL – Area limits of chromatic properties; (w) AL – Whiteness area limits. Values taken from 'Table 401: The columns for "area limits" give the theoretical limitations of the colour area.' In Fridell Anter [4 p100].*

In the analysis of observation results, the nominal colour of each façade was used as a reference notation with which all observational data was compared. From the assessments of perceived colour, averages were calculated for each façade. This allowed calculation of differences in NCS blackness (s), chromaticness (c), whiteness (w) and hue (Φ) between nominal colour and average perceived colour.

A comparison between different lighting situations was made for all nine façades together to give a basis for a hypothesis in a possible future larger study.

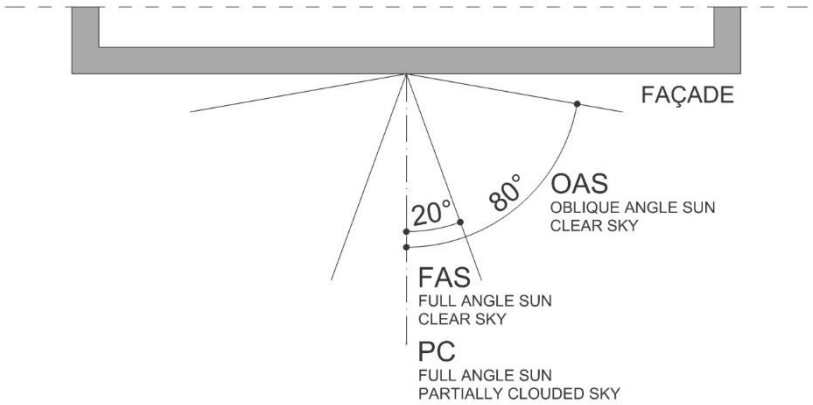


Figure 19: Diagram for the categories with the light's angle of incidence when façades are exposed to direct sunlight: Full Angle Sun (FAS), Oblique Angle Sun (OAS) and Partially Clouded (PC). Source: [4 p147].

The following categories for daylight conditions were used (Figure 19):

- **FAS**: 'Full Angle Sun' under clear sky conditions; direct sunlight cast on the façade at an angle no more than twenty degrees from a right angle to the façade.
- **OAS**: 'Oblique Angle Sun' under clear sky conditions; direct sunlight cast on a façade at an oblique angle to the façade (between twenty and eighty degrees from a right angle). This

daylight condition occurred only once during the observations (façade B on 06.06.2015, 10:15). This registration was analysed together with those from FAS daylight conditions.

- **DL**: 'Diffuse Light' under overcast sky conditions; diffuse light cast on the façade.
- **PC**: 'Partially Clouded'; direct sunlight cast on the façade although clouds were present in the sky; lit with direct sunlight at an angle of no more than twenty degrees from a right angle to the façade.
- **SF**: 'Shadowed Façade'; clear sky conditions with the façade not exposed to direct sunlight, but in shadow and thereby lit with diffuse light.

These categories were adopted, with modifications, from Fridell Anter's study [4 p147]. The number of observations and daylight situations for each façade are presented in Tables 2 to 5.

Results – differences between nominal colour and perceived colour

Differences (Δ- values) are computed between nominal and perceived colours for the aforementioned attributes blackness (s), chromaticness (c), whiteness (w) and hue (Φ), for each property using the 100 unit scales defined within the NCS. Positive values of differences for blackness, chromaticness and whiteness indicate that the perceived colour has more of the respective property than the nominal colour. Positive values of differences for hue indicate a clockwise shift, and negative values for hue differences indicate an anti-clockwise shift on the NCS circle. As the number of façades is low, no statistical analysis can be made, but we can still see whether the results appear to be consistent and agree with previous results presented by Fridell Anter [4 p104, Table 403].

Nuance differences between nominal colour and perceived colour

The calculated nuance differences between nominal colour and perceived colour are elaborated per nuance area. As illustrations, the colour samples are presented (scanned NCS samples) for each façade. These visual representations should be understood only as an approximation as colours are not displayed the same on all screens or reproduced identically by all printers (Figures 20-28).

Results for the nuance area Q1 (Table 2)

Results for the nuance area Q1 (Table 2) show no significant shift in blackness, chromaticness and whiteness. This does not coincide with Fridell Anter's Swedish results [4], but as only one façade was observed in this nuance area, no conclusions can be drawn from this.

Façade	Nominal colour	Daylight conditions	Number of observations	Average perceived colour	Blackness Δs	Chromaticness Δc	Whiteness Δw
A	**0510-** Y20R	PC, DL	8	**0611-** Y07R	+1	+1	-2
Results Fridell Anter [4]			19 (9 façades)		-6 (+-3)	+1 (+-1)*	+5 (+-3)

*Table 2: Difference between nominal and average perceived colours for nuance area Q1 in the Warsaw study. Referring to the Swedish study, the numbers in parenthesis denote confidence interval 99% and the results marked with * denote that the difference in direction between nominal colour and perceived colour is not statistically significant.*

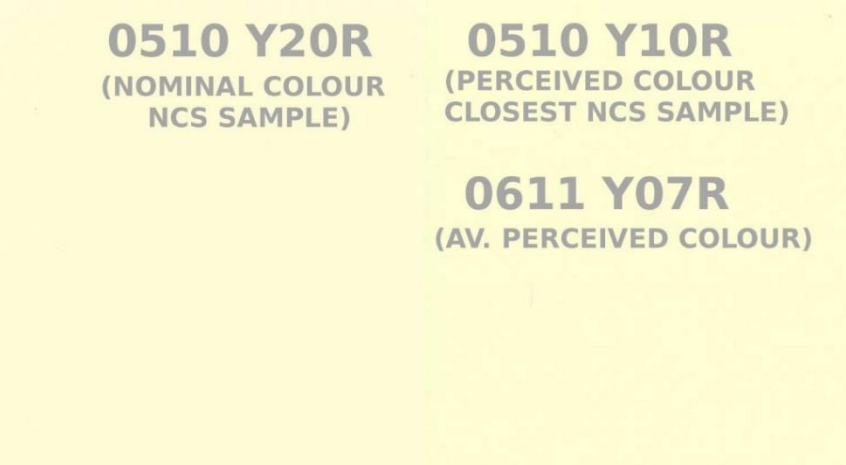


Figure 20: Visual representations of the nominal colour (left) and the average perceived colour (right) of façade A (Table 2).

Results for the nuance area Q4 (Table 3)

Blackness: All façades show a tendency to perceived blackness being less than nominal blackness. The average for this tendency is 12 blackness units. The difference between nominal blackness and perceived blackness is similar for all façades and for all cases falls within the confidence interval of the Swedish study, which strongly is in agreement with previous results.

Chromaticness: The shift in chromaticness shows no pattern but for half of the façades it falls within the confidence interval of the Swedish study. No implication can be drawn from this.

Whiteness: All façades show a tendency to perceived whiteness being higher than nominal whiteness. The average for this tendency is 9 whiteness units. The difference between nominal whiteness and perceived whiteness varies between 4 and 16 and for only half of the façades it falls within the confidence interval of the Swedish study. This means that the direction, but not the size of the whiteness shift, is in agreement with previous results.

Façade	Nominal colour	Daylight conditions	Number of observations	Average perceived colour	Blackness Δs	Chromaticness Δc	Whiteness Δw
B	**2030-** Y20R	DL, OAS	5	**0930-** Y10R	-11	0	+11
G	**3020-** Y60R	PC, DL, FAS, FS	12	**1717-** Y61R	-13	-3	+16
H	**3030-** Y70R	PC, DL	5	**2232-** Y70R	-8	+2	+6
I	**3030-** Y70R	DL, FAS	5	**1640-** Y62R	-14	+10	+4
Average					**-12**	**+2**	**+9**
Results Fridell Anter [4]			33 (12 façades)		-11 (+-3)	+1 (+-3)*	+10 (+-4)

*Table 3: Difference between nominal colour and average perceived colour for nuance area Q4 in the Warsaw study. Referring to the Swedish study, the numbers in parenthesis denote confidence interval 99% and the results marked with * denote that the difference in direction between nominal colour and perceived colour is not statistically significant.*

Figure 21: The nominal colour (left) and the average perceived colour (right) of façade B (Table 3).

Figure 22: The nominal colour (left) and the average perceived colour (right) of façade G (Table 3).

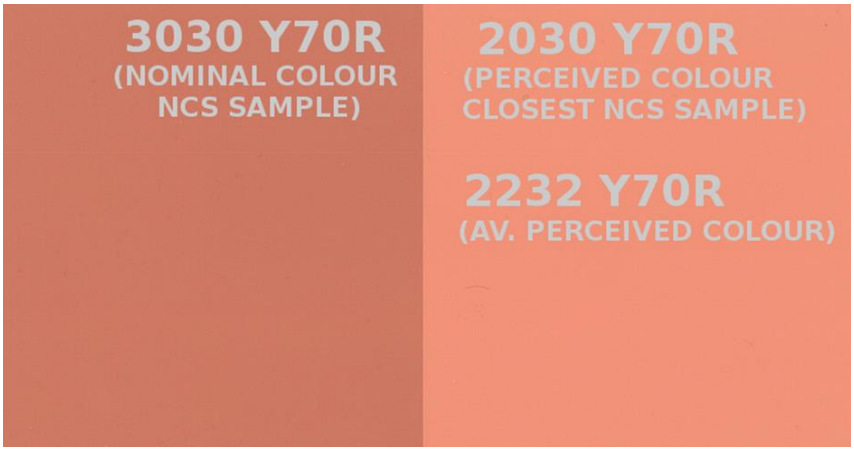


Figure 23: The nominal colour (left) and the average perceived colour (right) of façade H (Table 3).

Figure 24: The nominal colour (left) and the average perceived colour (right) of façade I (Table 3).

Results for the nuance area Q6 (Table 4)

Blackness: Both façades show a tendency to perceived blackness being less than nominal blackness. The average for this tendency is 11 blackness units. The difference between nominal blackness and perceived blackness is similar for both façades and strongly is in agreement with previous results.

Chromaticness: The chromaticness is relatively stable, but these findings do not agree with previous results.

Whiteness: Both façades show a tendency to perceived whiteness being 12 whiteness units higher than nominal whiteness. The direction, but not the size, of the whiteness shift is in agreement with previous results.

Façade	Nominal colour	Daylight conditions	Number of observations	Average perceived colour	Blackness Δs	Chromaticness Δc	Whiteness Δw
C	**3045-** Y40R	PC, DL, FAS, FS	14	**1845-** Y34R	-12	0	+12
E	**3045-** Y10R	PC, DL, FAS, FS	15	**2142-** Y10R	-9	-3	+12
Average					**-11**	**-2**	**+12**
Results Fridell Anter [4]			34 (10 façades)		-11 (+-3)	+5 (+-4)	+6 (+-4)

Table 4: Difference between nominal colour and average perceived colour for nuance area Q6 in the Warsaw study. Referring to the Swedish study, the numbers in parenthesis denote confidence interval 99%.

Figure 25: The nominal colour (left) and the average perceived colour (right) of façade C (Table 4).

Figure 26: The nominal colour (left) and the averaged perceived colour (right) of façade E (Table 4).

Results for the nuance area Q8 (Table 5)

Blackness: Both façades show a tendency to perceived blackness being less than nominal blackness. The average for this tendency is 12 blackness units. The result is in agreement with previous results.

Chromaticness: The shift in chromaticness shows no pattern, but the average is in agreement with previous results.

Whiteness: The shift in whiteness shows no pattern.

Façade	Nominal colour	Daylight conditions	Number of observations	Average perceived colour	Blackness Δs	Chromaticness Δc	Whiteness Δw
D	**4040-** Y60R	PC, DL, FAS, FS	11	**2539-** Y54R	-15	-1	+16
F	**4030-** Y85R	PC, DL, FAS	9	**3142-** Y80R	-9	+12	-3
Average					**-12**	**+6**	**+7**
Results Fridell Anter [4]			44 (13 façades)		-9 (+-2)	+8 (+-3)	+1 (+-3)*

*Table 5: Difference between nominal colour and average perceived colour for nuance area Q8 in the Warsaw study. Referring to the Swedish study, the numbers in parenthesis denote confidence interval 99% and the results marked with * denote that the difference in direction between nominal colour and perceived colour is not statistically significant.*

Figure 27: The nominal colour (left) and the average perceived colour (right) of façade D (Table 5).

Figure 28: The nominal colour (left) and the average perceived colour (right) of façade F (Table 5).

Hue differences between nominal colour and perceived colour

For analysis, the Warsaw façades were grouped according to their nominal hues. The grouping was based on the findings in the Swedish study [4], as presented in Figure 29. The groups in the Warsaw study were:

Hue range H1: Façades with nominal hues from Y10R to Y20R. In the Swedish study, the perceived hues of façades within this range tended to shift anti-clockwise (from red towards yellow) as compared to the nominal hues.

Hue range H2: Façades with nominal hues from Y40R to Y60R. In the Swedish study, the perceived hues of façades within this range showed no significant shift as compared to the nominal hues.

Hue range H3: Façades with nominal hues from Y70R to Y90R. In the Swedish study, the perceived hues of façades within this range tended to shift clockwise (from yellow towards red) as compared to the nominal hues.

The results for each of these hue ranges are shown in Tables 6-8.

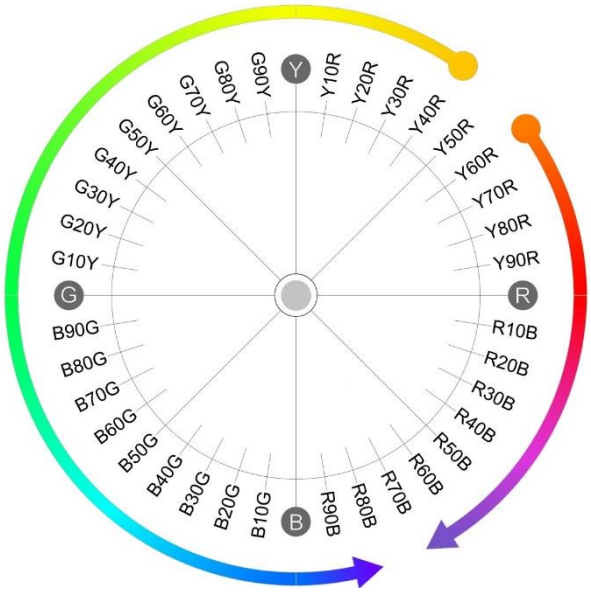


Figure 29: Recurring tendencies for hue shifts from a nominal colour to a perceived colour, as presented in Fridell Anter's Swedish study [4 p107]. Arrows indicate direction, but not size of shifts.

Results for hue range H1 (Table 6)

Average hue shift is 8 units with direction from red towards yellow. There are however large differences between the façades, and the one with the darkest and most chromatic nominal colour shows no hue shift. This suggests agreement with the Swedish results, which showed a tendency of hue shift from red towards yellow, predominantly for pale nuances and weaker for darker and/or more chromatic colours.

Façade	Nominal colour	Number of observations	Average perceived colour	Hue difference ΔΦ
E	3045-**Y10R**	15	2142-**Y10R**	0
A	0510-**Y20R**	8	0611-**Y07R**	-13
B	2030-**Y20R**	5	0930-**Y10R**	-10
			Average	**-8**

Table 6: Differences of hue (ΔΦ) between nominal colours and average perceived façade colours for hue range H1 (nominal hues Y10R-Y20R).

Results for hue range H2 (Table 7)

The average hue shift is 4 units in the direction from red towards yellow. There are, however, large differences between the façades, where the two most chromatic ones shift towards yellow, and the one with less chromaticness remains stable. The Swedish study included only a few observations of façades in this range, and could determine no tendency for a hue shift.

Façade	Nominal colour	Number of observations	Average perceived colour	Hue difference ΔΦ
C	3045-**Y40R**	14	1845-**Y34R**	-6
D	4040-**Y60R**	11	2542-**Y53R**	-7
G	3020-**Y60R**	12	1717-**Y61R**	+1
			Average	**-4**

Table 7: Differences of hue (ΔΦ) between nominal colours and average perceived façade colours for hue range H2 (nominal hues Y40R-Y60R).

Results for hue range H3 (Table 8)

The average hue shift is 4 units in the direction from red towards yellow. There are, however, large differences between the façades, even between those with identical nominal colours, a finding that cannot be explained within this study. The result, which thus should be seen as very tentative, suggests no agreement with the Swedish study, which for this hue range showed a tendency of shift from yellow towards red.

Façade	Nominal colour	Number of observations	Average perceived colour	Hue difference ΔΦ
H	3030-**Y70R**	5	2232-**Y70R**	0
I	3030-**Y70R**	5	1640-**Y62R**	-8
F	4030-**Y85R**	9	3142-**Y80R**	-5
			Average	**-4**

Table 8: Differences of hue (ΔΦ) between nominal colours and average perceived façade colours for hue range H3 (nominal hues Y70R-Y90R).

Concluding comments on shifts of nuance and hue

For all nuance areas, except Q1 with only one façade, the perceived colour had less blackness than the nominal colour. The size of this shift varies around 10 blackness units, a result very similar to that of the Swedish study. The decreased blackness is balanced by an increased whiteness. Here the variation is larger both within the Warsaw study and between the Warsaw study and the Swedish study, but the tendency is still the same. For shifts in chromaticness, no recurrent pattern can be found.

The hue shift varies clearly within each of the three hue ranges and no recurrent pattern can be found. For those façades where a hue shift is found, it is, however, always in an anti-clockwise direction on the NCS circle, which means that the perceived colour is more yellowish and less reddish than the nominal colour. This is in agreement with the Swedish results for hue range H1 but contradictory for hue range H3, whereas no conclusion can be drawn for hue range H2.

Discussion

Impact of the viewing conditions on the difference between nominal colour and perceived colour

When comparing the Warsaw study with Fridell Anter´s Swedish study, it is necessary to consider the different conditions regarding the viewing situation:

- the general geographical location and the subsequent differences in incident light angle and intensity (levels of vertical illuminance). The Swedish study was done much further to the North (approximately 59°51') than the one in Warsaw (approximately 52°14'). The specific character of Nordic light is discussed by Matusiak [12] where she has shown that one of the most typical features of Nordic light, as compared to the daylight in most parts of the world, is a dominating low solar elevation angle, which among other things leads to more atmospheric scattering of light and consequently to a lower colour temperature of sunlight.
- the façade material. The Swedish study included mainly painted timber façades, whereas the Warsaw study dealt with plastered façades. This meant that the gloss and surface texture of the Swedish façades were relatively similar to that of the semi-matte NCS samples, whereas the Warsaw façades were more matte and had a rougher surface. This probably made it more

difficult to determine the nominal colours in the Warsaw study and may also have affected the perceived colours.

- the size of façades. The Swedish study included mainly one-story or two-story houses, whereas the ones in Warsaw were three to six stories high.
- the environment of façades. The Swedish study included mainly single-family houses surrounded by vegetation and with no directly adjacent neighbours, whereas the Warsaw study dealt with row house façades, without proximity to vegetation and sometimes facing a narrow street with similar row house façades.

There were also differences in the number of façades and observations, and in the training of observers:

- the Swedish study included approximately 100 façades, about half of which had hues between Y and R. For these, 120 observations were done with method B. The Warsaw study included nine façades, all with hues between Y and R. For these, 84 observations were made with method B. Due to the relatively small numbers, the results of the Warsaw study give a weaker ground for conclusions and cannot be properly statistically analysed.
- in the Swedish study, the observers were colour researchers with solid understanding of the NCS. In the Warsaw study the observers received their NCS training shortly before the observation. This might have affected the results in two ways: The Warsaw observers might have been less fluent in finding the colour they wanted, but they might also have less preconceptions of what they would find and therefore be more reliable.

Despite these differences, the two studies showed general but not total agreement regarding the nuance shift between nominal and perceived façade colours. In both studies, perceived colour was about 10 units less blackish than the nominal colour. Also for whiteness and chromaticness shifts, the two studies showed the same tendencies, but did not agree as clearly. This agreement in nuance shift also coincides with the findings of Balboa Blanco in her survey of façade colours in Mexico City [13]. We conclude that the main tendencies regarding nuance shift appear similar irrespective of geographic location and specific viewing conditions.

As for hue shifts, the studies in Warsaw and in Sweden did not yield the same results. The results of the Mexican study agreed partially with those found in Sweden, but the hue shifts were smaller in Mexico. The differences between the studies might be caused by different viewing situations, e.g. regarding simultaneous contrast effects against neighbouring façades and vegetation, and reflected light from façades opposite the street. We draw no further conclusions regarding any general tendencies for hue shifts.

Reflections regarding colour in Warsaw

The Warsaw study included only façades in the yellow-red range. For this range, the blackness shift between nominal colour and perceived colour agrees strongly with the result of the Swedish study. This implies that the results of the Swedish study – general decrease of blackness – should be valid in Warsaw also for façades of other colours.

This means that the colour that Canaletto saw when depicting the castle would be lighter – less blackish – than the nominal façade colour at that time. In her book The Colours of Rome, Bente Lange discusses the value of painted city views as historical sources. She concludes that up to the 20th century, the primary function of painted city views or *vedute* was to document experience, although one can never dismiss the possibility that the artist had other aims and thus chose to deviate from what he experienced (perceived) [14 p26]. Thus, a preliminary conclusion would be that the colours of the Royal

Castle on Canaletto's painting *Widok Zamku od strony Pragi* [View of the Castle from the side of Praga] were darker on the surface of the building than on the painting.

Conclusions

The important conclusion from the comparison between the study in Warsaw and Fridell Anter's Swedish results is, that between approximate perceived colours and nominal colours of observed façades, there is a consistent variation pattern for blackness. The Warsaw study involved only yellowish and reddish façades, but we draw the tentative conclusion that the general decrease in blackness between nominal colour and perceived colour shown for the Swedish conditions is valid, irrespective of hue and geographical position, and not influenced by localisation, daylight conditions or type of wall finishing.

The decreased blackness is by definition counter balanced by increased whiteness and/or chromaticness, but the material does not allow any further conclusions on general shifts of whiteness or chromaticness. For possible hue shifts, no conclusion can be drawn from the Warsaw study.

The part of the research where nominal colours and perceived colours were compared to the observations of façades under different daylight conditions is not presented in this article as the results were not sufficient to draw any definitive conclusion.

Finally, we encourage further research on perceived façade colour in different geographic locations and viewing conditions, which would enable comparisons and – possibly – more stable general conclusions.

Acknowledgements

Anna Sochocka's study of Warsaw was done as part of the course 'Nordic Light and Colours' (2012, 2015), given at NTNU Trondheim under the leadership of Professor Barbara Szybinska Matusiak and Docent Karin Fridell Anter.

References

1. Czeczot-Gawrak J (2010), Zamek Królewski w Warszawie projekt kolorystyki fasady południowo-wschodniej (trans. by AS: The project of a colour scheme for south-east façade of Royal Castle in Warsaw), *Kolorystyka zabytkowych elewacji od średniowiecza do współczesności. Historia i konserwacja. Materiały międzynarodowej konferencji z okazji 30-lecia wpisu Starego Miasta w Warszawie na Listę Światowego Dziedzictwa UNESCO Warszawa 22-24 września 2010*, 177-183, Krajowy Ośrodek Badań i Dokumentacji Zabytków (Warszawa).
2. Skyscrapercity forum (2015) – http://www.skyscrapercity.com/showthread.php?p=98552480; http://www.skyscrapercity.com/showthread.php?t=214856&page=92 – last accessed 23 October 2015.
3. Szczypek M (2015), Kolorystyka fasady południowo-wschodniej Zamku Królewskiego – https://www.zamek-krolewski.pl/__data/assets/pdf_file/0010/51589/Kolorystyka-fasady-poludniowo-wschodniej-Zamku-Krolewskiego.pdf – last accessed 23 October 2015.
4. Fridell Anter K (2000), What colour is the red house? Perceived colour of painted façades, *PhD Thesis*, KTH Royal Institute of Technology, Trita-ARK-Akademisk avhandling, Stockholm (Sweden). [http://arkitekturforskning.net/na/article/download/358/314 – last accessed 22 October 2015].

5. Knothe J (1956), *A tu jest Warszawa* (trans. AS: Here is Warsaw), Iskry (Warszawa).
6. Biegański P (2006)**,** The Historic Preservation Concept of Reconstruction, Guidelines and Supervision over the Rebuilding of the Old Town, *Proceedings of the 25th anniversary conference of the Old Town's entry onto the UNESCO Heritage List: Destroyed but not lost*, 15-22, Conservator of Monuments of Capital City of Warsaw (Warsaw).
7. Lauterbach A (1971), Zniszczenia i odbudowa Warszawy zabytkowej (trans. AS: The destruction and rebuilt of historic Warsaw), Kronika Warszawy (trans. AS: The chronicle of Warsaw), rocznik 1971, **2**, 4 (8), 64, Warszawa.
8. Zielińska U (2006), Polychrome Mural Decoration in Warsaw Old Town, *Proceedings of the 25th anniversary conference of the Old Town's entry onto the UNESCO Heritage List: Destroyed but not lost*, 67-82, Conservator of Monuments of Capital City of Warsaw (Warsaw).
9. Logvinenko AD (2013), Object-color manifold, *International Journal of Computer Vision*, **101**, 143-160.
10. Fridell Anter K and Billger M (2010), Colour research with architectural relevance: How can different approaches gain from each other?', *Color Research and Application*, **35** (2): 145-152.
11. Fridell Anter K (2015), Light and Colour – Concepts and their use, in *Colour and Light – Concepts and confusions*, Arnkil H (ed.), Aalto University publication series ART + DESIGN + ARCHITECTURE 2/2015, Finland, 45-66.
12. Matusiak BS (2013), Nordic daylight, in *Nordic Light and Colour* 2012, Matusiak BS and Fridell Anter K (eds.), Norwegian University of Science and Technology, Trondheim (Norway), 25-38.
13. Balboa Blanco C (2010), Comparison between light and color in Mexico City and Stockholm, *Masters Thesis*, KTH Lighting Lab, Stockholm (Sweden).
14. Lange B (1995), *The Colours of* Rome, The Danish Architectural Press and The Royal Danish Academy of Fine Arts.