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A DIGITAL IMAGE PROCESSING METHOD FOR URBAN SCENES BRIGHTNESS ASSESSMENT

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Abstract

The appearance of the city is strongly linked to many aspects such as climate, culture and sociological background. In cities with a prevalence of clear skies, one of the determining aspects is the climatic condition, which defines a luminous context where all elements appear significantly bright. In order to establish the luminosity of the urban scene and its components, an analysis of pictures taken in real environments is proposed, carried out through a digital image processing software developed by the authors. The information contained in each pixel of a digital image is used to assess the distribution of light in the picture. The pictures selected for assessment represent an urban scene as seen by a standing observer. In this situation the scene can be divided in three zones with similar features: pavement, sky and façades. The developed software provides output information for the aforementioned zones and the whole image consisting on light data (average, maximum, minimum and standard deviation) convertible to luminance (cd/m^2) if reference values are provided. The validity of the procedure is tested in this work and implemented in real pictures. After testing it, the software has proven to be easy to use and the results obtained in the examples have shown a trend in their values. The implementation of the software suggests that a wider number of cases of study would make possible to establish a pattern in the daylight distribution of urban scenes conceived as an addition of zones with different luminous appearance.

1. Introduction

In the last centuries, cities have gathered must of the population in the world, and this number is growing year after year. Factors such as economy, security and culture lead people to live in urban crowds, and cities have become the everyday landscape for people. The magnitude of

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cities is usually measured in terms of population, density, soil occupation and other dimensional parameters; but cities can also be described with numbers based on other criteria: climate data, mobility, economy, etc. The combination of these and other magnitudes have impact on the life of people since it significantly affects their quality of life. Despite the diversity of parameters, a city can be defined in quantitative and qualitative terms. The last aspect is highly connected to the image provided, which gives identity, structure and meaning to the city. It is determined by mental maps formed by elements such as paths, edges, districts, nodes and landmarks, as defined by Kevin Lynch in his work (Lynch, 1960). The first element, paths, plays an important role in ordering the whole, since it is one of the main elements which give identity and continuity to the city.

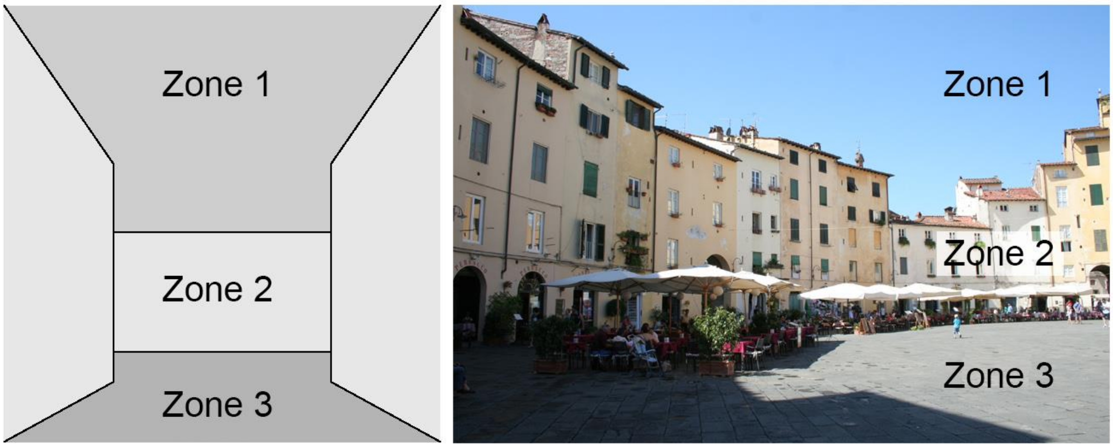
One of the qualitative aspects that characterize the city and its paths is the luminous appearance of urban scenes. It affects users' quality of vision when moving along the city because it becomes an important source of contrast in specific situations, especially under sunlight. It is noticeable in latitudes with high solar incidence due to the vertical position of sun and a favourable climate condition (Baker *et al*., 1993). The presence of daylight is generally perceived as a positive aspect because it implies health advantages for people (Lam, 1986) and at the same time it offers a valuable cue for estimating information about time, season and weather conditions of a place (Granzier and Valsecchi, 2014). The high intensity of solar radiation represents an appropriate situation for solar access in cities (Curreli and Coch. 2013) but at the same time it can generate visual contrast. As a consequence, people moving along the city have to cope with extreme luminance values within their visual field simultaneously and when passing from a bright scene to a darker one (Lopez-Besora *et al.*, 2016), which affects both visual comfort and performance. To deal with this subject, the present work is focused in two aspects: the characteristics of the urban scene and the brightness assessment.

1.1 The urban scene

The urban scene is here the framework used to assess visual contrast caused by brightness in cities. It is considered that contrast can be produced within a single scene or through a series of different brightness scenes. In the case of cities, the urban scene is defined by two aspects: urban space and field of vision. It comprises what is seen by users, standing moving observers which field of vision frames an outlined part of the urban landscape. Geometry is the basis of urban scenes definition, provided that they depend on both urban configuration and the limits of the human visual field.

The first variable is basically geometrical and it comprises the dimensional characteristics of the urban fabric. As for vision along streets, dimensional values which are not perceived by pedestrians are not considered for the analysis. In that sense, the most used quantitative parameter, density, can be defined in several ways (Alexander *et al.*, 1993) but it can be perceived in a different way depending on aspects such as building articulation, façade area or type of dwellings (Bergdoll and Williams, 1990; Zacharias and Stamps, 2004) and it often gives scarce information about the appearance of the city (Berghauser Pont and Haupt, 2010). Some authors set out the difference between physical and perceived density (Rapoport, 1975; Cheng, 2009) as a theory for urban definition based on density (Morganti *et al.*, 2012), even though they are not necessarily coincident. Nevertheless, other parameters such as the urban canyon (Strømann-Andersen *et al.*, 2011) are more appropriate to understand the appearance of the city since it is considered that the dimension of the urban canyon bears a closer connection with the perception of density experienced by pedestrians. This value is expressed by the relation between the wide of the street and the height of buildings. From that relation it can be deduced that horizontal and vertical surfaces (pavements and façades) configure two groups of elements or zones with similar features that share importance in street view scenes. The vision of these zones depends on the dimension of the street and buildings, as said above. However, another zone completes the urban scene and has to be considered, the sky vault. As a consequence, pedestrians' vision of the city is configured by a zone at the bottom occupied by the pavement (Zone 1), another zone in the middle of the scene with building façades (Zone 2), and another zone at the top with the sky (Zone 3), as shown in Figure 1. Depending on the dimension of the urban canyon, the proportion of each zone will be different. Besides the position and proportion of the different zones, it has to be noted that materials also play an important role in outdoor visual comfort (Rosso *et al.*, 2015) and the appearance of the city.

Figure 1. **Three zones division of urban scenes**

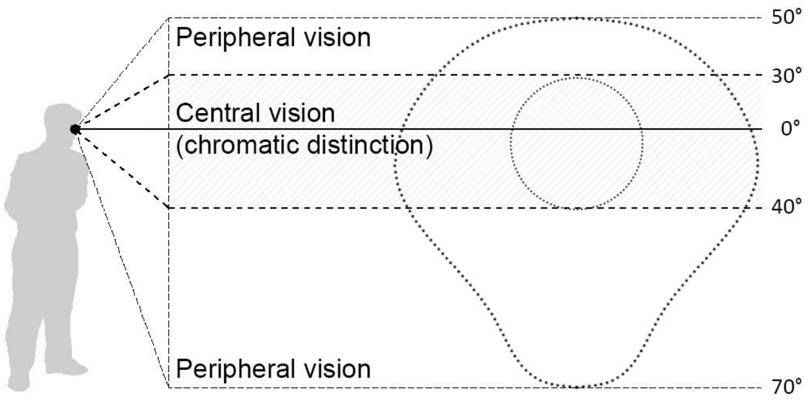


Source: authors. Self-elaboration of the results

The second variable is the human vision field. In normal conditions, the field of vision comprises almost everything located in front of the observer, with a small zone of precise vision at the centre coincident with the point of focus, and a peripheral area with different degree of sensitivity. The different sensitivity zones and the limits of the field are defined by angles depicted in two planes, horizontal and vertical (Panero and Zelnik. 2007).

These angles frame the visual scene and configure the vision of the city experienced by static pedestrians. However, urban visual scenes for moving observers are mainly defined for the upper and lower limits of the field, provided that the movement of walking observers is produced in a horizontal plane. As a consequence, the definition of lateral limits in urban visual scenes makes little sense, because they change constantly unlike the upper and lower ones, which remain almost unchanged (Figure 2).

Figure 2**. Visual field of moving observers**



Source: authors. Self-elaboration of the results

The combination of three zones division defined above (pavements, façades and sky) along with the visual field makes possible the definition of urban visual scenes in terms of geometry and visual sensitivity. In that sense, only the zone of the visual field where chromatic distinction is possible has been considered for the study: 30° to the top and 40° to the bottom (Panero and Zelnik. 2007), as shown in Figure 2.

For all said above, the urban scene is configured by three zones which vision is outlined by the limits of the visual field. This is a definition valid for any urban scene, even though depending on the context, the proportion of each zone can be different. Apart from this, the context also determines the luminosity of each zone, among other factors such as daylight availability (Compagnon, 2004) and materials (Rosso *et al.*, 2015). In this study, it is assumed that the defined zones (pavements, façades and sky) can be separately described in terms of brightness because each of them can be considered uniform on average. As a consequence, the assessment of urban scenes appears as an addition of weighted zones in terms of luminance and proportion in the field of vision.

1.2 Brightness and luminance

The combination of zones with different luminance in a visual scene can result in a source of contrast. The human visual system has a capacity of adaptation to a wide range of luminance values from very low to high values (10^{-7} - 10^{6} cd/m^2), and once adapted, the eye can cope with a luminance range of 1:1.000 (Jacobs, 2004). But if these values are located in the same scene or consecutive scenes with a little time interval between them, an excessive contrast can be produced. Besides, the same value of luminance is perceived in a different way depending on the surrounding values, as a consequence of simultaneous contrast. Here lies the difference between luminance and brightness: while luminance is referred to a physical value, brightness is the used term to express the sensation perceived by the observer, affected by aspects such as simultaneity.

Brightness in urban scenes is very important because the composition of the image can cause contrast in the same scene or between different ones. In environments with direct sunlight, surfaces show a shaded and a sunlit area with a large luminance difference, causing a strong contrast. In addition, when passing from a shaded street to a sunny one or from the exterior to the interior of a building, the consequence regarding contrast is similar (Lopez-Besora *et al.*, 2016). If average values of luminance are attributed to pavements, façades and sky, it seems possible to establish the visual appearance of the urban scene in terms of brightness.

The proposed method of brightness assessment in street view situations precisely tackles the distribution of different brightness surfaces within observers' visual field. Digital images physically represent this framework and at the same time contain valuable light information in their pixels. The combination of these two factors makes the analysis of digital images an efficient tool to assess the appearance of urban scenes as seen by pedestrians.

2. Methodology

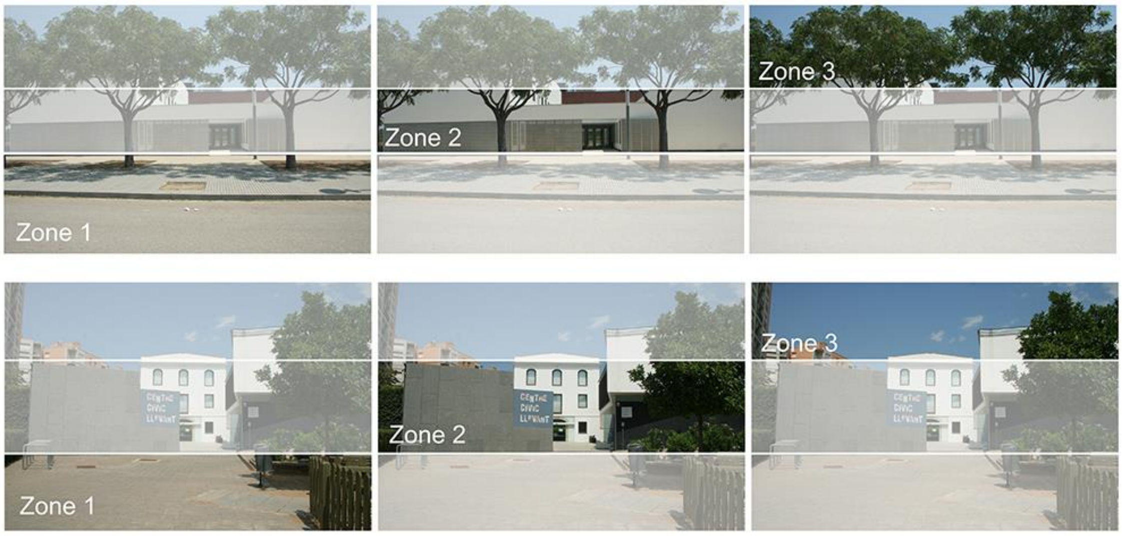
The aim of the study was the weighting in terms of light of a different zones urban scene. The existing procedures of image processing such as HDR (Howlett *et al.,* 2007; Inanici, 2010; Thanachareonkit *et al.,* 2011) and other image based methodologies (Demers, 2006; Inanici, 2006) provide information about the composition, distribution and values of light in a defined context. All of them conceive the image as a whole, offering a map of light distribution in the picture translated to luminance or lightness data. However, the introduction of the three zones division and the description of each zone in terms of luminance were considered more interesting for this specific analysis. It led to the conception of an assessment methodology consisting of an image processing software developed by the authors, in which the information on the luminosity is obtained in the defined zones from digital images and few input data. The source is BMP images coming from chosen environments and subsequently processed by the software. In the following sections, the procedure is thoroughly detailed.

2.1 Choice of representative images for processing

The depiction of the urban scene is performed by the choice of images taken with this specific purpose. Although the analysed pictures do not require complex technical requirements, some considerations must be taken into account before starting the process.

As for the content, it is preferable to choose places with a clear distinction among the aforementioned Zones 1 – 3: pavement, façades and sky. This distinction will be better analysed if it is depicted in horizontal stripes, just to replicate them later in the image with a horizontal pixel division. The best situation to reproduce this division is the frontal vision of buildings, that is to say perpendicular to the main direction of the street. As an example, images I.1 and I.2 (Figure 3) show the three zones distinction defined above in two cases of study; they were chosen for their simplicity and the ease of distinguishing the zones. The pictures were taken with the intention of analysing the whole image and their corresponding sky, façades and pavement areas. As for the mentioned zones, the division can be easily made in the selected pictures, even though some elements interfere and dilute the boundaries between areas. Despite this, the analysis of real situations serves as a test for the image processing procedure.

Figure 3. **Three zones division in images I.1 and I.2**



Source: authors. Self-elaboration of the results

It is important that the images represent urban scenes in an outdoor scenario clearly recognisable. In that sense, the MIT image scenes recognition procedure[2] analyses a given image in an online application and makes a prediction about the type of environment, semantic categories and sun scene attributes. This procedure was carried out with pictures I.1 and I.2, and the results provided a recurrent definition of outdoor environments with sun scene attributes of natural light, open area, pavement, trees, asphalt, direct sun and no horizon, characteristic of urban environments.

Once the location is decided and prior to taking the pictures, some technical requirements have to be considered; these requirements are not mandatory but advisable. The focal length of pictures should be short in order to expand the vision of the environment and reproduce as well as possible the visual scene. A focal length between 18 and 35 mm is recommended. Other parameters such as shutter speed, lens aperture and ISO speed depend on the light characteristics of the environment, and do not interfere in the results of the image processing. In the examples of images I.1 and I.2 (Table 1), the photometric parameters were suggested by the camera for an ISO speed 200 and a focal length of 18 mm (the pictures were taken with a digital camera Canon EOS 350D).

Table 1**. Photometric parameters of images I.1 and I.2**

	Focal length	**Shutter speed**	**Aperture**	**ISO**
Image I.1	18 mm	1/320	f/11	200
Image I.2	18 mm	1/400	f/11	200

Source: authors. Self-elaboration of the results

[2] http://places.csail.mit.edu/demo.html

For all said above, it can be deduced that any standard digital image can be used for processing as long as the framing includes the zones of the urban scene in a frontal view.

2.2 Processing software and input data

Using images from real environments was intended for brightness assessment in urban scenes as a whole and its zones separately. With this purpose in mind, the authors developed a software which extracts light data from the pixels within an image. In broad terms, it converts RGB information of each pixel in a number comparable to its luminosity. The software considers a range of luminosity from 0 to 765, where 0 corresponds to no luminosity (black) and 765 is the addition of the maximum value of red, green and blue (255 x 3). After the analysis of every single pixel, the software provides comprehensive information about the image composition in terms of luminosity. The software performs this operation for the whole image and for specific parts previously defined by the user.

Images must be located in the same folder of the software and converted to a BMP format. Then, the user can run it and follow the instructions. The software is able to recognise the resolution of the image (in pixels) but the mentioned three zones division is required; that is, the number of pixels of each horizontal division counted from the bottom of the image. This division reproduces the horizontal bands corresponding to pavement, façades and sky zones (Zones 1 – 3). In the cases of study, images I.1 and I.2 had a resolution of 3456 x 2304 pixels, and the division of each zone is shown in Table 2.

Table 2. **Horizontal pixel division of images I.1 and I.2**

	First *y* division	**Second *y* division**
Image I.1	924	1.521
Image I.2	711	1.564

Source: authors. Self-elaboration of the results

If no other input is provided, the software converts the RGB information of each pixel in unitless light data. However, if luminance measurements are carried out at the same time the pictures were taken, this information can be used as a reference to turn the output data into cd/m^2 units. If it is the case, the software asks for the coordinates of a reference pixel (x, y) as well as its luminance value in cd/m^2. Table 3 shows the position and luminance value of the reference pixel in images I.1 and I.2.

Table 3. **Position and reference luminance of images I.1 and I.2**

	Ref. pixel coordinates (x, y)	**Reference luminance (cd/m^2)**
Image I.1	(2.048, 881)	13.460
Image I.2	(1.827, 1194)	15.900

Source: authors. Self-elaboration of the results

In the cases of study, the reference luminance value was measured at the same time the pictures were taken. In both cases a point located in a surface with uniform colour and texture was chosen in order to easily identify it in the picture.

2.3 Output data

After introducing the input data and running the software, the system generates a *.dat* file with the information extracted from the image. It is presented as text, and the information provided corresponds to the whole image and the zones defined by the user in the input data. The output file provides the dimensions of the picture, the position of the pixel division, the coordinates of the calibration point along with the reference luminance, and the number of pixels contained in each zone defined by the division. After this synthesis of information about the picture, light data is provided. First, the values for the whole image of these parameters: average luminance (in cd/m^2 and 0-765); standard deviation (in cd/m^2 and 0-765); maximum and minimum luminance (in cd/m^2 and 0-765). Then, the same light data is given for Zones 1 – 3 (average luminance, standard deviation, maximum and minimum luminance). The software also calculates de ratio between standard deviation and average value for each zone of the visual scene.

3. Results and Discussion

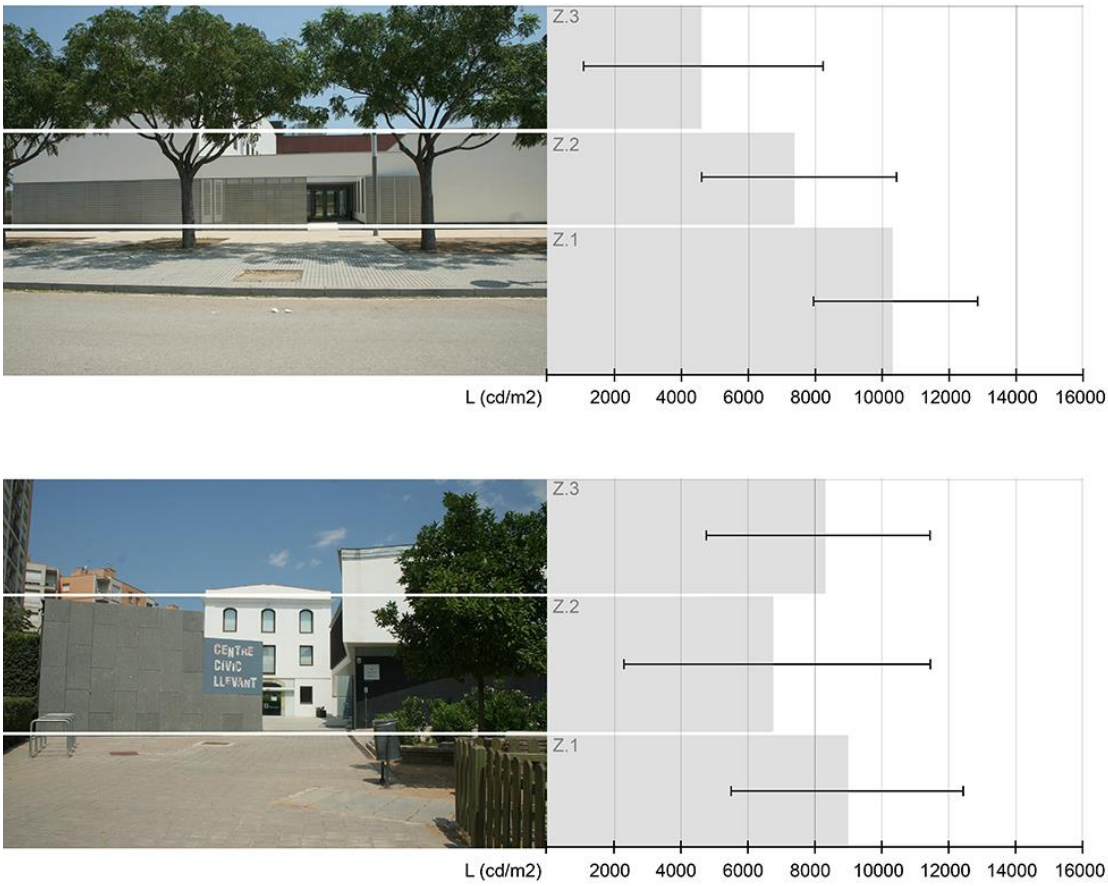
After the implementation of the software in Images I.1 and I.2, a list of results is obtained. The *.dat* file provides light data in a 0-765 scale and luminance values for Zones 1 – 3, as said above. The results are organized in Table 4, only with luminance values, and are graphically shown in Figure 4.

Table 4. **Luminance output data**

		Average luminance (cd/m^2)	**Standard deviation (cd/m^2)**	**L max (cd/m^2)**	**L min (cd/m^2)**
Image I.1	Zone 1	10.246,6	2.248,9	16.501,4	1.445,2
	Zone 2	7.544,3	2.983,6	15.315,0	539,2
	Zone 3	4.631,4	3.462,5	15.056,2	301,9
	Total image	7.638,1	3.819,6	16.501,4	301,9
Image I.2	Zone 1	8.945,2	3.345,9	15.372,8	167,1
	Zone 2	6.766,9	4.649,9	18.263,5	119,3
	Zone 3	8.189,1	3.397,4	17.260,8	143,2
	Total image	7.895,9	4.000,7	18.263,5	119,3

Source: authors. Self-elaboration of the results

Figure 4. **Images I.1 and I.2 and luminance results obtained in Zones 1, 2 and 3 (average luminance and standard deviation in cd/m^2)**



Source: authors. Self-elaboration of the results

The results from the analysed images allow a discussion about the validity of the urban scenes brightness assessment method, while the values obtained in the examples depict the vision of the city in specific environments under sunlight. The methodology has proven easy to use for any picture as long as the image clearly represents the zones in the urban scene. As the software divides the image in horizontal stripes, the selected images must represent as accurately as possible the zones in such composition. Nevertheless, if foreshortened scenes are depicted, the values of pavement, façades and sky can be mixed and offer a different result. The intention of the procedure was to characterize in terms of brightness each zone in the urban visual scene, and the procedure is an easy and useful tool to determine it. However, the reality of urban scenes is far more complex. Although the position and main characteristics of these zones is constant, in real environments some elements overlap from one zone to another. It is not considered a disadvantage but an opportunity to determine their influence in future assessments. Apart from this, other considerations can be made about the results obtained in the pictures analysed.

In the first image (I.1), the values of average luminance increase from the top to the bottom. At the same time, the trend of the standard deviation value is the inverse: it increases from the bottom to the top of the scene. In this case, there is a uniform pavement surface made of light concrete with only a small area which contains the shadows of trees darkening this zone. Above, the zone with the main façade has a white surface partially sunlit and shaded, and a dark area corresponding to the entrance court and porch. On average, this zone is darker than the pavement caused by the simultaneous existence of sun and shade surfaces, which also produces a higher standard deviation. Finally, the sky zone is darkened by the vision of trees, which have a much lower luminance than the rest of the elements in the scene. If no trees were present in this environment, a brighter and more uniform zone would be expected to appear. The maximum luminance values within the image were found in the pavements zone, while the minimum ones were located in the sky zone. The effect of trees in this environment is key to the visual outcome, as it offers the possibility of darkening an expected bright area, the sky. Apart from this, vegetation gives rise to the presence of shadow in the scene, which has visual but also thermal consequences in the environment (Rojas *et al.*, 2015).

The second image (I.2) represents another kind of environment. A very bright façade is preceded by a dark grey wall that configures the entrance to a court. In this case, a mass of vegetation is also present in the scene, even though in this case it does not cover the sky zone. Here, the presence of the sky is higher than in the previous example and the brighter zone is still the pavement. However, the absence of trees in the upper part of the scene increases the luminance value in Zone 3 with respect to image I.1. The progression of average luminance and standard deviation from the bottom to the top of image I.2 follows the same pattern of I.1, but the difference lies on the row of trees in I.1 which modify this trend, darkening the Zone 3 and increasing standard deviation. Without the presence of trees, the second scene shows a C-shape pattern in terms of average luminance values.

In both cases, the results of average luminance and standard deviation in pavements depict it as the brightest and most uniform zone of the urban visual scene. In general terms, the bottom of the scene is usually covered by fewer elements than other zones such as façades and for that reason it seems to be more homogeneous in terms of brightness. The façades zone, however, has shown an average luminance lower than the bottom of the scene and with a higher standard deviation. It may be caused by the presence of more elements and irregularities at this level, as well as the shadows of trees, which can act as solar control systems on lower level façades (Villalba *et al.*, 2014). A higher standard deviation in façades would indicate that there is more dispersion of pixels with different value than the other zones. No further information is provided about the distribution of these pixels in this zone and the whole scene, which could indicate a concentrated or disperse distribution of light patches in the scene. As for the top of the scene, it has been stated above the difference between images I.1 and I.2 concerning the presence of vegetation in the urban scene. The row of trees contributes to darken the top of the scene and introduces light and shade patches in this zone.

The position of the different sensitivity areas in the visual field of a moving observer, in relation with the zones in the urban visual scene, reveals that the brighter zones are located in the periphery. As a consequence, the point of focus of the observer is located in Zone 2, facing the façades. Nonetheless, is has to be pointed out that when we are walking, the vision is usually focused on the pavement, for security reasons. Since it has proved to be the brightest zone in the visual scene, pavements are expected to be an important zone in urban design.

4. Conclusion

The procedure has been tested in two images corresponding to Mediterranean sunlit environments. The definition of the urban visual scene in three zones has shown some benefits. First, the simplicity of the abstraction seems useful for a rough definition of urban scenes as a composition of zones. In addition, this distinction permits future assessments in order to establish the brightness of each zone. Besides, the analysis has shown the main characteristics of them, successfully integrating the complexity of a real environment.

As for the results obtained in the cases of study, it seems that there is a trend in the values offered by the software for a Mediterranean city. First of all, the pavement appears as the brightest and more uniform zone in the urban visual scene. Second, the façades zone shows its complexity with lower average luminance than pavements and higher standard deviation. As for the top of the scene, both cases showed different results, even though the presence of trees seems to be the decisive factor on darkening the top of the visual field. A composition with treetops turns the top of the scene into the darkest zone, while its absence completely changes the vision of the scene, which would be expected to show a configuration similar to image I.2. As a consequence, the sky zone without obstructions would be slightly darker than pavements.

To sum up, the method tested in this work has proven a useful tool to assess brightness in urban scenes where the chosen images and environments depict a particular city and context. The results have shown a trend in the distribution of brightness in the given scene where pavements play an important role.

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