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# A TECHNIQUE FOR URBAN COLOR MAPPING STARTING FROM THE CASE STUDY OF MARCO ZANUSO'S COLLEGIO DI MILANO

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**Abstract**

In pursuit of a more objective approach to efficiently support the urban color design, the aim of this study is the introduction of a multiscale approach to the urban space color analysis. The paper opens with the presentation of a robust method, based on scales of perception, then it analyses the urban color at different scales, and it deepens into color corrected images. Specific features, problems and solutions are then illustrated. The Collegio di Milano complex, designed by the famous architect Marco Zanuso, was selected as a case study to prove the methodology's effectiveness on a real complex placed into a wider urban area. As a final outcome the methodology introduced proved how urban color mapping is a versatile process where the main role is played by multi-scale presence of color perception and material.

**Keywords**

Urban color analysis, project of color, architecture, color design, Milan

## 1. *Introduction*

Urban color mapping is today a well-bounded task that could be defined as a mean to identify and document the main color characteristics of an urban environment. Studies usually focus on the artificial as well as the natural elements within an environment (Lenclos, 1982; Porter, 1997), or on identifying and documenting the color characteristics of the built environment only (Iijima, 1997). In both cases color mapping techniques used are similar and they are, in practice, minimal variant of the method developed at first by Jean-Philippe Lenclos, the so-called 'The Geography of Color', which therefore is the methodological reference of the urban color mapping. The first stage of Lenclos' color mapping process involved collecting all the natural and artificial elements from a specific area including natural as well as construction materials. Lenclos then translated these samples into painted color schemes that were classified and grouped to produce a color synthesis, or a color map, of the specific area.

Following the original approach by Lenclos based on a meticulous examination of the local color harmonies and materials (Lenclos, 1989), in urban environment mapping, color has traditionally been considered in terms of palettes definition used in the construction of buildings, exploiting a four steps process:

- Definition of the environment to be mapped;
- Identification & collection of samples of natural and/or artificial elements;
- Color matching of elements to an existing color notation system;
- Database production of environmental color characteristics.

The main outcome of the process is a color specifications database that provides a basis for subsequent evaluation, analysis, and review, especially in terms of planning decisions.

In the last fifty years Color Plans have become increasingly widespread and urban planning tools, aimed to coordinate the maintenance, restoration, and renovation of external buildings surfaces in historical, artistic environments, and historic centers, helped to design the appearance of the new parts of the city.

From the analysis of some Color Plans, it emerges that all of them, even considering their differences and specific characteristics, are structured on common/shared well-defined phases: historical analysis/research; data survey and acquisition; processing and design/elements for the project; implementation rules and control, dissemination/communication, and disclosure. This organization is today consolidated, and it produces well-defined results that could be summarized as a map of the color façades, considered as single homogeneous color, with limited integration at the small scale by the color map of the materials for details.

However, the urban color scheme is a complex and comprehensive work. The analysis of urban landscape colors needs a multi-dimensional viewpoint. It is necessary to investigate the overall appearance, characteristics, and cultural heritage of the urban area at the different scales and chronologically. Urban design operates across a variety of spatial scales and then the urban color design is an inherently multiscale process. Two motivations support this statement: one more general and one specifically related to the different scales of the built environment. Color harmony and contrast theories show that sizes and/or proportions are the main factors affecting visual perception and identification of the color (Westland et al., 2007). Secondly, colors of structural components at different scales result in different identities (Moughtin et al., 1999). These structural features create differences between small-scale and large-scale environments as identity. This implies the need to analyze the urban color at different scales: city, quarter, block/street, building, building elements. However, usual urban color analysis techniques are not multiscale, and the output is limited to the graphic of the buildings, using plan views or elevations, with more or less the same information just changing the scale of representation of the drawings. Color analysis is limited to the check of the building using digital images, schemes, cards, and color scales, but colors are not related to each other at the current scale and comparisons lack often of any critical analysis for the dominant color.

A second observation comes from the fact that architectural colors are based on available pigments and practical production, but modern digital tools are in general based on tristimulus colorimetry and color models, i.e., RGB. When using modern color reference systems and tools based on modern colorimetry to determine traditional color specifications, we should consider that our attention is focused on the fact that color definition starts mainly from the color hue, since the available range at the time of production was based on available pigments. Pigment compositions used to produce functional, affordable, and durable façade paint did not allow for achromatic colors and then we tend to overlook the lightness changes.

However, in many cities, variations of colors are based on the use of simple lightness changes. In other cases, when near neutral colors are used, all traditional colors have a significant, small, chromatic hue. In these cases, it is impossible to qualify the color using only the hue.

In this paper, we present a multiscale method dedicated to urban color analysis to support efficiently urban color design. The approach considers not only changes in hue but also in lightness of the colors, to support both chromatic and materials analysis.

Furthermore, improvements were developed over traditional methods exploiting the application of digital technology to the process of color mapping. In detail, we show some simple techniques allowing an easy color mapping at a large scale and for whole urban fronts.

The Collegio di Milano complex (Schiaffonati et al., 2019) and the surrounding area in the city of Milan (Italy) were chosen as a case study. This complex is particularly suitable to prove our method because the original intent of the project was to identify color hues by materials. Variations from the base colors were achieved by exploiting sharp shapes generating shadows. The variation of light shadows at different times of the day and in different periods of the year generates lightness differences recalling the typical way of the historical city center of Milan, where façade colors are near neutral with subtle variations achieved changing the lightness more than the hue. The analysis of the colors of the Piazza del Duomo buildings, in the center of Milan, shows how this feature is efficiently proven by the developed analysis technique.

## 2. *The color mapping method developed*

To support a workflow for multiscale urban color mapping able to capture and quickly show variations in hue and lightness, a global solution was developed. The method is based on color-corrected digital images to let them embed colorimetrically reliable information, allowing an accurate evaluation of the color (Fig. 1) and it moves within the consolidated structure illustrated in Fig. 2, using the typical tools of the urban color analysis (images, Color Order Systems, plan, elevations, cards, etc.).

Innovations have been inserted in a consistent framework given by an accurate selection of tools and instruments, according to the specific task to be performed and with the aim to let the planner/architect focus on the new design and not on the data acquisition and processing, following a well-defined workflow based on color hue and lightness and scales-specific tasks.

Basically, the developed method is based on Lenclos' color geography, which proved to be very effective and then today largely used in all the Color Plans (Lenclos & Lenclos, 1999).

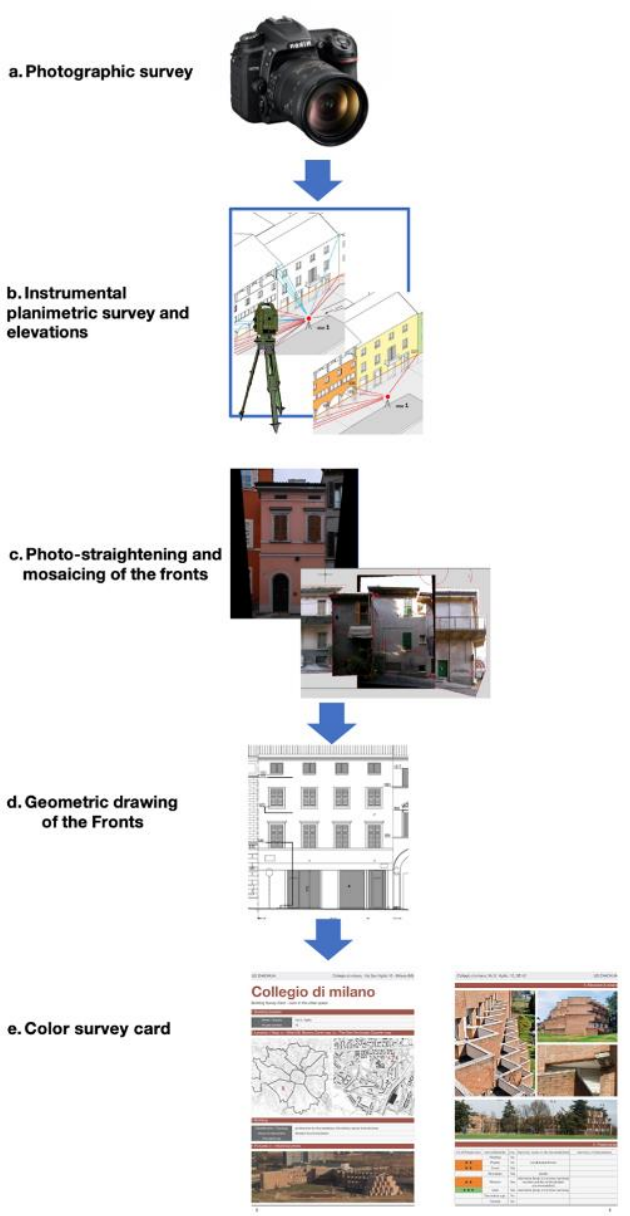


**Fig. 1:** Imaging workflow from acquisition to the color survey cards.

**Tab. 1:** Scales of perception, perceived objects and referential distances proposed for each scale.

| Scale of Perception | Perceived objects | Reference distance |
|---|---|---|
| Geographical | landscape features and buildings/settlements | 10,000 m |
| Broad Context | avenues/squares/skylines/built backgrounds | 1,000 m |
| Immediate Context | streets/neighboring buildings/rows of houses | 100 m |
| Architectural | houses/buildings/ building complexes | 10 m |
| Detail | stylistic elements/metal, glass, wood, stone | 1 m |
| Material | exposed construction materials/cladding and finishing materials/paint and coatings | .10 m |

Two observations led to develop a more sophisticated method.

The first is that the visual effect of colored buildings depends on the viewing distance and other factors. Since theories on color harmony and contrast showed how size and proportions are some of the main factors that influence the visual perception and identification of color, it is clear that every colorimetric analysis of a given environment is a multiscale work. In the literature (Moughtin et al., 1999), three scales are usually identified: the city scale, the neighborhood one (street or square), and the scale of the building with its details. The colors of the different structural components result in different identities at different scales (e.g., the chromatic identity of a single building can have an impact on a street; however, it may not necessarily have an impact on the entire neighborhood). Due to this reason, color should be analyzed through a multiscale technique (Carmona et al., 2003).

We then introduced scales of perception following (Arrarte-Grau, 2018) and focusing on scales defined as in Tab. 1. Here the architectural scale is at the core, with a 10m. observation distance. The intermediate scales of detail, context and broad context complement the sequence, from 1m to 100m and finally to 1000m respectively.

The information is processed according to the scale of perception: geographical scale (that works for identification and appreciation); broad context (where color allows identification and orientation); immediate context and architectural

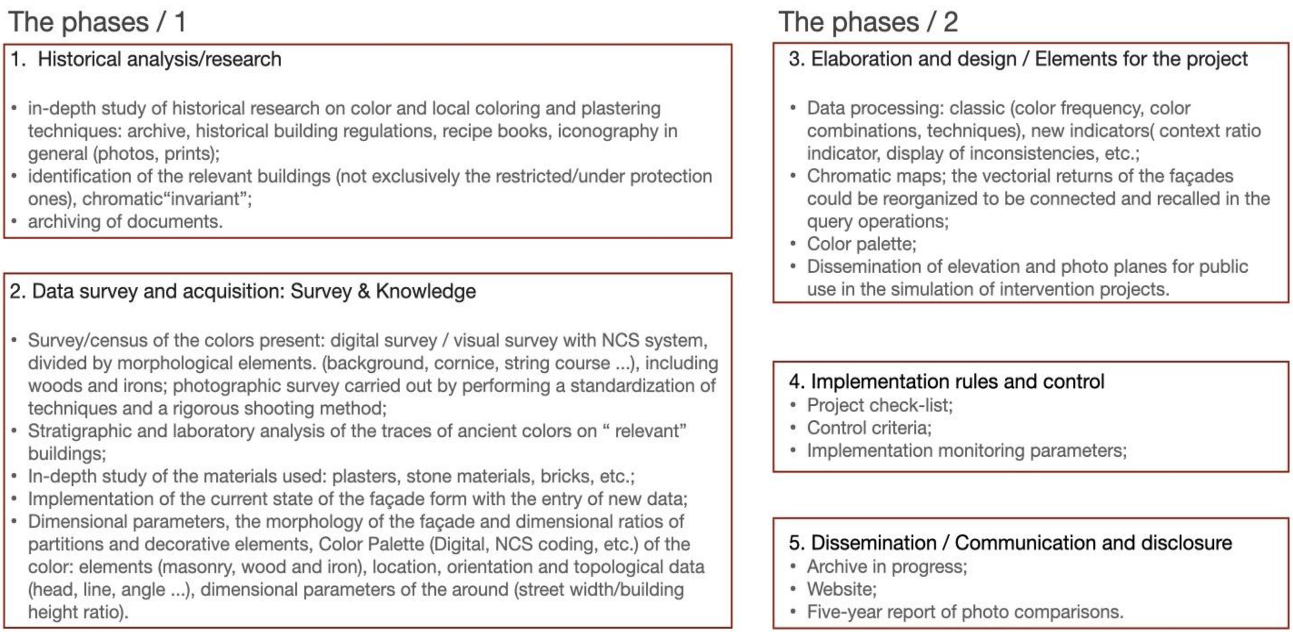


**Fig. 2:** Color-Design methods and phases.

scales (where color has a psychological or symbolic value); material scale.

The second main feature of the developed method is the explicit introduction of the color lightness mapping to explicitly capture differences of brightness and to emphasize features of urban environment where subtle variations of near neutral colors are dominant and/or perceived color changes are based on the illuminant changes. It was developed a specific visualization scale based on the ratio between the current lightness and the white color. This was coupled with a visualization of the hue based on a color wheel. This solution brings a quick and easy understanding of hue and lightness for different objects both at the same and different scales.

A survey card was designed based on the Pantone Matching System (Rhine, 2020), instead of the often-used Munsell color system (Munsell, 1905; Landa & Fairchild, 2005), and Natural Color System (NCS) (Hård et al., 1996). Despite some limitations - since it is mainly a visual reference only and not a color system - the PANTONE presents many advantages as a growing diffusion in many and different related fields, a consistent and easy conversion of captured color in the RGB values, and, specifically, inside the sRGB color space. This allows excellent quickness, usability and shareability among the many users involved in the urban color analysis and design process.

The developed workflow is shown in Fig.3.

## 3. *Techniques introduced*

In the urban color mapping field, many techniques have been developed to get a faithful color detection and reproduction. Today it is possible to refer to three main approaches:

- *Sample visual comparison with color atlas*: this technique is easy to use (De Mattiello & Rabuini, 2011), however, results are highly subjective, relying on the observer's personal visual experience.
- *Diffuse reflectance measurement* with instruments: color is defined using colorimeters, spectrophotometers (which, in addition, provide the curve of the diffuse reflectance as a wavelength function) or telephoto meters (which output the same data of spectrophotometers, but with the possibility to operate at relevant distances from the sample) (Garcia-Codoner et al., 2009). This is the most accurate, simple, and flexible technique today available to measure color, but it requires countless readings in case of non-uniform color (almost always) since measurements cover small areas.
- *Image-based methods* exploiting digital image capturing and processing technologies (Staresinic et al., 2011). These techniques can sample large areas, they are low costs and capable of high accuracy. They have been implemented by analyzing the urban color

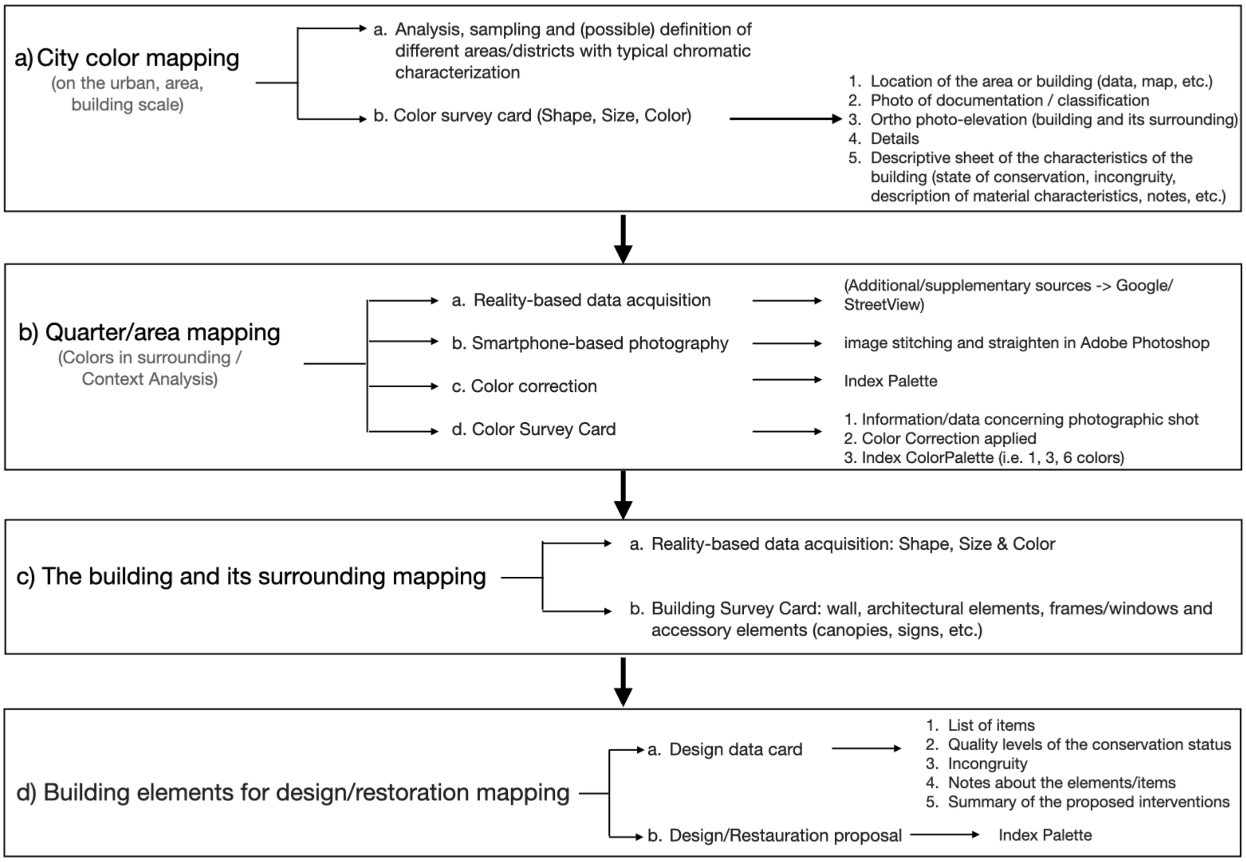


**Fig. 3:** The multiscale workflow.

features based on the dominant colors of digital images taken at sampling sites (Li et al., 2017).

Our workflow follows this last path exploiting digital images captured in RAW file format to ensure the most suitable results. The use of RAW files prevents from the loss of color information, since the digital signals coming from the analog-to-digital conversion of the signal of each photodetector are encoded at least at 10 bits for each sensor pixel, instead of the 8 bits in which the encoding of JPEG format usually takes place, leading to too generic or too specific adjustments given by the pre-sets on the digital camera regarding exposure, white balance, contrast, etc. (Schewe, 2013). Furthermore, the loss of information due to the lossy compression of the JPEG format is avoided. Basically, three techniques were introduced starting from the RAW images:

- color correction of all the images;
- image stitching to produce full elevations of façades and orthographic street views;
- image blur to extract the medium color of façades, coupled with image color indexing to extract color palettes of the dominant colors.

### *3.1 Color correction*

To achieve an accurate color description and reproduction using images, a key point is the determination of chromatic and tonal properties using the device dependent RGB pixel values of the image. However, the spectral responses of the color channels, in general, do not match those of the CIE Standard Colorimetric Observer. Information about the correspondence between the RGB values produced by the camera and the image irradiances is not generally available to users but it is essential for reproduction. The problem consists in recovering a linear relationship between the irradiance values and the pixel encoding produced by the camera, typically non-linear, and it is known as 'color characterization' or 'color correction' (CC). CC techniques aim to find a linear relationship between the irradiance values and the camera pixel encoding introduced by in-camera processing to enhance the visual quality of captured images. The most common CC techniques today in use are the color target-based approaches, as specified by ISO17321 (ISO, 2012). They establish the color relationship according to a set of color patches with available pre-measured spectral or colorimetric data. Target-based CC methods are valid for specific lighting geometry, color target materials, and surface structure.

Despite these problems, target-based CC is appropriate in the urban color analysis field, essentially due to its flexibility and ease of use, granting an accuracy appropriate enough to the need of the urban color design (Gaiani et al., 2021).

It involves a simple capture of an inexpensive, standard color pattern, it is well-rooted in the ICC color management workflows, and it could exploit commercial or open-source software as the Calibrite ColorChecker Camera Calibration (Calibrite, 2021).

We used a CC technique called SHAFT (SAT & HUE Adaptive Fine Tuning) (Gaiani & Ballabeni, 2018), a software for target-based CC developed by our group. The software is designed to minimize possible problems using target-based CC and it is supported by libRAW, a cross-platform open-source RAW image processing program (libRAW, 2021) to which are entrusted the operations of demosaicking, vignetting, and white balance.

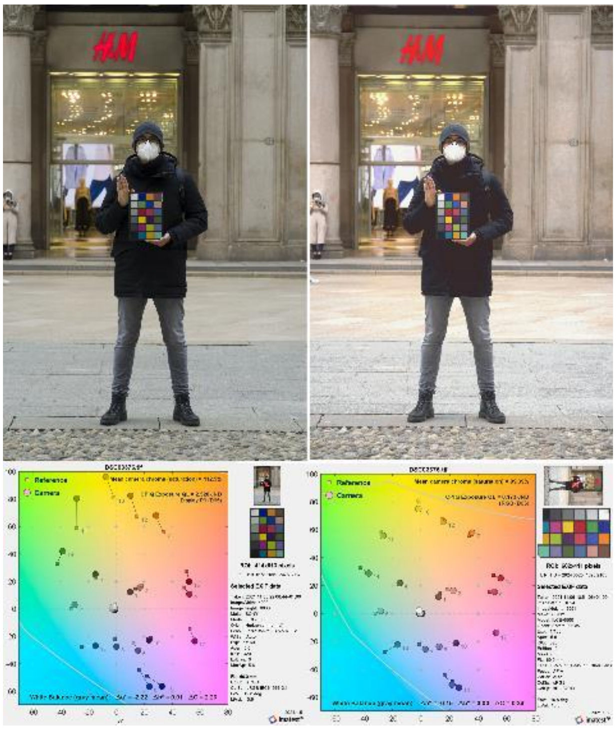

**Fig. 4:** Color corrected images: on the left using a manual correction (error $\Delta E_{00\ mean}$= 11,31); on the right using the SHAFT software (error $\Delta E_{00\ mean}$= 2,04).


**Fig. 5:** The target Calibrite ColorChecker Classic.

SHAFT is based on the CC linear approach by Bruce Fraser, the so-called Adobe Camera Raw (ACR) calibration script for calibration by iterative approximations. SHAFT is completely automated, it exploits previously proposed solutions for the target recognition on the image, and it is written in MATLAB to avoid the use of Adobe Photoshop. To limit the original main problem (i.e., failure of the process for images with high chromaticity) SHAFT is coupled with a polynomial regression correction based on least-squares fitting (Kim et al., 2005).

The SHAFT workflow is based as follows:

- RAW image 16-bit linearization and vignetting
- Image denoise
- Color target detection
- Exposure equalization and white balance
- Polynomial function for CC
- Image CC using the new fitting function
- SHAFT CC
- Image color rendition.

Obviously, SHAFT improves over a traditional 'manual' CC as it is possible to see in Fig. 4 where results of a 'manual' CC against a SHAFT-based CC on two selected images are reported.

The Calibrite ColorChecker Classic (XCC), made of 24 patches with known reflectance (McCamy et al., 1976) was used as a target, (Fig. 5). As rendered color space, was selected the IEC 61966-2-1 sRGB, 100% viewable on the common consumer monitor. Its limited range of colors, narrower than that of human perception is limited in our case because misrepresented colors are rarely found in our case studies (Stokes, et al. 1996).

### 3.2 *Image stitching*

Image stitching is the process of combining multiple photographic images with overlapping fields of view to produce a panorama or a high-resolution image (Eden et al., 2006).

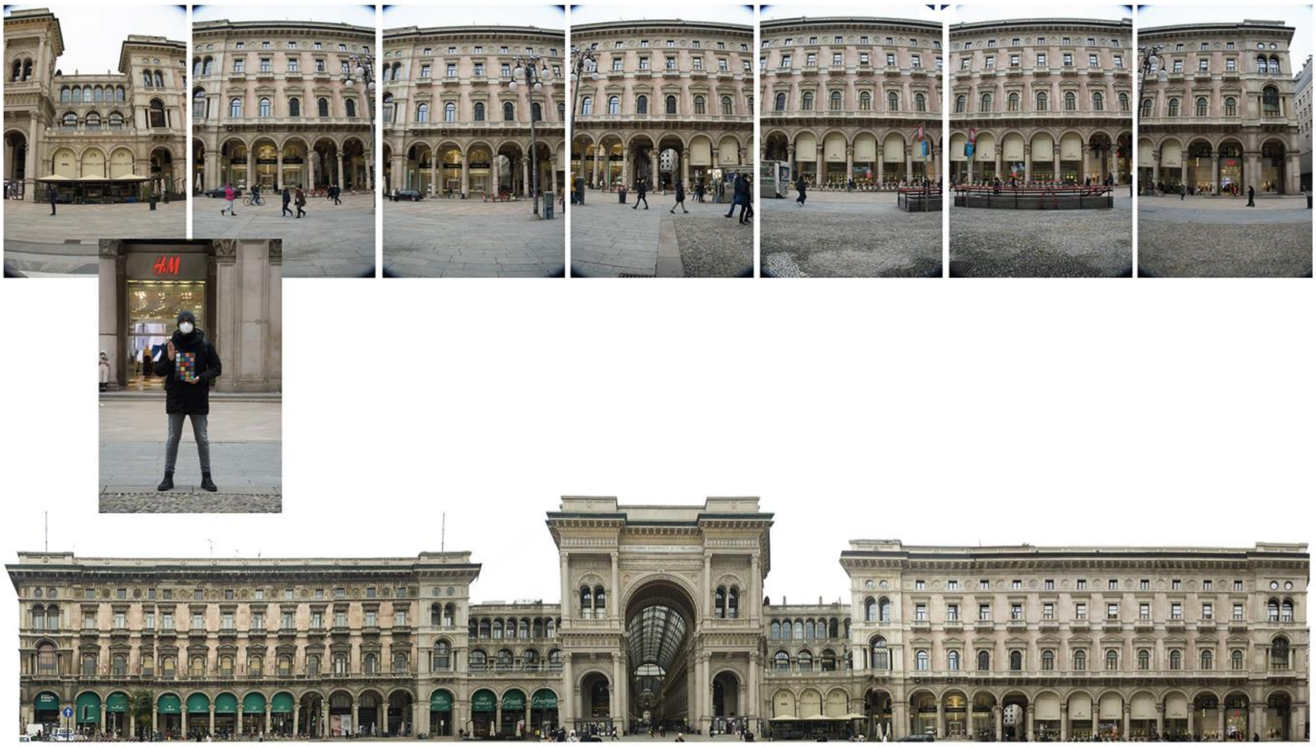


**Fig. 6:** Color corrected image stitching.

It constructs a wide-FOV view from a sequence of images by performing a pipeline consisting of three stages: calibration, registration and blending.

In the first stage, the corresponding relationships between the original images are established by pre-calibrating the intrinsic and extrinsic parameters of the cameras or estimating a motion model based on pixels by calculating the optical flow, per-pixel correspondence, or sparse feature matching. In the second step, the registration among the images is performed. An image plane (e.g., the first image plane or an estimated intermediate plane) is selected and then the registered images are deformed and aligned to the projection plane. Finally, the aligned images are fused together onto a large canvas by blending the same corresponding pixels in the overlapping regions between images and preserving the pixels in the non-overlapping regions.

Most image stitching algorithms hypothesize that the original images are captured by a camera rotating about its optical center (e.g., panoramic stitching), or that the scene is approximately planar. Violating these hypotheses results in inaccurate image registration, misalignment, and ghosting (Lyu et al., 2019; Szeliski, 2007).

Following this workflow, many well-known applications, such as Adobe Photoshop and PTGui (PTGui, 2021), effectively stitch multiple overlapping images to generate a wide-angle view.

We focused on the use of the Photomerge tool in Adobe Photoshop to simplify and speed up the whole process (Adobe, 2021). These stitching tools perform very well on standard datasets and carefully selected images, whereas real datasets stitching frequently fails.

To achieve seamless images, the stitching process requires nearly exact overlaps between images and identical exposures. In our case, we reached identical exposures by the accurate CC introduced (Fig. 6). Moreover, we avoided seams generated by the presence of parallax, lens distortion, scene motion, and light intensity varying across the whole scene (typical of the outdoor case) implementing a variant of the 3D method of image mosaic by Lempitsky and Ivanov (2007).

The issue of failures in the image registration is not relevant in our case, because the hypothesis that the scene is approximately planar is usually consistent (Hartley & Zisserman, 2003). Residual problems can be alleviated using incremental alignments.

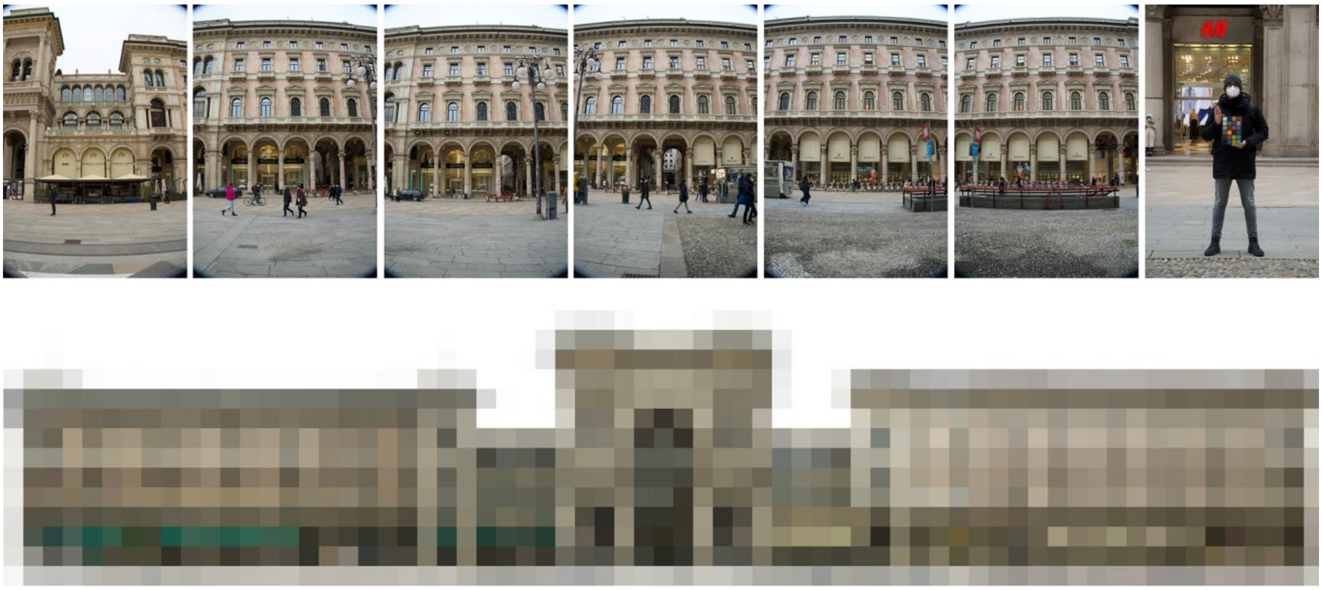

**Fig. 7:** Color-from a blurred image.

### *3.3 Image blur & image color indexing*

The evaluation of the urban façade color at the city scale requires the solution of the selection of the most dominant color problem between the million pixels collected along a street or in a quarter.

Our solution to this issue is based on the use of the dominant color of the urban façade as a color descriptor. The use of the dominant color as a color descriptor is not a new method. E.g., the MPEG standard defined the dominant color descriptor as an effective and intuitive quantification factor for expressing image dominant color attributes (Abdel-Mottaleb & Krishnamachari, 2004).

In the specific field of the urban color mapping, Zena O'Connor (O'Connor, 2006) got the dominant color using manual techniques based on the color picker tool of Adobe Photoshop. A grid was placed over the image, and it was entirely reduced in size by 75%. By reducing it, the color data within each grid segment is reduced via compression algorithms, whereby the color data are mathematically averaged. Each individual color area with each segment was identified and tallied, therefore building a database of color specifications.

Recently Zhong et al. (Zhong et al., 2021) used the urban façade color descriptor automatically extracted from street view images as those presenting the higher percentage of pixels in an image. This approach is used to describe the weighting of the dominant color and each pixel's color information in the urban façade's image area can be expressed as a point in the Hue, Saturation, Value color space. The dominant color of the image is then extracted through K-means clustering analysis of the scattered points in the HSV color space.

We developed a technique like the one developed by O'Connor and similarly exploiting the color picker, but instead of reducing and compressing the image, this is reduced to the 10% of the original size and then blurred using a gaussian blur filter (Getreuer, 2013) (Fig. 7). Finally, colors are indexed in a color palette. Indexed color encodes information not directly carried by the image pixel data but stored in a separate piece of data called a color lookup table (CLUT) or palette, consisting in an array of color specifications. Every element in the array represents a color, indexed by its own position within the array. Each image pixel does not contain the full specification of its color, but its index into the palette only. The palette itself stores a limited number of distinct colors (4 to 256 are the most common cases). For the images representing urban environments, the effective and efficient computation of color indices requires a drastic reduction in the number of colors used to represent the color contents of an image.

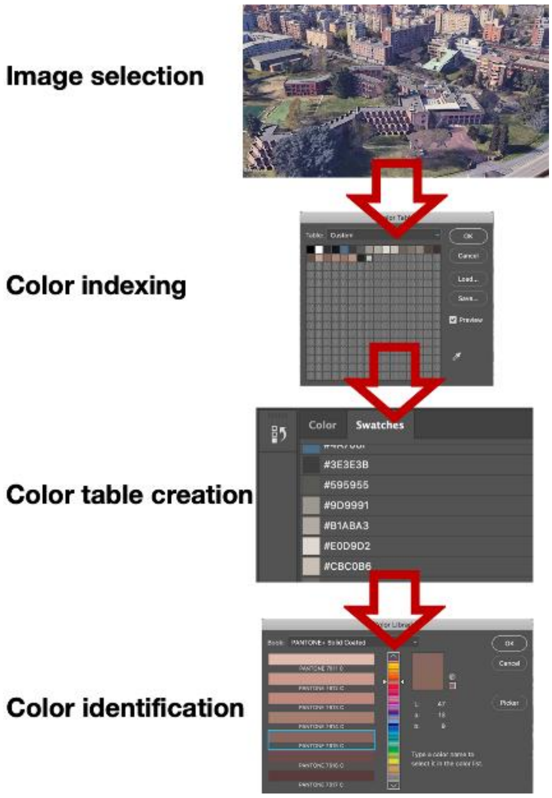


**Fig. 8:** The image color indexing technique to extract a color palette of the dominant colors.

To select a limited set of colors to approximate the image, color quantization techniques exploiting a predefined color palette (static quantization), or by clustering and/or spatial segmentation (dynamic quantization) must be used. In our case, a static quantization was used exploiting the Adobe Photoshop tools achieving a CLUT that stores and records a 24 colors palette representing the colors in the image.

To minimize the problem of a color in the original image that is not appearing in the table, which can generate color banding, and to simulate colors not in the color table as well, we employed a dithering filter, which mixes different-colored pixels in patterns, exploiting the tendency of human vision to blur nearby pixels together, giving a result visually closer to the original one. We used an error-diffusion method that produces a less structured dithering based on an error diffusion method. Once the number of colors has been reduced, many different strategies to represent color distributions can be used (Ciocca et al., 2002). In our case, the selected indexed colors were coded in the PANTONE+ Solid Coated color scale, exploiting the libraries implemented in Photoshop, allowing to identify the color through a well-recognized visual reference (Fig. 8).

## 4. *The Collegio di Milano case study*

Milan, a city in Northern Italy, is the second-most populous city and the largest metropolitan area in Italy. Milan has a historical center with façades presenting near-neutral colors, mainly grey, beige and brick red, well represented by the buildings surrounding the Piazza del Duomo, the hearth of the city.

The Collegio di Milano, designed by the famous Italian architect Marco Zanuso, is in the South part of the city, embedded into an expansion area developed mainly in the 1960-70s, the Barona boroughs near the Sant'Ambrogio Quarter (Fig. 9). In the 1970's – when the Collegio di Milano construction was planned - the zone selected for the site had considerable environmental value: not far from the city center, but, at the same time, facing onto a rural area that had not suffered unbridled urbanization. The Collegio di Milano is a sophisticated construction built in masonry between 1971 and 1974 as a center for assistance to African countries, offering around 100 rooms and shared amenities, into a more than 20,000 square meters wide park. Currently the complex is used as a residence for university students. The neighborhood consists principally of a large social housing estate designed by the architect Arrigo Arrighetti in 1963, shaped with several very long curved buildings that enclose a large central area with public green space.


**Fig. 9:** Plan and aerial view of the Collegio di Milano and the surrounding area (Source of the plan: Schiaffonati et al., 2019).

**Fig. 10:** Two views of the Collegio di Milano (Source: Schiaffonati et al., 2019).

The Zanuso's complex, as the Arrighetti's social estate intent was, somehow tries to keep the memory of a pre-existing landscape made of large farmland, with crops and woodland typical of the countryside. The Collegio di Milano was subject to renovations and additions several times, which partially altered its original design and image. During 2003, the carried-out renovation works involved the construction of accommodation for the professors on the top floor terrace, the construction of an iron and glass roof and the relocation of the caretaker's accommodation. In 2007 an extension was built with a second building designed by Studio Piuarch, echoing the original system planimetrically but with a simplified façade in brick red colored plaster.

Zanuso's building, consisting of two wings connected to a central core, creates a C letter open to the south-west (Fig. 9). The two long three-floor wings lead off from the central core to create a broad irregular courtyard partly open to the south-west that encloses an outdoor meeting space with direct access from the entrance hall.

Along the two wings a modular combination of volumes alternately rotated at a 45° angle gives the building a faceted appearance with each floor set back from the one beneath to open for a balcony module outside each room (Fig. 10).

The outer shell in brick has proved to be the ideal choice in maintaining the performance of the building, as well as the quality of its appearance.

Through research, we found that materials used are mainly brick veneer, plaster, wood, metal for frames and blinds, glasses, and gneiss marble.

Since the whole volume is clean, minimalist, and there is no rain-proof area, today it is possible to notice various degradation phenomena. The brick tiles have begun to fall off at the right-angle junction in the most fragile side; the ceilings of some balconies are leaking; finally, the brick color is dull and uneven due to weathering and time.

## *5. Results*

In Figg. 11-14 the results of our method applied to the case study in the Collegio di Milano are illustrated.

Fig. 11 shows the color mapping related to the Barona area. The surrounding environment of the complex is mainly divided into two tones, one hue distribution is the warm brick red color with blue metal blinds, like the complex, located in the north-east side of the complex (A-D building), typically in the Sant'Ambrogio Quarter area.

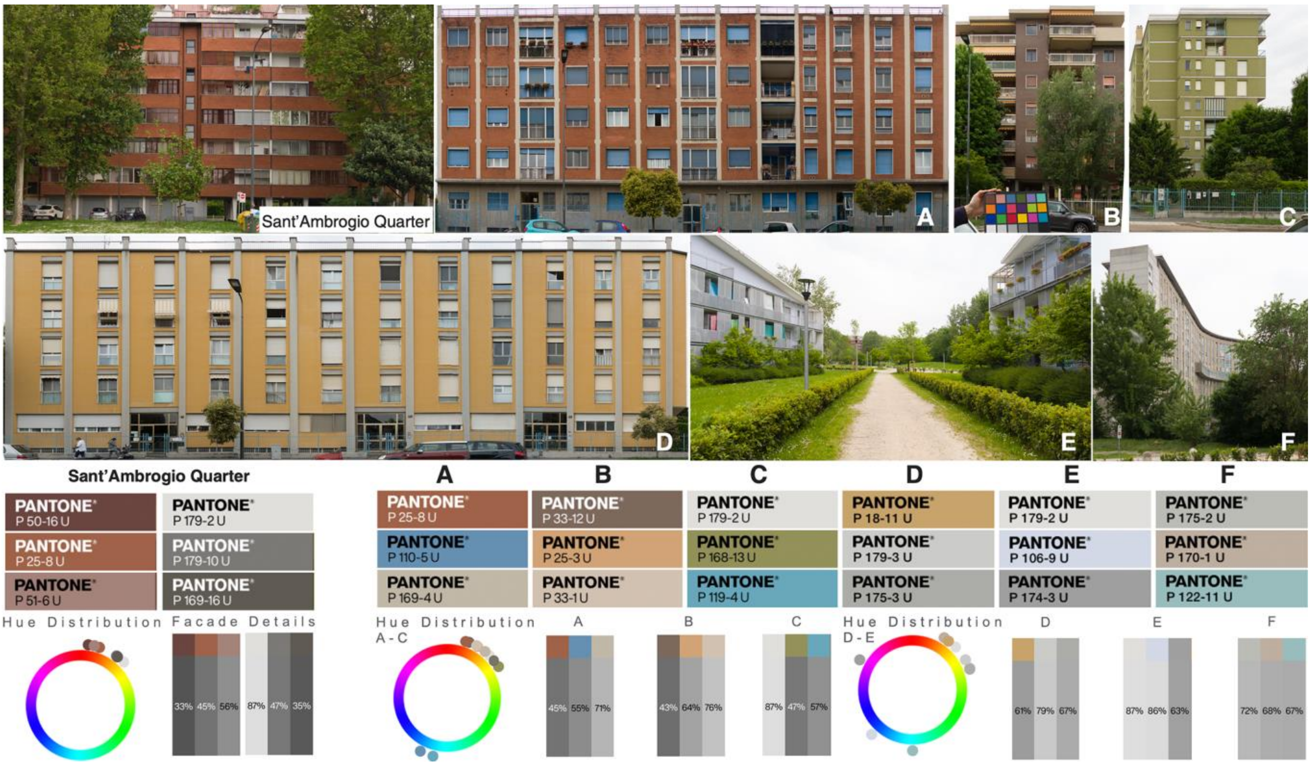


**Fig. 11:** Urban environmental color of the Barona area.

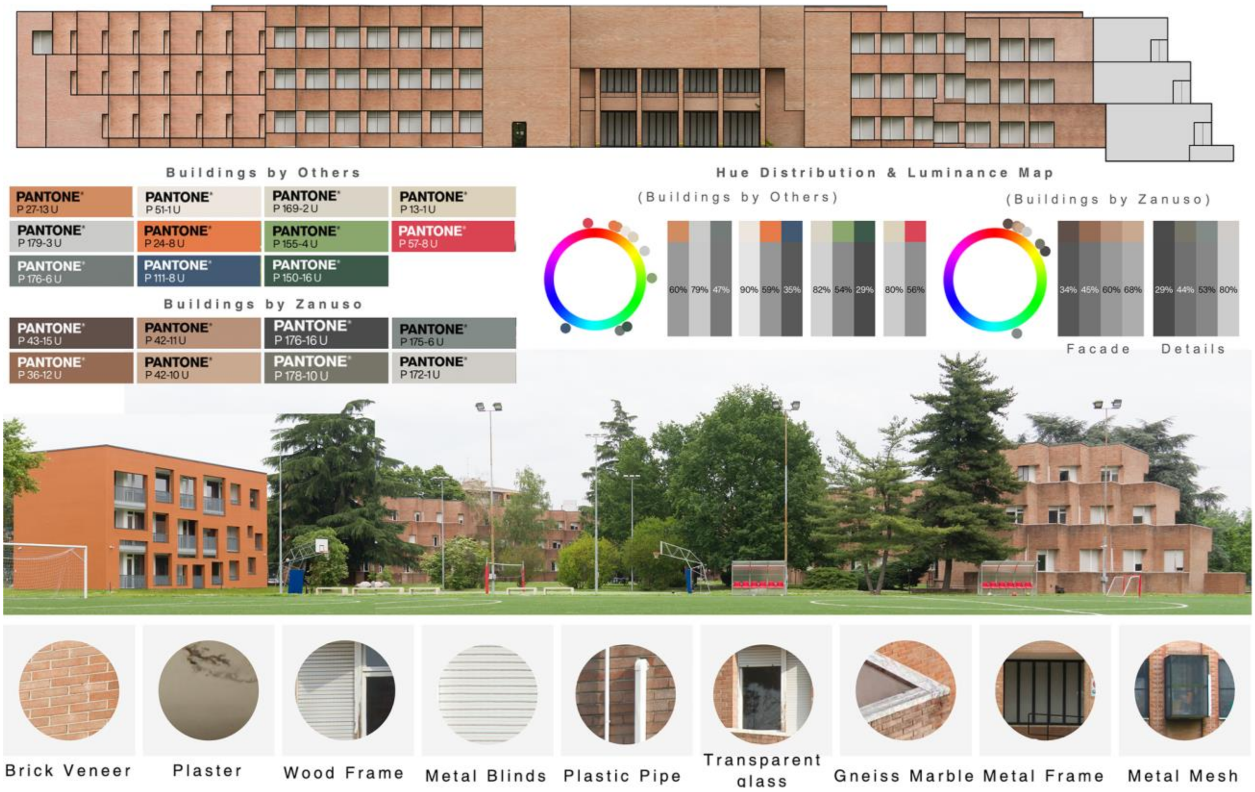


**Fig. 12:** Urban environmental color of Collegio di Milano.

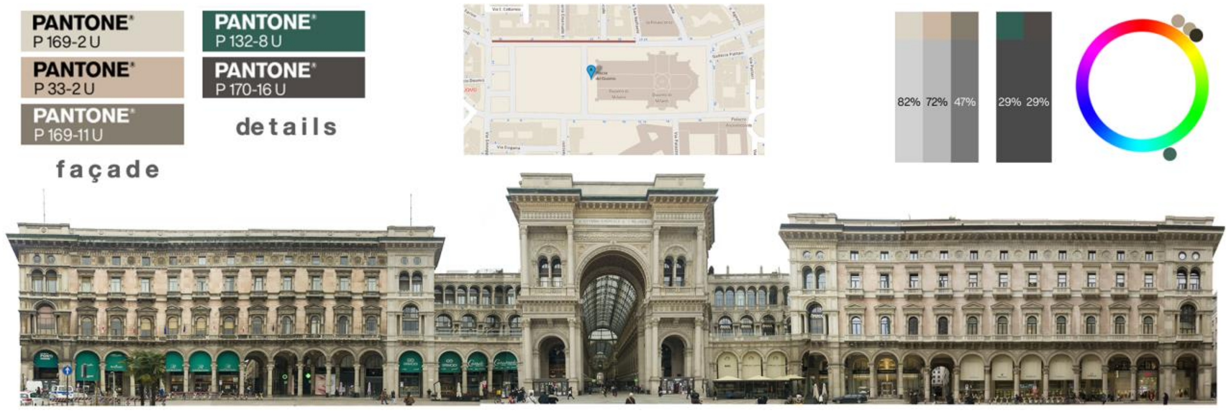


**Fig. 13:** Urban environmental color of buildings surrounding the Galleria Vittorio Emanuele in Piazza Duomo.

Another typical hue is the grey and yellow of the building on the west side of the complex, with San Paolo Hospital as the center. An overall rule is the lightness distribution of the warm color that ranges from 33% to 45%. The lightness distribution of light plaster decoration ranges from 71% to 87%. The lightness distribution of the blue and yellow façade ranges from 55% to 67%.

In Fig. 12 is the color mapping of the Collegio di Milano buildings and material details. The perceived color imagery of the Collegio landscape tend toward a clear tone (flat and harmonious). The color of the architecture complex's façade is in red burnt brick with an overall lightness distribution range 60%-68%. In the right-angle junction of most balconies, the color becomes dull, the lightness distribution ranges 34%-45%. The red, blue fitness equipment, and the green lawn present a triad of colors, which also give hue and contrast.

Fig. 13 shows the colors and the value of the urban environmental color of buildings

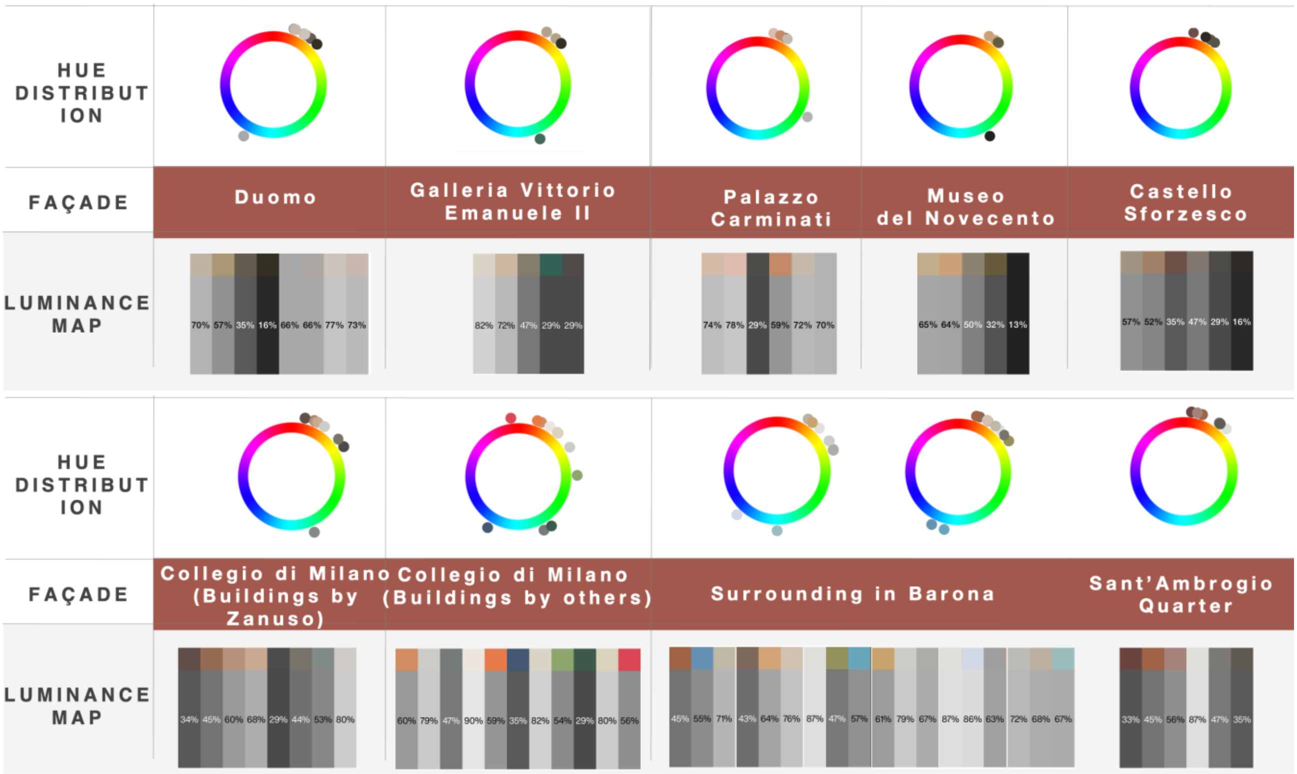


**Fig. 14**: Hue and lightness maps of the colors of Piazza del Duomo (top) and Collegio di Milano with its surroundings (bottom).

surrounding the Galleria Vittorio Emanuele in Piazza Duomo, selected as a reference for the historical center. Hue distribution in Piazza del Duomo Milan's façade is generally based on orangish or pinkish grey. The colors of these plasters, well representing the urban colors of Milan, are in harmony with the entire environment. About the luminance map, excluding the influence of external decoration, door openings, and window shadows, the index of the luminance map is mostly kept at about 60%-75%.

Fig. 14 shows the measurements of lightness and hue of Collegio di Milano complex and Piazza Duomo façades allowing us to quickly understand the mood of different urban environments. Due to the color guidance based on the landscape regulation in Milan, almost all the hue distribution of façade almost are the same.

In the upper right corner, the nuance is slightly different in each hue of the façade, with a wider range of yellows rather than reds, except for a few temporary decorations, which are in the opposite position of the hue circle, and even more restricted use of blue, greens hues are rare. This is in line with the analysis of each case (Figg. 11-13), where we have found links between specific hues and nuances to buildings' material, paint properties, texture, volume, and constructive details.

## *6. Conclusions*

Urban colors mapping is a multidimensional process where a main role is played by multi-scale presence of perception and material.

In this paper, we introduced a method to objectively consider this multidimensionality introducing multiscale analysis techniques, the concept of dominant color to map the color at the urban scale.

Finally, a technique to analyze both hue and lightness of a color and to use comparative analysis methods was developed and illustrated.

These developed methods and techniques were applied to the analysis of the Collegio di Milano case study demonstrating their effectivity.

We hope that the proposed method to measure the urban color will contribute to a more accurate evaluation of it, so that it will facilitate planning and design activities.

REFERENCES


Abdel-Mottaleb, M., & Krishnamachari, S. (2004). Multimedia descriptions based on MPEG-7: Extraction and applications. *IEEE Trans. Multimed.*, 6, 459-468. doi: 10.1109/TMM.2004.827500.

Adobe. (2021). Create panoramic images with photomerge. Retrieved from https://helpx.adobe.com/in/photoshop/using/create-panoramic-images-photomerge.html (Accessed November 8, 2021).

Arrarte-Grau, M. (2018). The scales of color perception in architecture. In *Proceedings of the International Colour Association (AIC) Conference 2018*, (pp. 71-76). Lisbon, Portugal: International Colour Association Incorporated.

Calibrite. (2021). Retrieved from https://calibrite.com/it/product/ (Accessed November 8, 2021).

Carmona, M., Heath, T., Oc, T., & Tiesdell, S. (2003). *Public Places-Urban Spaces: The Dimensions of Urban Design.* Oxford: Architectural Press.

Ciocca, G., Schettini, R., & Zuffi, S. (2002). A survey on methods for colour image indexing and retrieval in image databases. In M. Ronnier Luo & L. MacDonald (Eds.), *Colour Image Science: Exploiting Digital Media* (pp. 87-105), Hoboken, NJ, USA: John Wiley & Sons, Inc.

De Mattiello, M.L.F., & Rabuini, E. (2011). Colours in La Boca: Patrimonial Identity in the Urban Landscape. *Color Res. Appl.*, 36(3), 222–228. doi: 10.1002/col.20612.

Eden, A., Uyttendaele, M. & Szeliski R. (2006). Seamless Image Stitching of Scenes with Large Motions and Exposure Differences. In *2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'06)*, (pp. 2498-2505). Los Alamitos, USA: IEEE Computer Society Press.

Gaiani, M., & Ballabeni, A. (2018). SHAFT (SAT & HUE Adaptive Fine Tuning), a new automated solution for target-based color correction. In V. Marchiafava, & L. Luzzatto (Eds.), *Colour and Colorimetry Multidisciplinary Contributions*, XIVB, 69-80.

Gaiani, M., Apollonio, F.I., & Ballabeni, A. (2021). Cultural and architectural heritage conservation and restoration: which colour? *Coloration Technology*, 137(1), 44-55. doi: 10.1111/cote.12499

Garcia-Codoner, A., Verdu, J.L., Barchino, A.T., Guillen, R.V., & Lluch, J.S. (2009). Colour as a Structural Variable of Historical Urban Form. *Color Res. Appl.*, 34, 253-265. doi: 10.1002/col.20491.

Getreuer, P. (2013) A Survey of Gaussian Convolution Algorithms. *Image Processing On Line*, 3, 286–310. doi: 10.5201/ipol.2013.87.

Hård, A., Sivik, L. & Tonnquist, G. (1996) NCS Natural Color System - from Concepts to Research and Applications. Part I and II. *Color Res. Appl.*, 21, 180–220. doi: 10.1002/(SICI)1520-6378(199606)21:3 <180:AID-COL2>3.0.CO;2-O.

Hartley, R., & Zisserman, A. (2003). *Multiple view geometry in computer vision*. Cambridge, UK: Cambridge University Press. doi: 10.1017/CBO9780511811685.

Kim, E.-S., Lee, S.-H., Jang, S.-W., & Sohng, K.-I. (2005). Adaptive colorimetric characterization of camera for the variation of white balance. *IEICE Trans. on Electronics*, E88-C(11), 2086-2089. doi: 10.1093/ietele/e88-c.11.2086.

Iijima, S. (1997). Cross-cultural color differences of commercial facility between Great Britain and Japan. *Bulletin of Okayama Marketing University*, 33(2), 39-51.

International Organization for Standardization - ISO (2012). *ISO17321-1. Graphic technology and photography - Colour characterisation of digital still cameras (DSCs).*

Landa, E.R., & Fairchild, M.D. (2005). Charting Color from the Eye of the Beholder. *American Scientist*, 93(5), 436-443. doi: 10.1511/2005.5.436.

Lempitsky, V., & Ivanov, D. (2007). Seamless Mosaicing of Image-Based Texture Maps. In *2007 IEEE Conference on Computer Vision and Pattern Recognition.* Los Alamitos: IEEE, 1-6. doi: 10.1109/CVPR.2007.383078.

Lenclos, J.P. (1989). *The Geography of Color*. Tokyo, Japan: San'ei Shobo Publishing Co.

Lenclos, J.P., & Lenclos, D. (1982). *Les couleurs de la France: Maisons et paysages*, preface by Georges Henri Rivière. Paris, France: Éditions du Moniteur.

Li, M., Xu, J.G., & Zhang, X. (2017). Spatial-Sensitivity Analysis for Urban Color Planning: Study of Luoyang City, China. *J. Urban Plan. Dev*., 143(1), 05016014. doi: 10.1061/(ASCE)UP.1943-5444.0000345.

LibRAW. (2021). Retrieved from https://www.libraw.org/ (Accessed November 8, 2021).

Lyu, W., Zhou, Z., Chen, L., & Zhou, Y. (2019). A survey on image and video stitching. *Virtual Reality & Intelligent Hardware*, 1(1), 55-83. doi: 10.3724/SP.J.2096-5796.2018.0008.

McCamy, C. S., Marcus, H., & Davidson, J. G. (1976). A Color Rendition Chart. *J. Appl. Phot. Eng.* 11(3), 95-99.

Moughtin, C., Oc, T., & Tiesdell, S. (1999). *Urban Design: Ornament and Decoration*. Second edition. Oxford, Woburn, USA: Architectural Press.

Munsell, A.H. (1905) *A Color Notation*. Boston, USA: G.H. Ellis Co.

O'Connor, Z. (2006). Environmental colour mapping using digital technology: a case study. *Urban Design International,* 11, 21–28. doi: 10.1057/palgrave.udi.9000161

Porter, T. (1997). Environmental colour mapping. *Urban Design International*, 2 (1), 23-31. doi: 10.1057/udi.1997.4

PTGui. (2021). Retrieved from https://www.ptgui.com/ (Accessed November 8, 2021).

Rhyne, T.-M. (2020). Color basics for digital media and visualization. In *ACM SIGGRAPH 2020 Courses*. New York: ACM, Article 4, 1–78. doi: 10.1145/3388769.3407478

Schiaffonati, F., Majocchi, A. & Castaldo, G. (2019). *Designing Dwelling, The architecture of the Collegio di Milano*. Milano, Italia: Skira.

Schewe, J. (2013). *The Digital Negative: Raw Image Processing in Lightroom, Camera Raw, and Photoshop*. Berkeley, CA, USA: Peachpit Press.

Staresinic, M., Simoncic, B., & Bracko, S. (2011). Using a Digital Camera to Identify Colors in Urban Environments. *J. Imaging Sci. Technol*., 55, 060201.

Stokes, M., Anderson, M., Chandrasekar, S., & Motta, R. (1996). *A Standard Default Color Space for the Internet - sRGB*. Retrieved from http://www.w3.org/Graphics/Color/sRGB.

Szeliski, R. (2007). Image alignment and stitching: A tutorial. *Foundations and Trends in Computer Graphics and Vision,* 2(1), 1-104. doi: 10.1561/0600000009.

Westland, S., Laycock, K., Cheung, V., Henry, P., & Mahyar, F. (2007). Colour Harmony. *Journal of the International Colour Association*, 1, 1-15.

Zhong, T., Ye, C., Wang, Z., Tang, G., Zhang, W., & Ye, Y. (2021). City-Scale Mapping of Urban Façade Color Using Street-View Imagery. *Remote Sensing*, *13*(8), 1591. MDPI AG. doi: 10.3390/rs13081591.